Engineering Hydrology

Professor Doctor Sreeja Pekkat

Department of Civil Engineering

Indian Institute of Technology, Guwahati

Module 3 Lecture 40

Ponding Time

Hello all. Welcome back. In the previous lecture, we have derived the Green-Ampt's equation for infiltration. We have considered the fundamental laws, that is the continuity equation and the momentum equation. Finally, we have combined those two equations to form the final Green-Ampt equation.

So, while deriving Green-Ampt equation, we have assumed certain conditions, that is the infiltration is taking place in the presence of abundant quantity of water. Because we have assumed a ponding depth. In the case of rainfall occurring, when we will be getting a ponding depth? Water will be getting stagnating on the surface when all the pores present within the soil are filled with water.

So, initially soil will be comparatively in a dry state. In that stage, rainfall is occurring. And, water which is falling as rainfall will be infiltrating into the ground. And once the surface layer becomes saturated, then water becomes stagnating on the surface of the ground. Then only we will be getting a ponding depth. The equation which we have derived is giving the potential infiltration, that is sufficient quantity of water is available to us.

And the second assumption was, we have assumed a sharp wetting front. That is the wetting front is dividing the soil strata into 2 zones, that is unsaturated region below the wetting front and the saturated region above the wetting front. Initially, the soil was dry and when rainfall started, water started infiltrating into the ground and the soil started becoming saturated. And the boundary which is separating the soil which is in the initial state and the soil already saturated, that is the wetting front. That wetting front we have considered as a sharp wetting front. O therwise, we have already seen the soil moisture profile. In that case what we have seen?

We are dividing the subsurface zone above the wetting front into four zones. At the top we are having the saturation zone. Then comes the transition zone, transmission zone and wetting zone. As the water starts infiltrating into the ground in the downward direction, we have seen different zones present beneath the ground surface.

But while deriving the Green-Ampt equation, we have not considered four different zones. We have assumed that above the wetting front we are having the saturated zone and below the wetting front we are having the unsaturated soil which is in the initial condition. So, we need to have a clear understanding about ponding. Ponding process or what is meant by ponding, it is already clear. That is during the process of rainfall, water is infiltrating, all the pores are getting filled up with water and water start stagnating on the surface of the ground. But when this ponding will be starting? So, regarding that we do not have any idea. So, in this lecture, we are going to understand what is meant by ponding time.

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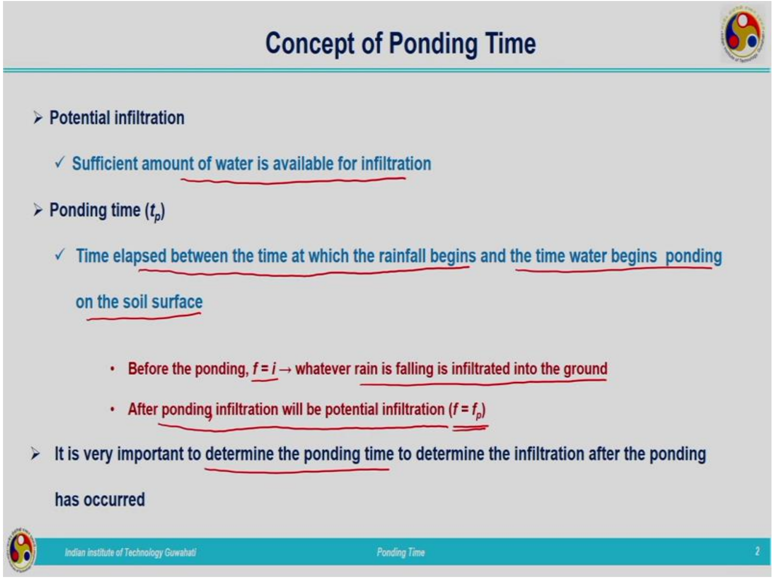

So, this lecture is related to ponding time. We know, in the case of potential infiltration, sufficient amount of water is available for infiltration. Now, when sufficient amount of water is available for infiltration means, all the pores present in the soil can be filled up with water. Then a saturation zone will be produced and water starts ponding on the surface.

So, ponding time is defined as the time elapsed between the time at which the rainfall begins and the time water begins ponding on the soil. So, we are getting rainfall at a particular time. At that particular instant we would not be getting ponding. So, once infiltration starts, near surface pores present in the soil gets filled up with water and it has reached the porosity value (maximum soil moisture), then the surface layer becomes saturated, then the ponding starts.

So, the time gap between the beginning of the rainfall to the ponding moment, that is the ponding time.

Before the ponding, that is when we are getting the rainfall, infiltration process is started, we will be having infiltration rate is equal to intensity of rainfall ($f = i$). That is whatever rainfall we are getting (intensity i), all this water will be getting infiltrated into the soil. That is the rain which is falling is infiltrated into the ground fully.

And after ponding, infiltration will be potential infiltration ($f = f_p$). Here, sufficient quantity of water is available to the soil. So, the infiltration will be continuing. That infiltration will be potential infiltration.

Now, it is very important to determine the ponding time. Then only we will be getting idea about how much is the quantity of water infiltrated just after ponding. So, we need to determine the ponding time to determine the infiltration after ponding has occurred.

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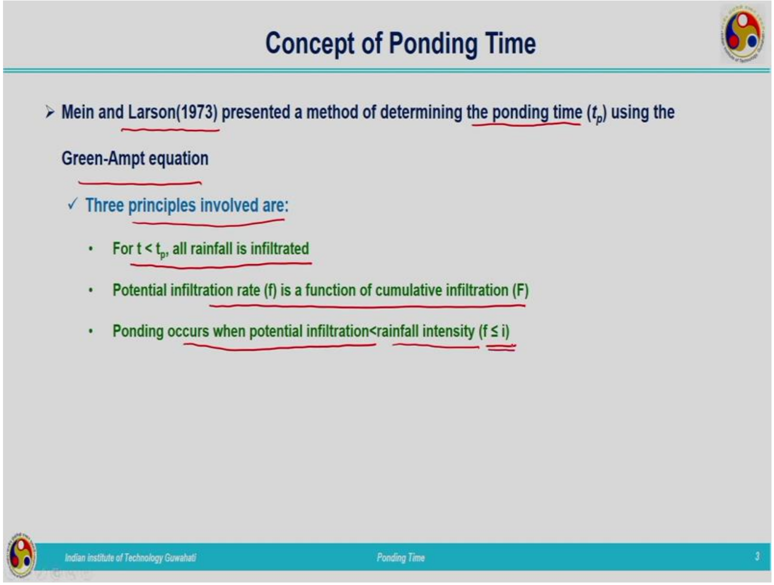

Mein and Larson in the year of 1973 presented a method for the determination of ponding time using Green-Ampt equation. So, in this, 3 important principles are involved. They are,

- For $t < t_p$ - all rainfall is infiltrated.

Initially soil was at a relatively dry condition. So, for $t < t_p$, that is ponding has not started, whatever rainfall we are getting, everything will be infiltrated into the ground.

- Potential infiltration rate (f) is a function of cumulative infiltration (F).

Larson and Mein have derived the equation based on Green-Ampt equation. So, definitely infiltration rate is a function of cumulative infiltration. So, specifically we are mentioning the infiltration rate as potential infiltration rate because Green-Ampt equation is derived on the assumption that there is a ponding depth of h_0. So, definitely we will be experiencing the potential infiltration.

- Ponding occurs when potential infiltration is less than rainfall intensity ($f \leq i$).

If $f > i$, entire rainfall will be infiltrated into the ground. After certain time, what will happen? Infiltration rate will be reducing. So, f will be $\leq i$. At that moment ponding occurs.

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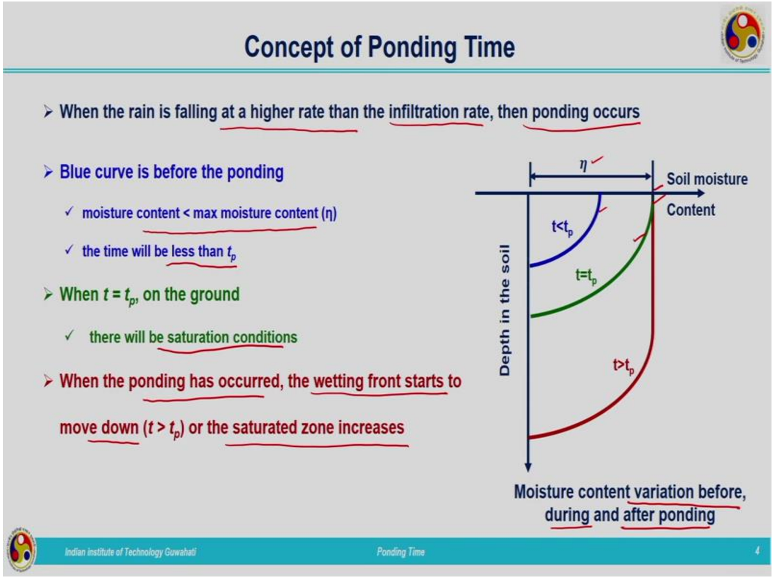

That is when rain is falling at a higher rate than the infiltration rate, then ponding occurs. This is the condition.

So, for deriving the concept of ponding time we need to look into the soil moisture profile again. That is moisture content variation before, during and after ponding. So, the same soil moisture profile I have drawn over here with our soil moisture along the X-axis and depth beneath the ground surface is marked on the Z-axis.

Now, the maximum soil moisture can go up to η, porosity. And before the rainfall starts or during the initial condition or the soil is in the unsaturated condition, then the soil moisture present in the soil will be less than that of η. Consider the case in which $t < t_p$ that is the ponding has not reached. In this case our soil moisture profile will be like this (shown in blue curve). Rainfall has started, some of the water is getting infiltrated into the ground but all the pores are not filled up with water. So, soil moisture prevailing within the soil will be less than that of the maximum amount of soil moisture, that is $\theta < \eta$. So, we can experience a soil moisture profile like this (blue curve).

Now, consider the time at which $t = t_p$. Now, here ponding occurs, so, all the pores near the surface are filled with water. So, the maximum moisture content η will be attained. So, the curve will be looking like this (green curve). When $t = t_p$, on the ground surface there will be saturation condition. Beneath the ground surface it will be still unsaturated but we are talking about the surface layer of soil where direct rainfall is occurring. So, that layer of soil will be saturated.

And when the ponding has occurred ($t > t_p$), the wetting front starts to move down or the saturated zone increases. So, the soil moisture profile will for $t > t_p$ will be looking like this (red curve). Maximum value of soil moisture is still at η. It cannot go beyond that. That is, it depends on the pores which are present in the soil.

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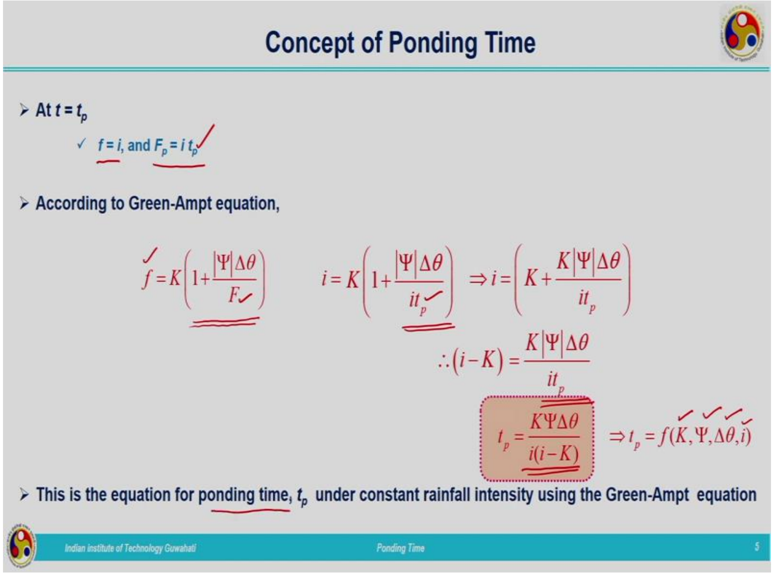

Now, at $t = t_p$,

$f = i$ and $F_p = i \times t_p$.

That is time t = ponding time, the cumulative infiltration is = $i \times t_p$ with the assumption that infiltration rate is equal to intensity of rainfall.

We have derived the equation corresponding to infiltration rate by making use of Green-Ampt principles. So, according to Green-Ampt equation, infiltration rate is given by

$$f = K\left(1 + \frac{|\Psi|\Delta\theta}{F}\right)$$

Our intention is to find an expression for t_p, ponding time. So, after substituting the values corresponding to f and F

$$i = K\left(1 + \frac{|\Psi|\Delta\theta}{it_p}\right)$$

$$\Rightarrow i = \left(K + \frac{K|\Psi|\Delta\theta}{it_p}\right) \Rightarrow (i - K) = \frac{K|\Psi|\Delta\theta}{it_p}$$

$$\Rightarrow t_p = \frac{K\Psi\Delta\theta}{i(i-K)}$$

$$\Rightarrow t_p = f(K, \Psi, \Delta\theta, i)$$

So, t_p is a function of hydraulic conductivity K, soil suction Ψ, $\Delta\theta$, soil moisture deficit and i is the intensity of rainfall.

This equation $t_p = \frac{K\Psi\Delta\theta}{i(i-K)}$ is the equation for ponding time under constant rainfall intensity i using the Green-Ampt equation.

Note- We have assumed a constant rainfall intensity i. Always it may not be constant. But for short interval of time, we can assume it to be constant. So, under constant rainfall intensity we can calculate the ponding time by making use of this equation.

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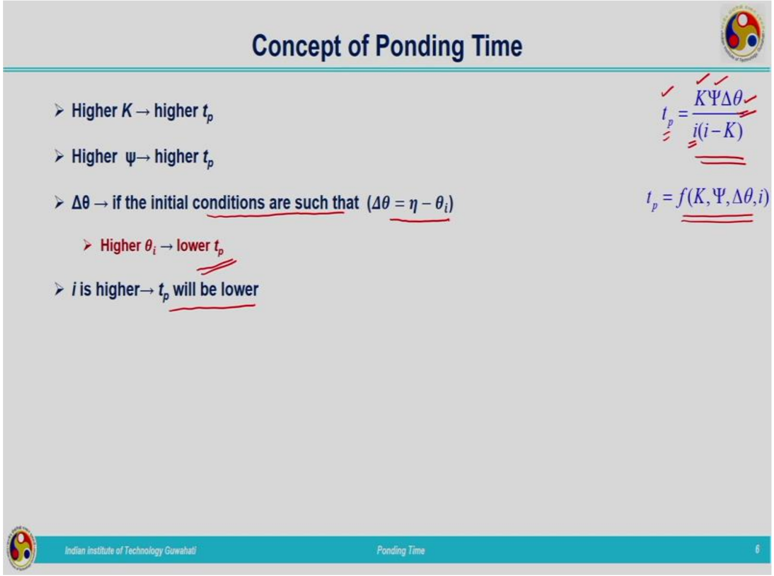

Now, we can have a look into this particular equation

$$t_p = \frac{K\Psi\Delta\theta}{i(i-K)} \Rightarrow t_p = f(K,\Psi,\Delta\theta,i)$$

- Higher the K value, t_p will be higher.

- Higher the Ψ value, t_p will be higher. Soil suction or the negative pressure is high means the soil is almost in a dry condition or it is towards the relatively dry condition. So, if it is dry, it will be having more infiltration. So, whatever rainfall is occurring, it will be getting infiltrated into the ground until it becomes saturated. So, as the Ψ value is high, t_p also will be high.

- Next term is $\Delta\theta$. So, $\Delta\theta$ is the soil moisture deficit, represented by (η - θ_i). It is the available pore space for water to be filled. If initial moisture conten θ_i is high, the value corresponding to soil moisture deficit will be less. If $\Delta\theta$ is less, means t_p will be lower. So, higher the initial moisture content, θ_i, lower will be the ponding time.

- One more factor is there. That is the rainfall intensity. If i is higher, t_p will be lower (because intensity of rainfall is coming in the denominator, so, inversely proportional). That you can understand. Heavy rainfall is occurring. Easily we will be getting ponding and after that overland flow. In the similar way soil is having some very good amount of soil moisture content. So, more and more water would not be infiltrating, early ponding will be taking place. That is what is mentioned by this condition.

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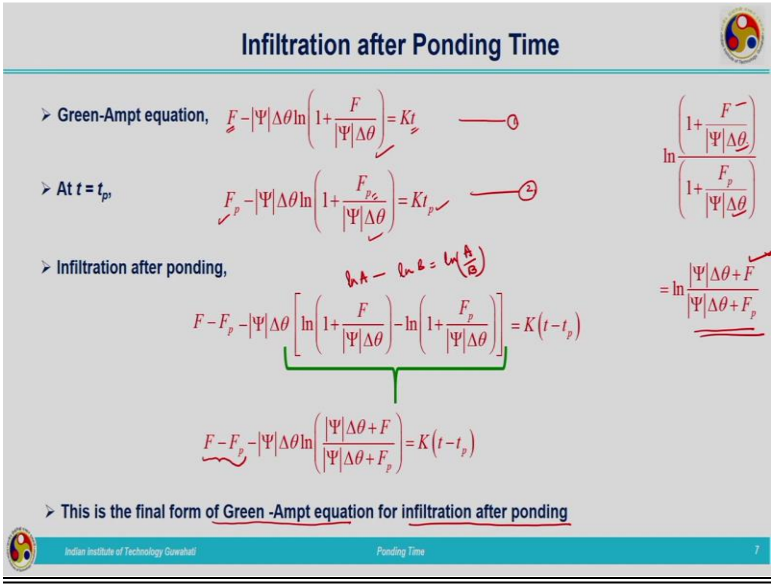

Now, we need to find out the expression for infiltration after ponding. That we are going to do by making use of Green-Ampt equation. Green-Ampt equation is given by this particular equation,

$$F - |\Psi|\Delta\theta \ln\left(1 + \frac{F}{|\Psi|\Delta\theta}\right) = Kt \quad ....(1)$$

At $t = t_p$, $F_p - |\Psi|\Delta\theta \ln\left(1 + \frac{F_p}{|\Psi|\Delta\theta}\right) = Kt_p$ ....(2)

So, the infiltration after certain time t (where $t > t_p$), can be calculated by using equation 1. And if the time $t = t_p$, it can be calculated by using equation 2. So, by subtracting equation 2 from equation 1, (F - F_p), we can calculate the amount of water getting infiltrated just after ponding started.

So, infiltration after ponding is given by

$$F - F_p - |\Psi|\Delta\theta \left[\ln\left(1 + \frac{F}{|\Psi|\Delta\theta}\right) - \ln\left(1 + \frac{F_p}{|\Psi|\Delta\theta}\right)\right] = K\left(t - t_p\right)$$

Now, look at this logarithmic term, that we can make in a simplified form.

We know $\ln A - \ln B = \ln\left(\frac{A}{B}\right)$

So, $$\left[\underbrace{\ln\left(1+\frac{F}{|\Psi|\Delta\theta}\right)}_{\ln A} - \underbrace{\ln\left(1+\frac{F_p}{|\Psi|\Delta\theta}\right)}_{\ln B}\right] = \ln\frac{\left(1+\frac{F}{|\Psi|\Delta\theta}\right)}{\left(1+\frac{F_p}{|\Psi|\Delta\theta}\right)} = \ln\frac{|\Psi|\Delta\theta + F}{|\Psi|\Delta\theta + F_p}$$

After substituting this expression for these terms,

$$F - F_p - |\Psi|\Delta\theta \ln\left(\frac{|\Psi|\Delta\theta + F}{|\Psi|\Delta\theta + F_p}\right) = K\left(t - t_p\right)$$

So, here we are having the difference $F - F_p$. This will be giving us the cumulative infiltration or the quantity of water which is infiltrated after the ponding time. This is the final form of Green-Ampt equation for infiltration after ponding.

So, in case we are going to calculate the infiltrated amount after ponding has taken place, we can make use of this particular equation. Infiltration expression for a particular time t is written. And we will be calculating F_p that is the infiltration corresponding to $t = t_p$ by using Green-Ampt equation. Difference between them will be giving us the quantity of water which is infiltrated into the ground after ponding has occurred.

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So, this typical part related to ponding time is taken from the textbook of Applied hydrology by Ven Te Chow and others. So, in this we have found out the expression for infiltration after ponding by making use of Green-Ampt equation. Certain principles are involved in this. One is at time $t = t_p$, we are assuming intensity of rainfall is equal to the infiltration rate f and by making use of the Green-Ampt equation, Green-Ampt equation is we know, it is for the ponding depth h_0, that is, we are getting the potential infiltration. So, potential infiltration rate is a function of cumulative infiltration. So, with these principles by making use of the Green-Ampt equation, we have derived the expression for infiltration after ponding. Thank you very much.