Engineering Hydrology
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Lecture 34
Infiltration

Hello, all. Welcome back. We were discussing about subsurface water. We have seen the pore space details, and after that we have seen the basic definitions related to pore space, such as moisture content, porosity and the different forces or the energy driving forces related to flow through unsaturated porous media. After that, we have derived the equation for one-dimensional unsteady flow equation for unsaturated flow. So that is the well-known Richard's equation.

First, we have derived the continuity equation, and after that we have derived the momentum equation related to flow through the unsaturated zone by making use of Darcy's Law. And a combination of these two principles, mass conservation and momentum conservation has been carried out to derive the well-known Richard's equation. Now, we can move on to the infiltration process, which is the hydrological process related to subsurface water in the unsaturated zone.

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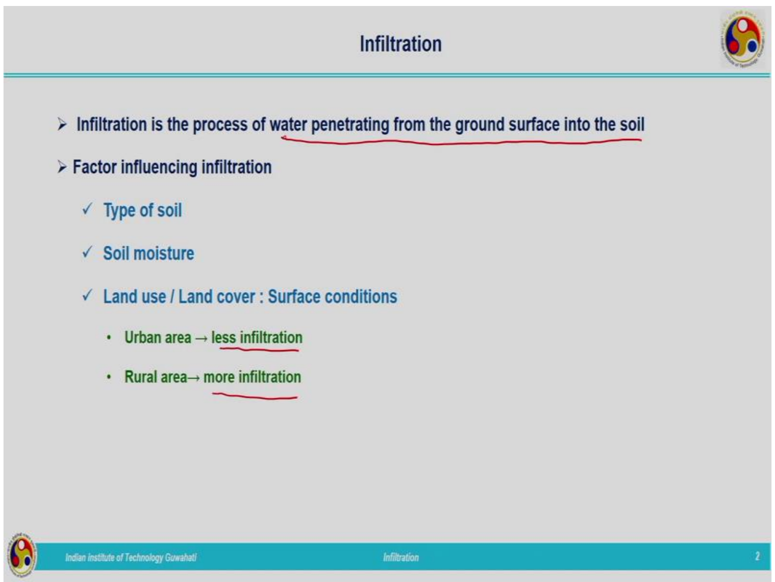

So, infiltration is the process of water penetrating from ground surface into the soil. So, whenever rainfall is occurring or due to some watering process, water will be moving into the ground. So that is the process of penetrating water from the ground surface into the soil is termed as infiltration. First, let us see what are the factors influencing infiltration. Basically, this is the process which is happening through the soil. Definitely, the type of soil will be an important factor.

So, first factor which is influencing infiltration is type of soil. We are having different types of soil. All these soils will be having different types of pore space or packing. So, based on that, the infiltration experienced by different soils also will be different. For example, if you are considering sandy soil, it is loose soil, and the infiltration which is taking place through that will be more compared to a clayey soil.

Second factor is the soil moisture. So, soil moisture is the water which is present in the voids in the unsaturated porous media. So, if the soil is dry, more pore space is available for soil moisture. If the soil is comparatively moist or some moisture is present in that, the amount of water infiltrating into that particular soil will be less compared to the dry soil.

So, the soil moisture plays an important role. Next is the land use, land cover, that is, the surface conditions. Different types of land use classifications are there. So, we can take two cases, one is of an urban area, second one can be of a rural area. So, in the case of urban area, majority of the land surface will be paved, we are having built up areas more. So, because of these paved surfaces, water which will be infiltrating into the ground will be less.

But in the case of forest land or in the rural area, the water which is infiltrating will be high, that is, urban area we are having less infiltration, and in the rural area we are having more infiltration. Urbanized area, if it is fully paved, then there will not be any infiltration taking place. So that is the reason why we are making use of paver blocks. Through those blocks, we are allowing water to infiltrate into the ground. It is not completely paved. In between, gaps are provided.

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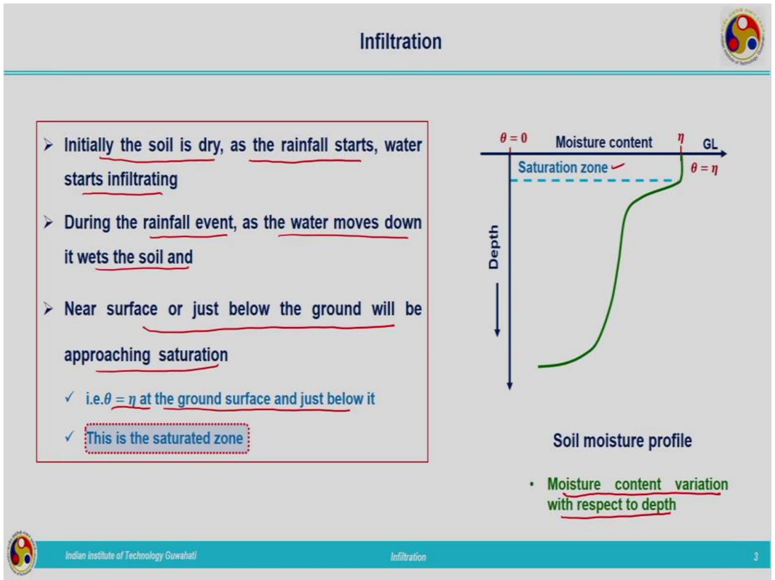

Now, for understanding the process of infiltration, we need to have idea about soil moisture profile. Soil moisture profile is the profile representing the moisture content variation with respect to depth. So, we can assume the ground surface as this horizontal line, which is representing the x-axis. Along the x-axis, we are going to plot the moisture content.

So, the minimum value of moisture content will be equal to 0 and it can go up to a maximum value of $\theta = \eta$, that is, the maximum value of moisture content can be equal to porosity. And we are marking along the z-direction, the depth of the soil strata. So, this is representing the depth beneath the ground surface.

Initially, the soil will be in dry condition. As the rainfall starts, water starts infiltrating into the soil. During this rainfall event, the water moves down and make the soil wet. So as the water is passing through the soil, soil moisture content will be increasing, and the soil will become wet. And again and again the rainfall is continuing, what will happen then? Almost the surface layer become saturated.

So near surface or just below the ground surface will be approaching saturation, because the rainfall is not stopping, continuously taking place. Even though infiltration is taking place, all the pores present in the near surface layer will be filled with water. In this layer θ will be ≈ η at the ground surface or just below it. This zone is termed as the saturation zone.

So, if we are plotting the moisture profile, moisture content variation (represented by means of this green line), we can have a saturation region at the location where $\theta = \eta$. So, this region is termed as saturation zone. So, beneath the ground surface we can divide into different number of zones. Totally, we are dividing into four zones. First zone, very close to the ground surface is termed as the saturation zone. Now, second zone is coming just below the saturation zone.

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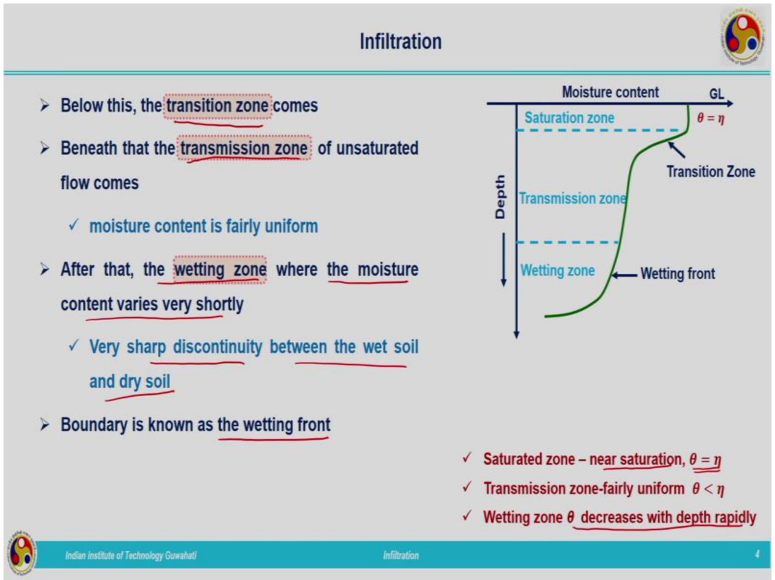

So just below the saturation zone, we will be having transition zone. From the name itself it is clear that it is in a transition state. At the top we are having the saturation zone, all the void or the pores are filled with water, and just below that we are having the unsaturated region. So, in the region separating the saturation zone and the unsaturated zone, there will be a transition taking place. That zone is termed as transition zone. It is very thin.

So here, we will be having transition zone (temporary phenomenon). And below that, we will be having the transmission zone. That is exclusively for the unsaturated region. Within that zone, the soil moisture is fairly uniform. Even though it is in the unsaturated state, the volumetric moisture content will be almost uniform. This region is the transmission zone.

And when we go deeper again and again, we can understand that the moisture content will be varying abruptly. Within short interval of depth, there will be a large variation taking place in the soil moisture content. So, after that, the wetting zone will be coming and in that zone the moisture content varies very shortly.

So, this is the wetting zone. In this, we are having a very sharp discontinuity between the wet soil and dry soil. We can very clearly understand up to what level water has reached. Beneath that, there will be dry soil present. So, the boundary between this wet soil and dry soil can be clearly visible. That is termed as the wetting front. The boundary between this wet soil and dry soil is named as wetting front.

So different zones, we have seen. Totally, four zones are there and we can write again, the features related to these zones. Saturated zone, it is under near saturation. Approximately, we can tell $\theta \approx \eta$, or more or less $\theta = \eta$, porosity value. Then in the transmission zone, we are not talking about the transition zone, it is a very temporary region, and beneath that transmission zone is present. Within the transmission zone, even though $\theta < \eta$, it is more or less uniform.

And in the wetting zone, θ decreases with depth rapidly. There is a sharp variation in the moisture content as the depth is increasing. And the important term related to the boundary which is separating the wet soil and the dry soil is the wetting front. So, the four zones which we have seen are the saturation zone, transition zone, transmission zone, then wetting zone. So, this is the detailed explanation related to soil moisture profile during the process of rainfall.

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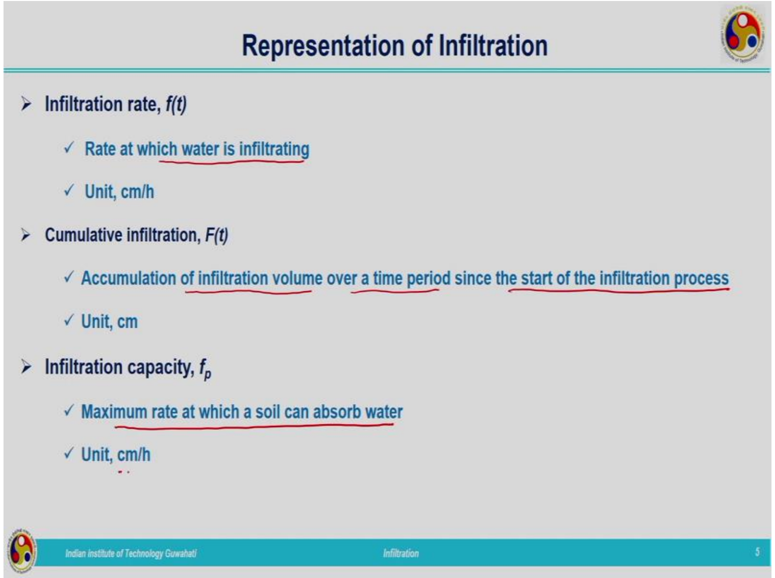

Now we need to know how the process called infiltration can be represented, because for any analysis we need to have proper representation of the hydrologic processes.

So, one way of representing infiltrated water is by means of infiltration rate. Just as in the case of intensity of rainfall, how we are expressing amount of rainfall occurred within particular time, that is, the unit was in length per time. In the similar way, infiltration rate is also the rate at which water is infiltrating. That is represented by *f(t)*, and the unit of infiltration rate is in cm/h. If you are making use of SI unit, it can be converted into SI units.

Second way of representing infiltration is by means of cumulative infiltration. Cumulative infiltration is denoted by *F(t)*. Usually *F* is the letter used for representing cumulative infiltration. So, cumulative infiltration is the accumulation of infiltration volume over a time period just after the start of the infiltration process. Within a particular interval of time how much quantity of water is infiltrated into the ground that is the cumulative infiltration. Total amount of water which is infiltrated that is represented by the cumulative infiltration. It is represented by means of cm, length unit.

Then another term is the infiltration capacity. It is represented by f_p. Infiltration capacity is similar to that of infiltration rate but the difference is that it is the maximum rate at which a soil can absorb water, that is, the maximum rate of infiltration is termed as the infiltration capacity. Always, it may not be at maximum. Depending upon the field condition it may be less than this particular infiltration capacity. That will be represented by means of infiltration rate. For this, also the unit is in cm/h.

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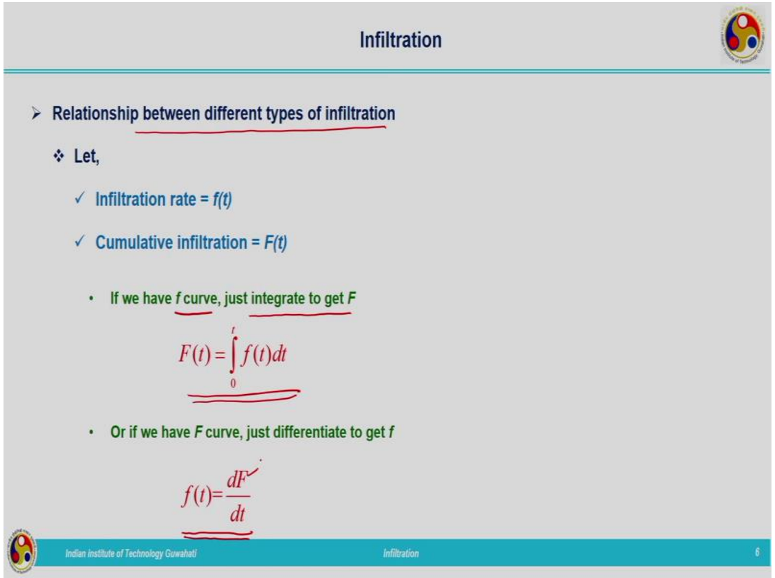

Now, we need to have relationship between different types of infiltration. We have seen infiltration rate and also cumulative infiltration. So, how are these two related? Let infiltration rate be *f(t)*, and cumulative infiltration is equal to *F(t)*. If we have the infiltration rate curve represented by *f* curve, we can just integrate that curve to get the cumulative infiltration curve.

$$F(t)=\int_0^t f(t)dt$$

0 to t is the time interval for which the infiltration was taking place. So, the *F(t)* or the cumulative infiltration can be obtained by integrating the infiltration rate over the entire duration of infiltration. If we are having the cumulative infiltration, that is, *F* is there with us, then for getting the infiltration rate we can just differentiate the *F* curve or the cumulative infiltration curve.

So, $f(t)$ or the infiltration rate can be obtained by differentiating the cumulative infiltration curve that is

$$f(t) = \frac{dF}{dt}$$

If infiltration rate is there with you; you can get the cumulative infiltration by integrating the infiltration rate over that period of time. And if the cumulative infiltration is there with you, you can differentiate that curve to get the infiltration rate.

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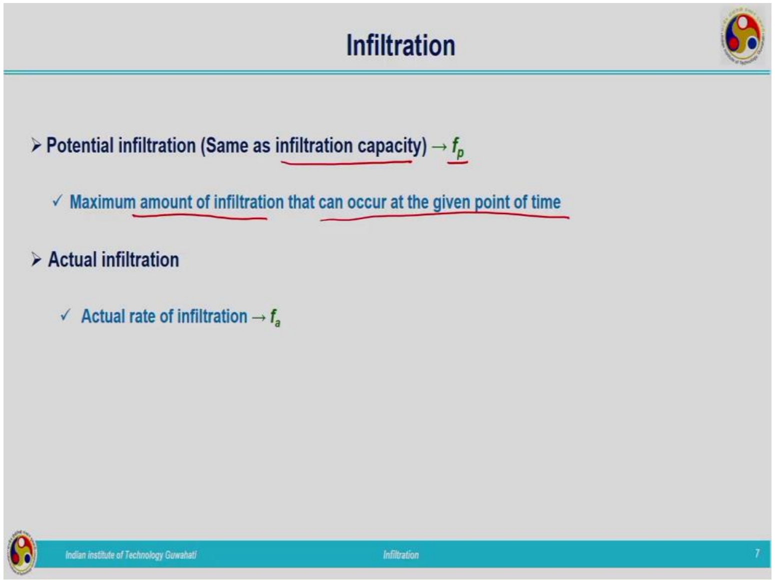

Now, different terminologies related to infiltration. One is, potential infiltration. This is similar to that of terminologies which we have seen in the case of evapotranspiration. We have seen two terms, one is potential evapotranspiration and the second one was actual evapotranspiration. In the same way, for representing infiltration also, we will be using the same terminology, that is, potential infiltration and the actual infiltration.

Potential infiltration is same as infiltration capacity. What was infiltration capacity? Maximum rate with which water can be infiltrated in the soil. So, potential infiltration is the maximum amount of infiltration that can occur at the given point of time. It is represented by f_p.

And second one is actual infiltration. Actual infiltration is the infiltration taking place at that particular time, in the field or in the laboratory. Always, we cannot expect potential infiltration because sometimes the water availability will be less. If the rainfall is only happening for a very short interval of time, maximum water which can be absorbed by soil, which can be infiltrated through the soil may not be occurring. Before that, the rainfall might have ceased. So maximum capacity of infiltration is represented by potential infiltration, and whatever exactly happening at the field or the lab, that is the actual rate of infiltration. That is represented by f_a.

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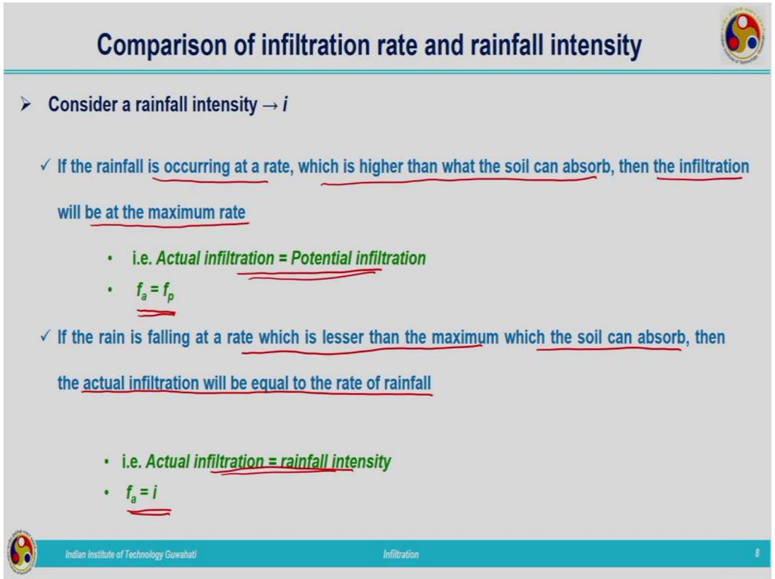

Now, we need to have a comparison between the rainfall intensity and infiltration rate because we are having the rainfall value and some amount of water is lost as evaporation, evapotranspiration, and water which is moving into the ground (represented by infiltration), and some amount will be used for satisfying different storage components (what are the different storage components, we will see later). But infiltration is a component which is representing a loss from the total amount of rainfall. So, we need to quantify it accurately.

So, consider a rainfall intensity of i, and if the rainfall is occurring at a rate which is higher than what the soil can absorb, then the infiltration will be at the maximum rate.

We are having a rainfall intensity i, the intensity of rainfall is very high compared to the water which can be absorbed by the soil as infiltration rate. So, in such case, we can tell that the actual infiltration is equal to potential infiltration. We are having maximum amount of water available from the rainfall so that the maximum holding capacity or the maximum infiltration capacity can be satisfied. So, in that case actual infiltration will be the maximum infiltration rate. So that is nothing but our potential infiltration. So, we can write $f_a = f_p$ in that case.

It may not be always like that. The rainfall intensity may be sometimes less than that of the maximum infiltration capacity. At that time, what will happen? If the rain is falling at a rate which is lesser than the maximum which the soil can absorb, then the actual infiltration will be equal to the rate of rainfall, that is, we are having a rainfall intensity which is lesser than that of the maximum absorbing capacity of the soil. In that case whatever is falling as rainfall will be getting infiltrated into the ground.

So, we are having the actual infiltration taking place at that time which is equal to the intensity of rainfall. It is not reaching up to the potential infiltration because the rainfall intensity is less than that of the absorbing capacity of soil. In that case, we can write actual infiltration is equal to rainfall intensity, $f_a = i$. So, this understanding is very important, whether we are experiencing maximum infiltration or the potential infiltration or we are experiencing the actual infiltration.

And we can relate it with the rainfall intensity. If the rainfall intensity is too high than that of potential infiltration, then actual infiltration will be equal to potential infiltration. If the rainfall intensity is less than that of the holding capacity or absorbing capacity of the soil or less than the potential infiltration, then we can tell that, actually what is the infiltration taking place will be equal to intensity of rainfall.

So this much about the basic understanding related to infiltration. We have seen what is meant by infiltration. For understanding the infiltration process, we have understood the soil moisture profile clearly and different zones, that is, four different zones which can be present beneath the ground surface during the time of rainfall is also clearly understood by means of a soil moisture profile.

After that, we have seen the representation of infiltration by means of infiltration rate and cumulative infiltration. And the relationship between them, also found. And we had a comparison between the infiltration rate and the rainfall intensity. And depending on the intensity of rainfall which we are experiencing and comparing it with the soil absorbing capacity, we can tell whether it is potential infiltration or the actual infiltration.

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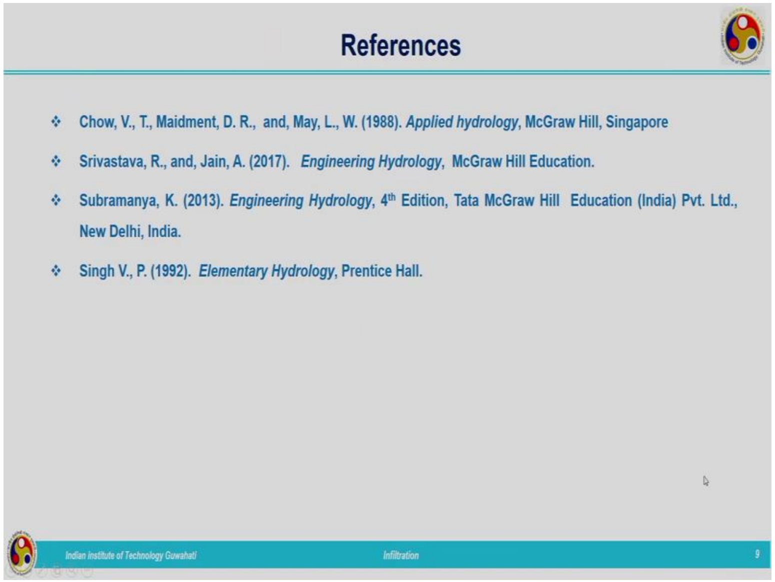

So, related to this, you can have a reading through these textbooks, reference books. And here, I am winding up this lecture. Thank you.