

Hydraulic Engineering
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Lecture – 03
Basics of fluid mechanics - I (Contd.)

Welcome back to lecture 3, the topic for today is fluid statics 1. So, this is also the part of the basic fluid mechanics that we have been doing in the last 2 lectures to get started.

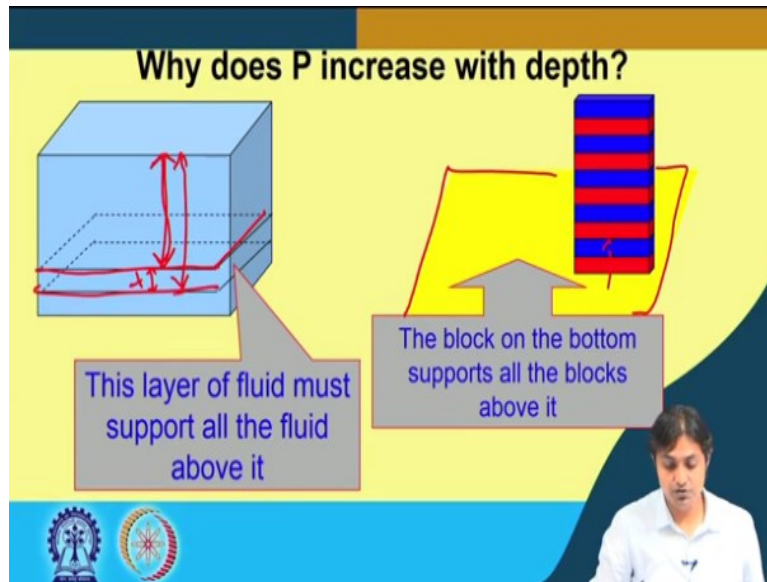
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The slide is titled "Variation of pressure with depth in a liquid". It features two bullet points on the left: "Anybody that does scuba diving knows that the pressure increases as then dive to greater depths" and "The increasing water pressure with depth limits how deep a submarine can go". To the right of the text are two illustrations: a scuba diver underwater and a submarine. Below the submarine illustration, the text "crush depth 2200 ft" is written. At the bottom of the slide, there is a blue banner with the "swayam" logo and other institutional icons. A small video inset of the professor is visible in the bottom right corner of the slide.

One of the most important question is the variation of pressure with depth in a liquid. How does the pressure vary? So, to be able to, you know, give a real feel has anyone of you have done scuba diving that you will observe that the pressure increases as then you go down. So, compared to if you are at the upper surface, than at the lower surface, at the lower depths the pressure will increase. The increasing water pressure with depth limits how deep a submarine can go.

These are the 2 classical example of the variation of pressure with depth and a liquid. Many of you might have observed this for in this case, the crush depth of 2200 feet is for this submarine. So, if the submarine goes below that due to the pressure of the water above the submarine, the submarine can, you know, crush.

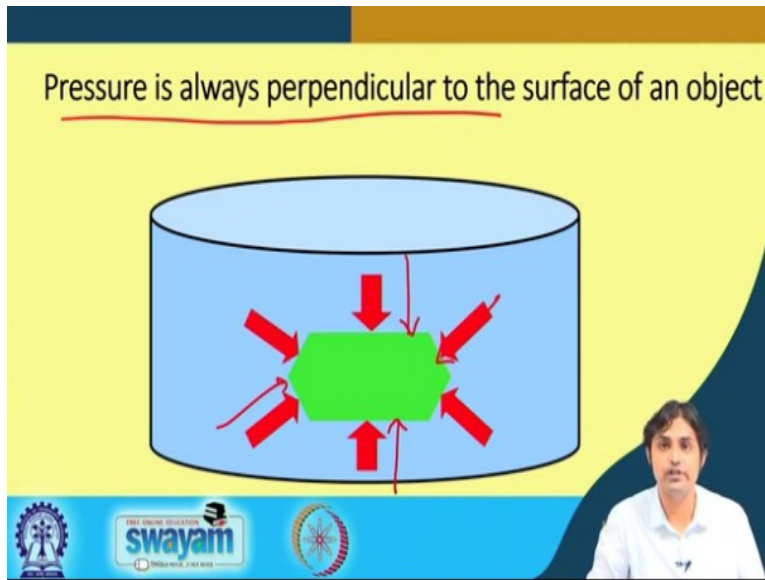
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So, now the important question is why P increases with depth. This is a volume of liquid. As you can see there are some layers on it. So, this is one layer, right? This is one layer. So, this means, this particular layer that have to support the entire liquid that is above this layer and the same is for this layer. So, this means, this layer will have to support this much plus this much. So, this is how you can understand, why does pressure increases with depth, this layer of fluid must support all the fluid that is above it.

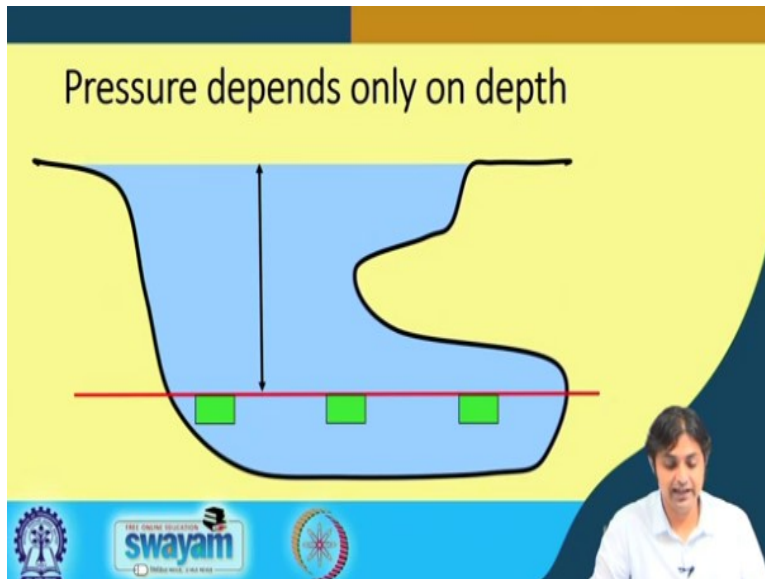
So, this is, this block the one that is shown in yellow in color shall be supporting all the blocks that are above it that is why, and another way to see why the pressure should increase with the depth.

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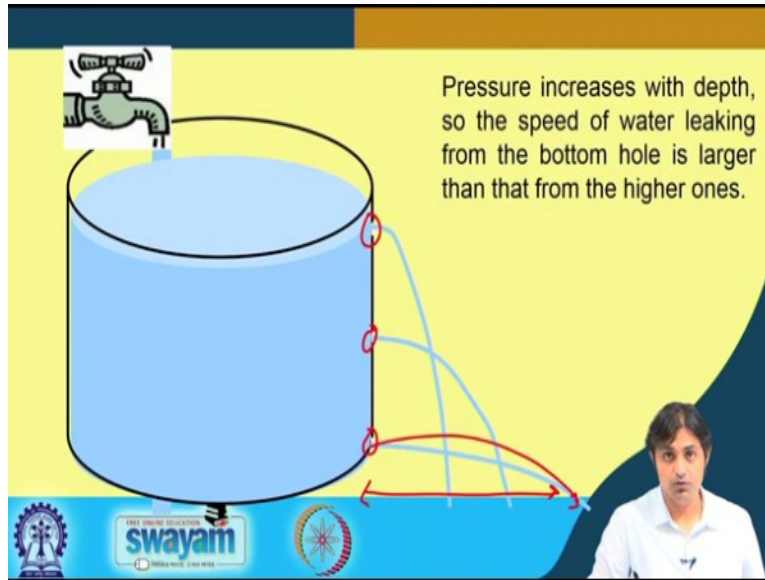
One of the other important feature of pressure is that pressure is always perpendicular to the surface, this is very important as you can see, if this is a surface we have a perpendicular like this, on this surface like this, on this surface like this, on this surface like this. Here we have already indicated by the red thick red arrows here.

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And the pressure does depend only on depth we are going to see that will do some basic derivation later in this lecture, where you will see that the dependence of pressure is only on depth is very important to note.

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See, this is one of the animated examples which everybody of you must have encountered in your real life. So, there is a tap and this is a tank with some holes in it or some stopper valve. The valves are here, here, and here. So, we start filling the water. Let us suppose water gets filled. If we open this one this valve, you see the water trajectory is going to be something like this. Similarly, the one above it will have a trajectory like this.

The third one will have another trajectory like this, what does it say the distance that each one of them is covering is decreasing as the valve is going up. This means that the pressure increases with depth. Therefore, the speed of water leaking from the bottom hole is larger than the one at higher holes, because larger the pressure larger the force, therefore, higher the speed in layman's term. This is for you to understand the, I mean basic concepts of how this pressure system works.

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Definitions and Applications

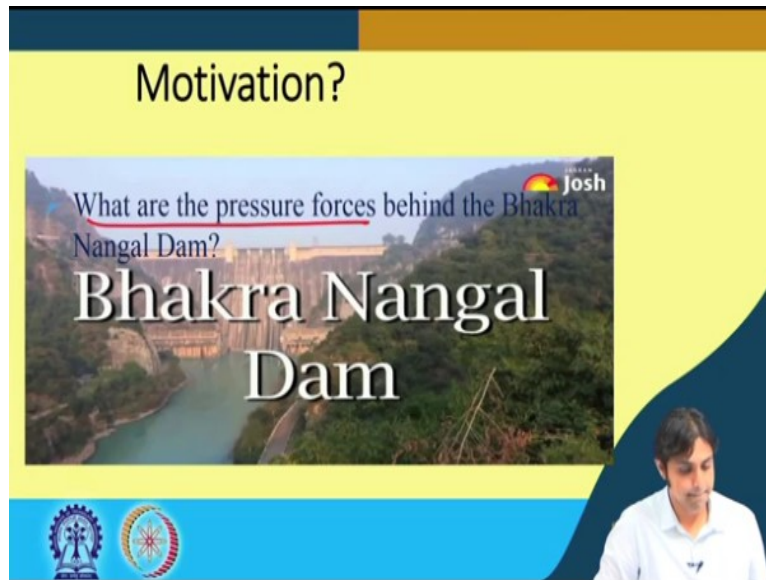
- Statics: no relative motion between adjacent fluid layers.
 - Shear stress is zero ✓
 - Only pressure can be acting on fluid surfaces
- Gravity force acts on the fluid (body force) ✓
- Applications:
 - Pressure variation within a reservoir
 - Forces on submerged surfaces
 - Tensile stress on pipe walls
 - Buoyant forces



Now, some definitions and applications, in fluid statics as we have seen there is no relative motion between the adjacent fluid layers, therefore, the shear stress is 0 as we have already seen this in our previous lecture. So, what can be acting on the fluid surface? So, only pressure can be acting in that case on the fluid surface there is no shear only pressure forces. Gravity force acts on the fluid and that is called the body force.

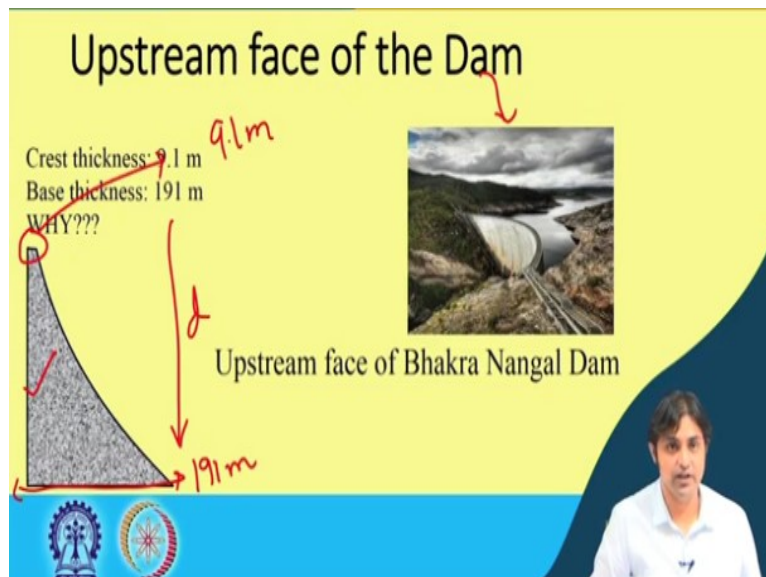
So, gravity force when it acts in the body it is defined as the body force. What will be the applications of this particular thing that we are studying about pressure? We can know the pressure variation within a reservoir. So, it find application in reservoir, we are also able to find forces on submerged surface you will see many cases in real life where the surfaces are submerged. We are also able to find using this app this principle the tensile stress on pipe walls and also we are going to see the buoyant forces because buoyancy plays an important role in this.

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What actually is the motivation, the motivations are enormous as an Indian, we know we have all heard of Bhakra Nangal Dam. So, the forces acting on the Bhakra Nangal Dam, this is one of the very important thing and for you as a student, I would consider this as the biggest motivation design of dams for example. So, the question is, what are the pressure forces behind the Bhakra Nangal Dam? If this is the first step towards any design, you need to determine the forces or the parameters that determine the stability.

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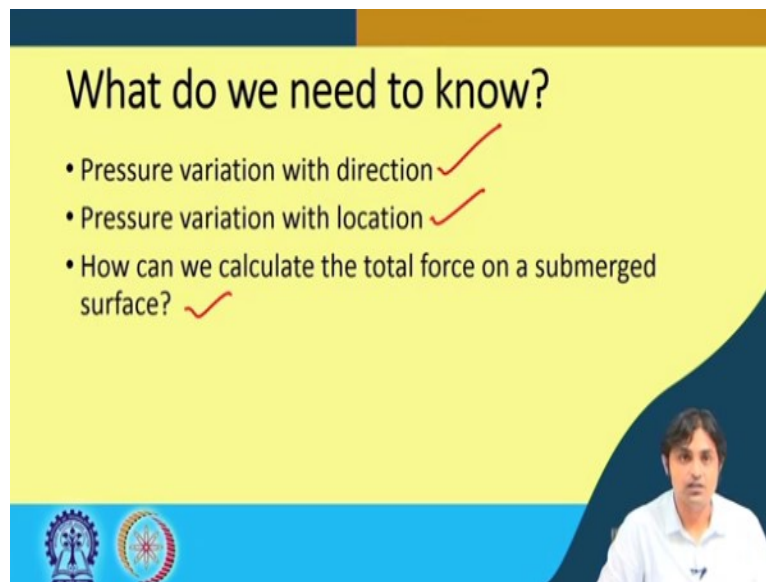


So, this is what I have shown here is the upstream face of the dam here. And the if you see it, if you put it in the 2 dimension this is what the Bhakra Nangal Dam looks like. So, this one here the crest thickness, this is the crest, this is only 9.1-meter, 9.1 meter, the however the base

thickness is 191 meter. And why that happens? It is very simple to explain that as you go deeper and deeper.

So, this represents the increasing water depth in this direction. So, as you go deeper and deeper the weight of the water that it needs to support increases therefore, the base of to resist the force, the base of the dam needs to be larger. This is a very, very simple explanation why we have a smaller crest and base thickness is very high.

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What do we need to know?

- Pressure variation with direction ✓
- Pressure variation with location ✓
- How can we calculate the total force on a submerged surface? ✓

What do we need to know in while studying about pressure, we need to know the variation of pressure with direction, we also need to know pressure variation with the location. Direction is say at in what angle θ for example, location is at what depth for example, and how are we able to calculate the total force on the submerged surface. So, these are the 3 questions that we are going to answer today.

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Pressure Variation with Direction(Pascal's law)

Equation of Motion

$$F = ma$$

$$ma_x = \rho \frac{\delta x \delta y}{2} a_x = 0$$

$$\sum F_x = p_x \delta y - p_s \delta s \sin \theta$$

$$\delta s \sin \theta = \delta y$$

$$p_x \delta y - p_s \delta y = 0$$

Pressure is independent of direction!

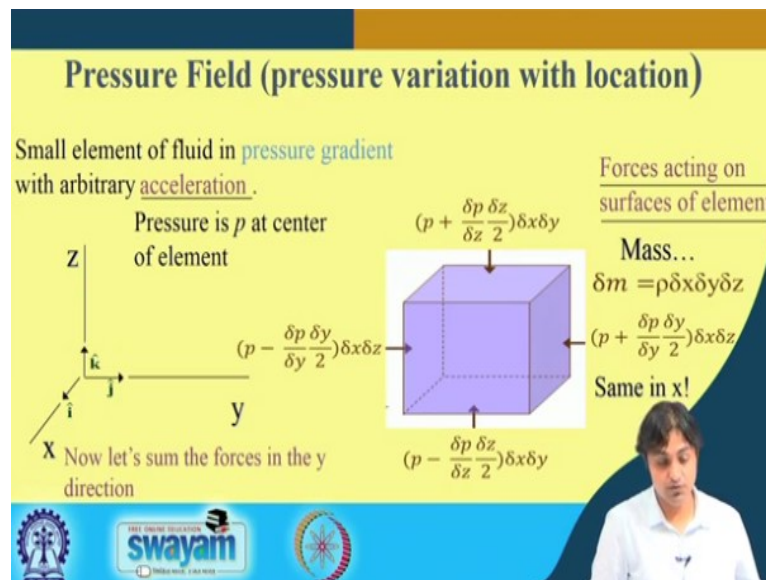
So, first we are going to see the Pascal's law, which is pressure variation with direction, very simple. This element a triangular element that is shown here this is a fluid element, this the length in x direction is δx , this angle is θ here, the y direction the length is δy and δ is the length of this surface. What we say first when we make a body diagram, we need to have the forces. So, the body force is of course, we talked about gravity. So, it is going to be the weight. What is going to be the weight? Very simple, its mass into $m \cdot g$, the mass can be written as $\rho \cdot V$. So, assuming in z direction, we have a unit length. So the area of this triangle is $\frac{1}{2} \delta x \delta y \cdot 1$, one will give us volume. So the mass is going to be $m = \rho \cdot g \cdot V$. So this is the weight of the element. Now looking at the surface forces, there will be surface forces acting what we have seen before, surface forces in case of fluid statics will be only due to the pressure.

So pressure will exert force on all the surfaces. So these 3 this one, this one, and this one are going to exert force on this surfaces, what is the magnitude, so, if there is the force on this the pressure is P_s it will be acting on this side. In a unit z direction so it will be P_s into area that is δs into 1 similarly in x direction it is going to be P_x if P_x is the pressure acting in this direction. And multiplied by δy into 1 and in this direction similarly it is going to be P_y into $\delta x \cdot 1$ because we have assumed, unit length in z direction.

Force is given by mass into acceleration $F=ma$. Therefore, mass into acceleration, mass is $m=\rho*V$. So $\frac{1}{2}\delta x\delta y\delta z$ because we assumed unit an a_x , this should be equal to 0. And the summation of the forces on this body in the y direction is going to be P_x , this one δy , there will be a component in this direction for P_s δS this will be given by $P_s * \delta S * \sin\theta$. So, this is this component here. If we also know that $\delta S * \sin\theta$ is equivalent to δy because of trigonometry.

Therefore, if we put $\delta S * \sin\theta$ as δy here we are going to get $P_x \delta y - P_s \delta y$. Very it is very obvious now, that the δy and δy should get canceled if they are not equal to 0. This give us $P_x = P_s$. Ok, this indicates that pressure is independent of the direction and this was one of the properties that we have seen in the beginning that pressure depends only upon depth, there is no directional influence on the variation of pressure. Great so, I will erase all ink so that, you are able to follow that in much more detail.

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So, then as we said we should also be able to understand the pressure variation with location. So, the small element of we assume a small element of fluid in pressure gradient with an arbitrary acceleration, we assume, that is, what assumption is we define our axis x in this direction. So, this is the x direction, this is the y direction and this is z direction, we are assuming up mass of fluid in cubical format, this is a fluid element.

So, as we have done always what we are going to do is we are going to write the forces, but first assume that at the center, so, I am going to use the pen now, the pressure at this center is P .

Therefore, this will now actually we will be able to help in the derivation and there is a uniform pressure gradient that is what our assumption is. So, we should be knowing the forces acting on the surface of the element. So, if the pressure at the center is P and then the pressure variation can be given in this direction as $\frac{\delta p}{\delta y}$.

So, this is pressure variation in y direction and what is the length this is $y/2$. So, in this direction it will be $p - \frac{\delta p}{\delta y} * \frac{\delta y}{2}$. So, this is going to be the P_1 for example, $P_1 = p - \frac{\delta p}{\delta y} * \frac{\delta y}{2}$ and it should be multiplied by the area this is any way as a 3 dimension element. So, this area that is it is going to be $\delta x \delta z$. So, this is the force on this side.

Similarly, on the other side if the pressure is p here, and the gradient in if we are subtracting when we are going backwards which will be added when we are going in the forward direction and $\delta x \delta z$. Similarly, for this surface, this will be because this is z direction. So, it will be

$p - \frac{\delta p}{\delta z} * \frac{\delta z}{2}$ to have the total pressure at this surface and overall multiplied by area this will give us a force and similarly in this direction as well, because we have assumed that the pressure increases in the upward direction.

So, well going down it should decrease its

$$(p - \frac{\delta p}{\delta z} * \frac{\delta z}{2}) * \delta x \delta y$$

I think this now, you should be able to write on your own these terms. So, what the mass of the element is going to be. Very simple, the delta m is going to be density multiplied by Volume. Volume is very simple $\delta x \delta z \delta y$. So, we have now written most of the things in one of these directions.

We can see we have assumed in the direction of y this, the same can be done in x also, but we are going to concentrate in one direction right now, y the variation of pressure in y direction for

example. So, as we have already written the forces here in all the 4 sites, we are going to do the force balance here. So, as I said I will try to erase. So, that you are able to, great.

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Simplify the expression for the force acting on the element

$$\delta F_y = \left(p - \frac{\partial p}{\partial y} \frac{\delta y}{2} \right) \delta x \delta z - \left(p + \frac{\partial p}{\partial y} \frac{\delta y}{2} \right) \delta x \delta z \quad \text{Same in xyz!}$$

$$\delta F_y = - \frac{\partial p}{\partial y} \delta x \delta y \delta z \quad \delta F_x = - \frac{\partial p}{\partial x} \delta x \delta y \delta z \quad \delta F_z = - \frac{\partial p}{\partial z} \delta x \delta y \delta z$$

This begs for vector notation!

$$\delta F_s = \left(\frac{\partial p}{\partial x} \mathbf{i} + \frac{\partial p}{\partial y} \mathbf{j} + \frac{\partial p}{\partial z} \mathbf{k} \right) \delta x \delta y \delta z$$

$$\delta F_s = - \nabla p \delta x \delta y \delta z$$

Surface Forces acting on element of fluid due to pressure gradient

So, now, we have to simplify the expression for the force acting on the element, very simple. So, in the y direction, the force is going to be this was the force, pressure force minus these forces. This was acting in this side and this force was acting from the right. So, p and p can get canceled, we will have the same in X, Y and Z. So I will just erase this one. So, the summation of δF_y , I mean, if you do this addition, it will be $\delta F_y = - \frac{\partial p}{\partial y} \delta x \delta z \delta y$.

Similarly, if we do as I said we can do the same in x direction, we are going to get $\delta F_y = - \frac{\partial p}{\partial x} \delta x \delta z \delta y$ this is important. And we can also get the same thing in z direction. So, it is going to be $\delta F_z = - \frac{\partial p}{\partial z} \delta x \delta z \delta y$ it is just the force that we have calculated the differential force because of pressure gradient. Now, we can write these forces in vectors.

So, if you see the pressure can be written as $\nabla p = \frac{\partial p}{\partial x} \mathbf{i} + \frac{\partial p}{\partial y} \mathbf{j} + \frac{\partial p}{\partial z} \mathbf{k}$. So, the summation of all the forces here, summation of all the forces, because this delta F_y is in y direction F_x in x direction, and F_z in z direction, we can write the total force. If you sum these three 1,2,3, you are going to get this equation which is $\delta F_s = - \left(\frac{\partial p}{\partial x} \mathbf{i} + \frac{\partial p}{\partial y} \mathbf{j} + \frac{\partial p}{\partial z} \mathbf{k} \right) \delta x \delta z \delta y$.

So, δF_s can be written as we can write this entire term as ∇p this is a standard mathematical notation and we keep this $\delta x \delta y \delta z$ as it is $\delta F_s = -\nabla p \delta x \delta y \delta z$. Now, the surface forces acting on the element of fluid due to pressure gradient. So this is the surface forces acting on element of the fluid due to the pressure gradient.

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Apply Newton's Second Law

$-\delta W \mathbf{k} = -\gamma \delta x \delta y \delta z \mathbf{k}$ Since the z axis is vertical, the weight of the element is

$\Sigma \delta F = \delta F_s - \delta W \mathbf{k} = \delta m \mathbf{a}$ Newton's second law

$\delta m = \rho \delta x \delta y \delta z$ Mass of element of fluid

$-\nabla p \delta x \delta y \delta z - \gamma \delta x \delta y \delta z \mathbf{k} = \rho \delta x \delta y \delta z \mathbf{a}$ Substitute into Newton's 2nd Law

$-\nabla p - \gamma \mathbf{k} = \rho \mathbf{a}$

General Equation of motion for fluid with no shearing stress

So, what happens? Now we have to apply the Newton's second law. So in z direction, if you see there is weight acting, which is balanced in the k direction weight can be written as $\gamma = \rho g$, and this is the volume. So, weight is mass, into gravity into, so, mass can be written as $\delta m = \rho \delta x \delta y \delta z$. Since z axis is vertical, the weight of this element can be written as, see there is a force component, so, the net force will be the surface forces plus the weight since the weight is acting downward we have assumed a negative sign here and this will be equal to $\delta m \cdot a$.

So, net force $\delta F = m \cdot a$, we are doing just the Newton's second law here. So, mass as we already seen is $\delta m = \rho \delta x \delta y \delta z$ this should be ρ , this is mass of the element of the fluid. So, the net force because there is no acceleration, so, the net force that has come to be

$$-\nabla p \delta x \delta y \delta z - \gamma \delta x \delta y \delta z \mathbf{k} = \rho \delta x \delta y \delta z \mathbf{a}$$

, this is the weight and this is the pressure forces. This is the weight and this you will see this is acceleration mass into acceleration. This is surface force. This is body force.

So, now substitute into Newton's second law, if you see we can get $\delta x \delta y$ canceled from everywhere. So, the final equation, so that you are able to see I will erase all ink here will be. So, this is the general equation of motion for fluid with no shearing stress this is very very important equation you should remember this. Great.

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Fluid at Rest

$\nabla p + \gamma \mathbf{k} = 0$ For fluid at rest $\mathbf{a} = 0$

Or in component form

$\frac{\partial p}{\partial x} = 0$ $\frac{\partial p}{\partial y} = 0$ $\frac{\partial p}{\partial z} = -\gamma$

In horizontal plane the pressure does not change and varies only with depth as written by ordinary differential equation

$\frac{dp}{dz} = -\gamma$

γ may or may not be constant

Now, as you see this equation here,

$$-\nabla p - \gamma \mathbf{k} = \rho \mathbf{a}$$

, one of the special cases is when the fluid is at rest. So, in case of fluid at rest the acceleration should be 0. And if we put $\mathbf{a}$ is equal to 0 in the previous equation we can get $\nabla p + \gamma \mathbf{k}$, $\mathbf{k}$ this is the direction is equal to 0. Or if you write in component form, we can write δp because this is this is z direction.

So, in x a direction there is only pressure. So, $\frac{\delta p}{\delta x} = 0$, $\frac{\delta p}{\delta y} = 0$, but in z direction it will be

$\frac{\delta p}{\delta z} = -\gamma$. In horizontal plane, the pressure, so, what does it mean in horizontal plane the pressure does not change and varies only with depth as written by ordinary differential equation. So, in case of no acceleration there will be no pressure variation, in x and y direction only in z.

So, this equation z direction can be written as $\frac{dp}{dz} = -\gamma$. Now, one of the important thing is γ may or may not be constant and that is what we are going to see next.

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Pressure Variation When the Specific Weight is Constant

- What are the two things that could make specific weight (γ) vary in a fluid?

$\gamma = \rho g$

Changing density ✓
Changing gravity ✓

$\frac{dp}{dz} = -\gamma$

$dp = -\gamma dz$ Constant specific weight! (Incompressible Fluid) ✓

$\int_{p_1}^{p_2} dp = -\gamma \int_{z_1}^{z_2} dz$ Piezometric head is constant in a static incompressible fluid ✓

$p_2 - p_1 = -\gamma(z_2 - z_1)$ $\frac{p_1}{\gamma} + z_1 = \frac{p_2}{\gamma} + z_2$

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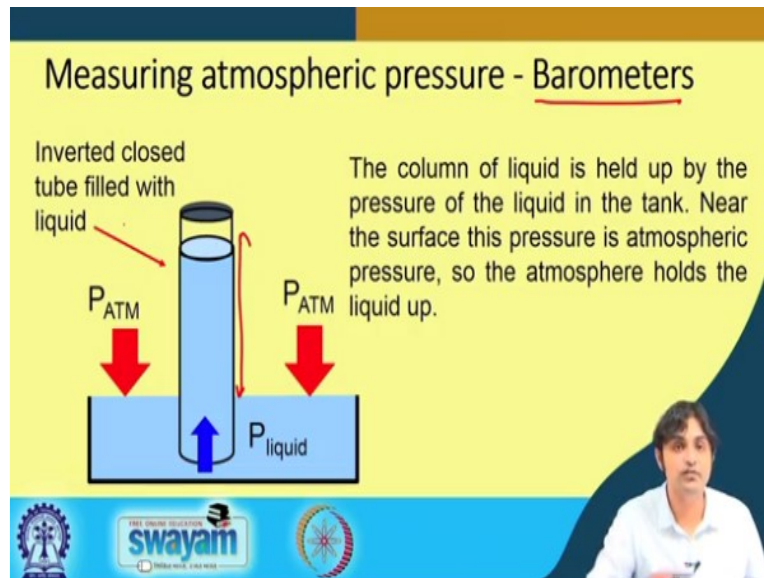
What are the 2 things that could make specific weight γ vary in a fluid? That is, very simple because γ you already know gamma is written $\gamma = \rho g$. So the 2 things are if the change in density is changing or if the gravity is changing, there these 2 I mean that can happen if you go to higher elevations both can be affected the density gravity if you go on from one latitude to the other, you might have read from your physics class that if you go to some place some other place on Earth, gravity might be a little different, not very different from but we wish consider all those cases.

So, if we can write the previous equation where the previous equation was what $\frac{dp}{dz} = -\gamma$. So this is what we exactly written, we have took dz on this side. Let us assume that the specific weight is constant and this happens for this type of fluid which is incompressible fluid. So ρ is constant and under assumption of gravity also does not change this type of fluid is called incompressible fluid.

We will be dealing with incompressible fluid throughout this course. So, if it is incompressible fluid we can simply integrate from p_1 to p_2 and from z_1 to z_2 because γ is constant, we can take

this out of the integration and we can simply write to $p_2 - p_1 = -\gamma(z_2 - z_1)$. So, rearranging will give this one $\frac{p_1}{\gamma} + z_1 = \frac{p_2}{\gamma} + z_2$. So, this is called piezometric head and this head is constant in a static incompressible fluid that is one important take from this slide.

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An important question is, how do we measure atmospheric pressure. One of the simplest devices the barometers. See, what happens is that the column of liquid is held up by the pressure of the liquid in the tank. Near the surface this pressure is atmospheric pressure, so the atmosphere holds the liquid up. So, this which I mean this liquid is being supported by the atmospheric pressure, this is an inverted closed tube filled with liquid.

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Mercury Barometer (Question)

What is the local atmospheric pressure (in kPa) when R is 750 mm Hg?

$S_{Hg} = 13.6 = \frac{\rho_{Hg}}{\rho_{water}}$

$P_2 = \text{Hg vapor pressure}$

Assume constant ρ

So, this is the barometer. This is the principle of working of barometers. Now, a simple question is, what is the local atmospheric pressure when R is 750 millimeters of Hg. This is R we are just going to see we have given the $\frac{\rho_{Hg}}{\rho_{water}} = 13.6$ then we have assumed incompressible fluid constant ρ , we are going to see how it works. So, this is point 1 here and this is point 2 here.

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Mercury Barometer (Question)

What is the local atmospheric pressure (in kPa) when R is 750 mm Hg?

$S_{Hg} = 13.6 = \frac{\rho_{Hg}}{\rho_{water}}$

$$\frac{p_1}{\gamma} + z_1 = \frac{p_2}{\gamma} + z_2$$

$$p_1 = p_2 + \gamma_{Hg}(z_2 - z_1)$$

$$p_1 = \gamma_{Hg} R$$

$$\gamma_{Hg} = S_{Hg} \gamma_{water}$$

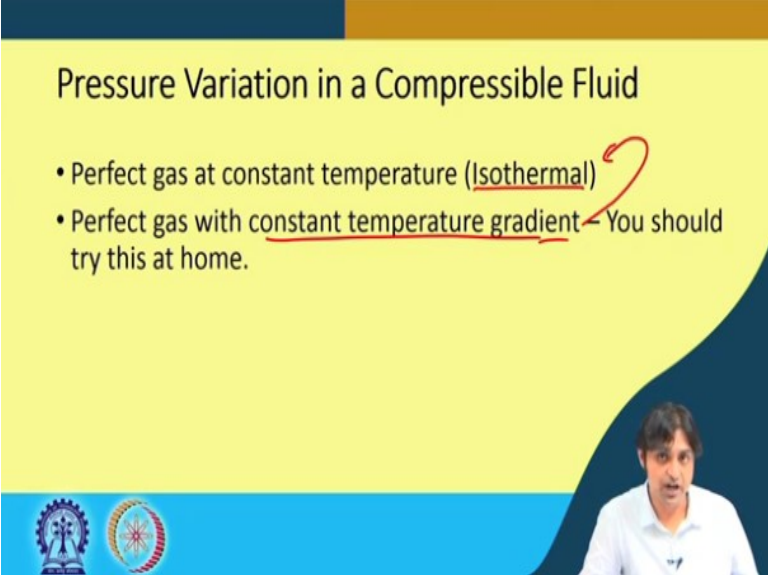
$$\underline{p_1 = S_{Hg} \gamma R}$$

$$p_1 = 13.6(9806 \text{ N/m}^3) 0.75 \text{ m} = \underline{100,000 \text{ Pa}}$$

So, we have seen this equation piezometric head is constant. So, we can also write let me erase this one. P_1 is $P_1 = P_2 + \gamma_{Hg}(Z_2 - Z_1)$. We are putting this piezometric head equation between point 1 and point 2 and we want to calculate the pressure at p_1 . p_2 atmospheric pressure so, atmospheric pressure we assume gauge pressure that can be assumed 0 that you have read in

fluid mechanics. So, pressure at point one will be $\gamma_{Hg} (Z_2 - Z_1)$ we have seen was R if you just go back here this $P_2 - p_1 = \gamma_{Hg} (Z_2 - Z_1)$ this is point 2. So, this $(Z_2 - Z_1) = R$. So, going to γ_{Hg} , γ_{Hg} can be written as $S_{Hg} \gamma_w$. So, pressure will be $P = S_{Hg} \gamma_w * R$, on calculation it is going to give almost hundred 100,000 Pascal. So, this is one example as well of calculating the pressure p_1 but this is also indicating how this barometer system works.

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Pressure Variation in a Compressible Fluid

- Perfect gas at constant temperature (Isothermal)
- Perfect gas with constant temperature gradient - You should try this at home.

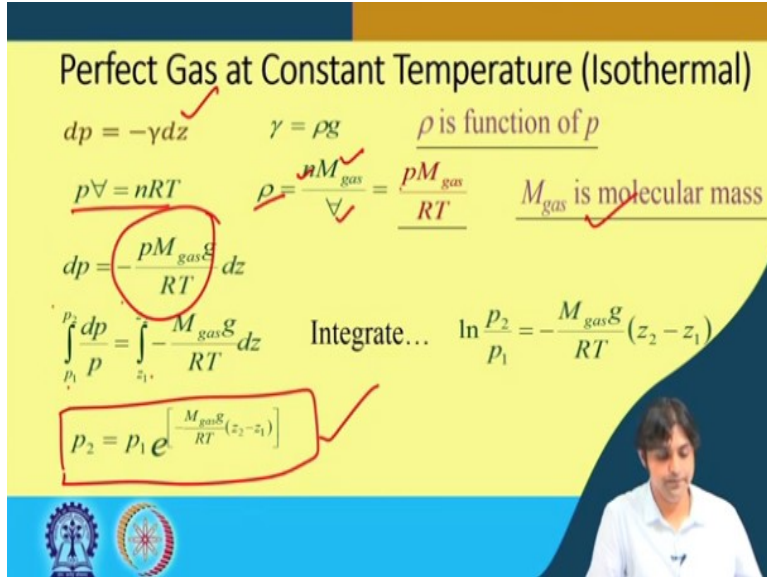
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Now, we must also be a little aware about the pressure variations in a compressible fluid. So, there are 2 processes, one is perfect gas at constant temperature isothermal that we have been seeing till now. Secondly perfect gas with constant temperature gradient and actually you should try this at home. We are not going to cover at this because in working this is the derivation is same as isothermal I mean with different the way it works is the same. So, you should try this at home after watching this lecture.

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Perfect Gas at Constant Temperature (Isothermal)

$dp = -\gamma dz$ $\gamma = \rho g$ ρ is function of p
 $pV = nRT$ $\rho = \frac{M_{gas}}{V} = \frac{pM_{gas}}{RT}$ M_{gas} is molecular mass
 $dp = -\frac{pM_{gas}g}{RT} dz$
 $\int_{p_1}^{p_2} \frac{dp}{p} = \int_{z_1}^{z_2} -\frac{M_{gas}g}{RT} dz$ Integrate... $\ln \frac{p_2}{p_1} = -\frac{M_{gas}g}{RT} (z_2 - z_1)$
 $p_2 = p_1 e^{-\left[\frac{M_{gas}g}{RT} (z_2 - z_1)\right]}$



Now, we are going to do perfect gas at constant temperature that is isothermal process, we start with the same old equation $dp = -\gamma dz$. And where gamma is $\gamma = \rho g$ where the ρ is a function of P. So, because in gas it is $PV = nRT$ that is the thumb rule for isothermal. So, ρ can be written as $n \cdot M_{gas} / V$ or in other terms we can write it as pM_{gas} / RT , M_{gas} is the molecular mass which we have seen in lecture number 1.

So, dp will be $dp = -\gamma dz$, so this is $-\gamma$. Correct? Because we already seen here, we just multiplied the density with G here. So, now, we start simply integrating from P 1 to p 2, and z1 to z2 simple integration, and if you integrate this, we are going to get because it is dp / p . So, that becomes $\ln (p_2/p_1)$ and dz is a simple integration yielding $(Z_2 - Z_1)$. So, the pressure at point 2 in a constant temperature will be given as

$$p_2 = p_1 e^{-\left[\frac{M_{gas}g}{RT} (Z_2 - Z_1)\right]}$$

So, in case of constant temperature isothermal the perfect gas, the pressure variation will be like this. So, very simple derivation but a little more intriguing than the one that we did before for you know, pressure variation within the liquid where we got simply piezometric head.

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Pressure Measurement

- Barometers ✓ Measure atmospheric pressure ✓
- Manometers ✓
 - Standard ✓ Pressure relative to atm. ✓
 - Differential ✓ Pressure difference between 2 pts. ✓
- Pressure Transducers (Read yourself)



Pressure measurement devices, we have discussed one already barometers, there are manometers a standard manometer or a differential manometer and the pressure transducers. This is out of the scope, but you must have already done it in your fluid mechanics class, probably in your second year. So, what does barometers do? Barometers measure the atmospheric pressure. Manometers, this standard manometer measures the pressure relative to the atmosphere differential the pressure it measures the pressure difference between 2 points.

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Standard Manometers

What is the ^{gauge} pressure at A given h?

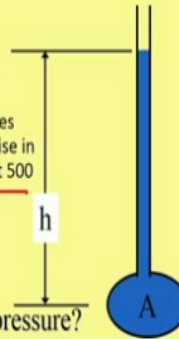
$p = \gamma h$ ✓

Pressure in water distribution systems commonly varies between 175 to 700 kPa. How high would the water rise in a manometer connected to a pipe containing water at 500 kPa?

$h = p/\gamma$

$h = 500,000 \text{ Pa} / (9800 \text{ N/m}^3)$

$h = 51 \text{ m}$ Why is this a reasonable pressure?




For standard manometers. What is the pressure? So how it works is very simple example. So, what is if we are asked, what is the pressure at A given the height, more importantly we should mention what is the gauge pressure. Because gauge means we are not counting the atmospheric

pressure. So, p can be written as simply γh . So, pressure in water distribution system for example, commonly varies between 175 to 700 kilo Pascal's.

So, how high would the water rise in a manometer connected to a pipe containing water at 500 kPa . So, the question actually here is, if we want to measure the pressure in a water distribution system, what will this height h in a manometer be? We are already told that the pressure variation in a distribution system varies between 175 to 700. In this example, they have asked us we choose 500 kilopascals. So, very simple equation we substitute p pressure is given γh we know, so, h can be written as $h = p/\gamma$ p is 500,000 Pascal divided by γ is 9800 N/m^3 . So, this will give the height 51 m of water will rise in the manometer that has water in it that is why you see 51 m is too high. So, that is why this is the reason of using denser liquids like mercury, the height to which it will rise will be much less compared to the simply if you want to calculate you can divide it by you know 13.6.

So, it will be something like around less than, you know, 4 m or something.

So, why is this a reasonable pressure. I mean, this is the reasonable pressure. I think you think about it, we can discuss that in the forum.

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Another example for a differential you know, manometer. So, find the gauge pressure in the center of the sphere. So, this is not a differential. So, we are we are going to measure the high

pressures. So, find the gauge pressure in the center of the sphere, here the sphere contains fluid up till here with γ_1 density and the manometer contains fluid with density γ_2 . So, we have to find pressure here. So, this is point 1, we assume we assume point 2 here and we assume point 3 here, the center.

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The slide is titled "Manometers for High Pressures". It contains the following text and diagram:

What do you know? $P_1 = 0$

Use statics to find other pressures.

$$P_1 + \gamma_1 h_1 - \gamma_2 h_2 = P_3$$

For small h_1 use fluid with high density. Mercury!

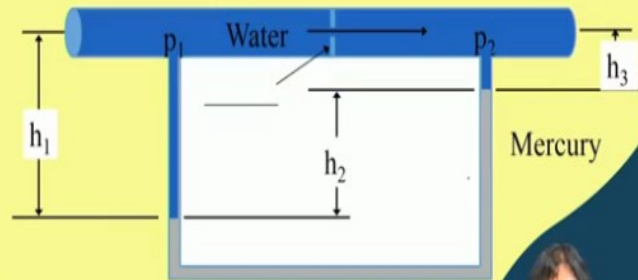
The diagram shows a U-tube manometer. The left leg is connected to a sphere containing fluid of density γ_1 . The right leg is open to the atmosphere. The fluid in the manometer has density γ_2 . The height of the fluid in the left leg is h_1 and the height in the right leg is h_2 . Point 1 is at the top of the left leg, point 2 is at the interface between the two fluids in the left leg, and point 3 is at the bottom of the U-tube. A presenter is visible in the bottom right corner of the slide.

So, what do we know, we know that pressure at 1 is 0 because this is exposed to atmosphere. We have to use statics to find the other pressures here. So, P_1 so, if the pressure at here it is $p_1 + h_1 \gamma_1$ because the same fluid the pressure is increasing as direction multiplied by the density, this is the pressure $h_1 \gamma_1$. So, now we are going up by how much, h_2 , if you want to go to the center we are going up so $-h_2 \gamma_2$ should be equal to p_3 .

So, we have found out p_3 is $P_3 = p_1 + h_1 \gamma_1 - h_2 \gamma_2$. So, we know p_1 that is 0 we know h_1 we know γ_1 we know h_2 we know γ_2 . So, we can easily find out P_3 , for small h for the small h_1 we know this one we use fluid with high density, because in reality the atmospheric pressure must be taken into account p_1 . So, we generally use mercury in manometers.

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Differential Manometers



Find the drop in pressure between point 1 and point 2.



So, I think we will start with this particular slide in our next lecture and talk about differential manometers. Thank you so much.