Streeter . B.S Messey | Fluid Mechanics MECH1201 —wednesday
Som

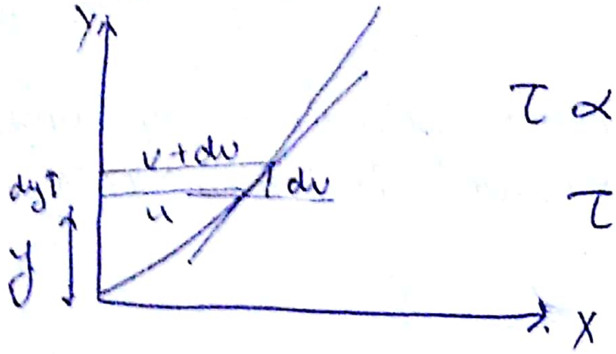
Fluid is a substance which deforms continuously under the action of shear force however it may be small.

• Properties:-

1) Density (ρ) $\to$ kg/m^3.
2) Specific weight. (γ) $\to$ $\frac{\text{Weight}}{\text{Volume}} = N/m^3$.
3) Specific volume (v) $\to$ $\frac{\text{Volume}}{\text{mass}} = \frac{1}{\rho} = m^3/kg$.
4) Specific gravity $\to$ $\frac{\text{Density of any substance}}{\text{Density of pure water at } 4^\circ c}$

• Viscosity $\to$ definition
  Causes of Viscosity $\to$ Intermolecular force of cohesion
  $\to$ Molecular momentum exchange
• State Newton's law of viscosity.
  Dimensional formula & unit of viscosity.
  Kinematic viscosity.

• Viscosity is a property by which ~~ti~~ a fluid offers resistance to deformation under the influence of a shear force.



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

$$\tau = \mu \frac{du}{dy} \Rightarrow \mu = \frac{\tau}{du/dy}$$

• Newton law of viscosity :-
The straight and parallel motion of a parallel fluid, a tangential ~~force~~ stress is proportional to velocity gradient in a direction ⊥lar to the layer.

$$\tau = \mu \frac{du}{dy}$$

μ ↓ coefficient of viscosity or
" " dynamic viscosity or.
simply viscosity term.

~~F/A~~

$$\mu = \frac{M\cancel{L}T^{-2}/L^{\cancel{2}}}{\cancel{L}T^{-1}/\cancel{L}}$$

$$\boxed{1\frac{N \cdot S}{m^2} = 10 \text{ Poise}}$$

$$= \frac{MT^{-2}}{LT^{-1}} = \frac{M}{LT}$$

$$\tau = \frac{\text{dyne} \cdot \text{sec}}{cm^2} \quad (\text{Poise})$$

= Poise → $\frac{\text{dyne sec}}{cm^2}$ or $\frac{N\,sec}{m^2}$

kinematic viscosity $= \nu = \frac{\mu}{\rho\ \cancel{sec}} = \frac{L^2}{T} \left(\frac{m^2}{sec}\right) \rightarrow$ stoke $\left(\frac{cm^2}{sec}\right)$

why μ is called coefficient of dynamic viscosity
and ν is called " " kinematic viscosity?

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Viscosity → viscous Force / Drag force.

Causes of viscosity : (1) Intermolecular force of attraction (main cause for liquid).

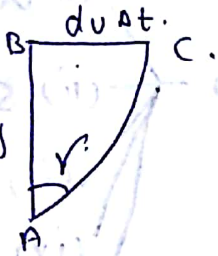
(2) Molecular momentum Exchange among gas layers. (main cause for gas).

<u>effect of viscosity</u> :—

• Velocity gradient $\left(\frac{dv}{dy}\right)$ → rate of angular deformation

γ

angular deformation



$$\gamma \simeq \tan\gamma = \frac{du\,\Delta t}{dy}.$$

∴ rate of angular deformation $= \frac{\gamma}{\Delta t} = \frac{du}{dy}$ = velocity gradient.

$\boxed{\tau = \mu \frac{du}{dy}}$ → Newton law of viscosity.

Viscous Force $= F_s = \cancel{Vis}\cdot \tau A_s$. { A_s = surface Area }

<u>Variation of viscosity with temp</u>

For liq → $\mu\downarrow$ $T\uparrow$. cohesive force consideration.

For gas → $\mu\uparrow$ $T\uparrow$ molecular momentum more

<u>No Slip condition</u> :— It refers to the situation when a fluid is in motion over a solid surface and their are exist no relative velocity between the fluid layer and the solid surface in contact. That's why when a fluid moves over a solid surface at rest the

velocity of fluid layer in contact with solid surface have zero velocity

For static fluid, $\frac{du}{dy} = 0$ _ $\tau = 0$.

A fluid ~~wi~~ having no viscosity / Ideal fluid / Inviscid fluid ($\mu = 0$)

For real fluid $\mu > 0$, $\frac{du}{dy} > 0$

Fluid Properties
- (i) Density (ρ) → kg/m^3.
- (ii) Sp. weight (γ) → N/m^3.
- (iii) Sp. volume (v) → m^3/kg.
- (iv) Sp. gravity → (S) → Relative density (unitless)
- (v) viscosity

viscosity
causes of viscosity
unit of μ & ν
Newton's of law of viscosity.
Ideal & real fluid.
Temp. ~~de~~ effect on viscosity.
No slip condition of viscosity fluid.

Newtonian fluid ($\tau = \mu \frac{du}{dy}$)

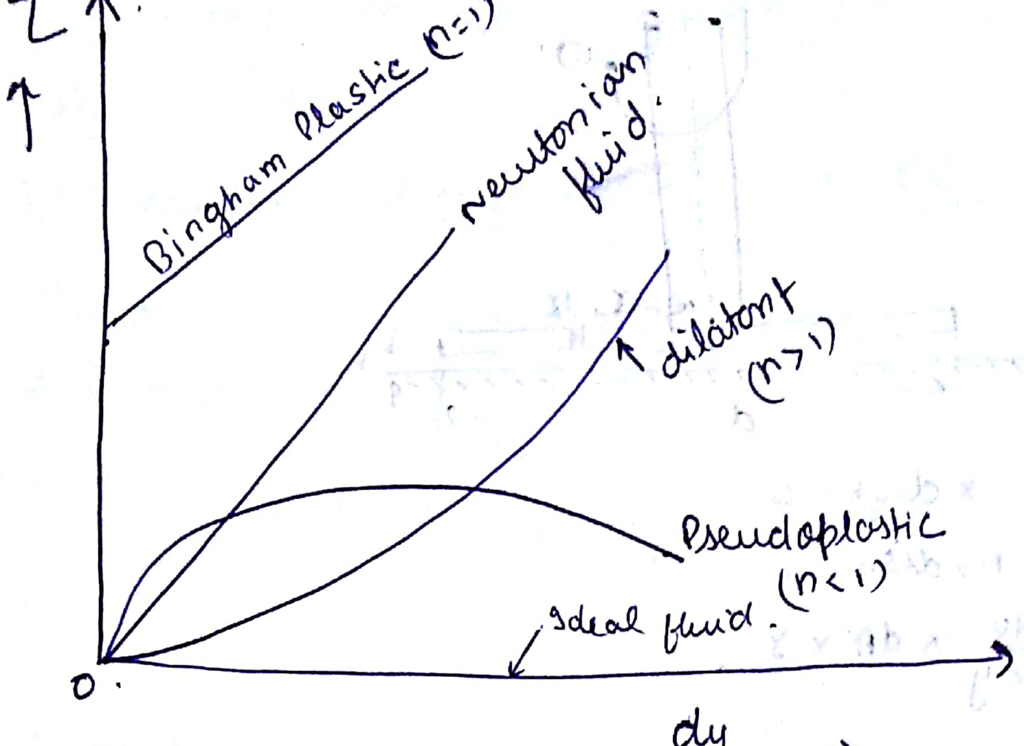
Non Newtonian fluid ($\tau = A\left(\frac{du}{dy}\right)^n + B$)

↓

Bingham Plastic (drilling muds).

Pseudoplastic (Blood, paper pulp)

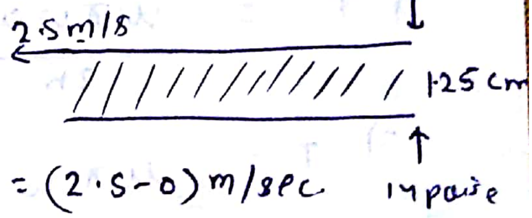
Dilatant (Butter, printer's ink)



<u>Rheology curve</u>

<u>Prob.</u> <u>2marks</u>

Two horizontal plates are placed 1.25 cm apart, the space between them is filled with oil having viscosity 14 poise. Calculate the stress shear in the oil if the upper plate is moving with the 2.5 m/sec.



$\rightarrow$ $\tau = \mu \frac{du}{dy}$

$du = (2.5 - 0)$ m/sec

$dy = 1.25$ cm

$= \frac{14 \times \cancel{2.5} \times 100}{\cancel{1.25}\ .5}$

$= 2800$ dyne/cm^2 $= 280$ N/m^2.

<u>Prob</u> A circular disc of a diameter 'd' is slowly rotate in a liquid of large viscosity 'μ' at a small distance 'h' from a fixed surface. Derive and Expression for torque 'T' necessary to maintain an angular velo 'ω',

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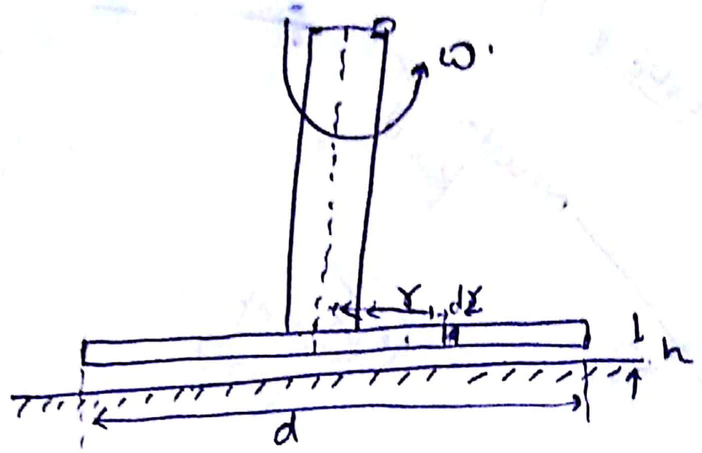


$$dT = \text{Force} \times \text{distance}$$
$$= \tau \times A \times \text{distance}$$
$$= \mu \frac{du}{dy} \times dA \times r$$
$$= \mu \times \frac{r\omega}{h} \times 2\pi r\,dr \times r$$

$$\int_0^T dT = \frac{2\pi\mu\omega}{h}\int_0^a r^3\,dr \qquad \{a = \text{radius}\}$$

$$\Rightarrow T = \frac{2\pi\mu\omega}{h}\left[\frac{r^4}{4}\right]_0^a$$

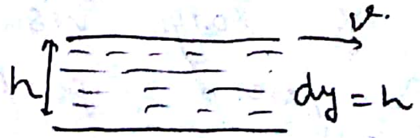
$$\Rightarrow T = \frac{\mu\pi\omega a^4}{2h}$$

$$\Rightarrow T = \frac{\mu\pi\omega (d/2)^4}{2h}$$

$$\therefore T = \frac{\mu\pi\omega d^4}{32h}$$

4) Solving Problems to find Viscous force, Torque, Power

① Linear Motion :–



$dv = v - 0 = v$

Step 1 → Calculate the velocity difference between fixed surface & moving surface. $dv = V - 0 = V$.

Step 2 → Find the clearance / gap behaviour between fixed & moving surface : $dy = h$.

Step 3 → Calculate velocity gradient . $\frac{du}{dy} = \frac{V}{h}$.

Step 4 ⇒ From Newton's law of viscosity , we can calculate shear stress , $\tau = \mu \frac{du}{dy} = \mu \frac{V}{h}$.

Step 5 → Find viscous force / Drag force

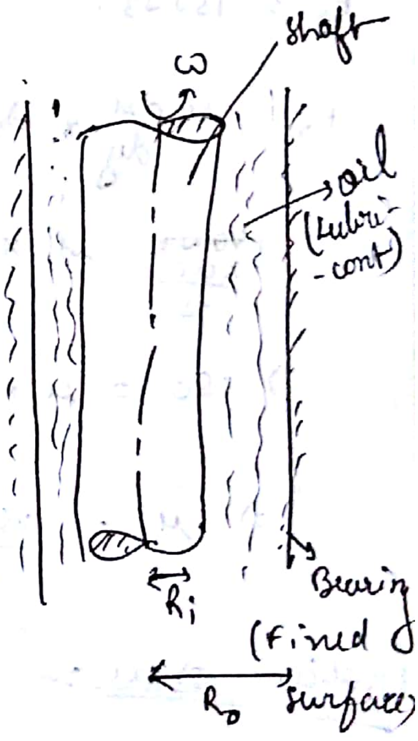
$$\boxed{F_s = \tau A_s}$$

where A_s : surface area of solid surface which is within the fluid.

Step 6 → Power , $\boxed{P = F_s \times V}$

$$\Rightarrow P = \mu \frac{du}{dy} A_s V . = \mu \frac{A_s V^2}{h}$$

II) Angular Motion :-



2) Find the circumferencial velocity at shaft surface $\boxed{V = R_i \omega}$

3) Clearance

$$dy = R_o - R_i$$

4) shear stress,

$$\boxed{\tau = \mu \frac{du}{dy} = \frac{\mu R_i \omega}{R_o - R_i} \quad \left(\begin{aligned} du &= V - 0 \\ &= R_i \omega \end{aligned}\right)}$$

5) ~~For~~ viscous force,

$$F_s = \tau A_s .$$

$$= \frac{\mu R_i \omega A_s}{R_o - R_i} = \frac{\mu R_i \omega}{R_o - R_i} (2\pi R_i L)$$

$$\boxed{F_s = \frac{2\pi \mu R_i^2 \omega L}{R_o - R_i}}$$

R_i = radius of shaft

R_o = Inner radius of Bearing

N r.p.m.

1) $\omega = \frac{2\pi N}{60}$ rad/s

6) Torque developed = Transmitted $\boxed{F_s \times R_i = \frac{2\pi \mu R_i^3 \omega L}{R_o - R_i}}$

Power required = $T\omega$.

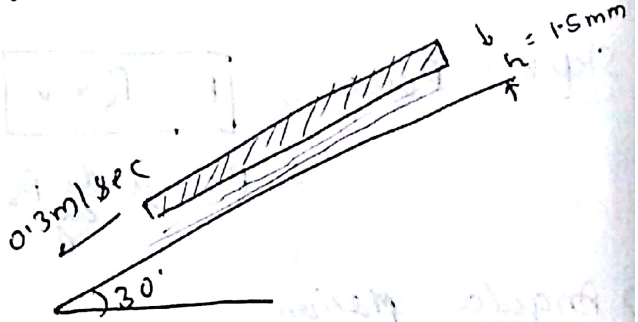
$$\boxed{\boxed{P = T\omega} = \frac{2\pi\,\omega^2 R_i^3\,\omega L}{R_o - R_i}}$$

Q) Calculate the dynamic viscosity of an oil which is use for lubrication between a square plate of size $(0.8 \times 0.8)\,m^2$ con at inclined plate with inclination angle 30°. The weight of the plate is 300 N and its slides down inclined with uniform velocity 0.3 m/sec. Thicknes of oil film = 1.5 mm.

$A_s = (0.8 \times 0.8)\,m^2$

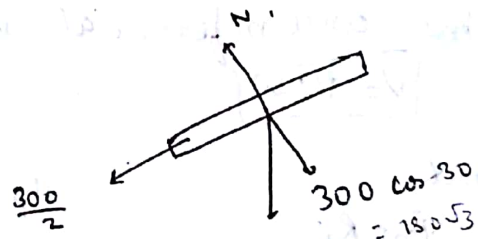
$h = 1.5 \times 10^{-3}\,m$.

$F_{s_{||}} = 150\sqrt{3}$.



$F_s' = \mu \frac{du}{dy} \times A_s$.

$\Rightarrow \cancel{150\sqrt{3}}\ \frac{300}{2} = \mu \times \frac{0.3}{1.5 \times 10^{-3}} \times 0.8 \times 0.8$



$\Rightarrow 150 = \mu \times \frac{64}{5 \times 10^{-1}}$

$\Rightarrow \mu = \frac{15 \times 5}{64} = 1.171$ ~~Poise~~ $N\text{-}s/m^2$

Problem sheet :-

1) $u(y) = \frac{2}{3}y - y^2$, $\mu = 0.863$ Pa-sec.

$\frac{du}{dy} = \frac{2}{3} - 2y$

$\tau = \mu \frac{du}{dy} = 0.863 \times \left(\frac{2}{3} - 2y\right)$

$\tau_{y=0} = 0.863 \times \frac{2}{3} = 0.575\ N/m^2$

$\tau_{y=0.15} = 0.863\left(\frac{2}{3} - 0.3\right)$

$= 0.316\ N/m^2$

2) $\mu = 8.5$ Poise.

$$\cancel{\tau_{y=20} = 8.5 \times \frac{(120-0)}{20-0} = 51 \ N/cm^2}$$

2) $\mu = 8.5$ Poise.

$V = A + By + cy^2$. $\qquad \frac{du}{dy} = B + cy$.

$V = 0$ at $y = 0$.

$V = 120$ cm/s. at $y = 20$ cm.

$\frac{du}{dy} = 0$ at $y = 20$ cm.

Substituting this value,

$A = 0$.

$20B + 400C = 120$. $\qquad | \quad 0 = B + 2 \times 20C$.

$\Rightarrow B + 20C = 6 \qquad \Rightarrow B = -40C$.

$\Rightarrow -40C + 20C = 6$

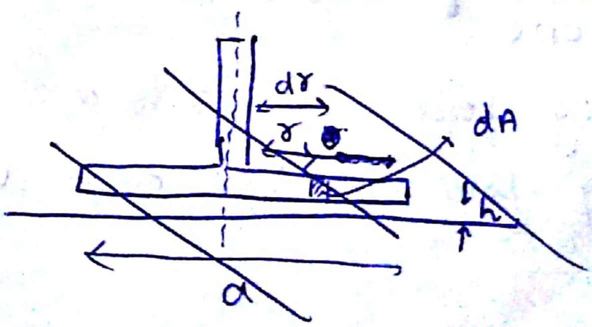
$\Rightarrow C = \frac{6}{-20} = -0.3 \qquad | \quad B = 12$.

$V = 12y - 0.3y^2$.

$\frac{du}{dy} = 12 - 0.6y$.

distance	du/dy (s^{-1})	$\tau = 8.5 \times du/dy \times 0.1$ (N/m^2)
0	12	10.2
10	6	5.1
20	0	0

3).



ressibility of any substance is a measure of change in volume under the action of external s, namely, the normal compressive forces.

normal compressive stress of any fluid element rest is known as hydrostatic pressure.

he compressibility of the liquid is expressed by its Bulk Modulus of Elasticity (K). If the pressure of unit volume of liquid is increased by 'dP', it will cause a volume decrease '-dV'; the ratio $\left(\frac{-dP}{dV}\right)$ is the Bulk Modulus of Elasticity (K). For any olume V of liquid,

$$\left(K = \frac{-dP}{\frac{dV}{V}} \right)$$

Its unit is Pascal.

• (Compressibility is the reciprocal of Bulk Modulus of Elasticity).

a) A liquid compressed in a cylinder has a volume of 1 L at 1 MN/m^2 and a volume of 995 cm^3 at 2 MN/m^2. What is its Bulk Modulus of Elasticity.

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$\rightarrow 1\ L = 1000\ cm^3$

$$K = -\frac{dp}{\frac{dv}{v}} = \frac{-(2-1)}{\left(\frac{995-1000}{1000}\right)}$$

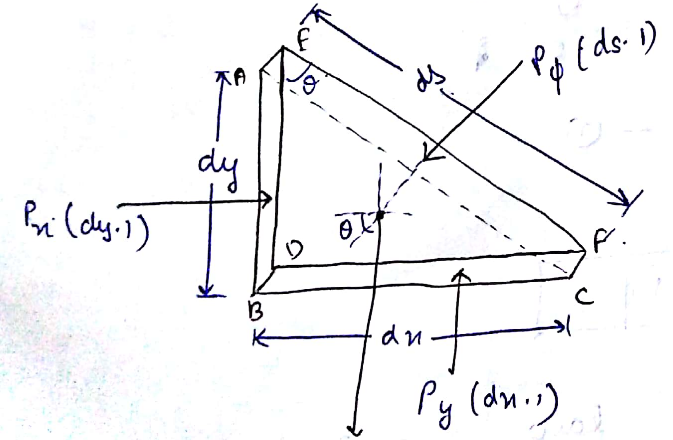
$$= 200 \times 10^6\ Pa$$

$$\doteq 200\ MPa\ \text{Ans.}$$

Fluid Statics

State and Prove Pascal's law of static fluid.

Pressure at any point in static fluid is Equal in all direction. This Statement is known as Pascal's law of Static fluid.



$$W = mg = \rho v g = \rho g\left(\frac{1}{2} \times dx \cdot dy\right) \times 1$$

$$= \frac{1}{2}\rho g\, dx\, dy.$$

$\Sigma F_x = 0$

$\Rightarrow P_x (dy \cdot 1) - P_\phi (ds \cdot 1) \cos\theta = 0.$

$\Rightarrow P_x dy - P_\phi ds \cdot \frac{dy}{ds} = 0.$

$\Rightarrow P_x dy - P_\phi dy = 0.$

$\because dy \neq 0$

$\therefore P_x = P_\phi. \quad — (1)$

$\Sigma F_y = 0.$

$P_x dx - \frac{1}{2} \rho g \, dx dy - P_\phi ds \sin\theta = 0.$

$\Rightarrow P_x dx - \frac{1}{2} \rho g \underbrace{dx dy}_{0} - P_\phi dx = 0.$ $\Rightarrow$ {dx & dy are very small}.

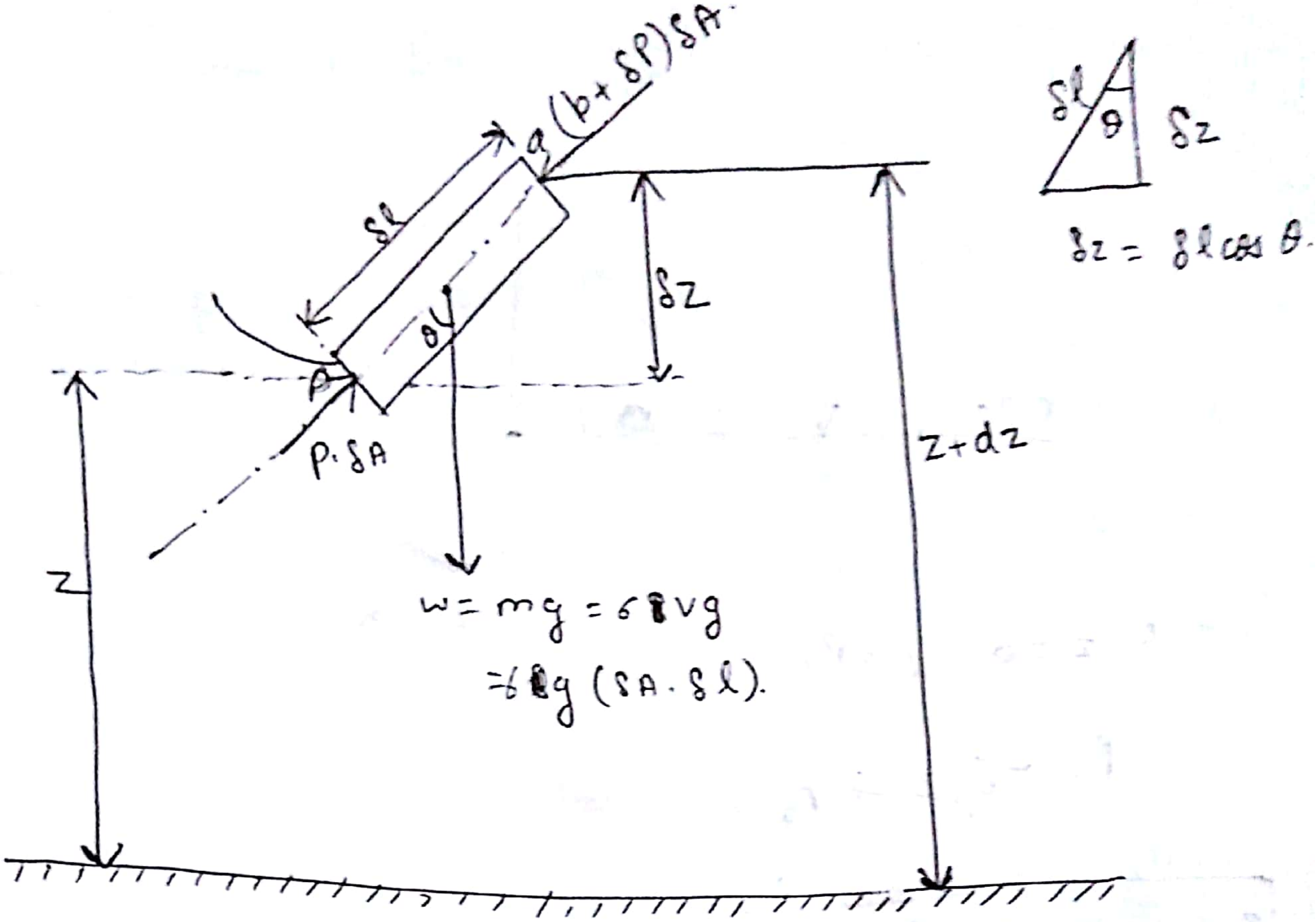
$\Rightarrow P_x - P_\phi - \frac{1}{2} \rho g \underbrace{dy}_{0} = 0.$ $\{\because dx \neq 0\}$.

$\Rightarrow P_x = P_\phi \quad — (2).$

from (1) & (2),

$$\boxed{P_x = P_y = P_\phi.}$$

Write Hydrostatic law and Derive the law. →



$\Sigma F_x = 0$

$\Rightarrow P\cdot\delta A - (P+\delta P) - \rho g\,\delta A\,\delta l \cos\theta = 0$

$\Rightarrow P\cdot\delta A - P\,\delta A - \delta P\,\delta A - \rho g\,\delta A\,\delta z = 0$

$\because \delta A \neq 0.$

$\delta P = -\rho g\,\delta z.$

In the limit when $\delta z \to 0.$

$$\boxed{\frac{dP}{dz} = -\rho g} \longrightarrow \text{I}$$

This is known as Hydrostatic law

$$P = -\rho g z + \text{const.} \longrightarrow (2)$$

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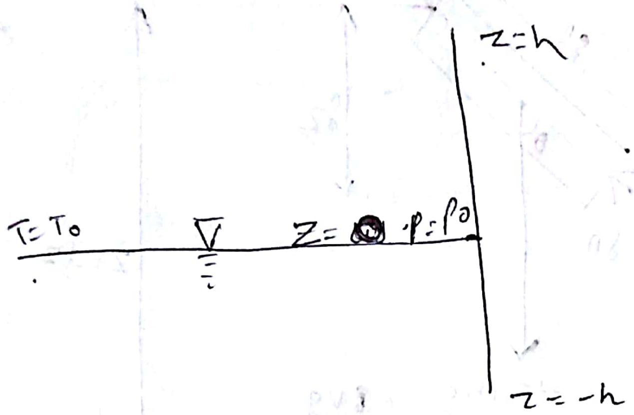

when $z = 0$, $p = P_0$.

$$P = -\rho g z + p_0$$

$$\boxed{z = -h \quad , \quad P = P_0 + \rho g h.}$$

ales of Pressure measurement

$P + \rho g z = \text{const.}$ ⟶ Piezometric pressure.

$\frac{p}{\rho g} + z = \text{cont}$ ⟶ Piezometric head.

$P_{abs} = P_{atm} + P_{gauge}$.