# FLUID MECHANICS (20CE C05)

# OVERVIEW

CHAITANYA BHARATHI
INSTITUTE OF TECHNOLOGY (A)
Affliated to Osmania University

Lecture slides by
**Dr. Jnana Ranjan Khuntia**

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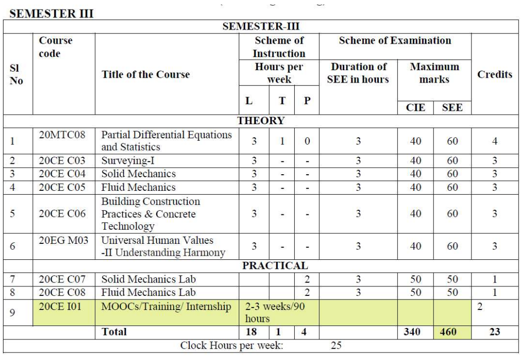
## Total Course Contents



SEMESTER III

| Sl No | Course code | Title of the Course | Scheme of Instruction | | | Scheme of Examination | | | Credits |
|---|---|---|---|---|---|---|---|---|---|
| | | | Hours per week | | | Duration of SEE in hours | Maximum marks | | |
| | | | L | T | P | | CIE | SEE | |
| SEMESTER-III | | | | | | | | | |
| THEORY | | | | | | | | | |
| 1 | 20MTC08 | Partial Differential Equations and Statistics | 3 | 1 | 0 | 3 | 40 | 60 | 4 |
| 2 | 20CE C03 | Surveying-I | 3 | - | - | 3 | 40 | 60 | 3 |
| 3 | 20CE C04 | Solid Mechanics | 3 | - | - | 3 | 40 | 60 | 3 |
| 4 | 20CE C05 | Fluid Mechanics | 3 | - | - | 3 | 40 | 60 | 3 |
| 5 | 20CE C06 | Building Construction Practices & Concrete Technology | 3 | - | - | 3 | 40 | 60 | 3 |
| 6 | 20EG M03 | Universal Human Values -II Understanding Harmony | 3 | - | - | 3 | 40 | 60 | 3 |
| PRACTICAL | | | | | | | | | |
| 7 | 20CE C07 | Solid Mechanics Lab | | | 2 | 3 | 50 | 50 | 1 |
| 8 | 20CE C08 | Fluid Mechanics Lab | | | 2 | 3 | 50 | 50 | 1 |
| 9 | 20CE I01 | MOOCs/Training/ Internship | 2-3 weeks/90 hours | | | | | | 2 |
| | | **Total** | **18** | **1** | **4** | | **340** | **460** | **23** |
| Clock Hours per week: 25 | | | | | | | | | |

**L : Lecture, T : Tutorial , P : Practical/Drawing/Seminar/Project**

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## FM: Course Objectives

**To enable the students**

| | |
|---|---|
| **1** | **To understand fluid properties, fluid pressure and forces, basic concepts and continuity equation** |
| **2** | **To understand the fluid motion, energy equation, analyze the forces on various objects** |
| **3** | **To know various measuring instruments in finding the fluid pressure, velocity, and discharge** |
| **4** | **To understand and analyze different flow characteristics of laminar and turbulent flows** |
| **5** | **To understand water hammer effect in pipes and to understand dimensional analysis and models studies** |

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## Course Outcomes

**At the end of the course, the student should have learnt**

| | |
|---|---|
| **CO1** | **To evaluate the various properties of fluid, analyse fluid flow and forces.** |
| **CO2** | **To apply the various laws and principles governing fluid flow to practical problems.** |
| **CO3** | **To measure pressure, velocity and discharge of fluid flow in pipes, channels, and tanks.** |
| **CO4** | **To apply laws related to laminar and turbulent flow in pipes.** |
| **CO5** | **To evaluate water hammer effect in pipes and to apply dimensional and model laws to fluid flow applications.** |

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## All units:

### Unit – I

- **Fluid Properties**: Definition of fluid, Properties of fluids- Density, Specific Weight, Specific Volume, Specific Gravity, Bulk Modulus, Vapour Pressure, Viscosity, Capillarity and Surface tension, Newton's law of Viscosity.
- **Fluid Statics:** Pascal's Law, Hydrostatic Law, Absolute and gauge pressure. Forces on immersed bodies: Total pressure, centre of pressure, pressure on curved surface.
- **Buoyancy:** Buoyancy, Metacentre, stability of submerged and floating bodies**.**
- **Fluid Kinematics:** Classification of fluid flow- steady unsteady, uniform, non-uniform-, one-, two- and three dimensional flows. Concept of streamline, stream tube, path line and streak line.
- **Law of mass conservation** – continuity equation from control volume and system analysis. Rotational and Irrotational flows, Stream function, Velocity potential function, flow net.

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## All units:

### Unit – II

- **Fluid Dynamics:** Convective and local acceleration, body forces and surface forces, Euler's equation of motion from control volume and system analysis.
- **Law of Energy Conservation:** Bernoulli's equation from integration of the Euler's equation. Signification of the Bernoulli's equation, its limitations, modifications and application to real fluid flows.
- **Impulse Momentum Equation:** Momentum and energy Correction factor. Application of the impulse momentum equation to evaluate forces on nozzles and bends. Pressure on curved surface- vortex flow- forced and free vortex.

## All units:

### Unit – III

**Measurement of Pressure:** Piezometer and Manometers - Bourdon Gauge.

**Measurement of Velocity:** Pitot tube and Current meter.

**Measurement of Discharge in pipes and tanks:** Venturi-meter, Orifice-meter, nozzle meter, elbow meter and rotameter. Flow through mouthpiece and orifice.

**Measure of Discharge in Free surface flows:** Notches and weirs.

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## All units:

### Unit – IV

**Flow through Pressure Conduits:** Reynold's Experiment and its significance. Upper and Lower Critical Reynold's numbers, Critical velocity. Hydraulic gradient. Laminar flow through circular pipes. Hagen Poiseuille equation. Turbulent flow characteristics. Head loss through pipes. Darcy-Weisbach equation. Friction factor. Moody's diagram. Minor loss, Pipes in Series and Pipes in parallel.

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## All units:

### Unit – V

**Unsteady Flow in Pipes:** Water hammer phenomenon, pressure rise due to gradual and sudden valve closure, critical period of the pipeline, power transmission through pipes.

**Dimensional Analysis and Models Studies:** Dimensional analysis - Rayleigh Method, Buckingham method, geometric, kinematic and dynamic similarity, similarity laws, significance of Reynolds and Froude model law, different types of models and their scale ratios, distorted and undistorted models, scale effect in models.

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# FLUID MECHANICS (20CE C05)

## UNIT-I

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## Syllabus

### Unit – I

- **Fluid Properties**: Definition of fluid, Properties of fluids- Density, Specific Weight, Specific Volume, Specific Gravity, Bulk Modulus, Vapour Pressure, Viscosity, Capillarity and Surface tension, Newton's law of Viscosity.
- **Fluid Statics:** Pascal's Law, Hydrostatic Law, Absolute and gauge pressure. Forces on immersed bodies: Total pressure, centre of pressure, pressure on curved surface.
- **Buoyancy:** Buoyancy, Metacentre, stability of submerged and floating bodies**.**
- **Fluid Kinematics:** Classification of fluid flow- steady unsteady, uniform, non-uniform-, one-, two- and three dimensional flows. Concept of streamline, stream tube, path line and streak line.
- **Law of mass conservation** – continuity equation from control volume and system analysis. Rotational and Irrotational flows, Stream function, Velocity potential function, flow net.

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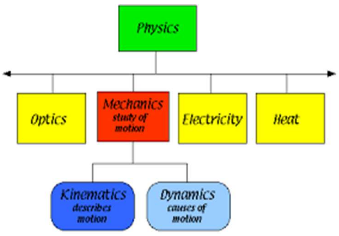
## Brief Introduction

Science
↓
Physics
↓
Mechanics

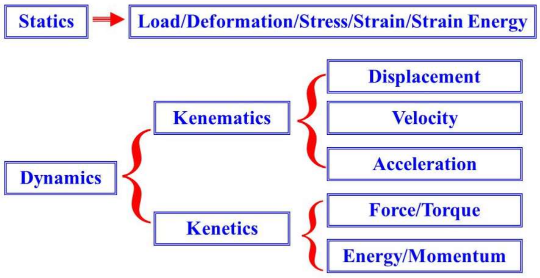


1. Solid mechanics
2. Fluid Mechanics:- i) Air ii) Water

Continued…

## Classification of "*Mechanics*"

***~studies of motion and the cause of motion~***



**Statics** → **Load/Deformation/Stress/Strain/Strain Energy**

**Dynamics**
- **Kenematics**
  - **Displacement**
  - **Velocity**
  - **Acceleration**
- **Kenetics**
  - **Force/Torque**
  - **Energy/Momentum**

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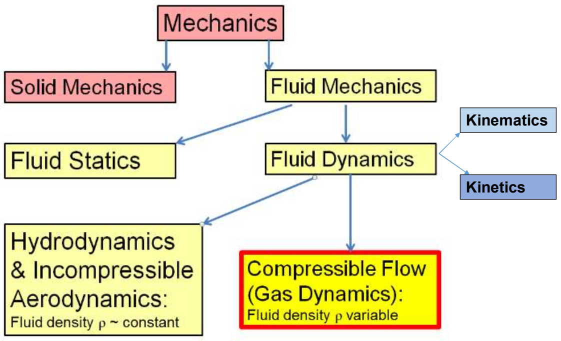

Mechanics
- Solid Mechanics
- Fluid Mechanics
  - Fluid Statics
  - Fluid Dynamics
    - Kinematics
    - Kinetics
    - Hydrodynamics & Incompressible Aerodynamics: Fluid density ρ ~ constant
    - Compressible Flow (Gas Dynamics): Fluid density ρ variable

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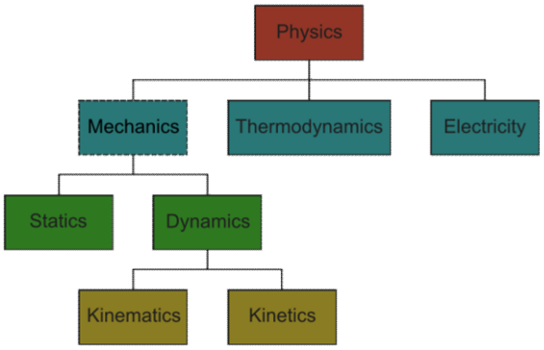
Continued…



Physics
- Mechanics
  - Statics
  - Dynamics
    - Kinematics
    - Kinetics
- Thermodynamics
- Electricity

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Continued…

**Fluid: A fluid is a substance capable of flowing.**

**Or**

**A fluid is a substance which deforms continuously when subjected to external shearing force.**

- So it has no definite shape of its own, but conforms to the shape of the containing vessel.

Example: liquid, gas and vapour

Mechanics: The oldest physical science that deals with both stationary and moving bodies under the influence of forces.

Statics: The branch of mechanics that deals with bodies at rest.

Dynamics: The branch of mechanics that deals with bodies at motion.

-Kinematics: Deals with the velocity, acceleration and the patterns of flow only, forces and energy causing the velocity, acceleration are not considered

-Kinetics: It deals with the relations between velocities, accelerations of fluid with the forces or energy causing them.

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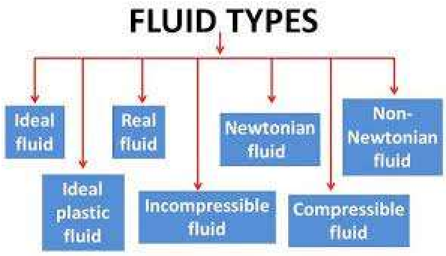
Continued…

- Fluid mechanics: The science that deals with the behavior of fluids at rest (*fluid statics*) or in motion (*fluid dynamics*), and the interaction of fluids with solids or other fluids at the boundaries.



FLUID TYPES
- Ideal fluid
- Ideal plastic fluid
- Real fluid
- Incompressible fluid
- Newtonian fluid
- Compressible fluid
- Non-Newtonian fluid

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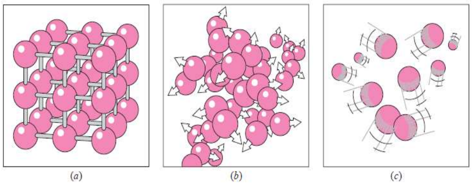

**FIGURE 1–5**

The arrangement of atoms in different phases: (*a*) molecules are at relatively fixed positions in a solid, (*b*) groups of molecules move about each other in the liquid phase, and (*c*) molecules move about at random in the gas phase.

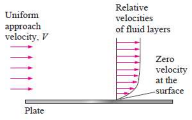

**FIGURE 1–9**

A fluid flowing over a stationary surface comes to a complete stop at the surface because of the no-slip condition.

# Units and Dimensions

- SI Units

M L T

kg metre second

- CGS Units

M L T

gram cm second

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# Characteristics of a Fluid

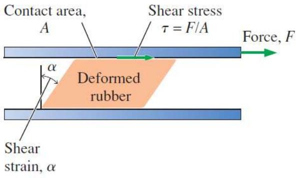
**Fluid:** A substance in the liquid or gas phase.

A solid can resist an applied shear stress by deforming.

*A fluid deforms continuously under the influence of a shear stress*, no matter how small.

In solids, stress is proportional to *strain*, but in fluids, stress is proportional to *strain rate*.

When a constant shear force is applied, a solid eventually stops deforming at some fixed strain angle, whereas a fluid never stops deforming and approaches a constant *rate* of strain.



Deformation of a rubber block placed between two parallel plates under the influence of a shear force. The shear stress shown is that on the rubber—an equal but opposite shear stress acts on the upper plate.

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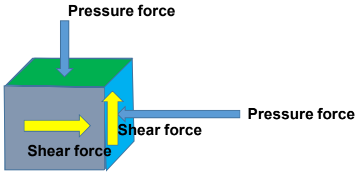
**Force due to pressure**

**Force due to friction / shear force**



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**Stress:** Force per unit area.

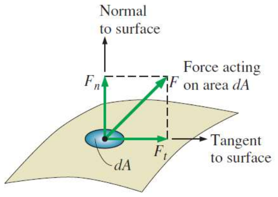
**Normal stress:** The normal component of a force acting on a surface per unit area.

**Shear stress:** The tangential component of a force acting on a surface per unit area.

**Pressure:** The normal stress in a fluid at rest.

**Zero shear stress:** A fluid at rest is at a state of zero shear stress.

When the walls are removed or a liquid container is tilted, a shear develops as the liquid moves to re-establish a horizontal free surface.



$$\text{Normal stress: } \sigma = \frac{F_n}{dA}$$

$$\text{Shear stress: } \tau = \frac{F_t}{dA}$$

The normal stress and shear stress at the surface of a fluid element. For fluids at rest, the shear stress is zero and pressure is the only normal stress.

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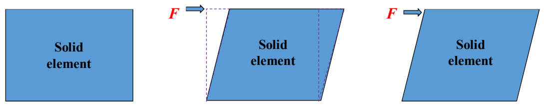
# Shear Force applied on a solid element



**But**

**Fluid- Can not resist shear**

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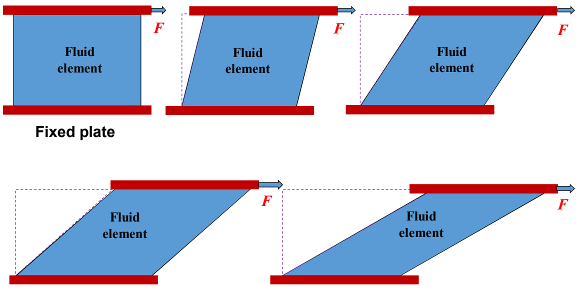
# Shear Force applied on a fluid element

**A fluid is a substance which deforms continuously when subjected to external shearing force**



Consider the behavior of a fluid element between the two infinite plates shown in Fig. 2.9*a*. The rectangular fluid element is initially at rest at time *t*. Let us now suppose a constant rightward force $\delta F_x$ is applied to the upper plate so that it is dragged across the fluid at constant velocity $\delta u$. The relative

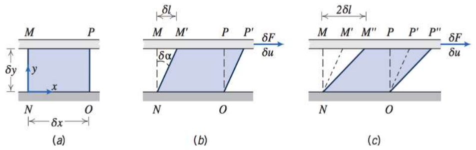


**Fig. 2.9** (a) Fluid element at time *t*, (b) deformation of fluid element at time *t* + δ*t*, and (c) deformation of fluid element at time *t* + 2δ*t*.

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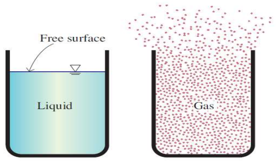
In a **liquid**, groups of molecules can move relative to each other, but the volume remains relatively constant because of the strong cohesive forces between the molecules. As a result, a liquid takes the shape of the container it is in, and it forms a free surface in a larger container in a gravitational field.

A **gas** expands until it encounters the walls of the container and fills the entire available space. This is because the gas molecules are widely spaced, and the cohesive forces between them are very small. Unlike liquids, a gas in an open container cannot form a free surface.

*Gas* and *vapor* are often used as synonymous words.

**Gas:** The vapor phase of a substance is customarily called a *gas* when it is above the critical temperature.

**Vapor:** Uusually implies that the current phase is not far from a state of condensation.



Unlike a liquid, a gas does not form a free surface, and it expands to fill the entire available space.

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## Comparison between liquid and gas

- Although liquids and gases share some common characteristics, they have many distinctive characteristics on their own. It is easy to compress a gas whereas liquids are incompressible.
- A given mass of the liquid occupies a fixed volume, irrespective of the size and shape of the container. A gas has no fixed volume and will expand continuously unless restrained by the containing vessel.
- For liquids a free surface is formed in the volume of the container. A gas will completely fill any vessel in which it is placed and therefore, does not have a free surface.

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## Application Areas of Fluid Mechanics

Fluid dynamics is used extensively in the design of artificial hearts. Shown here is the Penn State Electric Total Artificial Heart.

Natural flows and weather

Power plants

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## Continued…

Boats

Aircraft and spacecraft

Human body

Cars

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## Continued…

Wind turbines

Piping and plumbing systems

Industrial applications

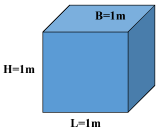
# Properties of fluids

## 1. DENSITY

- Mass Density-The *density* (also known as *mass density* or *specific mass*) of a liquid may be defined as *the mass per unit volume at a standard temperature and pressure.*
- It is usually denoted by ρ (rho).

$$\rho = m/V$$

- S.I. unit = $kg/m^3$ and CGS unit = $gram/cm^3$
- Density of water: $\rho = 1000\ kg/m^3$



**V** = $1m^3$

**m** = 1000 kg

**ρ** = $1000\ kg/m^3$

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# Continued…

- $\rho = m/V$
- S.I. unit = $kg/m^3$ and CGS unit = $gram/cm^3$
- CONVERSION of SI unit to CGS unit

- CONVERSION of $kg/m^3$ to $gram/cm^3$

1 kg = 1000gram
$1\ m^3 = 1m \times 1m \times 1m$
$1\ m^3 = 100cm \times 100cm \times 100cm$
$1\ m^3 = 10^6\ cm^3$
$kg/m^3 = 1000gram/10^6cm^3 = 10^{-3}\ gram/cm^3$

- Density of water: $\rho = 1000\ kg/m^3$
  $= 1000 \times 10^{-3}\ gram/cm^3$
  $= 1\ gram/cm^3$

Density of water: $\boldsymbol{\rho} = 1000\ kg/m^3 = 1\ gram/cm^3$

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Continued…

## 2. Specific Weight OR Weight Density

- Weight Density- *It is* (also known as *specific weight*) of a liquid may be defined as *the weight per unit volume at a standard temperature and pressure.*
- It is usually denoted by $\gamma$ (gamma).

$$\gamma = W/V$$

(weight is a force)

- S.I. unit = $N/m^3$ and CGS unit = $Dyne/cm^3$

$$\gamma = W/V$$
$$\gamma = mg/V$$
$$\gamma = (m/V)g$$
$$\gamma = \rho g$$

- *Specific Weight* of water: $\gamma = 9.81\ kN/m^3 = 9810\ N/m^3$

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Continued…

**3. Specific Volume:** It is defined as volume per unit mass of fluid. It is denoted by $S_v$ or $v$. **Unit: $m^3/kg$**

Mathematically, $S_v$ or $v = V/m = 1/\rho$

**4. Specific Gravity**

- Specific gravity of a liquid is the ratio of the mass density of the liquid to the mass density of a standard fluid.

**or**

- Specific gravity of a liquid is the ratio of the specific weight of the liquid to the specific weight of a standard fluid.
- It is represented by S.
- For liquids, the standard fluid is pure water at 4°C.

Unit: It is dimensionless and has no units.

$$S = \frac{mass\ density\ of\ liquid}{mass\ density\ of\ pure\ water} \qquad S = \frac{Specific\ weight\ of\ liquid}{specific\ weight\ of\ pure\ water}$$

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## Example

If 3.5 $m^3$ of oil weighs 32.95 kN. Calculate mass density, specific weight and specific volume, specific gravity of oil**.**

**Sol.**

$$\text{Specific weight } \gamma = \frac{\text{weight}}{\text{volume}} = \frac{32.95}{3.5}$$
$$= 9.414\ kN/m^3$$

$$\gamma = \rho g$$

$$\text{Mass density } \rho = \frac{\gamma}{g} = \frac{9.414 \times 10^3}{9.806} = 960.0\ kg/m^3$$

**Specific volume= $1/\rho = 1/960\ m^3/kg$**

**Specific gravity of Oil**

$$S = \frac{mass\ density\ of\ liquid}{mass\ density\ of\ pure\ water} = \frac{960}{1000} = 0.96$$

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## Example

*Calculate the specific weight, specific mass, specific volume and specific gravity of a liquid having a volume of 6 m3 and weight of 44 kN.*

**Solution:** Volume of the liquid = $6\ m^3$
Weight of the liquid = 44 kN

**Specific weight, $w$ :**

$$w = \frac{\text{Weight of liquid}}{\text{Volume of liquid}} = \frac{44}{6} = \mathbf{7.333\ kN/m^3}\ \text{(Ans.)}$$

**Specific mass or mass density, ρ :**

$$\rho = \frac{w}{g} = \frac{7.333 \times 1000}{9.81} = \mathbf{747.5\ kg/m^3}\ \text{(Ans.)}$$

$$\text{Specific volume, } v = \frac{1}{\rho} = \frac{1}{747.5} = \mathbf{0.00134\ m^3/kg}\ \text{(Ans.)}$$

**Specific gravity, $S$ :**

$$S = \frac{w_{liquid}}{w_{water}} = \frac{7.333}{9.81} = \mathbf{0.747}\ \text{(Ans.)}$$

**Example: HW**

Calculate the specific weight, specific mass, specific volume and specific gravity of a liquid having a volume of 8 $m^3$ and weight of 55 kN.

# HYDRAULIC ENGINEERING
# (20CE C09)

## OVERVIEW

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## Vision and Mission

### Department Vision

- To strive for excellence in academics, research and consultancy in the field of Civil Engineering and contribute to the sustainable development of the country by producing quality Civil Engineers with professional and ethical values.

### Department Mission

1. Maintaining high academic standards to develop analytical thinking and independent judgment among the students so that they are fit for industry and higher studies.
2. Promoting skills and values among the students to prepare them as responsible global citizens who can solve complex problems.
3. Preparing the students as good individuals and team members with professional attitude, ethics, concern for environment and zeal for lifelong learning who can contribute to society.

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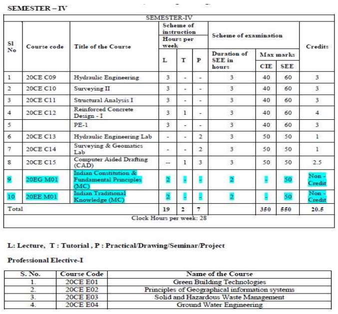
## Total Course Contents



**SEMESTER – IV**

SEMESTER-IV

| Sl No | Course code | Title of the Course | Scheme of instruction Hours per week | | | Scheme of examination | | | Credits |
|---|---|---|---|---|---|---|---|---|---|
| | | | L | T | P | Duration of SEE in hours | Max marks | | |
| | | | | | | | CIE | SEE | |
| 1 | 20CE C09 | Hydraulic Engineering | 3 | - | - | 3 | 40 | 60 | 3 |
| 2 | 20CE C10 | Surveying II | 3 | - | - | 3 | 40 | 60 | 3 |
| 3 | 20CE C11 | Structural Analysis I | 3 | - | - | 3 | 40 | 60 | 3 |
| 4 | 20CE C12 | Reinforced Concrete Design - I | 3 | 1 | - | 3 | 40 | 60 | 4 |
| 5 | | PE-1 | 3 | - | - | 3 | 40 | 60 | 3 |
| 6 | 20CE C13 | Hydraulic Engineering Lab | - | - | 2 | 3 | 50 | 50 | 1 |
| 7 | 20CE C14 | Surveying & Geomatics Lab | - | - | 2 | 3 | 50 | 50 | 1 |
| 8 | 20CE C15 | Computer Aided Drafting (CAD) | -- | 1 | 3 | 3 | 50 | 50 | 2.5 |
| 9 | 20EG M01 | Indian Constitution & Fundamental Principles (MC) | 2 | - | - | 2 | - | 50 | Non - Credit |
| 10 | 20EE M01 | Indian Traditional Knowledge (MC) | 2 | - | - | 2 | - | 50 | Non - Credit |
| Total | | | 19 | 2 | 7 | | 350 | 550 | 20.5 |
| Clock Hours per week: 28 | | | | | | | | | |

**L: Lecture, T : Tutorial , P : Practical/Drawing/Seminar/Project**

**Professional Elective-I**

| S. No. | Course Code | Name of the Course |
|---|---|---|
| 1. | 20CE E01 | Green Building Technologies |
| 2. | 20CE E02 | Principles of Geographical information systems |
| 3. | 20CE E03 | Solid and Hazardous Waste Management |
| 4. | 20CE E04 | Ground Water Engineering |

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## HHM: Course Objectives

The objective of this course is to

| | |
|---|---|
| 1 | **Understand and analyze the open channel flows, steady uniform flow and computation of friction and energy losses.** |
| 2 | **Understand and analyze the non-uniform flows and flow profile, energy dissipation** |
| 3 | **Exposure to the basic principles of aerodynamic forces, boundary layer formation and effects.** |
| 4 | **Understand the turbines; design the impulse turbine and its performance.** |
| 5 | **Familiarize with reaction turbines and its design, understand performance of reaction turbines and centrifugal pump** |

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## Course Outcomes

At the end of the course, the student will be able to

| | |
|---|---|
| CO1 | **Apply the concepts of open channel flow and design the efficient channel cross section.** |
| CO2 | **Apply the concepts of non-uniform open channel flow to the field problems.** |
| CO3 | **Interpret the basics of computation of drag and lift forces in the field of aerodynamics, boundary layer effect.** |
| CO4 | **Design the impulse turbines, run the turbines under efficient conditions.** |
| CO5 | **Design the reaction turbines, draw characteristic curves of turbines and centrifugal pump** |

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## All units: HHM

### Unit – I

**Uniform flow through open channels:**

Differences between pipe flow and channel flow, velocity and pressure distributions in channel cross-section, energy and momentum correction coefficients, uniform flow, Manning and Chezy formulae, most efficient channel cross-section, specific energy and specific force, concept of critical depth and its applications.

## All units:

### Unit – II

**Non-uniform flow through open channels:** Critical flow, Significance of Froude Number, dynamic equation of gradually varied flow, classification of gradually varied flow profiles and computation of flow profiles.

**Hydraulic Jump-** Momentum equation for a jump in horizontal rectangular channel, energy dissipation in hydraulic jump. Introduction to surges.

## All units:

### Unit – III

**Boundary layer:** Definition, laminar and turbulent boundary layers, boundary layer thickness, displacement thickness, momentum thickness and energy thickness, hydro dynamically smooth and rough boundaries, boundary layer separation and control.

**Drag and lift:** Fundamental concepts of drag and lift forces. Drag on sphere, cylinder, flat plate and aerofoil. Principles of streamlining, Magnus effect.

## All units:

### Unit – IV

**IMPACT OF JETS:** Hydrodynamic force of jets on stationary and moving flat, inclined and curved vanes, jet striking centrally and at tip, velocity triangles at inlet and outlet, expressions for Work done and efficiency-Angular momentum principle and torque.

**HYDRAULIC TURBINES-I:** Introduction, Classification, head and efficiencies, unit quantities, specific speed, power developed by turbine. Principles and design of Impulse turbine, velocity triangles, characteristic curves.

## All units:

### Unit – V

**HYDRAULIC TURBINES-II:** Reaction turbine - main components and working, work done and efficiencies, design of Francis turbine and Kaplan turbine, unit quantities, specific speed, characteristic curves, draft tube theory.

**Cavitation:** causes, effects.

**Centrifugal Pumps:** Components, work done and efficiency, minimum starting speed, Euler head equation, specific speed and characteristic curves of centrifugal pumps, Pumps in series and parallel.

## Definition of hydraulic engineering

: a branch of civil engineering that deals with the use and control of flowing water (as for power or in placer mining)

Laboratory

Natural

## Measuring the Flow of a Stream | The Float Method

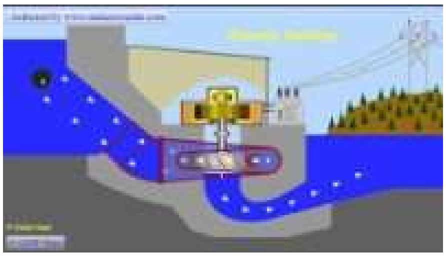
## Applications

- This area of civil engineering is intimately related to the design of bridges, dams, channels, canals, and levees, and to both sanitary and environmental engineering.
- Common topics of design for hydraulic engineers include hydraulic structures such as dams, levees, water distribution networks including both domestic and fire water supply, distribution and automatic sprinkler systems, water collection networks, sewage collection networks, storm water management, sediment transport, and various other topics related to transportation engineering and geotechnical engineering.

## Hydraulic Machines

- Hydraulic machine are those machines which convert hydraulic energy (energy possessed by water) into mechanical energy (which is further converted into electrical energy) or mechanical energy into hydraulic energy.
- The hydraulic machines, which convert the hydraulic energy into mechanical energy, are called **turbine** while the hydraulic machines which convert the mechanical energy into hydraulic energy are called **pumps**.

## Turbine



## Micro Hydro Power

## Flooding Explanation- Learn about Flood

# HYDRAULIC ENGINEERING
## (20CE C09)

## UNIT-I

CHAITANYA BHARATHI
INSTITUTE OF TECHNOLOGY (A)
Affiliated to Osmania University

Lecture slides by
**Dr. Jnana Ranjan Khuntia**

## Syllabus

### Unit – I

**Uniform flow through open channels:**

Differences between pipe flow and channel flow, velocity and pressure distributions in channel cross-section, energy and momentum correction coefficients, uniform flow, Manning and Chezy formulae, most efficient channel cross-section, specific energy and specific force, concept of critical depth and its applications.

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## Introduction

- Hydraulic engineering is the application of the principles of fluid mechanics to problems dealing with the collection, storage, control, transport, regulation, measurement, and use of water.
- Before beginning a hydraulic engineering project, one must figure out how much water is involved.
- Hydraulic engineering as a sub-discipline of civil engineering is concerned with the flow and conveyance of fluids, principally water and sewage.
- One feature of these systems is the extensive use of gravity as the motive force to cause the movement of the fluids.

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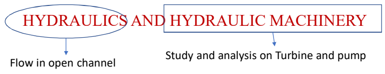
## Introduction



HYDRAULICS AND HYDRAULIC MACHINERY

Flow in open channel

Study and analysis on Turbine and pump

Open channel flow is needed to study for the following purposes :

- Estimate of discharge in a river or canal
- Development of relationship between depth of flow and the discharge in a channel
- Design of canal
- Estimating the area of submerged due to construction of dam on a river

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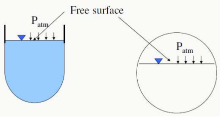
## OPEN-CHANNEL FLOW

- Open-channel flow is a flow of liquid (basically water) in a conduit with a free surface.
- That is a surface on which pressure is equal to local atmospheric pressure.
- The governing force for the open channel flow is the gravitational force component along the channel slope apart from inertia and viscous forces.
- Water flow in rivers and streams are obvious examples of open channel flow in natural channels.
- Other occurrences of open channel flow are flow in irrigation canals, sewer systems that flow partially full, storm drains, and street gutters.
- The flow in a pipe takes place due to difference of pressure (pressure gradient), whereas in open channel it is due to the slope of the channel bed (i.e.; due to gravity).



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## Continued..

In case of open channel flow, as the pressure is atmospheric, the flow takes place under the force of gravity which means the flow takes place due to the slope of the bed of the channel only. The hydraulic gradient line coincides with the free surface of water.

### Overview of Open Channel Flow

- Definition: Any flow with a free surface at atmospheric pressure
- Driven entirely by gravity
- Cross-section can vary with location and time, and is often irregular
- Examples
  - Rivers, streams, natural channels
  - Storm runoff, flood waves, tides, tsunamis
  - Canals, culverts, aqueducts, other constructed channels
  - Sewers for stormwater and sanitary wastes
  - Weirs, gates, and other flow-measuring or flow-control devices

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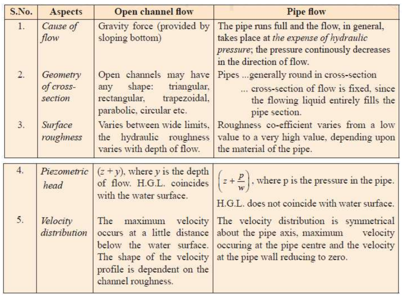
## Comparison Between Open channel flow and Pipe flow



| S.No. | Aspects | Open channel flow | Pipe flow |
|---|---|---|---|
| 1. | *Cause of flow* | Gravity force (provided by sloping bottom) | The pipe runs full and the flow, in general, takes place at *the expense of hydraulic pressure*; the pressure continously decreases in the direction of flow. |
| 2. | *Geometry of cross-section* | Open channels may have any shape: triangular, rectangular, trapezoidal, parabolic, circular etc. | Pipes ...generally round in cross-section<br>... cross-section of flow is fixed, since the flowing liquid entirely fills the pipe section. |
| 3. | *Surface roughness* | Varies between wide limits, the hydraulic roughness varies with depth of flow. | Roughness co-efficient varies from a low value to a very high value, depending upon the material of the pipe. |
| 4. | *Piezometric head* | $(z + y)$, where $y$ is the depth of flow. H.G.L. coincides with the water surface. | $\left(z + \frac{p}{w}\right)$, where p is the pressure in the pipe.<br>H.G.L. does not coincide with water surface. |
| 5. | *Velocity distribution* | The maximum velocity occurs at a little distance below the water surface. The shape of the velocity profile is dependent on the channel roughness. | The velocity distribution is symmetrical about the pipe axis, maximum velocity occuring at the pipe centre and the velocity at the pipe wall reducing to zero. |

## Comparison between open channel flow and pipe flow

| Aspect | Open Channel | Pipe flow |
|---|---|---|
| Cause of flow | Gravity force (provided by sloping bottom) | Pipes run full and flow takes place under hydraulic pressure. |
| Cross-sectional shape | Open channels may have any shape, e.g., triangular, rectangular, trapezoidal, parabolic or circular etc | Pipes are generally round in cross-section which is uniform along length |
| Surface roughness | Varies with depth of flow | Varies with type of pipe material |
| Piezometric head | (z+h), where h is depth of channel | (z+P/γ) where P is the pressure in pipe |
| Velocity distribution | Maximum velocity occurs at a little distance below the water surface. The shape of the velocity profile is dependent on the channel roughness. | The velocity distribution is symmetrical about the pipe axis. Maximum velocity occurs at the pipe center and velocity at pipe walls reduced to zero. |

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## Classification of Channels

The various types of channels are:

**1. Natural channel.** It is the one which has irregular sections of varying shapes, developed in a natural way.

**Examples:** Rivers, streams etc.

**2. Artificial channel.** It is the one which is built artificially for carrying water for various purposes. They have the cross-sections with regular geometrical shapes (which usually remain same throughout the length of the channel).

**Examples:** Rectangular channel, trapezoidal channel, parabolic channel, circular channel etc.

**3. Open channel.** A channel without any cover at the top is known as an open channel.

**Examples:** Irrigation canals, rivers, streams, flumes and water falls.

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## Classification of Channels

**4. Covered or closed channels.** The channel having a cover at the top is known as a covered or closed channel.

**Examples:** Partly filled conduits carrying public water supply such as sewerage lines, underground drains, tunnels etc. not running full of water.

**5. Prismatic channel.** A channel with constant bed slope and the same cross-section along its length is known as a prismatic channel.

The prismatic channels can be further subdivided as:

(i) Exponential channel. It is the one in which area of cross-section of flow is directly proportional to any power of depth of flow in channel.

**Examples:** Rectangular, triangular and parabolic channels.

(ii) Non-exponential channel. Trapezoidal and circular channels are non-exponential channels.

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## Types of Flow in Channels

The flow in channels is classified into the following types, depending upon the change in the depth of flow with respect to space and time:

1. Steady flow and unsteady flow

2. Uniform flow and non-uniform (or varied) flow

3. Laminar flow and turbulent flow

4. Subcritical flow, critical flow and supercritical flow

---

### 1. Steady Flow and Unsteady Flow

- When the flow characteristics (such as depth of flow, flow velocity and the flow rate at any cross-section) do not change with respect to time, the flow in a channel is said to be *steady*.

  Mathematically, $\frac{\partial y}{\partial t} = 0, \frac{\partial V}{\partial t} = 0, \text{ or } \frac{\partial Q}{\partial t} = 0$

  where $y$, $V$ and $Q$ are depth of flow, velocity and rate of flow respectively.
- The flow is said to be *unsteady flow* when these flow parameters vary with time.

  Mathematically, $\frac{\partial y}{\partial t} \neq 0; \frac{\partial V}{\partial t} \neq 0 \text{ or } \frac{\partial Q}{\partial t} \neq 0.$

### 2. Uniform Flow and Non-uniform (or varied) Flow

- Flow in a channel is said to be *uniform* if the depth, slope, cross-section and velocity *remain constant* over a given length of the channel.

  Mathematically, $\frac{\partial y}{\partial l} = 0, \frac{\partial V}{\partial l} = 0$

  Uniform flows are possible only in prismatic channels only. A uniform flow may be either steady or unsteady, depending upon whether or not the discharge varies with time; *unsteady uniform flow is rare in practice.*

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### 2. Uniform Flow and Non-uniform (or varied) Flow

- Flow in a channel is said to be *non-uniform* (*or varied*) when the channel depth *varies* continuously from one section to another.

  Mathematically, $\frac{\partial y}{\partial l} \neq 0, \frac{\partial V}{\partial l} \neq 0$

  Varied flow may be further classified as:

  (*i*) *Rapidly varied flow* (*R.V.F.*). In this type of flow depth of flow *changes abruptly over a comparatively small length of channel.*

  *Examples*: Hydraulic jump and the hydraulic drop.

  (*ii*) *Gradually varied flow* (*G.V.F.*). In this case the change in depth of flow takes place gradually in a long length of the channel.

### 3. Laminar Flow and Turbulent Flow

The flow in the open channel may be characterised as laminar or turbulent depending upon the value of Reynolds number, defined as:

$$Re = \frac{\rho V R}{\mu} \qquad \text{...(16.1)}$$

where, $V$ = Average velocity of flow in the channel, and
$R$ = Hydraulic radius (defined as the ratio of area of flow to wetted perimeter)

When $Re < 500$ ...flow is *laminar*
$Re > 2000$ ...flow is *turbulent*
$500 < Re < 2000$ ...flow is *transitional*.

### 4. Subcritical Flow, Critical Flow and Supercritical Flow

Since gravitational force is a predominant force in the case of channel flow, therefore Froude number, $Fr = \frac{V}{\sqrt{gD}}$ (where $V$ and $D$ are the mean velocity of flow and hydraulic depth of the channel respectively) is an important parameter for analysing open channel flows. Depending upon Froude number the channel flow may be characterised as:

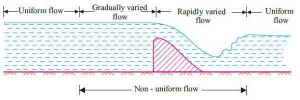


Fig: Uniform and non-uniform flow.

(*i*) When $Fr < 1$ (or $V < \sqrt{gD}$): The flow is described as *subcritical* (or *tranquil* or streaming)

(*ii*) When $Fr = 1$: The flow is said to be in a *critical* state.

(*iii*) When $Fr > 1$: The flow is said to be *supercritical* (or *rapid* or *shooting* or *torrential*)

Some of the types of channel flow are shown in Fig. 16.1

## Important Definitions

1. **Depth of flow ($y$).** It is the vertical distance of the lowest point of a channel section (bed of the channel) from the free *surface*.
2. **Depth of flow section.** It is the depth of flow normal to the bed of the channel.

$$d = y \cos \theta \qquad \text{...(16.2)}$$

where, $\theta$ = The angle which the channel bed makes with the horizontal.

Since the slopes of the channels are very small,

$$\cos\theta \simeq 1 \text{ and } d \simeq y.$$

The depth of flow and depth of flow section are assumed equal, unless mentioned otherwise.

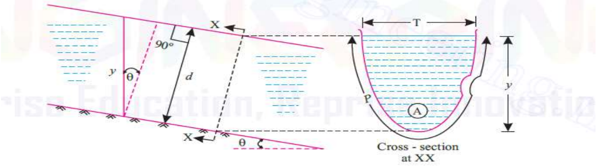
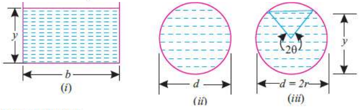


Fig: Terms related to flow through open channel

## Continued…

3. **Top width (T).** It is the width of the channel section at the free surface (*i.e.* the width of the liquid surface exposed to the atmospheric pressure.
4. **Wetted area (A).** It is the cross-sectional area of the flow section of the channel.
5. **Wetted perimeter (P).** It is the length of the channel boundary in contact with the flowing water at any section.
6. **Hydraulic radius (R).** It is ratio of the cross-sectional area of flow to wetted perimeter. It is also called *hydraulic mean depth*.

*i.e.*
$$R = \frac{A}{P} \qquad \text{...(16.3)}$$



(*i*) (*ii*) (*iii*)

*Examples*: (*i*) Rectangular open channel:

$$R = \frac{A}{P} = \frac{b \times y}{b + 2y}$$

## Continued…

(*ii*) Pipe running full:

$$R = \frac{A}{P} = \frac{(\pi/4) \times d^2}{\pi d} = \frac{d}{4}$$

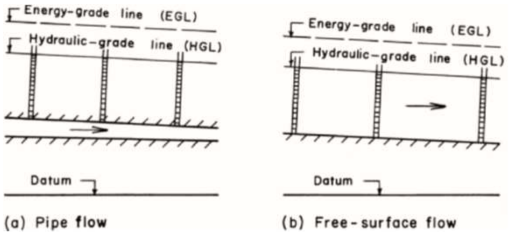
(*iii*) Pipe not running full:

$$R = \frac{A}{P} = \frac{\frac{r^2}{2}(2\theta - \sin 2\theta)}{2r\,\theta}$$

7. **Hydraulic depth (D).** It is the ratio of the wetted area $A$ to the top width $T$.

*i.e.*
$$D = \frac{A}{T}$$

## Hydraulic- and energy-grade lines



## Velocity Distribution in A Channel Section

- The velocity of flow at any channel section is not uniformly distributed.
- The non-uniform distribution of velocity in an open channel is due to the presence of a free surface and the frictional resistance along the channel boundary.
- The velocity distribution in a channel is measured either with the help of a pitot tube or a current meter.
- The general patterns for velocity distribution as represented by lines of equal velocity, in some of the common channel sections are illustrated in Fig..

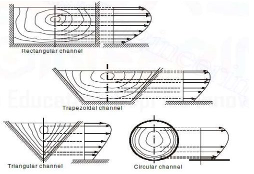
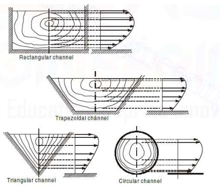


Fig. Typical patterns of velocity distribution in various channel sections

## Velocity Distribution in A Channel Section

- A velocity distribution curve along a vertical line of the channel section is also shown in Fig..
- In a straight reach of a channel maximum velocity usually occurs below the free surface at a distance of 0.05 to 0.15 of the depth of flow.
- The velocity distribution in a channel section depends on the various factors such as the shape of the section, the roughness of the channel and the presence of bends in the channel alignment.



- The mean velocity of flow in a channel section can be computed from the vertical velocity distribution curve obtained by actual measurements.
- It is observed that the velocity at 0.6 depth from the free surface is very close to the mean velocity of flow in the vertical section.
- A still better approximation for the mean velocity of flow is obtained by taking the average of the velocities measured at 0.2 depth and 0.8 depth from the free surface.

## Velocity Distribution in A Channel Section

- The flow velocity in a channel section varies from one point to another. This is due to shear stress at the bottom and at the sides of the channel and due to the presence of free surface.
- The flow velocity may have components in all three Cartesian coordinate directions. However, the components of velocity in the vertical and transverse directions are usually small and may be neglected.
- Therefore, only the flow velocity in the direction of flow needs to be considered. This velocity component varies with depth from the free surface.

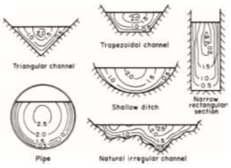


Fig: Velocity distribution in different channel sections

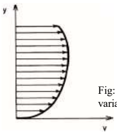
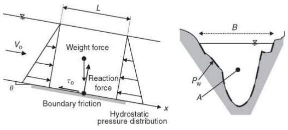


Fig: Typical velocity variation with depth

## Pressure Distribution in A Channel Section

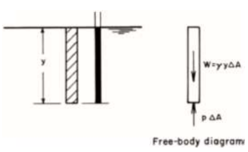
- The boundary conditions at the free surface of an open-channel flow are always that both the pressure and the shear stress are zero everywhere. But a flow can have a free surface but not be an open-channel flow.
- The flow in a pressure conduit is confined by solid walls on every side, while the flow in an open channel **has a free surface on one side**.
- For steady, fully developed channel flow, the pressure distribution within the fluid is merely **hydrostatic**.



## Pressure Distribution in A Channel Section

- The pressure distribution in a channel section depends upon the flow conditions.
- Let us consider several possible cases, starting with the simplest one and then proceeding progressively to more complex situations.

**Static Conditions**



- If $p$ =pressure intensity at the bottom of the liquid column, then the force due to pressure at the bottom of the column acting vertically upwards = $p\Delta A$. The weight of the liquid column acting vertically downwards = $\rho g y\Delta A$. Since the vertical component of the resultant force is zero, we can write

$p\Delta A = \rho g y \Delta A$ or $\boxed{p = \rho g y}$

- In other words, the pressure intensity is directly proportional to the depth below the free surface.

## Pressure Distribution in A Channel Section

**Horizontal, Parallel Flow**

- Let us now consider the forces acting on a vertical column of liquid flowing in a horizontal, frictionless channel (Fig.)

- Let us assume that there is no acceleration in the direction of flow and the flow velocity is parallel to the channel bottom and is uniform over the channel section.

$$\rho g y\Delta A = p\Delta A$$

or

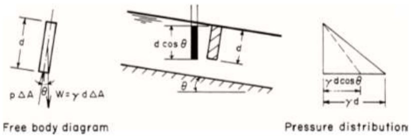
$$p = \rho g y = \gamma y$$

- in which $\gamma = \rho g$ = specific weight of the liquid.
- Note that this pressure distribution is the same as if the liquid were stationary; it is, therefore, referred to as the hydrostatic pressure distribution.

## Pressure Distribution in A Channel Section

**Parallel Flow in Sloping Channels**

- Let us now consider the flow conditions in a sloping channel such that there is no acceleration in the flow direction, the flow velocity is uniform at a channel cross section and is parallel to the channel bottom; i.e., the streamlines are parallel to the channel bottom.



- The cross-sectional area of the column is $\Delta A$. If $\theta$ = slope of the channel bottom, then the component of the weight of column acting along the column is $\rho g d\Delta A \cos\theta$ and the force acting at the bottom of the column is $p\Delta A$.

## Continued…

- There is no acceleration in a direction along the column length, since the flow velocity is parallel to the channel bottom. Hence, we can write $p\Delta A = \rho g d \Delta A \cos\theta$, or $p = \rho g d \cos\theta = \gamma d \cos\theta$.
- By substituting $d = y\cos\theta$ into this equation ($y$ = flow depth measured vertically, as shown in Fig. ), we obtain $\boxed{p = \gamma y \cos^2\theta}$
- Note that in this case the pressure distribution is not hydrostatic in spite of the fact that we have parallel flow and there is no acceleration in the direction of flow.
- However, if the slope of the channel bottom is small, then $\cos\theta \approx 1$ and $d \approx y$. Hence, $p \approx \rho g d \approx \rho g y$.
- If we assume that the slope of the channel bottom is small, then the pressure distribution may be assumed to be hydrostatic if the streamlines are almost parallel and straight, and the flow depths measured vertically or normal to the channel bottom are approximately the same.

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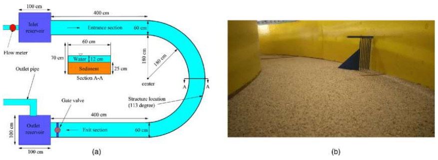
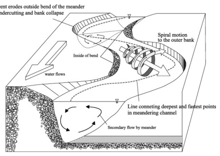
## Pressure Distribution in A Channel Section: Curved Channel



(a) (b)



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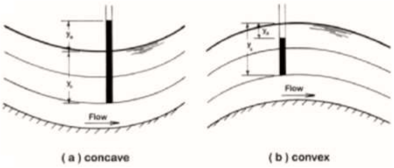
## Pressure Distribution in A Channel Section: Curved Channel

**Curvilinear Flow**

- In the previous three cases, the streamlines were straight and parallel to the channel bottom. However, in several real-life situations, the streamlines have pronounced curvature.
- To determine the pressure distribution in such flows, let us consider the forces acting in the vertical direction on a column of liquid with cross-sectional area $\Delta A$ *(as shown in Fig.)*



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## Continued…

$$\boxed{\text{Mass of the liquid column} = \rho y_s \Delta A}$$

If $r$ = radius of curvature of the streamline and $V$ is the flow velocity at the point under consideration, then

$$\text{Centrifugal acceleration} = \frac{V^2}{r}$$

and

$$\text{Centrifugal force} = \rho y_s \Delta A \frac{V^2}{r}$$

- Dividing the centrifugal force by the area of the column and converting the pressure to pressure head, we obtain the following expression for the pressure head, $y_a$, acting at the bottom of the liquid column due to centrifugal acceleration

$$\boxed{y_a = \frac{1}{g} y_s \frac{V^2}{r}}$$

---

## Continued…

- The pressure due to centrifugal force is in the same direction as the weight of column if the curvature is concave, as shown in Fig. a, and it is in a direction opposite to the weight if the curvature is convex (Fig. b).
- Therefore, the total pressure head acting at the bottom of the column is an algebraic sum of the pressure due to centrifugal action and the weight of the liquid column, i.e.,

$$\boxed{\text{Total pressure head} = y_s\left(1 \pm \frac{1}{g}\frac{V^2}{r}\right)}$$

- A positive sign is used if the streamline is concave, and a negative sign is used if the streamline is convex.
- Note that the first term in above Eq. is the pressure head due to static conditions while the second term is the pressure head due to centrifugal action.
- Thus, the liquid in a piezometer inserted into the flow rises, as shown in Fig. a. In other words, pressure increases due to centrifugal action in concave flows and decreases in convex flows (Fig. b).

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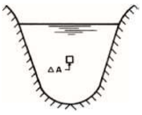
## Energy Correction Coefficients

- The flow velocity in a channel section usually varies from one point to another.
- Therefore, the mean velocity head in a channel section, $(V^2/2g)_m$, is not the same as the velocity head, $V_m^2/(2g)$, computed by using the mean flow velocity, $V_m$, in which the subscript m refers to the mean values.
- This difference may be taken into consideration by introducing an energy coefficient, $\alpha$, which is also referred to as the velocity head, or Coriolis coefficient.



- Referring to Fig., the mass of liquid flowing through area $\Delta A$ per unit time = $\rho V \Delta A$, in which $\rho$ = mass density of the liquid. Since, the kinetic energy of mass m traveling at velocity $V$ is $(1/2)mV^2$, we can write

## Energy Coefficients

- Kinetic energy transfer through area *ΔA* per unit time

$$= \frac{1}{2}\rho V \Delta A V^2 = \frac{1}{2}\rho V^3 \Delta A \qquad (1)$$

- Hence, Kinetic energy transfer through area *A* per unit time $= \frac{1}{2}\rho \int V^3\,dA$ (2)
- It follows from Eq. 1 that the kinetic energy transfer through area ΔA per unit time may be written as $(\gamma V\,\Delta A)V^2/(2g)$ = weight of liquid passing through area ΔA per unit time × velocity head, in which γ = specific weight of the liquid.
- Now, if $V_m$ is the mean flow velocity for the channel section, then the weight of liquid passing through total area per unit time $= \gamma V_m \int dA$; and the velocity head for the channel section $= \alpha V_m^2/(2g)$, in which α = velocity head coefficient. Therefore, we can write
- Kinetic energy transfer through area per unit time $= \rho\alpha V_m \frac{V_m^2}{2}\int dA$ (3)

---

## Continued…

- Hence, it follows from Eqs. 2 and 3 that

$$\boxed{\alpha = \frac{\int V^3 dA}{V_m^3 \int dA}} \qquad (4)$$

- Figure shows a typical cross section of a natural river comprising of the main river channel and the flood plain on each side of the main channel.
- The flow velocity in the floodplain is usually very low as compared to that in the main section. In addition, the variation of flow velocity in each subsection is small.
- Therefore, each subsection may be assumed to have the same flow velocity throughout. In such a case, the integration of various terms of Eq. 4 may be replaced by summation as follows:

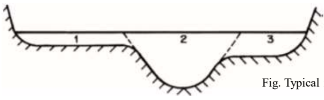


Fig. Typical river cross section

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## Continued…

$$\alpha = \frac{V_1^3 A_1 + V_2^3 A_2 + V_3^3 A_3}{V_m^3 (A_1 + A_2 + A_3)} \qquad (5)$$

in which

$$V_m = \frac{V_1 A_1 + V_2 A_2 + V_3 A_3}{A_1 + A_2 + A_3} \qquad (6)$$

- By substituting Eq. 1-9 into Eq. 1-8 and simplifying, we obtain

$$\boxed{\alpha = \frac{(V_1^3 A_1 + V_2^3 A_2 + V_3^3 A_3)(A_1 + A_2 + A_3)^2}{(V_1 A_1 + V_2 A_2 + V_3 A_3)^3}} \qquad (7)$$

- Note that Eq. 17 is written for a section which may be divided into three subsections each having uniform velocity distribution. For a general case in which total area *A* may be subdivided into *N* such subareas each having uniform velocity, an equation similar to Eq. 7 may be written as

$$\boxed{\alpha = \frac{\sum_{i=1}^{N}(V_i^3 A_i).\,(\sum A_i)^2}{(\sum V_i A_i)^3}} \qquad (8)$$

---

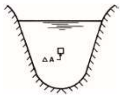
## Momentum Correction Coefficients

- Similar to the energy coefficient, a coefficient for the momentum transfer through a channel section may be introduced to account for nonuniform velocity distribution.
- This coefficient, also called Boussinesq coefficient, is denoted by ***β***. An expression for this may be obtained as follows.

The mass of liquid passing through area $\Delta A$ per unit time $= \rho V \Delta A$. Therefore, the momentum passing through area $\Delta A$ per unit time $= (\rho V \Delta A)V = \rho V^2 \Delta A$. By integrating this expression over the total area, we get

- Momentum transfer through area *A* per unit time

$$\boxed{= \rho \int V^2\,dA} \qquad (9)$$



- By introducing the momentum coefficient, *β*, we may write the momentum transfer through area *A* in terms of the mean flow velocity, $V_m$, for the channel section, i.e.,

---

## Momentum Coefficients

- Momentum transfer through area *A* per unit time = $\beta\rho V_m^2 \int dA$ (10)
- Hence, it follows from Eqs. 9 and 10 that

$$\boxed{\beta = \frac{\int V^2\,dA}{V_m^2 \int dA}} \qquad (11)$$

- Theoretical values for *α* and *β* can be derived from the power law and the logarithmic law for velocity distribution in wide channels.

**Table 1-2. Values of $\alpha$ and $\beta$ for typical sections***

| Channel section | $\alpha$ | $\beta$ |
|---|---|---|
| Regular channels | 1.10-1.20 | 1.03-1.07 |
| Natural channels | 1.15-1.50 | 1.05-1.17 |
| Rivers under ice cover | 1.20-2.00 | 1.07-1.33 |
| River valleys, overflooded | 1.50-2.00 | 1.17-1.33 |

* Compiled from data given by Chow [1959]

---

## Continued…

- For turbulent flow in a straight channel having a rectangular, trapezoidal, or circular cross section, ***α*** is usually less than 1.15.
- Therefore, it may not be included in the computations since its value is not precisely known and it is nearly equal to **unity**.

Ex. 1: The velocity distribution in a channel section may be approximated by the equation, $V = V_o(y/y_o)^n$, in which $V$ is the flow velocity at depth $y$; $V_o$ is the flow velocity at depth $y_o$, and $n$ = a constant. Derive expressions for the energy and momentum coefficients.

## Solution:

- Let us consider a unit width of the channel. Then, we can replace area $A$ in the equations for the energy and momentum coefficients by the flow depth $y$.
- Now, $V_m = \frac{\int V\,dA}{\int dA}$
- For a unit width, this equation becomes $V_m = \frac{\int V\,dy}{\int dy}$
- By substituting the expression for $V$ into this equation, we obtain

$$V_m = \frac{\int_0^{y_o} V_o(\frac{y}{y_o})^n\,dy}{\int_0^{y_o} dy}$$

$$= \frac{V_o}{y_o^n}\frac{y^{n+1}}{n+1}\Big|_0^{y_o}\frac{1}{y_o}$$

$$\boxed{= \frac{V_o}{n+1}}$$

- By substituting $V = V_o(y/y_o)^n$ , $V_m = V_o/(n+1)$, and $dA = dy$ into Eq. 4 , we obtain

---

## Continued…

$$\alpha = \frac{\int_0^{y_o} V_o^3(y/yo)^{3n}dy}{[V_o/(n+1)]^3\int_0^{y_o} dy}$$

$$= \frac{(V_o^3/y_o^{3n})[y^{3n+1}/(3n+1)]}{y_o[V_o/(n+1)]^3}$$

$$\boxed{= \frac{(n+1)^3}{3n+1}}$$

- Substitution of $V = V_o(y/y_o)^n$ and $V_m = V_o/(n + 1)$ into Eq. 11 yields

$$\beta = \frac{\int_0^{y_o} V_o^2(y/y_o)^{2n}\,dy}{[V_o/(n+1)]^2\int_0^{y_o} dy}$$

$$= \frac{(V_o^2 y_o)/(2n+1)}{[V_o/(n+1)]^2 y_o}$$

$$\boxed{= \frac{(n+1)^2}{2n+1}}$$

---

## Uniform Flow in Channels

- When water flows in an open channel resistance is offered to it, which results in causing a loss of energy.
- The resistance encountered by the flowing water is generally counteracted by the components of gravity forces acting on the body of the water in the direction of motion [Fig. (b)].

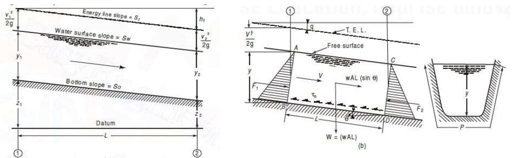


Fig. (a) Uniform flow in open channel (b) Forces on a segment of channel having uniform flow

---

## Continued…

- A uniform flow will be developed if the resistance is balanced by the gravity forces.
- The magnitude of the resistance, when other physical factors of the channel are kept unchanged, depends on the velocity of flow.
- When water enters the channel, the velocity and hence the resistance are smaller than the gravity forces, which results in an accelerating flow in the upstream reach of the channel.
- The velocity and the resistance increase gradually until a balance between the resistance and gravity forces is reached. From this point onwards the flow becomes uniform.
- Several uniform-flow formulae have been developed which correlate the mean velocity of uniform flow in open channels with the hydraulic radius, energy line slope and a factor of flow resistance.
- The most widely used uniform-flow formulae are the Chezy and Manning formulae which are described in the following paragraphs.

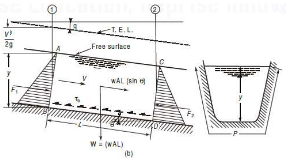
---

The **main features of uniform flow in a channel** can be summarized as follows:

1) The depth of flow, wetted area, velocity of flow and discharge are constant at every section along the channel reach.
2) The total energy line, water surface and the channel bottom are all parallel, that is, their slopes are all equal, or $S_f = S_w = S_0 = S$, where $S_f$ is energy line slope, $S_w$ is water surface slope and $S_0$ is channel bottom slope.

Figure (a) shows a short reach of prismatic channel having uniform flow. Applying Bernoulli's equation between sections 1 and 2 at a distance $L$ apart, we obtain

$$y_1 + \frac{V_1^2}{2g} + Z_1 = y_2 + \frac{V_2^2}{2g} + Z_2 + h_f$$



where $h_f$ is the loss of energy between the two sections. Since the flow is uniform, $y_1 = y_2$; $V_1 = V_2$. Thus from the above expression

$$Z_1 - Z_2 = h_f$$

or

$$\frac{Z_1 - Z_2}{L} = S_0 = \frac{h_f}{L} = S_f = S_w.$$

---

- The depth of a uniform flow is called the normal depth and it is generally represented by $y_n$.
- The fundamental equation for uniform flow in channels may be derived by applying Newton's second law of motion. In uniform flow since the velocity of flow does not change along the length of the channel, there is no acceleration. Hence the sum of the components of all the external forces in the direction of flow must be equal to zero. Consider a short reach of channel of length L in which uniform flow occurs, as shown in Fig. (b). The forces acting on the free-body of water ABCD in the direction of flow are as follows:

1) The forces of hydrostatic water pressure $F_1$ and $F_2$ acting on the two ends of the free body. As the depths of water at these two sections are the same, the forces $F_1$ and $F_2$ are equal and hence they cancel each other.
2) The component of weight of the water in the direction of flow, which is ($wAL \sin\theta$), where w is specific weight of water, A is the wetted cross-sectional area of channel and θ is the angle of inclination of the channel bottom with the horizontal.
3) The resistance to the flow is exerted by the wetted surface of the channel. If P is the wetted perimeter of the channel and $\tau_0$ is the average shear stress at the channel boundary, the total resistance to flow will be ($PL\tau_0$).

# RIVER ENGINEERING (18CE E20)

## OVERVIEW

CHAITANYA BHARATHI
INSTITUTE OF TECHNOLOGY (A)
Affliated to Osmania University

Lecture slides by
**Dr. Jnana Ranjan Khuntia**

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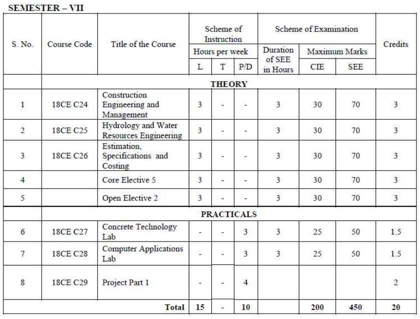
## Total Course Contents



SEMESTER – VII

| S. No. | Course Code | Title of the Course | Scheme of Instruction | | | Scheme of Examination | | | Credits |
|---|---|---|---|---|---|---|---|---|---|
| | | | Hours per week | | | Duration of SEE in Hours | Maximum Marks | | |
| | | | L | T | P/D | | CIE | SEE | |
| | **THEORY** | | | | | | | | |
| 1 | 18CE C24 | Construction Engineering and Management | 3 | - | - | 3 | 30 | 70 | 3 |
| 2 | 18CE C25 | Hydrology and Water Resources Engineering | 3 | - | - | 3 | 30 | 70 | 3 |
| 3 | 18CE C26 | Estimation, Specifications and Costing | 3 | - | - | 3 | 30 | 70 | 3 |
| 4 | | Core Elective 5 | 3 | - | - | 3 | 30 | 70 | 3 |
| 5 | | Open Elective 2 | 3 | - | - | 3 | 30 | 70 | 3 |
| | **PRACTICALS** | | | | | | | | |
| 6 | 18CE C27 | Concrete Technology Lab | - | - | 3 | 3 | 25 | 50 | 1.5 |
| 7 | 18CE C28 | Computer Applications Lab | - | - | 3 | 3 | 25 | 50 | 1.5 |
| 8 | 18CE C29 | Project Part 1 | - | - | 4 | | | | 2 |
| | | **Total** | **15** | - | **10** | | **200** | **450** | **20** |

**Core Elective 5**:
1. 18CE E18 - Design of Steel Structures-II
2. 18CE E19 - Airport Engineering
3. 18CE E20 - River Engineering
4. 18CE E21 - Water and Air Quality Modeling
5. 18CE E22 -Applications of Data Analytics in Civil Engineering

**Open Elective 2:**
1. 18ME O07 – Intellectual Property Rights
2. 18EG O02 – Gender Sensitization
3. 18CS O01 – Basics of Artificial Intelligence
4. 18EE O04 – Energy Conservation

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## RE: Course Objectives

**To enable the students to understand**

| | |
|---|---|
| 1 | **The concepts of river morphology** |
| 2 | **The methods of stage measurement.** |
| 3 | **Hydraulic river models.** |
| 4 | **River protection and training works** |
| 5 | **Design flood protection structures** |

---

## Course Outcomes

**At the end of the course, the students will be able to**

| | |
|---|---|
| **CO1** | **define basic terms and understand the concepts of river morphology.** |
| **CO2** | **determine scour depth of hydraulic structure and identify methods of stage measurement.** |
| **CO3** | **understand hydraulic river models.** |
| **CO4** | **identify river training works and understand protective measures.** |
| **CO5** | **design flood protection structures.** |

---

## All units:

### Unit – I

**River morphology:**

Behaviour of river flow, role of sediments in rivers, changes in regimes. Sediment transport mechanics - bed forms, bed load transport, and transport of suspended sediment, critical shear stress, and sediment transport equations.

---

## All units:

### Unit – II

**Aggradation and Degradation:**

Local scour at bridge piers and other hydraulic structures, measurements in rivers - stage measurements, channel geometry, discharge, and sediment samplers and suspended and bed load measurement.

## All units:

### Unit – III

**Hydraulic modelling of rivers:**

Hydraulic similitude, physical river models- fixed and movable bed models; sectional models, distorted models, mathematical models for aggradations, degradation and local scour.

## All units:

### Unit – IV

**River Protection and Training Works:**

Introduction, classification of river training, types of training works, protection for revetments, dikes, gabions, spurs, bank protective measures and bed control structures.

## All units:

### Unit – V

**Design of river flood protection structures:**

Diversion and cofferdam, river regulations systems, dredging and disposal, river restoration.

# RIVER ENGINEERING (18CE E20)

## UNIT-I

CHAITANYA BHARATHI
INSTITUTE OF TECHNOLOGY (A)
Affliated to Osmania University

Lecture slides by
**Dr. Jnana Ranjan Khuntia**

## Syllabus

### Unit – I

**River morphology:**

**Behaviour of river flow, role of sediments in rivers, changes in regimes. Sediment transport mechanics - bed forms, bed load transport, and transport of suspended sediment, critical shear stress, and sediment transport equations.**

## Introduction

- In the last few decades, water demand in the globe has increased in many folds.
- Rivers, one of the major source of water demand for domestic, agricultural, and industrial uses, are often not utilized properly for long-term sustainability.
- Therefore, it is a challenging task for engineers for understanding water, sediment and energy transport processes in rivers in both spatial and temporal scales.
- This course will address how to understand and model hydro-fluvial processes and designing of advanced river intervention structures.

## Introduction

### RIVER ENGINEERING

- **River Engineering** is a branch of civil engineering dealing with the design and construction of various structures to improve and/or restore rivers for both human and environmental needs.
- With utilization of modern day, state of the art technologies in data collection and modeling, river engineering can improve navigation, reduce dredging, and enhance or create new habitat.
- River engineering involves the management of sediment and the control of erosion. Sedimentation is one of mankind's largest natural problems.

## Introduction

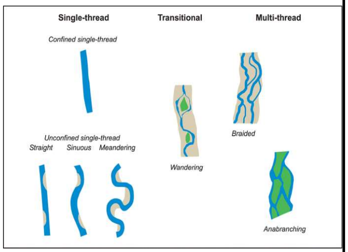
- Sediment can choke rivers, clog water intakes for municipal water supply, halt or hinder the transportation of commodities via navigation, and destroy backwaters and wetlands.
- Erosion can endanger private property and infrastructure, cause major river cutoffs, and increase sedimentation.

### What are major importance of rivers?

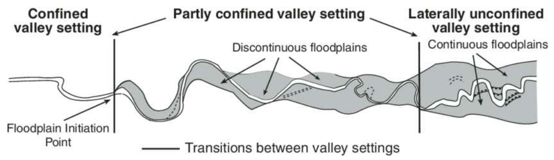
- Humans use rivers **for irrigation in agriculture, for drinking water, for transportation, to produce electricity through hydroelectric dams, and for leisure activities like swimming and boating**. Each of these uses can affect the health of a river and its surrounding ecosystems.

## Introduction: River morphology

- Morphology (of river) is a field of science which deals with the change of river plan form and cross sections due to sedimentation and erosion. In this field, dynamics of flow and sediment transport are the principal elements.
- The terms river morphology and its synonym stream morphology are used to describe the shapes of river channels and how they change in shape and direction over time.



## Introduction



- In the study of rivers, specifically looking at how the channel geometry changes with time, there are five main physical factors described that affect the channel morphology:

(1) bank and bar stability;
(2) sediment size distribution;
(3) sediment supply;
(4) flow variability; and
(5) downstream slope, width and height.

## Behaviour of river flow

**Types of Rivers and their Characteristics**

Classification of Rivers on the Basis of the Topography of the River Basin. Depending upon the topography of the basin, the river reaches can be classified into two main classes, i.e. .

(i) Rivers in hills (Upper reaches) ;
(ii) Rivers in alluvial plains, known as rivers in flood plains (Lower reaches)
(iii) Tidal rivers

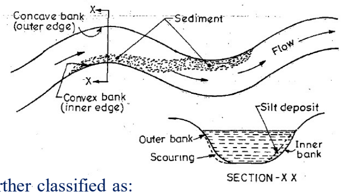
All these three types of river reaches are described below :

*(i)* Rivers in hills (Upper Reaches). The rivers generally take off from the mountains and flow through the hilly regions before traversing the plains. These upper reaches of the rivers may be termed as *Rivers in Hills.*

## Behaviour of river flow

(ii) Rivers in Alluvial Flood Plains (Lower Reaches). The chief characteristics of these river reaches is the zig-zag fashion in which they flow, called meandering.

- They meander freely from one bank to another and carry sediment which is similar to bed material. Material gets eroded constantly from the concave bank (outer edge) of the bend and gets deposited either on the convex side (inner· edge) of the successive bends or between two successive bends of the bar.
- A **bar** in a river is an elevated region of sediment (such as sand or gravel) that has been deposited by the flow.



- Rivers in flood plains can be further classified as:

(a) Aggrading; (b) Degrading; (c) Stable; (d) Braided; and (e) Deltaic.

# Behaviour of river flow

(iii) Tidal Rivers.

- The tail reaches of the rivers adjoining the oceans are affected by the. tides in the ocean.
- The ocean water enters the river during the flood tide and goes out into the ocean during the ebb tide.
- The river, therefore, undergoes periodical rise and fall in its water level, depending upon the nature of the tide.
- The distance up to which the tidal effect is experienced, depends upon various factors, such as the shape and configuration of the river, the tidal range, freshet discharge, etc.

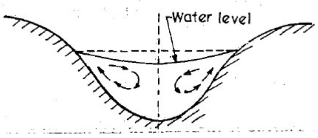
# Continued..

- The chief factor which is responsible for moulding the behaviour of rivers is the silt and sediment that flows in the river.
- The sediment carried by the river poses numerous problems, such as: increasing of flood levels, silting of reservoirs, silting of irrigation and navigation channels; meandering of rivers, splitting up of a river into a number of interlaced channels, etc.
- The meandering causes the rivers to leave their original courses, forces them to flow along new courses, and thus devastating vast areas of land and affecting important and valuable nearby structures, such as bridges, railway lines, roads, etc.

# Continued..

**a. Straight Reaches.**

- In a straight reach of a river, the river cross-section is in the shape of a trough/channel, with high velocity flow in the middle of the section.
- Since the velocity is higher in the middle, the water surface level will be lower in the middle and higher at the edges, as shown in Fig.
- Due to the existence of this transverse gradient from sides towards the centre, transverse rotary currents get developed, as shown in Fig.
- However, straight reaches are very few in alluvial rivers.

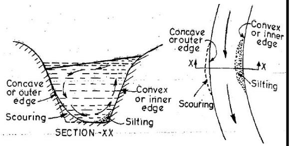


# Continued..

**b. Bends.**

- Every alluvial river tends to develop bends, which are characterized by scouring on the concave side and silting on the convex side, as shown in Fig.
- The silting and scouring in a bend may continue due to the action of the centrifugal force.

- When the flow moves round a bend, a centrifugal force is exerted upon the water, which results in the formation of transverse slope of water surface from the convex edge to the concave edge, creating greater pressure near the convex edge (see Fig.).
- To keep its own level, water tends to move from the convex side towards the concave side.



- These rotary currents cause the erosion of concave edge and deposition on convex edge, forming shoals on the convex sides. When once a bend is formed, the flow tends to make the curvature larger and larger.

# Continued..

**c. Meanders:** When once a river deviates from its axial path and a curvature is developed (either due to its own characteristics or due to the impressed external forces), the process moves downstream by building up shoals on the convex side by means of secondary currents.
The formation of shoals on the convex side, results in further shifting of the outer bank by erosion on the concave side.

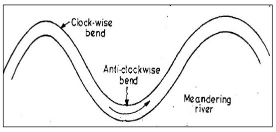


Fig: Meandering River

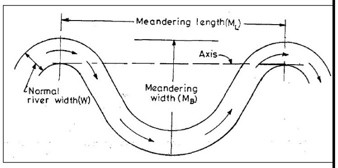


Fig: Meander Parameters.

# Continued..

- Formation of successive bends of reverse order may lead to the formation of a complete S curve called meander.
- When consecutive curves of reverse order connected with short straight reaches called (crossings) are developed in a river reach, the river is stated to be a meandering river (Fig.).
- In order to study the behaviour of a meandering river, the river may be supposed to follow a sine curve.
- There are four variables, which govern the meandering process. They are: (i) Valley slope, (ii) Silt grade and silt charge, (iii) Discharge, (iv) Bed and side materials and their susceptibility to erosion.
- All these factors considerably affect the meandering patterns, and all of them are interdependent.