Open Channel Flow

1. INTRODUCTION TO FLOW

Flow is defined as the movement of a fluid under the action of forces such as gravity or pressure difference.

Open Channel Flow is the flow of liquid with a free surface exposed to atmospheric pressure and is mainly driven by gravity.

Examples:

• Rivers and streams

• Canals and irrigation channels

• Drains and sewers flowing partially full

2. COMPARISON BETWEEN OPEN CHANNEL FLOW AND PIPE FLOW

Open Channel Flow:

• Free surface is present

• Flow is driven by gravity

• Pressure distribution is hydrostatic

• Flow may be uniform or non-uniform

• Governed by Chezy's and Manning's equations

Pipe Flow:

• No free surface

• Flow is driven by pressure difference

• Pressure distribution is not hydrostatic

• Pipe runs full

• Governed by Darcy–Weisbach equation

3. GEOMETRICAL PARAMETERS OF AN OPEN CHANNEL

• Depth of flow (y): Vertical distance from bed to water surface

• Area of flow (A): Cross-sectional area of water

• Wetted perimeter (P): Length of channel boundary in contact with water

• Hydraulic radius (R): R = A / P

• Top width (T): Width of water surface

• Hydraulic depth (D): D = A / T

• Bed slope (S): Slope of the channel bottom

4. CLASSIFICATION OF OPEN CHANNELS

Based on Nature:

• Natural channels – rivers, streams

• Artificial channels – canals, drains

Based on Geometry:

• Rectangular

• Trapezoidal

• Triangular

• Circular (partially full)

Based on Boundary:

• Rigid boundary channels

• Mobile boundary channels

5. CLASSIFICATION OF OPEN CHANNEL FLOW

Based on Time:

• Steady flow

• Unsteady flow

Based on Space:

• Uniform flow

• Non-uniform flow

  - Gradually varied flow

  - Rapidly varied flow

Based on Reynolds Number:

• Laminar flow

• Turbulent flow

Based on Froude Number:

$Fr = V / \sqrt{(gD)}$

• Subcritical flow: $Fr < 1$

• Critical flow: $Fr = 1$

• Supercritical flow: $Fr > 1$

6. PREVIOUS YEAR / EXAM-ORIENTED QUESTIONS

Short Answer Questions:

1. Define open channel flow.

2. List any four examples of open channel flow.

3. Define hydraulic radius.

4. What is wetted perimeter?

5. Define Froude number.

Short Notes:

1. Difference between open channel flow and pipe flow.

2. Hydraulic depth and its significance.

3. Classification of open channels.

4. Uniform and non-uniform flow.

5. Subcritical and supercritical flow.

Long Answer Questions:

1. Explain open channel flow and compare it with pipe flow.

2. Describe the geometrical parameters of an open channel with neat sketches.

3. Explain the classification of open channel flows.

4. Discuss the importance of Froude number in open channel flow.

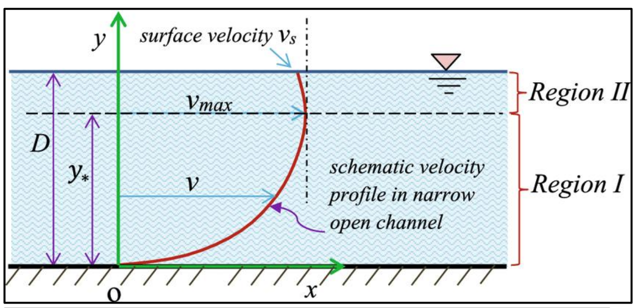
5. Explain different types of open channels based on geometry and boundary.

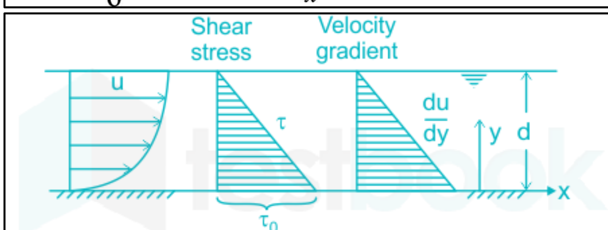
Velocity Distribution in open channel flow

Introduction

In open channel flow, the flow parameters such as velocity and pressure do not remain constant throughout the cross-section of the channel. Unlike ideal flow assumptions, practical open channel flow is affected by boundary friction, turbulence, and gravitational forces. As a result, both velocity and pressure vary across the depth and width of the channel. Understanding these variations is essential for the analysis and design of canals, rivers, and other hydraulic structures.

Velocity Distribution Along Depth





The vertical distribution of velocity, shear stress, and velocity gradient in steady uniform laminar open-channel flow

Velocity distribution in an open channel refers to the variation of flow velocity at different points within the channel cross-section. The velocity does not remain uniform because the fluid comes in contact with the channel boundaries such as the bed and side walls, which offer resistance to flow.

- Velocity is **zero at the channel bed** (no-slip condition)
- Velocity increases from bed towards the free surface
- **Maximum velocity occurs slightly below the free surface** (about **0.05–0.25 depth below surface**)

Reason for Maximum Velocity Below Surface

- Air resistance at the free surface
- Bed friction retards lower layers

- Turbulent mixing shifts maximum velocity downward

This phenomenon occurs due to the combined effects of air resistance at the free surface and turbulence within the flow. While the bed retards the flow near the bottom due to friction, the air exerts a small resisting force on the water surface. Turbulent mixing within the fluid causes the maximum velocity to shift slightly below the surface instead of occurring exactly at the top. Thus, the velocity distribution along the depth follows a curved profile, starting from zero at the bed, increasing gradually, and reaching a maximum below the free surface.

Important Empirical Relations

1. Average velocity

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

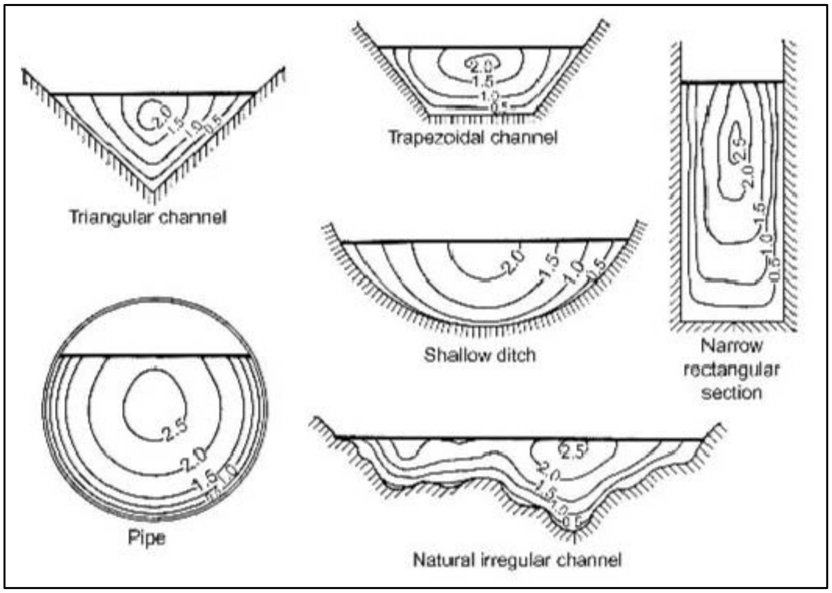
2. Velocity Measurement: Current meter, Pitot tube, Float method

Velocity Distribution Across Width

- Velocity is **maximum at the center**
- Velocity decreases towards side walls
- Due to **side wall friction**

Across the width of the channel, the velocity is maximum at the center and decreases towards the side walls. This reduction in velocity near the side walls is due to friction between the flowing water and the channel boundaries. The side walls slow down the adjacent layers of water, while the central portion of the channel remains comparatively less affected by boundary resistance.

Therefore, velocity distribution across the width is non-uniform, with higher velocities in the middle and lower velocities near the edges.



Factors Affecting Velocity Distribution

- Channel roughness
- Channel shape
- Flow depth
- Bed slope
- Turbulence
- Presence of bends and obstruction.

Pressure Distribution in Open Channel Flow: Introduction

Basic Concept: Pressure distribution in open channel flow is **hydrostatic**, provided:

- Flow is steady
- Acceleration effects are negligible

Pressure distribution in open channel flow is governed primarily by gravity. Since the water surface is exposed to the atmosphere, the pressure at the free surface is atmospheric. As we move downward into the fluid, the pressure increases due to the weight of the water above.

Under normal conditions of steady flow with negligible vertical acceleration, the pressure distribution in an open channel is hydrostatic in nature.

Pressure Distribution Along Depth

(Draw pressure vs depth diagram)

Pressure at any depth: At any depth below the free surface, the pressure is directly proportional to the depth of water. The pressure at a depth y below the free surface is given by

$$p = \gamma y$$

Where:

- p = pressure
- γ = specific weight of water
- y = depth below free surface

Characteristics

- Pressure is **zero (atmospheric) at free surface**
- Pressure increases **linearly with depth**
- Pressure diagram is **triangular**

As a result, the pressure distribution diagram along the depth of the channel is triangular in shape, with zero pressure at the free surface and maximum pressure at the channel bed. The resultant pressure force acting on the channel bed or side walls can be obtained by calculating the area of the pressure diagram. The line of action of this force acts at a distance of one-third of the depth from the bottom of the channel.

Resultant Pressure Force

$$p = \frac{1}{2}\gamma y^2 b$$

Where:

- b = channel width

Point of Application

- Acts at **y/3 from the bottom** (or **2y/3 from surface**)

Pressure Distribution Across Width

- At same depth → pressure is **equal across width**
- Independent of velocity variation

At the same depth below the free surface, the pressure remains the same across the width of the channel. This means that pressure distribution is uniform horizontally at a given depth and is independent of velocity variation. Even though velocity varies across the channel width, pressure depends only on the depth of water and the effect of gravity.

Comparison: Velocity vs Pressure Distribution

Aspect	Velocity Distribution	Pressure Distribution
Nature	Non-uniform	Uniform at same depth
Cause	Friction & turbulence	Gravity
Governing law	Empirical	Hydrostatic law
Diagram shape	Curved	Linear

5. Applications & Practical Importance Design of canals and channels

- Estimation of discharge
- Stability of channel linings
- Analysis of sediment transport
- Hydraulic structure design

Short Answer question

1. Why is maximum velocity below free surface?

2. State pressure distribution law in open channel flow.
3. What is the nature of pressure distribution?

Long Answer question

1. Explain velocity distribution in open channel flow with sketches.
2. Describe pressure distribution across a channel section.
3. Compare velocity and pressure distribution in open channel flow.

Characteristics and Development of Uniform Flow

Introduction: Uniform flow is one of the most important concepts in open channel hydraulics. Although perfectly uniform flow rarely occurs in nature, it is widely assumed in engineering practice because it simplifies analysis and design. The design of canals, drains, and irrigation channels is largely based on the principles of uniform flow. Understanding its characteristics and how it develops along a channel is therefore essential for civil engineers.

Uniform Flow – Definition

Uniform flow in an open channel is defined as the flow in which the depth of flow, velocity, and cross-sectional area remain constant along the length of the channel. Since these parameters do not change with distance along the channel, there is no acceleration of flow in the longitudinal direction.

In uniform flow, the flow conditions at any two sections along the channel are identical.

Characteristics of Uniform Flow

The important characteristics of uniform flow are described below.

1. Constant Depth and Velocity

In uniform flow, the depth of water and average velocity remain the same throughout the length of the channel. Since discharge is given by

Q=AV, constant area and velocity imply constant discharge.

2. Parallel Slopes: One of the most distinctive characteristics of uniform flow is that: The channel bed slope, The water surface slope, The energy grade line slope, are all parallel to each other. This indicates that energy loss due to friction is uniform along the length of the channel.

3. Hydrostatic Pressure Distribution

In uniform flow, vertical accelerations are negligible. Therefore, pressure distribution across the depth of flow is hydrostatic. Pressure at any depth depends only on the depth below the free surface and not on velocity variations.

4. Constant Energy Loss per Unit Length

The rate of energy loss due to friction remains constant along the channel length. This is why the friction slope is equal to the bed slope in uniform flow.

5. Flow Driven by Gravity and Balanced by Resistance

In uniform flow, the gravitational force component acting along the slope of the channel is exactly balanced by the resistance offered by the channel boundaries. As a result, the flow continues at constant velocity without acceleration.

6. Occurrence Mainly in Artificial Channels

Uniform flow conditions are more commonly achieved in long, straight, prismatic artificial channels such as irrigation canals and lined drains, where slope, roughness, and cross-section are constant.

Equations Governing Uniform Flow

Since uniform flow occurs under steady conditions with constant depth and velocity, empirical resistance equations are used to calculate flow parameters.

Manning's Equation

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

Where:

V = mean velocity
R = hydraulic radius
S = slope of energy grade line (equal to bed slope in uniform flow)
n = Manning's roughness coefficient

Discharge is calculated as: Q = AV

Chezy's Equation

$V = C\sqrt{RS}$

Both equations assume uniform flow conditions.

Development of Uniform Flow

Concept of Flow Development: Uniform flow does not start immediately at the entrance of a channel. When water enters a channel from a reservoir, gate, or transition, the flow depth and velocity initially vary along the channel length. Over a certain distance, the flow gradually adjusts to the channel conditions and finally attains uniform flow. This process is known as the development of uniform flow.

Stages in Development of Uniform Flow

1. Initial Non-Uniform Flow Region

At the channel entrance, the depth and velocity are influenced by upstream control conditions. The flow is non-uniform because the depth does not correspond to the normal depth required for uniform flow.

2. Gradually Varied Flow Region

As the flow moves downstream, it gradually adjusts to the channel slope, roughness, and cross-sectional shape. The depth changes slowly along the length, and the flow remains nearly hydrostatic. This region is governed by gradually varied flow principles.

3. Achievement of Uniform Flow

After sufficient length, the flow depth becomes equal to the normal depth, and velocity becomes constant. At this stage, uniform flow conditions are said to be fully developed.

The length required to achieve uniform flow depends on: Channel slope, Roughness, Initial depth, Discharge, Channel geometry.

Normal Depth and Uniform Flow

The depth of flow corresponding to uniform flow is called the normal depth. It is the depth at which the gravitational force component is exactly balanced by frictional resistance.
Normal depth is calculated using Manning's or Chezy's equation and plays a crucial role in channel design.

Practical Importance of Uniform Flow

Uniform flow concepts are extensively used in: Design of irrigation canals, Design of lined and unlined channels, Estimation of discharge capacity, Flood control channels, Drainage systems.

Conclusion: Uniform flow is characterized by constant depth, velocity, and energy loss along the channel length. It occurs when gravitational forces are balanced by boundary resistance. Although idealized, uniform flow forms the foundation for open channel design. The development of uniform flow involves an initial non-uniform region followed by gradual adjustment until normal depth is attained.