# Forces on Submerged Surfaces

The forces on submerged surfaces can also be affected by other factors, such as the orientation and angle of the surface, the surface roughness, and the presence of other objects or obstructions in the fluid. Therefore, the calculation and analysis of these forces require a detailed understanding of fluid mechanics and the physical properties of the surface and the fluid. By understanding the forces on submerged surfaces, engineers and designers can optimize the design and performance of various structures and devices, and ensure their safety and stability in different operating conditions.

## Types of Forces on Submerged Surfaces

There are several types of forces on submerged surfaces, including hydrostatic forces, hydrodynamic forces, and other forces caused by fluid flow or external factors. Here are some of the main types of forces on submerged surfaces:

### Hydrostatic Forces

Hydrostatic forces are the forces exerted on a submerged surface due to the pressure distribution of the fluid. These forces are always perpendicular to the surface, and their magnitude is dependent on the depth of the surface, the surface area, and the density of the fluid. Hydrostatic force is commonly used in various applications such as determining the buoyancy force on a submerged object or the force on a dam due to the water pressure. The calculation of hydrostatic forces involves using the basic principles of fluid mechanics and the physical properties of the fluid and the surface. For example, in a fluid with uniform density and pressure distribution, the hydrostatic force on a flat surface is proportional to the depth of the surface and the surface area. In other cases, where the fluid density or pressure distribution is non-uniform, the calculation of hydrostatic forces can become more complex.

### Hydrodynamic Forces

Hydrodynamic forces are the forces exerted on a submerged surface due to the motion of the fluid. These forces are dependent on the velocity of the fluid, the viscosity of the fluid, and the shape and size of the surface. The hydrodynamic force is commonly used in various applications such as determining the drag force on a ship or the lift force on an airplane wing. The calculation of hydrodynamic forces is complex and requires advanced knowledge of fluid mechanics and computational methods. One approach to calculating these forces is through the use of the Navier-Stokes equations, which describe the motion of fluid particles in response to applied forces. However, due to the complexity of these equations, simplified models and numerical simulations are often used to estimate the hydrodynamic forces on a surface.

### Lift Forces

Lift forces are the forces that act perpendicular to the flow direction and are caused by differences in the pressure distribution on a surface. These forces are commonly used in aerodynamic applications, such as the lift force on an airplane wing or the drag force on a wind turbine blade. The lift force is proportional to the velocity of the fluid, the density of the fluid, the shape and size of the surface, and the angle of attack. The angle of attack is the angle between the surface and the direction of the flow. This is a key concept for the GATE CE exam. When the angle of attack is small, the lift force is proportional to the angle of attack, and the surface acts like a flat plate. However, as the angle of attack increases, the lift force increases up to a certain point, after which it begins to decrease. This phenomenon is called the stall and is a major factor in the design and performance of aircraft wings.

### Drag Forces

Drag forces are the forces that act parallel to the flow direction and are caused by the friction between a surface and the fluid. These forces are commonly used in various applications, such as determining the drag force on a car or the flow resistance of a pipeline. The drag force is proportional to the velocity of the fluid, the density of the fluid, the shape and size of the surface, and the viscosity of the fluid. The calculation of drag forces is complex and requires advanced knowledge of fluid mechanics and computational methods. One common approach to calculating drag forces is through the use of the Reynolds number, which is a dimensionless parameter that relates the inertial forces to the viscous forces in a fluid. The Reynolds number is used to predict the onset of turbulence, which can significantly increase the drag force on a surface.

### Vortex-induced Forces

Vortex-induced forces are a type of hydrodynamic force that is generated by the formation of vortices in the fluid flow around a submerged surface. Vortices are swirling flow patterns that occur when fluid flows around a surface and can be generated by factors such as flow separation, wakes, and shear layers. Vortex-induced forces can cause significant vibrations and stresses on a submerged surface, which can affect the performance and lifespan of various structures and devices. One common example of vortex-induced forces is the vibration of cables and bridges caused by wind-induced vortices. As wind flows around a bridge or cable, it can generate vortices that cause the cable to vibrate, which can lead to fatigue and eventual failure. Another example is the vortex shedding that occurs behind a cylinder or sphere in fluid flow, which can generate oscillating forces that can cause structural damage or noise.

## Hydrostatic Forces on an Inclined Plane Submerged Surface

Consider a plane surface of arbitrary shape immersed in a liquid in such a way that the plane of the surface makes an angle θ with the free surface of the liquid as shown in the figure.

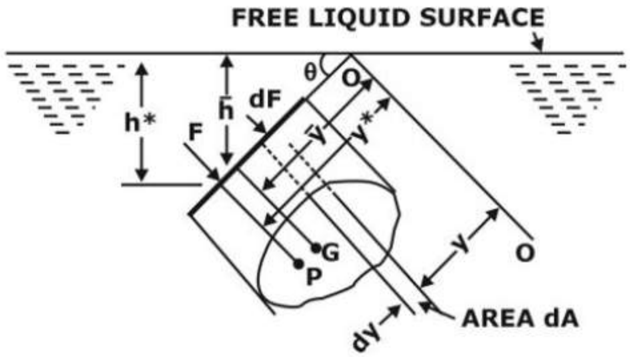



**Fig: Inclined Plane submerged surface in a liquid**

## Formula for Hydrostatic Forces on an Inclined Plane Submerged Surface

The force is given by: $\mathbf{F = \rho g A \bar{h}}$

Hence force is independent of the angle of inclination (θ). Thus, a force for Horizontal and vertical submerged bodies will also be given by the same expression.

Centre of Pressure (h*)

It is defined as the point where the whole hydrostatic force is assumed to act.

$$h^* = \frac{I_G \sin^2 \theta}{A\bar{h}} + \bar{h}$$

Plane vertical surface (θ = 90°)

Thus, the Centre of pressure for the vertical submerged surface is given by

$$h^* = \frac{I_G \sin^2 \theta}{A\bar{h}} + \bar{h}$$

$$h^* = \frac{I_G \sin^2 90^\circ}{A\bar{h}} + \bar{h}$$

$$h^* = \frac{I_G}{A\bar{h}} + \bar{h}$$

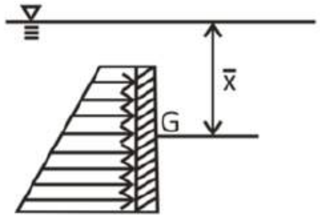



**Fig: Vertical submerged surface**

Plane horizontal surface (θ = 0°)

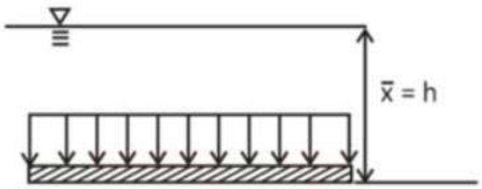



**Fig: Horizontal submerged surface**

centre of pressure for the vertical submerged surface is given by:

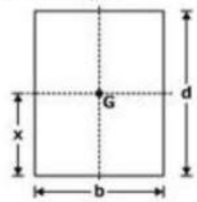
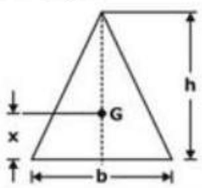
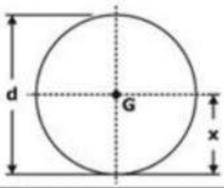
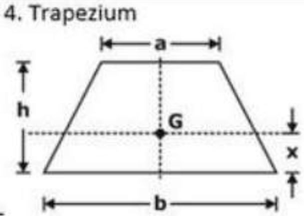
$$h^* = \frac{I_G \sin^2 \theta}{A\bar{h}} + \bar{h}$$

$$h^* = \frac{I_G \sin^2 0^\circ}{A\bar{h}} + \bar{h}$$

$$h^* = \bar{h}$$

Thus, the centre of pressure of a body submerged parallel to free surface will be equal to the distance of centroid of the body from the free surface.

The moments of inertia and other geometric properties of some important plane surfaces

| Plane surface | C.G. from the base | Area | Moment of inertia about an axis pasing through C.G. and parallel to base ($I_G$) | Moment of inertia about ($I_0$) |
|---|---|---|---|---|
| 1. Rectangle   | $x = \frac{d}{2}$ | bd | $\frac{db^3}{12}$ | $\frac{db^3}{3}$ |
| 2. Triangle   | $x = \frac{h}{3}$ | $\frac{bh}{2}$ | $\frac{bh^3}{36}$ | $\frac{bh^3}{12}$ |
| 3. Circle   | $x = \frac{d}{2}$ | $\frac{\pi d^2}{4}$ | $\frac{\pi d^4}{64}$ | – |
| 4. Trapezium   | $x = \left(\frac{2a+b}{a+b}\right)\frac{h}{3}$ | $\frac{(a+b)}{2} \times h$ | $\left(\frac{a^2+4ab+b^2}{36(a+b)} \times h^3\right)$ | – |

## Hydrostatic Forces on Curved Surfaces

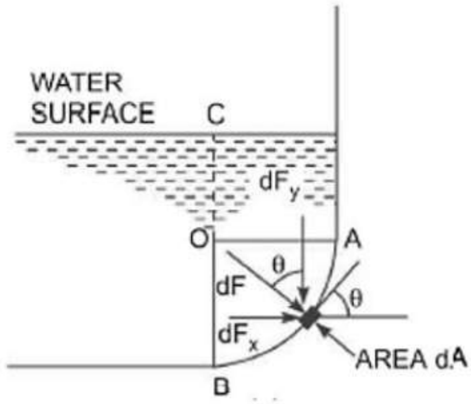



**Fig: Hydrostatic force on a curved surface**

- AC = curved surface
- FY = vertical component of FR
- FX = Horizontal component of FR
- FR = Resultant force on a curved surface.

# Applications of Forces on submerged Surfaces

Forces on submerged surfaces have a wide range of applications in various fields, such as civil engineering, mechanical engineering, marine engineering, and aerospace engineering. Here are some examples:

1. **Dams and levees:** Hydrostatic forces play a critical role in the design and analysis of dams and levees. The hydrostatic force acting on the structure must be calculated accurately to ensure the stability and safety of the structure.
2. **Ships and submarines:** Hydrodynamic forces, including lift, drag, and vortex-induced forces, are important factors in the design and performance of ships and submarines. The shape and size of the hull, the propulsion system, and the control systems must be optimized to minimize the drag and maximize the lift.
3. **Wind turbines:** Hydrodynamic forces are also important in the design of wind turbines. The lift and drag forces on the turbine blades must be optimized to maximize the energy output and minimize the structural stress.
4. **Aircraft:** Lift and drag forces are critical in the design and operation of aircraft. The shape and size of the wing, the angle of attack, and the airspeed must be optimized to maximize the lift and minimize the drag.
5. **Heat exchangers:** Hydrodynamic forces can affect the performance of heat exchangers, such as tube bundles and shell-and-tube heat exchangers. The flow rate, velocity, and pressure drop must be optimized to maximize the heat transfer and minimize the pressure drop.
6. **Bridges and towers:** Vortex-induced forces can cause vibrations and fatigue in cables, towers, and other structural components of bridges and towers. The

geometry and orientation of the structure must be optimized to minimize the formation of vortices and the resulting forces.

In each of these applications, understanding and controlling the forces on submerged surfaces is critical to ensuring the safety, efficiency, and performance of the structure or device. Engineers and scientists must use advanced knowledge of fluid mechanics and computational methods to accurately calculate and predict these forces, and to optimize the design and operation of the structure or device.