Fluid Mechanics (Civil)

LECTURE NOTES

Module-I

Branch - Civil Engineering

B TECH

Semester – 4th Semester

Department of Civil Engineering

Govt College of Engineering, Keonjhar

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Definition

Mechanics is the oldest physical science that deals with both stationary and moving bodies under the influence of forces. The branch of mechanics that deals with bodies at rest is called statics, while the branch that deals with bodies in motion is called dynamics.

The sub category fluid mechanics is defined as the science that deals with the behaviour of fluids at rest (*fluid statics)* or in motion (*fluid dynamics), and the interaction of fluids with solids* or other fluids at the boundaries.

The study of fluids at rest is called fluid statics.

PROPERTIES OF FLUIDS

DENSITY or MASS DENSITY

The density, or more precisely, the volumetric mass density, of a substance is its mass per unit volume. The symbol most often used for density is ***ρ*** (Greek letter rho).

Mathematically, density is defined as mass divided by volume

$\rho =$

Where ρ is the density, m is the mass, and V is the volume. In some cases (for instance, in the United States oil and gas industry), density is loosely defined as its weight per unit volume.

SPECIFIC WEIGHT or WEIGHT DENSITY

The specific weight (also known as the unit weight) is the weight per unit volume of a matterial. It is denoted as the symbol w.

Mathematically,

$w = \rho g$

SPECIFIC GRAVITY

It is defined as the ratio of the weight density of a fluid to weight density of a standard fluid. For liquids the standard fluid is taken as water and for gases the standard fluid is given as air. It is denoted as S.

S(for liquids) =

S(for gases) =

COMPRESSIBILITY

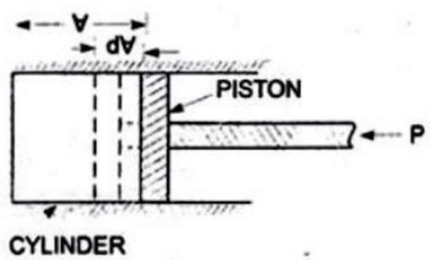
Compressibility is a measure of the relative volume change of a fluid or solid as a response to a pressure (or mean stress) change.

Compressibility is the reciprocal of the bulk modulus of elasticity, K which is defined as the ratio of compressive stress to volumetric strain.

Consider a cylinder fitted with a piston as shown in the Fig. Let *V= Volume of a gas enclosed in the cylinder*

p =Pressure of gas when volume is V

Let the pressure is increased *to p+ dp, the volume of gas* decreases from *V to V –dV.*



Then increase in pressure = dp

Decrease in volume = dV

Volumetric strain = -dV/V

-ve sign means the volume decreases with increase of pressure.

Bulk modules $K = \frac{\text{Increase of pressure}}{\text{Volumetric strain}}$

$$= \frac{dp}{\frac{-dV}{V}} = -\frac{dp}{dV}V$$

ELASTICITY

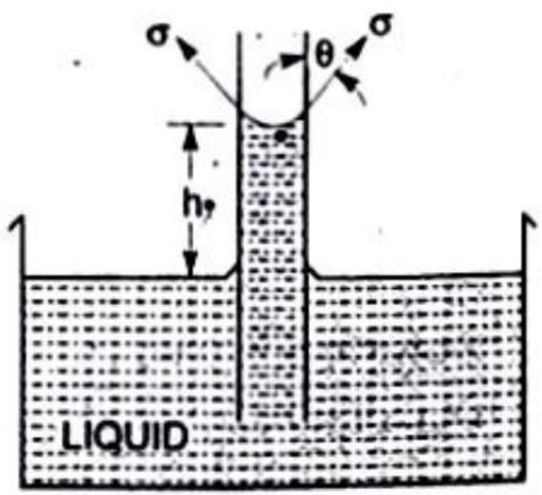
Elasticity is the ability of a body to resist a distorting influence or stress and to return to its original size and shape when the stress is removed. Solid objects will deform when forces are applied on them. If the material is elastic, the object will return to its initial shape and size when these forces are removed.

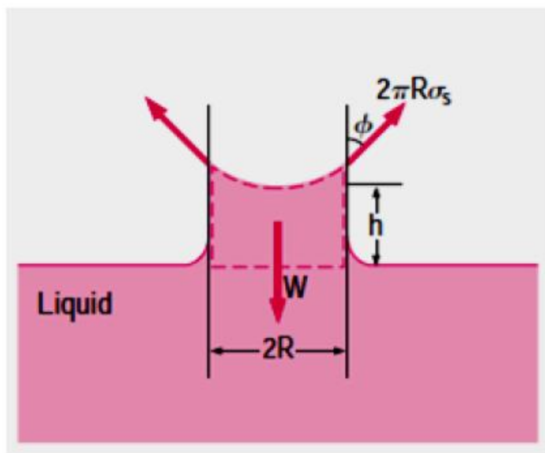
SURFACE TENSION

It is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquids such that the contact surface behaves like a membrane under tension. The magnitude of this force per unit length of the free surface will have the same value as the surface energy per unit area. It is denoted as (called sigma).Unit is N/m.

CAPILLARITY

Capillarity is defined as a phenomenon of rise or fall of a liquid surface in small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid. The rise of liquid surface is known as capillary rise while the fall of liquid surface is known as capillary depression. It is expressed in terms of cm or mm of liquid. Its value depends upon the specific weight of the liquid, diameter of the tube and surface tension of the liquid.





Consider a glass tube of small diameter ‘d’ opened at both ends and is inserted in a liquid, say water.The liquid will rise in the tube above the level of the liquid. Let h = the height of the liquid in the tube. Under a state of equilibrium, the weight of the liquid of height h is balanced by the force at the surface of the liquid in the tube. But the force at the surface of the liquid in the tube is due to surface tension.

Expression for Capillary Rise…

Let σ= Surface tension of liquid

θ= Angle of contact between the liquid and glass tube

The weight of the liquid of height h in the tube = (Area of the tube x h) x ρx g

$$= \frac{\pi}{4} d^2 \times h \times \rho \times g$$

where ρ = Density of liquid

Vertical component of the surface tensile force

$$= (\sigma \times \text{Circumference}) \times \cos\theta$$

$$= \sigma \times \pi d \times \cos\theta$$

For equilibrium, equating (1.17) and (1.18), we get

$$\frac{\pi}{4} d^2 \times h \times \rho \times g = \sigma \times \pi d \times \cos\theta$$

or

$$h = \frac{\sigma \times \pi d \times \cos\theta}{\frac{\pi}{4} d^2 \times \rho \times g} = \frac{4\sigma\cos\theta}{\rho \times g \times d}$$

VISCOSITY

It is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid. When two layers of a fluid, a distance ‘dy’ apart, move one over the other at different velocities, say u and u+du.

This shear stress is proportional to the rate of change of velocity with respect to *y. It is denoted by symbol* τ called Tau. Mathematically,

$$\tau \propto \frac{du}{dy}$$

where μ(called m*u) is the constant of proportionality and is known as the coefficient of dynamic viscosity* or only viscosity. It *represents the rate of shear strain or rate of shear deformation or velocity gradient. we have*Thus viscosity is also defined as the shear stress required to produce unit rate of shear strain.

$$\mu = \frac{\text{Shear stress}}{\frac{\text{Change of velocity}}{\text{Change of distance}}} = \frac{\text{Force/Area}}{\left(\frac{\text{Length}}{\text{Time}}\right) \times \frac{1}{\text{Length}}}$$

$$= \frac{\text{Force/(length)}^2}{\frac{1}{\text{Time}}} = \frac{\text{Force} \times \text{Time}}{(\text{Length})^2}$$

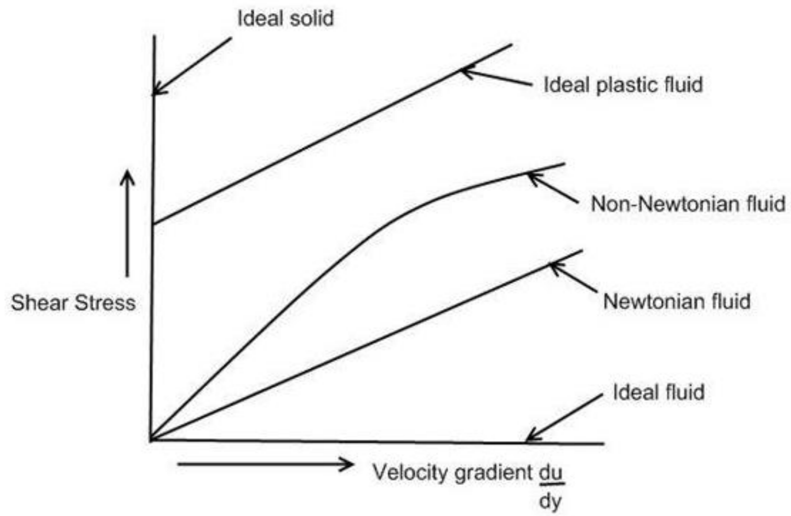
It is defined as the ratio between the dynamic viscosity and density of fluid.lt is denoted by the Greek symbol (ν) called 'nu'.

Newtons law of viscosity:

It states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain. The constant of proportionality is called the co-efficient viscosity. Fluids which obey the above relation are known as Newtonian fluids and the fluids which do not obey the above relation are called Non-newtonian fluids.

Variation of Viscosity with Temperature

Temperature affects the viscosity. The viscosity of liquids decreases with the increase of temperature while the viscosity of gases increases with increase of temperature. This is due to reason that the viscous forces in a fluid are due to cohesive forces and *molecular* *momentum transfer*. *In liquids the cohesive forces predominates the molecular momentum* transfer due to closely packed molecules and with the increase in temperature, the cohesive forces decreases with the result of decreasing viscosity.



Fluid statics

Pressure is defined as a normal force exerted by a fluid per unit area. We speak of pressure only when we deal with a gas or a liquid. The counterpart of pressure in solids is normal stress. Since pressure is defined as force per unit area, it has the unit of newtons per square meter (N/m2), which is called a pascal (Pa). That is,

1 Pa = 1 N/m2

The pressure unit pascal is too small for pressures encountered in practice. Therefore, its multiples kilopascal (1 kPa =103Pa) and megapascal (1 MPa =106Pa) are commonly used.

- The actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum (i.e., absolute zero pressure). Most pressure-measuring devices, however, are calibrated to read zero in the atmosphere, and so they indicate the difference between the absolute pressure and the local atmospheric pressure. This difference is called the gage pressure.

- Pressures below atmospheric pressure are called vacuum pressures and are measured by vacuum gages that indicate the difference between the atmospheric pressure and the absolute pressure.
- Absolute, gage, and vacuum pressures are all positive quantities and are related to each other by

$$P_{gage} = P_{abs} - P_{atm}$$
$$P_{vac} = P_{atm} - P_{abs}$$

Pressure is the compressive force per unit area, and it gives the impression of being a vector. However, pressure at any point in a fluid is the same in all directions. That is, it has magnitude but not a specific direction, and thus it is a scalar quantity.
the pressure at a point in a fluid has the same magnitude in all directions. It can be shown in the absence of shear forces that this result is applicable to fluids in motion (rigid body motion, no relative motion between layers) as well as fluids at rest. This important result is known as **Pascal's law.**

Pressure in a fluid increases with depth because more fluid rests on deeper layers, and the effect of this "extra weight" on a deeper layer is balanced by an increase in pressure.

Where W =mg = ρgxz is the weight of the fluid element.

Dividing by Δx and rearranging gives

$\gamma s = \rho g$ is the specific weight of the fluid.

Thus, we conclude that the pressure difference between two points in a constant density fluid is proportional to the vertical distance z between the points and the density $\rho$of the fluid. In other words, pressure in a fluid increases linearly with depth.

Pressure variation with depth:

For fluids whose density changes significantly with elevation, a relation for the variation of pressure with elevation can be written as

$$\frac{dP}{dz} = -\rho g$$

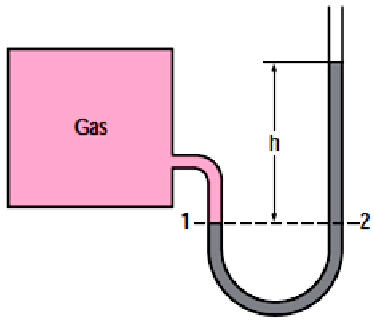
Pressure is independent of the shape of the container. The pressure is the same at all points on a given horizontal plane in the same fluid.

The Manometer

An elevation change of Δz in a fluid at rest corresponds to $dP/\rho g$, which suggests that a fluid column can be used to measure pressure differences. A device based on this principle is called a **manometer,** and it is commonly used to measure small and moderate pressure differences. A manometer mainly consists of a glass or plastic U-tube containing one or more fluids such as mercury, water, alcohol, or oil. To keep the size of the manometer to a manageable level, heavy fluids such as mercury are used if large pressure differences are anticipated.

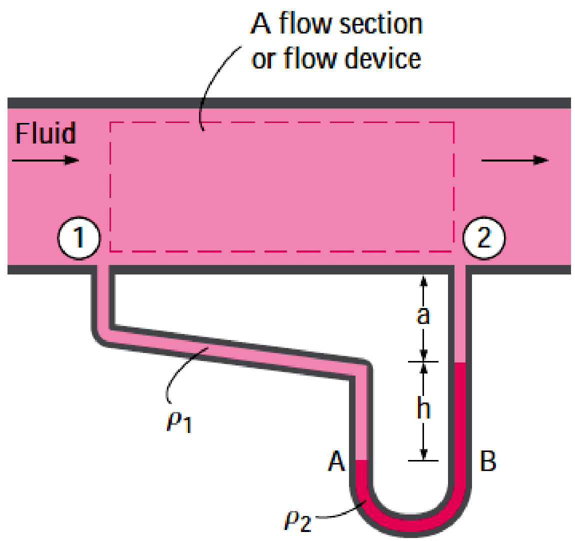
U-tube manometer

Consider the manometer that is used to measure the pressure in the tank. Since the gravitational effects of gases are negligible, the pressure anywhere in the tank and at position 1 has the same value. Furthermore, since pressure in a fluid does not vary in the horizontal direction within a fluid, the pressure at point 2 is the same as the pressure at point 1, P2=P1.



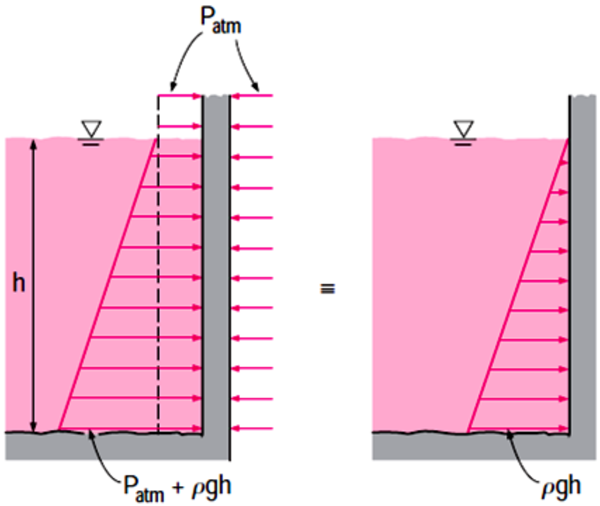
Differential Manometer

Manometers are particularly well-suited to measure pressure drops across a horizontal flow section between two specified points due to the presence of a device such as a valve or heat exchanger or any resistance to flow. This is done by connecting the two legs of the manometer to these two points, as shown in the Fig. The working fluid can be either a gas or a liquid whose density is ρ1. The density of the manometer fluid is ρ2, and the differential fluid height is *h*.



Hydrostatic Forces on Submerged Plane surfaces

A plate exposed to a liquid, such as a gate valve in a dam, the wall of a liquid storage tank is subjected to fluid pressure distributed over its surface. On a plane surface, the hydrostatic forces form a system of parallel forces, and we often need to determine the magnitude of the force and its point of application, which is called the **center of pressure.**



(a) P_{atm} considered (b) P_{atm} subtracted

In most cases, the other side of the plate is open to the atmosphere (such as the dry side of a gate), and thus atmospheric pressure acts on both sides of the plate, yielding a zero resultant. In such cases, it is convenient to subtract atmospheric pressure and work with the gage pressure only. The magnitude of the resultant force acting on a plane surface of a completely submerged plate in a homogeneous (constant density) fluid is equal to the product of the pressure the centroid of the surface and the area A of the surface.

Centre of pressure

The line of action of the resultant hydrostatic force, in general, does not pass through the centroid of the surface—it lies underneath where the pressure is higher. The point of intersection of the line of action of by equating the moment of the resultant force to the moment of the distributed pressure force about the *x-axis. It gives* the resultant force and the surface is the **center of pressure.**

The vertical location of the line of action is determined by the following equation:

$$y_P F_R = \int_A yP\,dA = \int_A y(P_0 + \rho g y \sin\theta)\,dA = P_0 \int_A y\,dA + \rho g \sin\theta \int_A y^2\,dA$$

Center of pressure

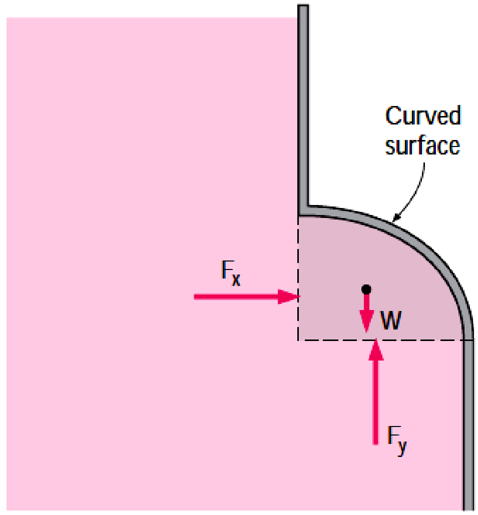
where yPis the distance of the center of pressure from the x-axis and

$$I_{xx,\,O} = \int_A y^2\,dA$$

is the second moment of area (also called the area moment of inertia) about the x-axis. The second moments of area are widely available for common shapes in engineering handbooks, but they are usually given about the axes passing through the centroid of the area. Fortunately, the second moments of area about two parallel axes are related to each other by the **parallel axis theorem,** which in this case is expressed as

Hydrostatic Forces on submerged curved surfaces

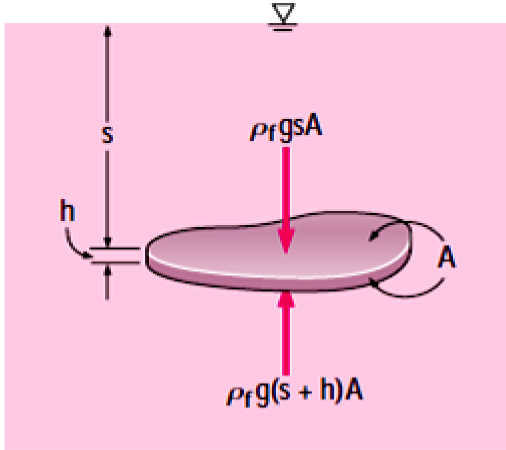
When a curved surface is above the liquid, the weight of the liquid and the vertical component of the hydrostatic force act in the opposite directions.



Buoyancy, Floatation, and stability

It is a common experience that an object feels lighter and weighs less in a liquid than it does in air. This can be demonstrated easily by weighing a heavy object in water by a waterproof spring scale. Also, objects made of wood or other light materials float on water.

These and other observations suggest that a fluid exerts an upward force on a body immersed in it. This force that tends to lift the body is called the **buoyant force** and is denoted by FB. The buoyant force is caused by the increase of pressure in a fluid with depth. Consider, for example, a flat plate of thickness h submerged in a liquid of density ρf parallel to the free surface, as shown in the Fig. The area of the top (and also bottom) surface of the plate is A, and its distance to the free surface is s. The pressures at the top and bottom surfaces of the plate are **ρfgs** and **ρfg(s + h),** respectively.

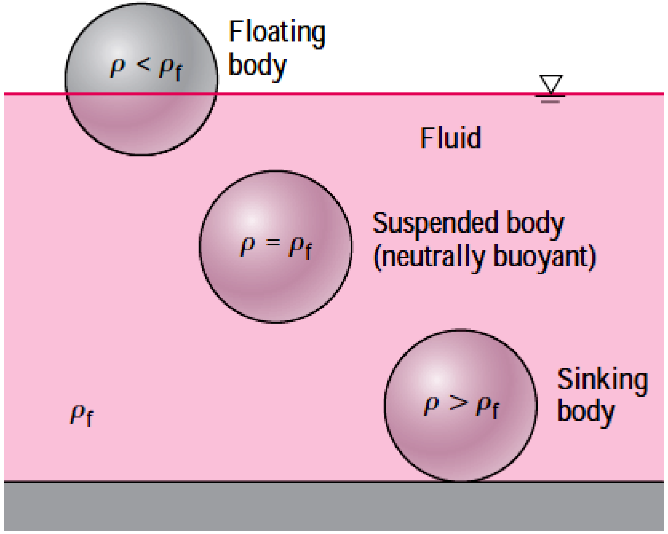


A body immersed in a fluid

1)Remains at rest at any point in the fluid when its density is equal to the density of the fluid,

2)Sinks to the bottom when its density is greater than the density of the fluid, and

3)Rises to the surface of the fluid and floats when the density of the body is less than the density of the fluid



Stability of Immersed and Floating Bodies

An important application of the buoyancy concept is the assessment of the stability of immersed and floating bodies with no external attachments. This topic is of great importance in the design of ships and submarines. A body is said to be in a stable equilibrium position if, when displaced, it returns to its equilibrium position. Conversely, it is in an unstable equilibrium position if, when displaced (even slightly), it moves to a new equilibrium position. Stability considerations are particularly important for submerged or floating bodies since the centre of buoyancy and gravity do not necessarily coincide. A small rotation can result in either a restoring or overturning couple.