ENGINEERING MECHANICS

1. Introduction

- ➢ 1.1 Concept of engineering mechanics definition of mechanics, statics, dynamics, Application of engineering mechanics in practical fields, Definition of Engineering Mechanics.
- ➢ 1.2 Definition, basic quantities and derived quantities of basic units and derived units
- ➢ 1.3 Different systems of units (FPS, CGS, MKS and SI) and their conversion from one To another, density, force, pressure, work, power, velocity, acceleration
- ➢ 1.4 Concept of rigid body, scalar and vector quantities

2. Laws of forces

- ➢ 2.1 Definition of force, measurement of force in SI units, its representation, types of Force: Point force/concentrated force & uniformly distributed force, effects of force and characteristics of a force
- ➢ 2.2 Different force systems (coplanar and non-coplanar), principle of transmissibility Of forces, law of super-position
- ➢ 2.3 Composition and resolution of coplanar concurrent forces, resultant force, method Of composition of forces, laws of forces, triangle law of forces, polygon law of Forces - graphically, analytically, resolution of forces, resolving a force into two Rectangular components
- ➢ 2.4 Free body diagram
- ➢ 2.5 Equilibrant force and its determination
- ➢ 2.6 Lami's theorem (concept only)

3. Moment

- ➢ 3.1 Concept of moment
- ➢ 3.2 Moment of a force and units of moment
- ➢ 3.3 Varignon's theorem (definition only)
- ➢ 3.4 Principle of moment and its applications (Levers – simple and compound, steel yard, safety valve, reaction at support)
- ➢ 3.5 Parallel forces (like and unlike parallel force), calculating their resultant
- ➢ 3.6 Concept of couple, its properties and effects
- ➢ 3.7 General conditions of equilibrium of bodies under coplanar forces and beams, fixed support, roller support, over hanging, Uniformly distributed load, point load, varying load
- ➢ 3.8 Position of resultant force by moment

4. Centre of Gravity

- ➢ 4.1 Concept, definition of centroid of plain figures and centre of gravity of symmetrical solid bodies
- ➢ 4.2 Determination of centroid of plain and composite lamina using moment method only, centroid of bodies with removed portion
- ➢ 4.3 Determination of center of gravity of solid bodies - cone, cylinder, hemisphere and sphere; composite bodies and bodies with portion removed

5. Moment of Inertia

- ➢ Concept of moment of inertia and second moment of area and radius of gyration, theorems of parallel and perpendicular axis, second moment of area of common geometrical sections: rectangle, triangle, circle (without derivations). Second moment of area for L, Tand I sections, section modulus

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6. Simple Machines

- ➢ 6.1 Definition of effort, velocity ratio, mechanical advantage and efficiency of a machine and their relationship, law of machines
- ➢ 6.2 Simple and compound machine (Examples)
- ➢ 6.3 Definition of ideal machine, reversible and self locking machine
- ➢ 6.4 Effort lost in friction, Load lost in friction, determination of maximum mechanical advantage and maximum efficiency
- ➢ 6.5 System of pulleys (first, second, third system of pulleys), determination of velocity ratio, mechanical advantage and efficiency

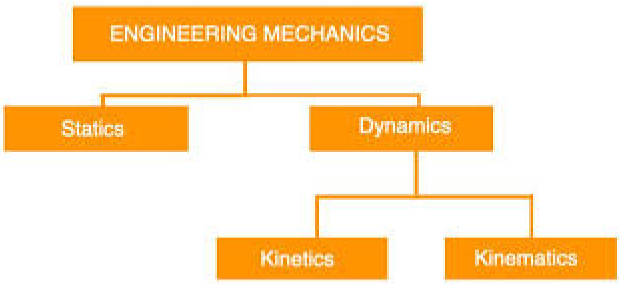
UNIT 01 –

INTRODUCTION TO ENGINEERING MECHANICS

1.1 Meaning of Engineering Mechanics

- ❖ Engineering Mechanics is the branch of applied science which studies the behavior of physical bodies when subjected to forces. It explains how and why bodies remain at rest or move when forces act on them.
- ❖ It is the foundation of all branches of engineering because every structure or machine experiences forces.
- ❖ Engineering Mechanics combines principles of physics and mathematics to solve engineering problems.

1.2 Branches of Engineering Mechanics



Engineering Mechanics is divided into:-

(A) Statics

Statics deals with bodies at rest or in equilibrium.

A body is said to be in equilibrium when:

- It has no acceleration.
- The net force acting on it is zero.

- The net moment acting on it is zero.

Mathematical conditions of equilibrium:

$\Sigma Fx = 0$
$\Sigma Fy = 0$
$\Sigma M = 0$

Applications:

- ➔ Designing beams
- ➔ Calculating reactions at supports
- ➔ Stability of buildings
- ➔ Bridge analysis

(B) Dynamics

Dynamics deals with bodies in motion.

It is divided into:

a) Kinematics – Study of motion without considering forces.
b) Kinetics – Study of motion considering forces causing motion.

1.3 Fundamental and Derived Quantities

- ❖ Fundamental Quantities - These are independent quantities.

  - ➔ Length (meter)
  - ➔ Mass (kg)
  - ➔ Time (second)
  - ➔ Derived Quantities

- ❖ Derived Quantities - These are obtained from fundamental quantities.

  - ➔ Velocity = Distance / Time
  - ➔ Acceleration = Velocity / Time
  - ➔ Force = Mass × Acceleration
  - ➔ Work = Force × Distance
  - ➔ Power = Work / Time
  - ➔ Pressure = Force / Area

- ➔ Density = Mass / Volume

1.4 Systems of Units

- ★ CGS System – cm, gram, second
- ★ FPS System – foot, pound, second
- ★ MKS System – meter, kilogram, second
- ★ SI System – International System (standard modern system)

1.5 Scalar and Vector Quantities

SCALAR QUANTITIE

Scalar quantities have magnitude only.

Examples: mass, time, energy.

VECTOR QUANTITIE

Vector quantities have magnitude and direction.

Examples: force, velocity, acceleration.

Vector addition follows triangle law and parallelogram law.

UNIT 02 –
LAWS OF FORCES

2.1 CONCEPT OF FORCE

What is Force?

Force is an external agent which:

- ➔ Changes the state of rest of a body
- ➔ Changes the state of motion of a body
- ➔ Changes the direction of motion
- ➔ Causes deformation
- ➔ Produces rotation

In simple words, force is a push or pull.

But in engineering mechanics, force is much more than a push or pull — it is a vector quantity that has both magnitude and direction, and it produces measurable mechanical effects.

Mathematical Definition of Force

According to Newton's Second Law of Motion:

Force = Mass × Acceleration

$$[F = m \times a]$$

Where:

F = Force (Newton)

m = Mass (kg)

a = Acceleration (m/s^2)

1 Newton is defined as:

The force required to accelerate a mass of 1 kg by 1 m/s^2.

Characteristics of a Force

A force is completely specified only when the following four characteristics are known:

- Magnitude – How large the force is.
- Direction – In which direction it acts.
- Line of Action – The straight line along which force acts.
- Point of Application – The exact point where force is applied.

If any one of these is missing, the force is not fully defined.

Effects of Force in Engineering

In engineering systems, force can:

- Produce translation (straight motion)
- Produce rotation (turning effect)
- Produce deformation (change in shape)
- Produce internal stresses in materials

Example:

i- A beam under load bends (internal stresses develop).

ii- A wrench rotates a nut (rotational effect).

iii-A vehicle accelerates (translational effect).

Types of Forces in Engineering Mechanics

1. Concentrated Force (Point Load)

A force assumed to act at a single point.
Example: Weight of a hanging load attached to a beam.

2. Distributed Force
A force spread over a surface or length.

Types:
- ➔ Uniformly Distributed Load (UDL)
- ➔ Uniformly Varying Load (UVL)

Example: Weight of a wall acting along its entire base.

2.2 FORCE SYSTEMS

When multiple forces act on a body, they form a force system.

(A) Coplanar Force System

Forces acting in the same plane.

Types:
- ➢ Coplanar Concurrent Forces :- All forces meet at a single point.
- ➢ Coplanar Parallel Forces :- All forces are parallel.

(B) Non-Coplanar Force System

Forces not acting in the same plane (3D problems)

2.3 PRINCIPLE OF TRANSMISSIBILITY OF FORCES

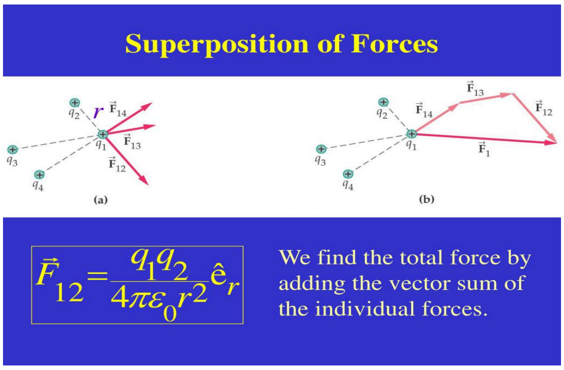
This principle states: "The external effect of a force on a rigid body remains unchanged if the force is moved anywhere along its line of action."

Important: This principle applies only to rigid bodies.

Example: If you push a box along the same straight line, the motion effect remains the same.

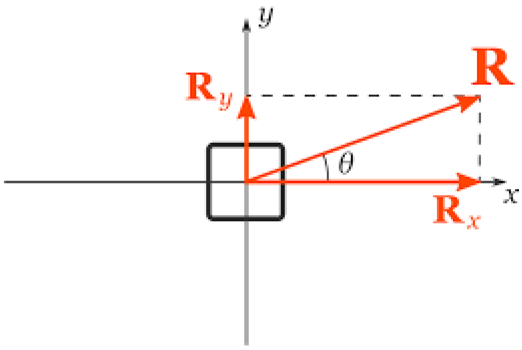
2.4 LAW OF SUPERPOSITION OF FORCES

The superposition of forces principle states that when multiple forces act on a single object simultaneously, the resultant force is the vector sum of all the individual forces. This principle is based on the linearity of forces, meaning each force operates independently of the others.



2.5 RESULTANT OF FORCES

The resultant of a system of forces is a single force that produces the same effect as the entire force system.



If R is the resultant:

$$R = \sqrt{(\Sigma Fx)^2 + (\Sigma Fy)^2}$$

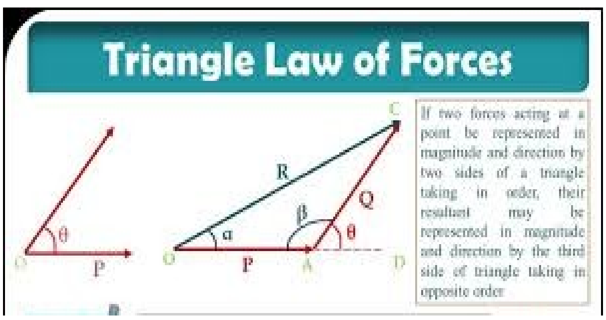
Direction:

$$\tan\theta = \Sigma Fy / \Sigma Fx$$

2.6 TRIANGLE LAW OF FORCES

Statement: If two forces acting at a point are represented in magnitude and direction by two sides of a triangle taken in order, then the third side taken in opposite order represents the resultant.

This law is used for graphical solution.



2.7 POLYGON LAW OF FORCES

Extension of triangle law for more than two forces.
If several forces acting at a point are represented by sides of a polygon taken in order, the closing side of polygon represents the resultant.

2.8 RESOLUTION OF A FORCE

Resolution means splitting a force into components.

For a force F inclined at angle θ:

Horizontal component:

$F_x = F \cos\theta$

Vertical component:

$F_y = F \sin\theta$

These components are mutually perpendicular.

2.9 FREE BODY DIAGRAM (FBD)

A free body diagram is the most important tool in engineering mechanics.
It involves:

- ➔ Isolating the body from surroundings
- ➔ Showing all external forces
- ➔ Showing support reactions
- ➔ Indicating dimensions and directions

Without FBD, solving problems becomes impossible.

2.10 EQUILIBRANT FORCE

Equilibrant force is the force which brings a system into equilibrium.

It is:

- ❖ Equal in magnitude
- ❖ Opposite in direction
- ❖ Collinear with resultant
- ❖ Equilibrant = – Resultant

2.11 LAMI'S THEOREM

If a body is in equilibrium under the action of three concurrent forces, then:
Each force is proportional to the sine of the angle between the other two forces.

Mathematically:

$F_1 / \sin \alpha = F_2 / \sin \beta = F_3 / \sin \gamma$

Conditions:

- Exactly three forces
- Concurrent forces
- Body must be in equilibrium

UNIT 03 – MOMENT

3.1 CONCEPT OF MOMENT

Meaning of Moment

In engineering mechanics, a force does not only cause translation (straight motion), it can also cause rotation.

The turning effect of a force about a point or axis is called Moment.

In simple words:

If you push a door near its hinges, it hardly rotates.
If you push it at the handle (far from hinge), it rotates easily.
This happens because the turning effect depends on distance from pivot.

Mathematical Definition of Moment

Moment = Force × Perpendicular distance from pivot

$M = F \times d$

Where:

F = Force (Newton)
d = Perpendicular distance from point (meter)

Unit of Moment: Newton-meter (N·m)

- ❖ Important Points About Moment
  - ➔ Moment depends on distance from pivot.
  - ➔ Larger distance → Larger moment.
  - ➔ If force passes through pivot → Moment = 0.
  - ➔ Moment is a vector quantity.
  - ➔ Direction of moment is either clockwise or anticlockwise.

3.2 TYPES OF MOMENT

1. Clockwise Moment

When force rotates body in clockwise direction.

2. Anticlockwise Moment

When force rotates body in anticlockwise direction.

In equilibrium problems, we assume:

- Clockwise moment positive (or negative)
- Anticlockwise opposite sign

(Sign convention depends on problem)

3.3 VARIGNON'S THEOREM (PRINCIPLE OF MOMENTS)

Statement: "The moment of the resultant of a system of forces about any point is equal to the algebraic sum of the moments of the individual forces about the same point."
This means: Instead of finding resultant first, we can directly take moments of individual forces.

Mathematically:

Moment of R = Sum of moments of all forces

This theorem simplifies calculations in beam problems.

3.4 PRINCIPLE OF MOMENTS

For a body in equilibrium:

Sum of clockwise moments = Sum of anticlockwise moments

OR

$\Sigma M = 0$

This principle is used to calculate support reactions in beams.

3.5 APPLICATIONS OF MOMENT

Moment principle is used in:

★ Levers
★ Compound levers
★ Steel yard balance
★ Safety valves
★ Beam reactions

3.6 PARALLEL FORCES

Parallel forces are forces having parallel lines of action.

Two types:

(A) Like Parallel Forces

Forces acting in same direction.

Resultant = Sum of forces.

(B) Unlike Parallel Forces

Forces acting in opposite directions.

Resultant = Difference of forces.

Position of Resultant of Parallel Forces

Position is found using moment principle:

$R \times x$ = Sum of moments

Where: x = Distance of resultant from reference point.

3.7 CONCEPT OF COUPLE

A couple consists of:

Two equal and opposite parallel forces separated by a distance.

Important:

- ➔ Resultant force = 0
- ➔ Produces rotation only
- ➔ Cannot be balanced by single force
- ➔ Moment of couple = Force × distance
- ➔ Unit: N·m

Example: Turning steering wheel.

3.8 GENERAL CONDITIONS OF EQUILIBRIUM

For coplanar force system:

$\Sigma F_x = 0$

$\Sigma F_y = 0$

$\Sigma M = 0$

These three equations are sufficient to solve beam problems.

3.9 TYPES OF SUPPORTS

1. Hinged Support

- ★ Prevents translation
- ★ Allows rotation
- ★ Provides two reactions (horizontal & vertical)

2. Roller Support

- ★ Prevents vertical movement
- ★ Allows horizontal movement
- ★ Provides one reaction

3. Fixed Support

- ★ Prevents translation and rotation
- ★ Provides three reactions

3.10 TYPES OF LOADS ON BEAMS

Point Load

- ➢ Acts at single point.
- ➢ Uniformly Distributed Load (UDL)
- ➢ Constant load per unit length.
- ➢ Uniformly Varying Load (UVL)
- ➢ Load increases gradually.

3.11 OVERHANGING BEAM

A beam extending beyond support is called overhanging beam.
Moment analysis becomes important in such beams.

UNIT 04 –
CENTRE OF GRAVITY

4.1 CONCEPT OF CENTRE OF GRAVITY

- ➔ Every body has weight.
- ➔ Weight acts vertically downward.
- ➔ The point through which total weight of body acts is called:
    - ◆ Centre of Gravity (C.G.)
    - ◆ If a body is supported at its C.G., it balances perfectly.

4.2 DIFFERENCE BETWEEN CENTRE OF GRAVITY AND CENTROID

Centre of Gravity:

- Related to weight
- Applicable to physical bodies

Centroid:

- Geometrical center of area
- Applicable to plane figures
- For uniform density, centroid = centre of gravity.

4.3 IMPORTANCE OF C.G.

- ➔ Determines stability of structures
- ➔ Important in vehicle design
- ➔ Used in balancing machines
- ➔ Important in structural design
- ➔ Lower C.G. → More stable body.

4.4 DETERMINATION OF CENTROID BY MOMENT METHOD

For composite areas:

$\bar{x} = \Sigma(Ax) / \Sigma A$
$\bar{y} = \Sigma(Ay) / \Sigma A$

Steps:

- ❖ Divide area into simple shapes.
- ❖ Find area of each shape.
- ❖ Find centroid of each shape.
- ❖ Multiply area by centroid distance.
- ❖ Apply formula.

4.5 CENTRE OF GRAVITY OF STANDARD SOLIDS

- ★ Cylinder → At mid height (h/2)
- ★ Cone → h/4 from base
- ★ Sphere → At centre
- ★ Hemisphere → 3r/8 from base

These are standard positions.

4.6 COMPOSITE BODIES

If portion is removed:

- Take removed portion as negative area.
- Apply same moment formula.

4.7 STABILITY OF BODIES

A body is stable if:

- ➢ Vertical line through C.G. falls within base.
- ➢ If line falls outside base → Body topples.

Example: Tall buildings require wide base for stability.

UNIT 5-
<u>FLOW THROUGH PIPES</u>

Flow through pipes is an important topic in fluid mechanics. It deals with the movement of fluid inside closed conduits under pressure.

5.1 Definition of Pipe Flow

Pipe flow refers to the flow of liquid through a completely filled closed conduit (pipe).

Examples:

A. Water supply pipelines
B. Oil pipelines

C. Sewage pipelines

In pipe flow, pressure difference is the main driving force.

5.2 Reynolds Number

Reynolds number (Re) determines whether flow is laminar or turbulent.

Formula:

$$Re = \rho VD / \mu$$

Where: ρ = Density
V = Velocity
D = Diameter of pipe
μ = Dynamic viscosity

Types of Flow Based on Reynolds Number:

$Re < 2000$ → Laminar Flow
$2000 < Re < 4000$ → Transition Flow
$Re > 4000$ → Turbulent Flow

5.3 Laminar and Turbulent Flow (Reynolds Experiment)

- ➔ The concept was explained by Osborne Reynolds through his famous experiment.
- ➔ He injected colored dye into water flowing in a glass tube.
- ➔ If dye flows in straight line → Laminar flow
- ➔ If dye mixes and spreads → Turbulent flow

5.4 Critical Velocity

Critical velocity is the velocity at which flow changes from laminar to turbulent.

Formula:

$$V_c = (Re \times \mu) / (\rho D)$$

It depends on:

- Viscosity
- Density
- Diameter

5.5 Velocity Distribution in Laminar Flow

In laminar flow:

- ❖ Velocity is maximum at center

- ❖ Velocity is zero at pipe wall
- ❖ Velocity distribution is parabolic
- ❖ This happens due to viscosity.

5.6 Head Loss in Pipes

When fluid flows in pipe, energy is lost due to friction and other factors.

1. Head Loss Due to Friction

Given by Darcy-Weisbach formula:

$$hf = (fL\ V^2) / (2gD)$$

Where: f = friction factor

L = length

D = diameter

2. Minor Losses

These include:

- ➔ Sudden Expansion
- ➔ Sudden Contraction
- ➔ Entrance Loss
- ➔ Exit Loss
- ➔ Bend Loss
- ➔ Obstruction Loss

All these cause energy loss.

5.7 Flow Between Two Reservoirs

When two reservoirs are connected by a long pipe:

Flow occurs due to difference in water level.

Head loss = Difference in water levels

Used in:

Water supply systems

5.8 Pipes in Series

Pipes connected one after another.

Total head loss = Sum of individual losses

Discharge is same in all pipes.

5.9 Pipes in Parallel

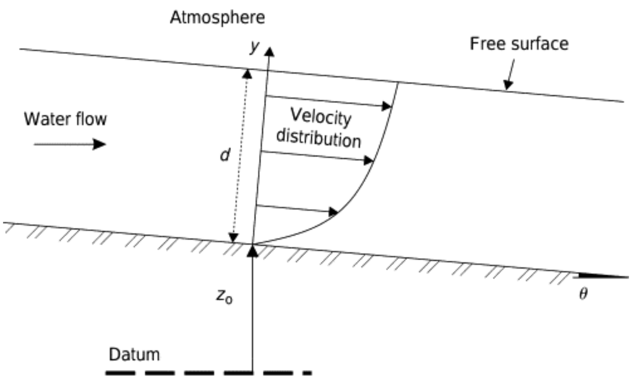
- Pipes connected side by side.
- Head loss is same in each pipe

Total discharge = Sum of individual discharges

UNIT 6-
FLOW THROUGH OPEN CHANNELS

6.1 Definition of Open Channel

An open channel is a waterway, canal or conduit in which a liquid flows with a free surface. An open channel flow describes the fluid motion in open channel. In most applications, the liquid is water and the air above the flow is usually at rest and at standard atmospheric pressure.



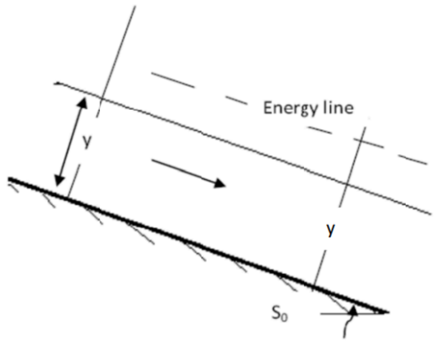
Examples:

- Rivers
- Canals

6.2 Types of Flow in Open Channel

1. Uniform Flow

If the flow properties, say the depth of flow in an open channel remain constant along the length of the channel, the flow is said to be uniform.



- *Uniform flow through open channel*

2. Non-Uniform Flow

A flow in which the flow properties vary along the channel is termed as non-uniform flow.

6.3 Chezy's Formula

Used to calculate velocity of flow.

$$V = C \sqrt{(RS)}$$

Where: C = Chezy constant

R = Hydraulic radius

S = Slope

6.4 Manning's Formula

More commonly used formula.

$V = (1/n) R^{(2/3)} S^{(1/2)}$

Where: n = Manning's coefficient

6.5 Most Economical Channel Section

A channel section that carries maximum discharge with minimum area.

(i) Rectangular Section

Condition: Width = 2 × Depth

(ii) Trapezoidal Section

Half of top width = sloping side length

6.6 Head Loss in Open Channel

Energy loss occurs due to:

- ➔ Friction
- ➔ Obstruction
- ➔ Change in section

UNIT 7-
FLOW MEASUREMENT

Flow measurement devices are used to measure discharge of fluid.

7.1 Venturimeter

a precision flow-measurement device used in engineering mechanics to measure the rate of fluid flow (discharge) through a pipe, operating on Bernoulli's principle.

Installed in pipe to measure discharge.
It has:

- ★ Converging section
- ★ Throat
- ★ Diverging section

Application: Water supply pipelines

7.2 Orifice and Orifice Meter

- ➢ An orifice is a small opening in pipe.
- ➢ Used to measure discharge.

Discharge formula:

$Q = Cd\ A\ \sqrt{(2gH)}$

Where: Cd = Coefficient of discharge

7.3 Pitot Tube

a fundamental engineering mechanics instrument used to measure fluid flow velocity (liquids and gases) by determining the difference between stagnation (total) pressure and static pressure

Used in:

- Aircraft
- Wind tunnels

7.4 Mouthpiece

a mouth piece is a short length of the pipe about three times its diameter connected to the face of an orifice, which is provided in the side or bottom of the vessel. It is used for the measurement of discharge of large quantities of liquid since; the rate of discharge through a mouth piece will be more than that of an orifice, for the same diameter and head.

7.5 Current Meter

The Current Meter is a world recognised design instrument for measuring the velocity of water in shallow natural water courses, rivers, canals, and pipe line. The provides solutions for all velocity measuring applications.

7.6 Notches and Weirs

Notches and weirs are hydraulic structures used to measure or control the flow rate (discharge) of liquids in open channels, tanks, and rivers.

NOTCHES

- ➔ A notch is typically a small, sharp-edged opening in a vertical plate attached to a tank or small channel, with the upstream liquid level below the top edge.
- ➔ Used to measure discharge in open channels.

Types of Notches:

- ❖ Rectangular notch
- ❖ Triangular (V-notch)
- ❖ Trapezoidal notch

WEIR

- ➔ A weir is a larger, often concrete or masonry, obstruction built across a river or open channel
- ➔ Weir is similar to notch but larger in size.