Engineering Hydrology

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Lecture 32

Subsurface Water

Hello, all. Welcome back. In the previous lecture we have concluded the module 2. Now let us move on to module 3. Module 2 was related to hydrological processes in the atmospheric water. We were discussing about different processes related to atmospheric water, and in detailed way we have seen, we have understood the concepts related to different hydrological processes in the atmospheric hydrology.

Now, let us move on to the processes related to the water which is present in the subsurface, that is beneath the ground surface. So, this is the third module. Third module is dealing with the subsurface water. And before going to the hydrologic processes, we need to have some idea about the soil water, subsurface interaction with water, air and soil. So, after getting basic idea about that we will move on to the processes related to subsurface water.

In the initial introduction itself, I have mentioned that subsurface water is the water which is present beneath the ground surface. So, two regions are there, one is saturated zone and the other one is the unsaturated zone. So here in this course, I will be dealing with the water which is present in the unsaturated zone. We will not be discussing about the water which is present in the saturated zone, that is groundwater. So, let us start with the subsurface water.

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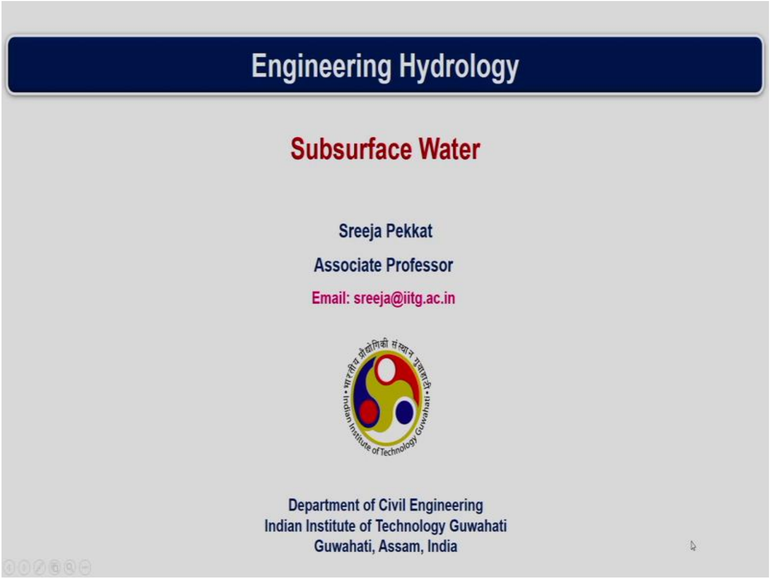

Whenever rainfall is occurring, what will happen, we need to satisfy different storage components. Some of the water will be stored on the plant leaves, grass et cetera.

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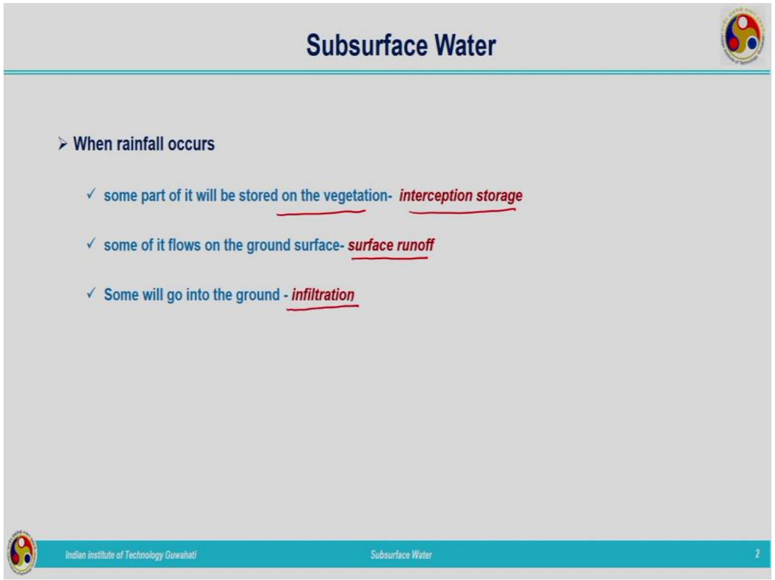

So, when rainfall occurs, some part of it will be stored on the vegetation. That is termed as Interception storage. And some of it flows on the ground. That is termed as surface runoff. And some will be going deep into the ground by means of infiltration. In this particular module we are going to study the hydrologic process named infiltration. Before understanding infiltration, we need to have some knowledge about the basic concepts of soil-water dynamics.

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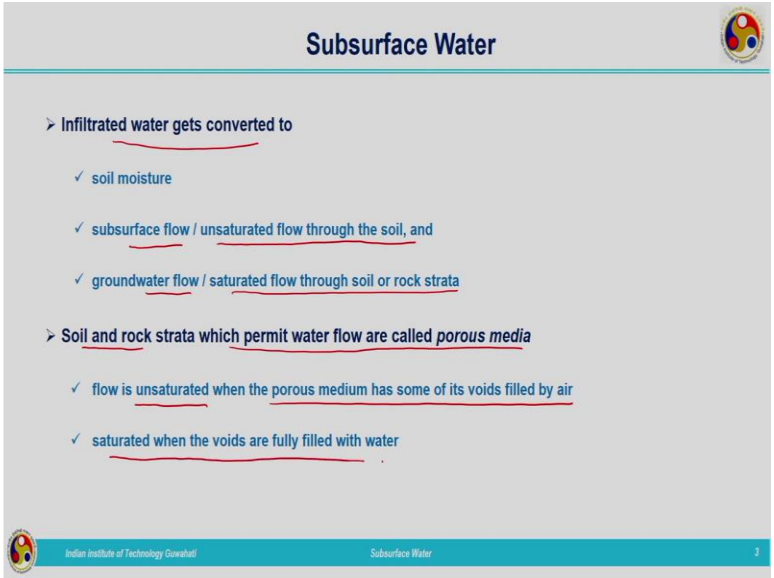

When we are talking about rainfall, we are getting different processes such as runoff, evaporation, infiltration. So, we have seen different hydrological processes. So, coming to infiltrated water, infiltrated water gets converted to soil moisture. That is, filling the voids which are present in the soil, some amount of water which is infiltrated is converted to soil moisture storage. Once that is satisfied, the flow within the subsurface starts. That is the subsurface flow or the unsaturated flow through the soil. And again deeper, if the infiltrated water is penetrating or percolating, it will be meeting the groundwater table and groundwater flow or saturated flow through the soil or rock strata will be there. So infiltrated water gets converted to soil moisture, unsaturated flow and saturated flow. So, these three processes are taking place beneath the ground surface.

And coming to the soil and rock strata, soil and rock strata which permit flow of water is called the porous media. Technically when we talk about, we will be telling the flow through the porous medium. What is meant by this porous media? Porous media is the one which is allowing the flow of water through soil and rock strata.

Flow is unsaturated when the porous medium has some of its voids filled with air. You imagine the case of a soil. Soil will be having some voids present in it, and if the voids are filled with air and water both, then it is termed as unsaturated flow. And if all the voids are filled with water, the flow is saturated.

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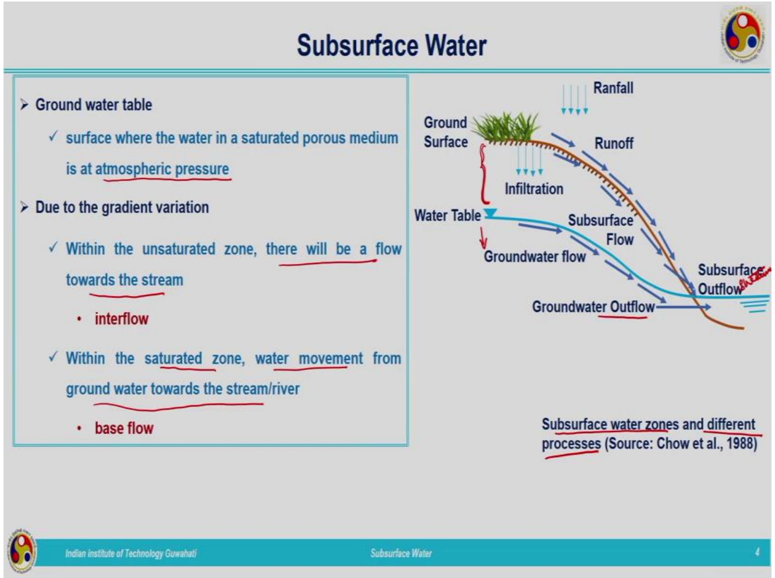

We need to understand this in a better way. That is, how the flow is taking place in the saturated zone and also how it is taking place in the unsaturated zone. And these two zones, saturated and unsaturated zones, there is a definite boundary between these two, that is known as the groundwater table. Groundwater table is the boundary which is separating the unsaturated zone and the saturated zone.

The water present at the groundwater table is having the pressure of atmospheric pressure. So below the groundwater table, we are having the saturated region, and above the groundwater table we are having the unsaturated region. We can understand this with the help of a schematic diagram. That is, we need to understand subsurface water zones and different processes taking place. After that, we will be discussing only about the flow within the unsaturated region.

So, let this be a ground surface. So here, we are considering a water body. And water body may be a river, stream or whatever is present in the location. And water table is extended like this. And this water table is the boundary between the saturated region and the unsaturated region. Below this water table, we will be having saturated region. And in this region we will be having the unsaturated region. This is the unsaturated zone, and below, this is saturated.

Now whenever rainfall is occurring, we know some water runs on the surface, and some water is getting infiltrated into the ground. Runoff will be taking place depending on the slope, and finally it will be meeting the streams. Now, looking at the gradient, once the soil moisture storage is satisfied (the water is added as soil moisture), what will happen? Depending on the gradient, there will be some flow starting in the unsaturated region.

So, within the unsaturated zone, there will be a flow towards the stream. It will be taking place like this. That is termed as the subsurface flow. And finally, it will be contributing towards the water body. That is termed as the subsurface outflow. It can be termed as subsurface outflow or interflow. From hydrology perspective we will be calling it as interflow. Now looking at the saturated zone, water movement from the ground water also will be there towards the stream.

So, water will be contributed from the ground water into the water bodies. So that is termed as groundwater outflow. This is also known as base flow. So here we are having different processes. Water is getting infiltrated into the ground. Some amount of water is stored as soil moisture, and after that, lateral flow will be taking place within the unsaturated zone depending on the gradient.

And the contribution from the unsaturated zone towards the water body, streams or river, that is termed as interflow. And in the case of ground water, if water is contributed towards the rivers or water body, that is termed as the base flow. These are the different processes. In general, if we briefly explain, these are the different processes taking place beneath the ground surface.

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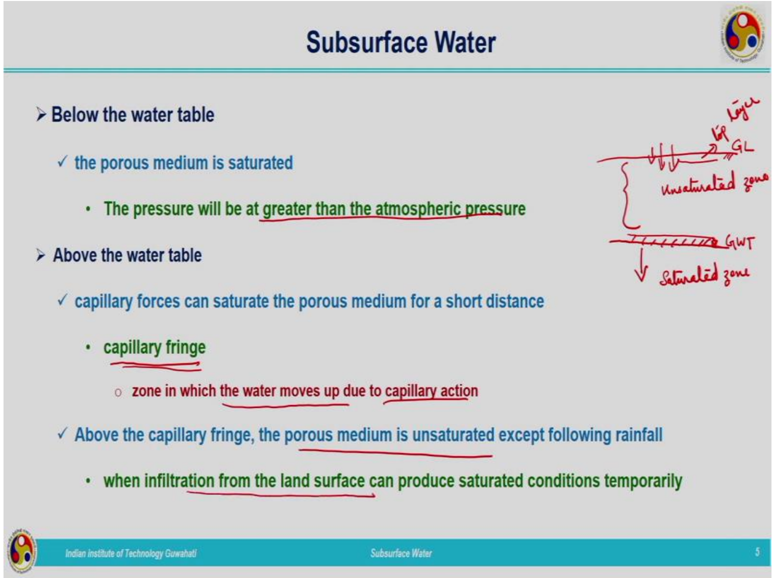

Now, let this be a ground water table. And below this, the region is saturated. And above the ground water table we are having the unsaturated region. Groundwater table is separating the region into two, saturated zone and the unsaturated zone.

Now, the pressure will be at atmospheric pressure at this ground water table. Beneath the ground water table, pressure will be greater than the atmospheric pressure. And what about in the unsaturated zone?

Above the water table, you can see, if I am drawing a line like this, this is the unsaturated zone. In that, we are having small, tiny pores present in the soil. So, through these pores water will be rising up due to capillary action. These tiny pores will be acting as a capillary tube. And you have already studied the capillary action in the course of fluid mechanics. In the similar way, through these tiny pores, water will be rising up due to the capillary action.

Because of that, a region will be formed for short distance just above the water table. That is termed as the capillary fringe. Due to capillary action, water will be rising within the capillary fringe. It is for a very small region. And within that, even though it is in the unsaturated region, and the water is rising due to capillary action. So, it is considered as negative because it is against the gravity.

Zone in which water moves up due to capillary action, this is the capillary fringe which we are considering. This is within the unsaturated zone. From the water table, through the tiny pores which are present in the soil, water is rising up due to capillary action. That region is termed as the capillary fringe. And above the capillary fringe, porous medium is unsaturated. Usually this region is unsaturated only.

But except certain temporary reasons will be there. That is, during the time of rainfall. So much of rainfall is occurring, water is getting infiltrated into the ground and continuously infiltration is taking place. So, this region or top layer of the soil may become saturated. So, this is a temporary phenomenon, top layer becoming saturated. And continuously the infiltration is taking place and the rainfall is continuing. So, the saturated layer thickness will be increasing. So, once the rainfall is receding, that will become again unsaturated because losses will be taking place from that saturated region.

So, this is the way in which we will be dividing the subsurface zone. Below the ground water table, we are having pressure greater than atmospheric. On the ground water table, we are having the atmospheric pressure. That is, in the saturated region, pressure is more than that of atmospheric pressure. In the unsaturated region, it will be less than atmospheric pressure because the flow is taking place against gravity. So, this unsaturated region becomes sometimes saturated due to the infiltration water from the land surface. And that is a temporary phenomenon.

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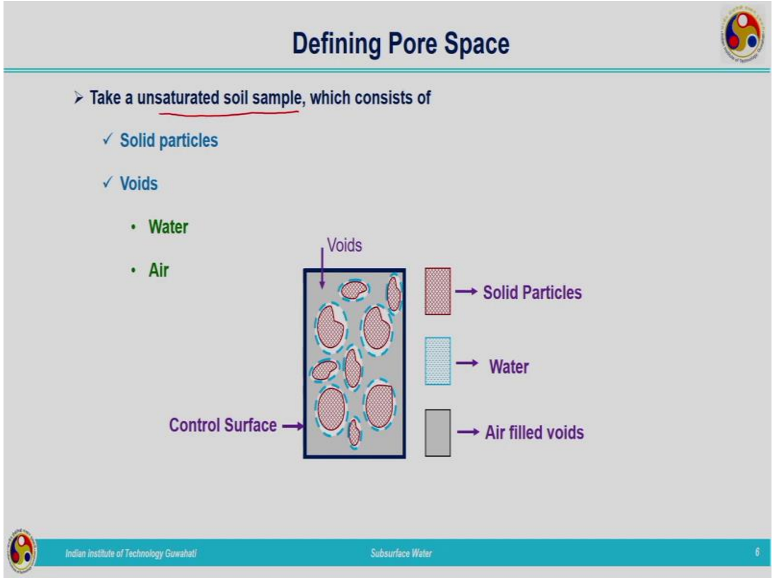

Now, we need to have some understanding about the pore space within the soil, because this understanding is very important for understanding the soil water dynamics. For that, what we are going to do, we are going to consider an unsaturated soil sample. Let this be a volume of unsaturated soil sample. It will be having a control surface marked by these blue bold lines. And it consists of solid particles and voids are there, voids consist of water and air.

So, water will be surrounding the solid particles, and remaining part will be filled with air. So, if we are considering a soil sample, in that, solid particles related to soil will be present, and some of the voids will be present. These voids will be partly filled with water and partly filled with air. So, depending upon the dryness, the forces which are prevailing there will be different. So, we need to have the understanding related to that.

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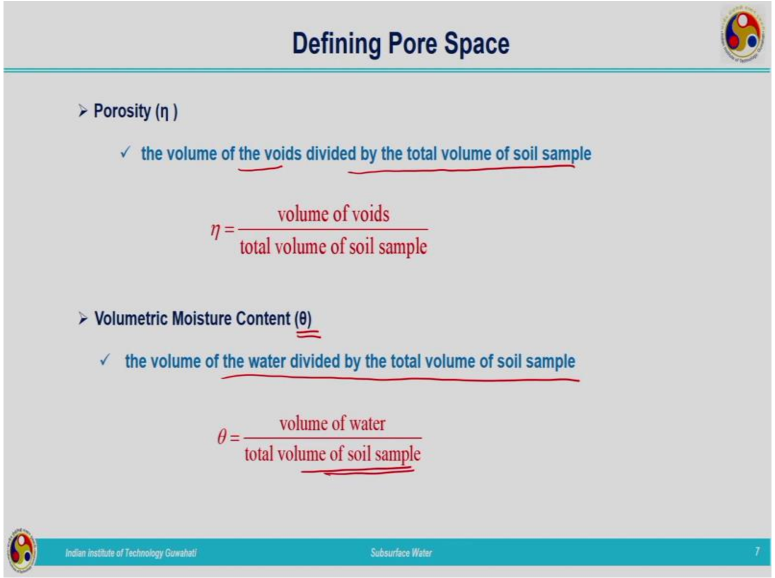

And different terminologies related to pore space are, one is porosity. Porosity is the volume of voids divided by the total volume of the soil sample. Porosity is represented by η. And η is given by this ratio.

$$\eta = \frac{\text{volume of voids}}{\text{total volume of soil sample}}$$

Now next term we need to understand when we are talking about soil water, that is, the volumetric moisture content, represented by θ. You might have studied volumetric water content and also gravimetric water content. Here in this course, I will be using only the volumetric moisture content. It is not gravimetric water content. So volumetric water content is obtained by using this ratio

$$\theta = \frac{\text{volume of water}}{\text{total volume of soil sample}}$$

These two terms (η and θ) are very important when we talk about the infiltration process.

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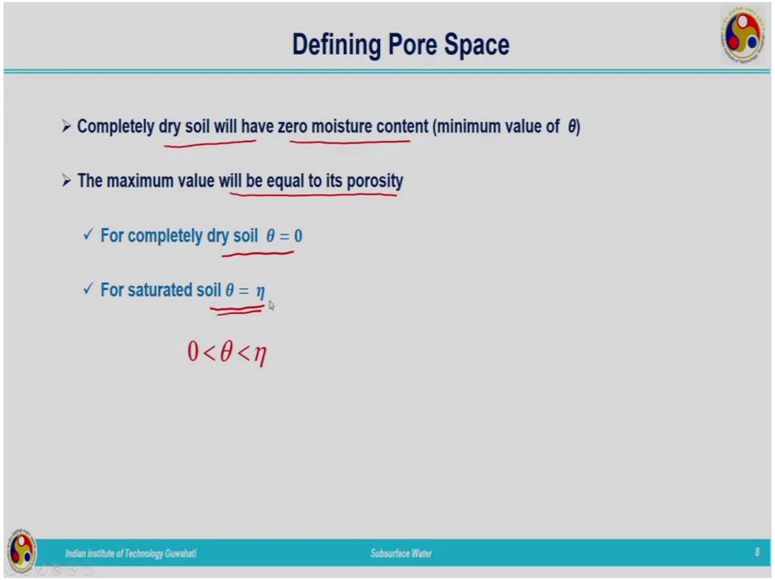

Now, you take the case of a completely dry soil, which is having zero moisture content, or the minimum value of moisture content. The maximum value will be equal to its porosity. We have seen the pore space within the soil sample. Solid particles are there, and some voids are there. Voids are filled with air and water. So, if the entire voids are filled by water, then all the pore space is occupied by water.

Then what will be the condition? θ will be equal to complete void space, that is, equal to porosity.

So, for completely dry soil, $\theta = 0$, and saturated soil, $\theta = \eta$. This should be clear to you, that is, when it is completely dry, there is no moisture present, we will be having the moisture content equal to zero. And second case is the saturated soil, in which all the voids are filled with water, no air is present. In that case, we are having the moisture content equivalent to porosity, that is, $\theta = \eta$. So, θ can vary between 0 and η ($0 < \theta < \eta$).

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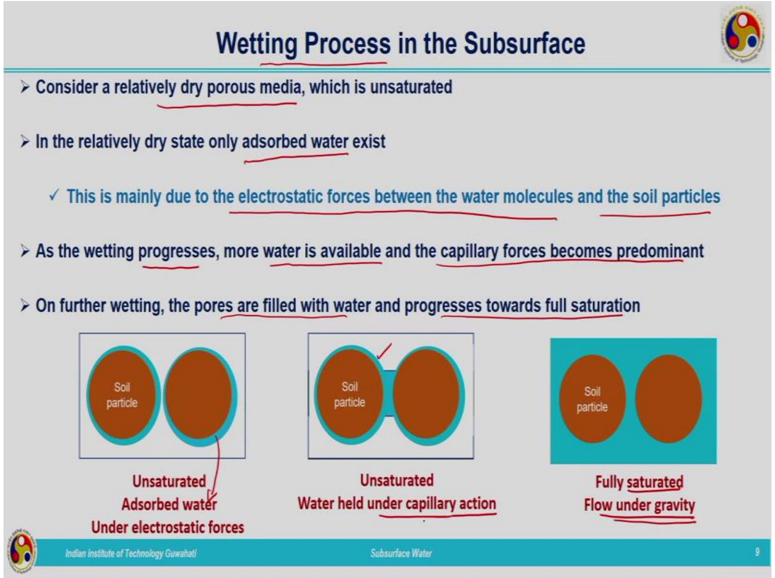

Now, we need to understand the wetting process in the subsurface because whenever infiltration is taking place, initially the soil was dry, and water is getting infiltrated into the soil and gradually the wetting of the soil is taking place. How this process is taking place, let us see, with the help of a soil sample.

Consider relatively dry porous media. So, this will be unsaturated. For understanding, I have drawn an exaggerated diagram. We are having two soil particles. Surrounding that, blue thin film is marked that is representing the water. This is an unsaturated soil in relatively dry state in which only adsorbed water will be present. This blue layer is representing the adsorbed water.

How this adsorbed water is forming a thin layer, thin film near to the soil particle? This is mainly due to the electrostatic forces between the water molecules and the soil particles. So, when the soil is relatively dry, the water molecules will be forming a thin layer, thin film close to the solid particles. This is mainly due to the electrostatic forces.

Now, we are wetting it. As the wetting is progressing, maybe due to infiltration process or maybe due to irrigation process, then more water is available and the capillary forces become predominant. If more and more water is available to the soil, capillary forces will start acting, it will become predominant. And what will happen? These water particles will form a bridge between two soil particles. That is what is shown in this figure.

This water will be forming a bridge like formation near to the soil particles. So, this is mainly due to capillary action. This is the unsaturated one, water is held under the capillary action. Now again the wetting process is continuing, then what will happen? All the pores will be filled with water.

Pores are filled with water and progresses towards the full saturated state. So entire voids are filled with water. So initially it was relatively dry condition, whatever moisture was available, it was forming a thin film surrounding the solid particles which is due to the electrostatic forces between the water molecules and the solid particles.

And wetting is progressing, and when more water is available to the soil, what will happen? The capillary action will be predominant there. Due to capillary action it will be forming a bridge between two solid particles. And again and again water is added to the system. All the pores are becoming filled with this water, and entire air will be escaped out of it, making the soil fully saturated, that is, all the pores are filled with water. This is the fully saturated case. That is, at the saturated state, the flow will be under gravity. In the unsaturated condition, capillary action is predominant.

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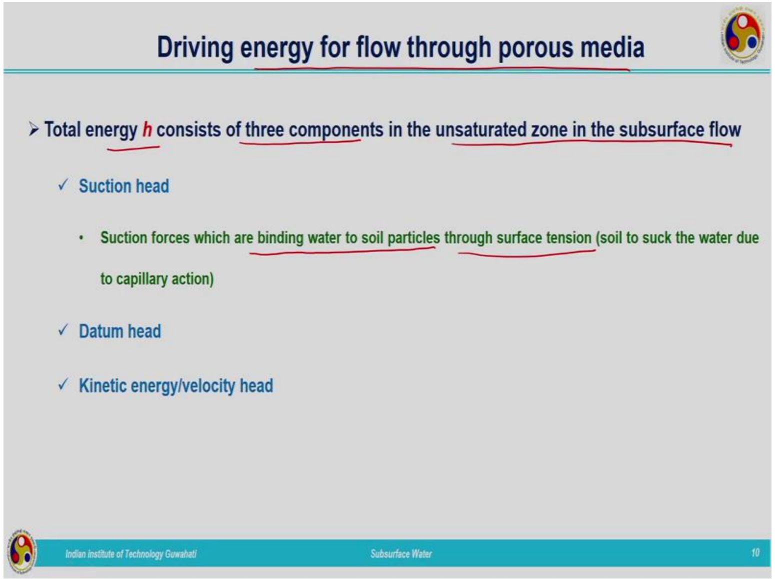

Now we need to understand the energy which is causing the flow within the subsurface, driving energy for flow through porous media. Total energy *h*, consists of three components in the unsaturated zone in the subsurface flow. I am not talking about the groundwater region, saturated region. It is exclusively related to subsurface flow, unsaturated region.

So, whenever we are talking about energy equation, Bernoulli's equation will be coming into our mind. So, in the similar way, we can write here the total energy consists of three components, one is related to suction head, second one is datum head, and third one is the kinetic energy head, or the velocity head.

In Bernoulli's equation, we were talking about pressure head, datum head, velocity head. Here instead of pressure head we are using the terminology of suction head. What is suction head? Suction forces are binding water to soil particles through surface tension. That is, due to capillary action, the water will be forming a bridge between the solid particles. That is also known as suction forces. And datum head is also termed as the gravity head, and kinetic energy is the velocity head.

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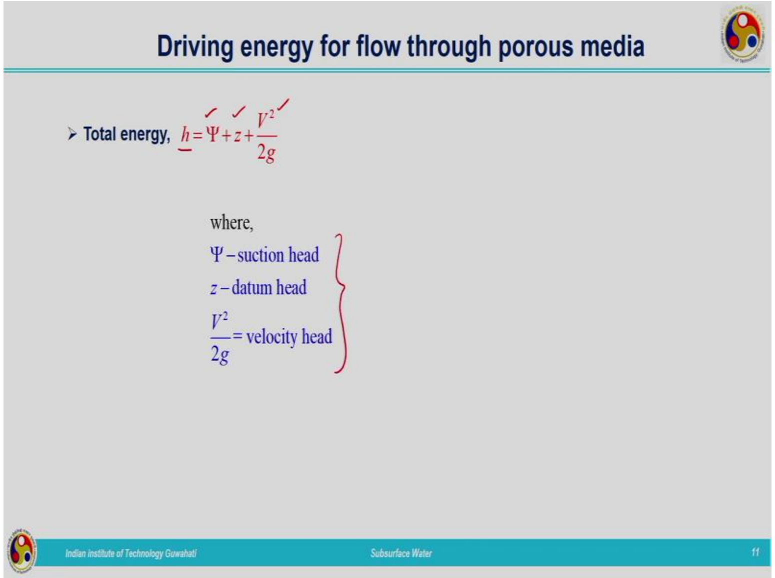

Now, if you are writing the expression for total energy, we can write

$$h=\Psi+z+\frac{V^2}{2g}$$

So here the flow is taking place through the voids which are present in the soil. So, in the unsaturated region, voids are filled with air and also water. These are the different heads; Ψ, suction head; z, datum head; and $\frac{V^2}{2g}$, velocity head.

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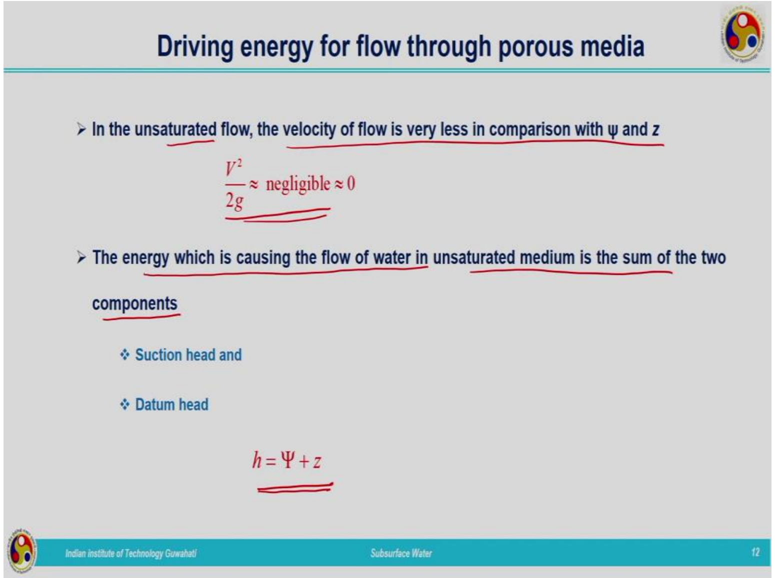

In the unsaturated flow, the velocity of flow (V) is very less in compared to Ψ and z. So, when comparing with the suction head, capillary forces and the gravity head, $V^2/2g$ will be very less.

$$\frac{V^2}{2g} \approx \text{negligible} \approx 0$$

And we can write, the energy which is causing the flow of water in unsaturated medium is the sum of two components. What are these two components? Suction head and datum head. So, this is represented by the equation

$$h = \Psi + z$$

Datum head is there, also known as elevation head, or sometimes we will be calling it as gravity head. All are the different names used for this z. And Ψ is due to capillary action. So sometimes it will be called as the negative pressure, suction head. All these are similar terminologies. So, when you are talking about the energy or head causing the flow within the unsaturated region, this expression should come into your mind. It consists of two components, that is, one is the datum head and the other one is the suction head. So how the suction head is coming into picture? It is due to the capillary action.

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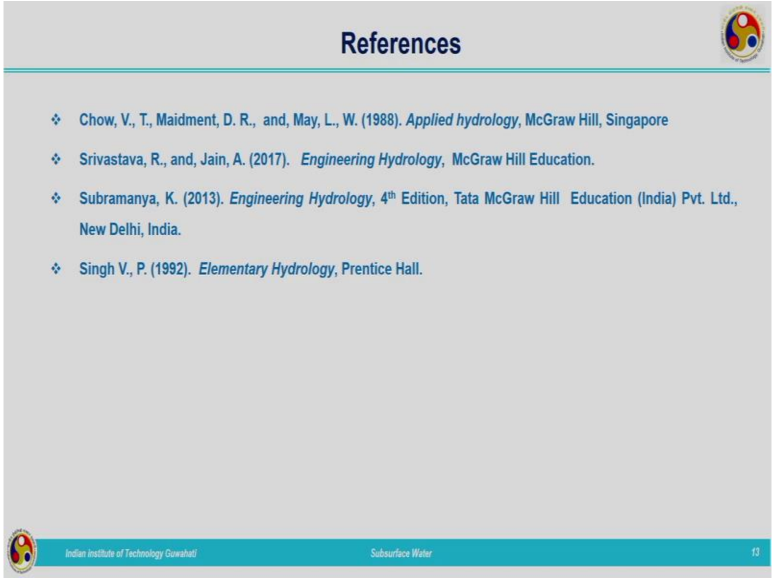

And regarding more understanding about the topic, you can have a reading through these text books. So here, I am winding up this lecture. So, in this lecture, we have seen the very basics, fundamentals related to soil water, that is, related to porous media, how flow is taking place, what are the different components of energy which is causing the flow, and basic definitions related to pore space, that is, the volumetric moisture content and also porosity.

So, these terminologies are required when we go for deriving the equation related to flow through porous media. That, we will see in the next class. Thank you.