Analysis and Design of Bituminous Pavements

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Lecture - 24

Environmental Effect - Part 01

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Hello everyone, welcome back. In this lecture, we are going to start talking about the effect of environmental effects on the performance of the bituminous pavement. So far, we were only talking about the measurement of modulus for different layers. Now we are going to see how the environmental effects affect those modulus parameters, to what degree these modulus parameters vary depending upon the environmental effects. Because ultimately, if there is a variation in modulus for a given stress condition, the strain is going to vary. If we take a typical pavement, the load that we experience from the vehicle is going to remain a constant.

Let us say that it is a typical loading scenario we experience in a pavement. So now, the amount of strain that we get for a given stress is going to ultimately depend on the modulus value. If my modulus value decreases significantly because of these environmental effects, then I am going to have a larger strain that I will experience in my pavement. As the strain keeps increasing and if the strain is not able to recover back quickly, we are going to have large amount of permanent deformation.

In this aspect, it is important to quantify the effect of environmental factors on this modulus value. How sensitive is this modulus value depending on the environmental condition? Again, depending upon the type of layer, for a granular layer, the climatic parameter that changes the modulus is different. For a bituminous layer, the climatic parameter that influences the modulus is different. So, we have to identify what is the climatic parameter that influences this modulus value and what is the sensitivity of this modulus to these climatic parameters. So, that is what we are going to discuss in the next 2 or 3 lectures.

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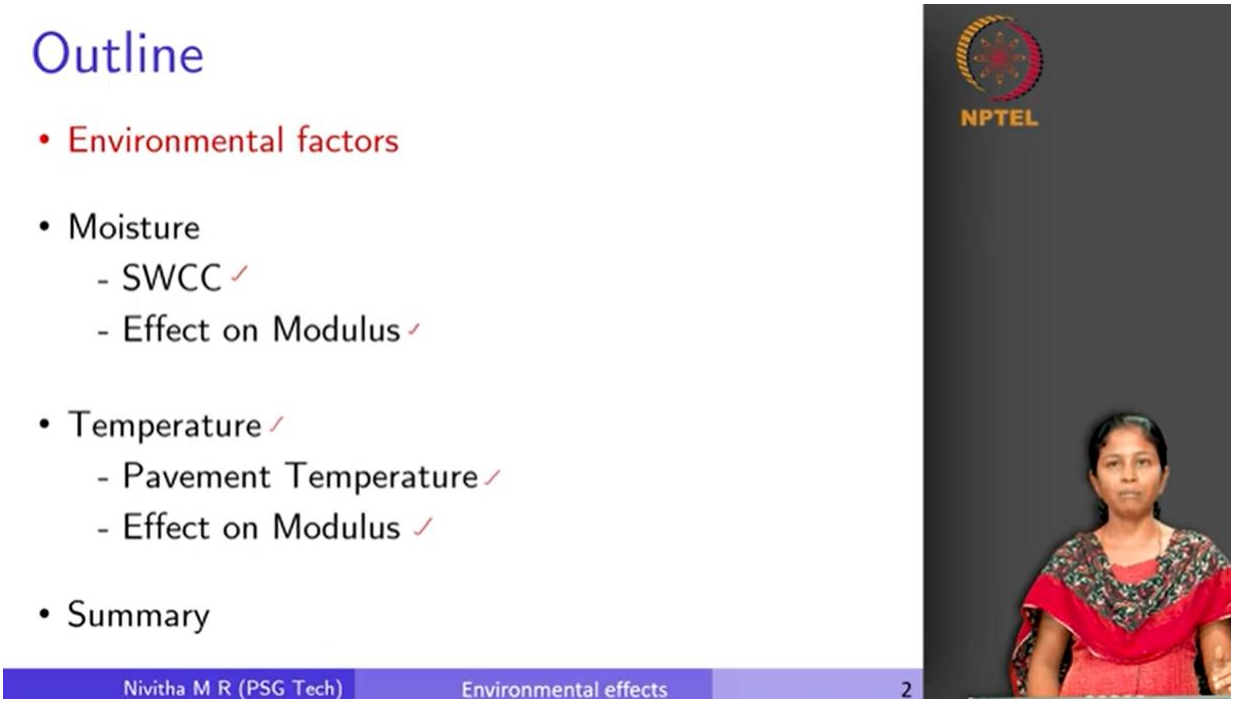

This is the outline. We are going to first talk about environmental factors. We are not going to go into the depth of these environmental factors, just identify what are these environmental factors

and then we start quantifying what is the influence of these environmental factors on the moisture content. We are going to talk about soil water characteristic curve, which is used to quantify the strength and permeability aspects of the soil.

Then we are going to see what the effect of moisture on the modulus parameter is. Similarly, we are going to take another parameter which is temperature. Though there are a lot of environmental parameters that will be influencing the performance of the pavement, we will be seeing that moisture and temperature are the 2 main parameters that we will be concerned about from the design perspective, at least from the influence on the modulus value. We will talk about pavement temperature, what will be the effect on modulus, and finally we will summarize. So, this is the outline of this presentation wherein we will be talking about the influence of environmental factors, identifying them and quantifying the sensitivity of modulus.

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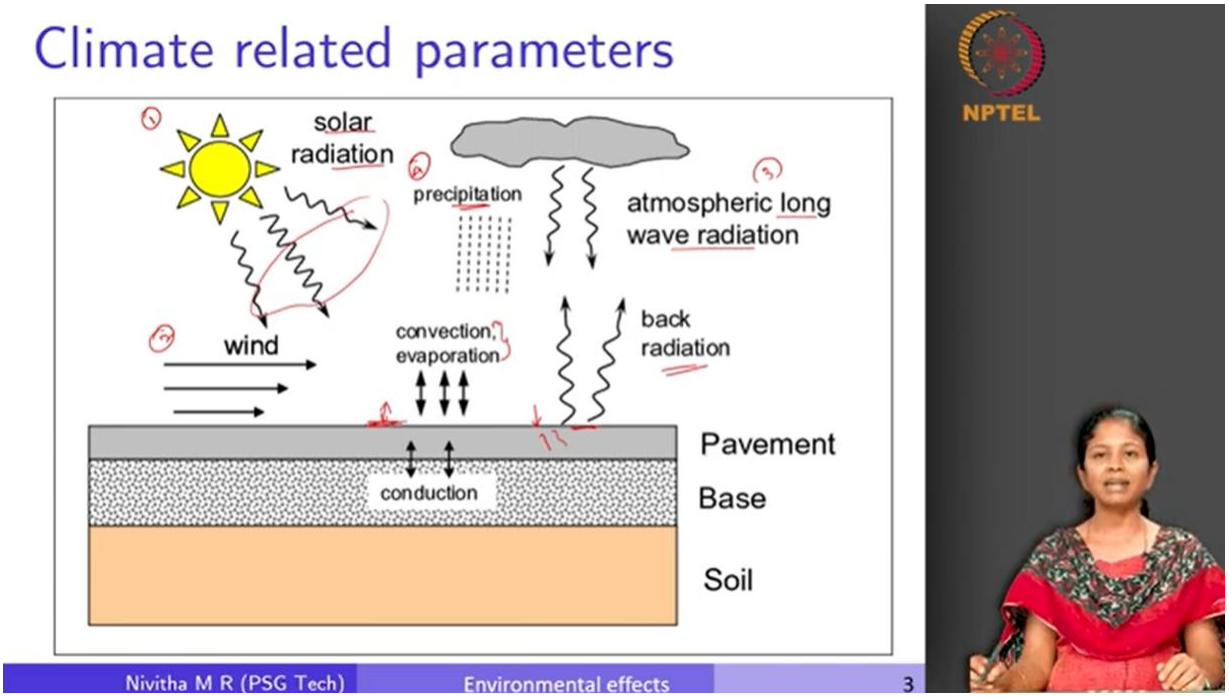

This is a very generic representation of the effect of environmental factors on the pavement. So, let us start identifying what are the parameters. The first one is solar radiation. The solar radiation is amount of radiation that we receive directly from the sun. We know that during summer, the solar radiation will be high and during winter the solar radiation will be less and so

on. So, this solar radiation is the first and foremost parameter which influences the temperature conditions of your pavement. The next parameter is wind speed. So, this wind speed influences the degree of heat transfer that happens between atmosphere and pavement. So, we have that defined using a convection and evaporation process.

In the convection process, once the solar radiation falls on the pavement, the surface of the pavement is heated to a certain degree and the temperature rises. Now the air temperature might be slightly lesser. Now there is a convection which happens between the atmospheric air and the surface of the pavement. And we also have evaporation that is happening between these two states. One is the pavement and the other one is the atmospheric air. So, wind is the second parameter. It does not have any separate influence on its own, but it is going to govern the influence of other parameters on the pavement.

The third one is atmospheric long wave radiation which falls on the pavement. It is not a solar radiation which comes from the sun. These are called as long wave radiations. Now these radiations will fall on the surface of the pavement. Some amount of these radiations will be absorbed by the pavement and some amount of radiations will be given back which is called as the back radiation. So, this back radiation is what is scattered from the pavement and it is going back into the atmosphere. This is also another source of heat to the pavement surface. Apart from this, we also have precipitation.

Precipitation is nothing but the rainfall. So, we have rainfall which occurs as natural phenomena. Because of this rainfall, the rainwater falls on surface of the pavement. So, this rainwater is going to influence the temperature of the pavement surface. So, one is the effect of rainfall on the temperature conditions of the pavement and the other one is the effect of rainfall on the moisture content in the pavement.

So, because of this precipitation, water is going to fall on the pavement and rain on the sides. We will see shortly how this moisture is going to enter into this pavement system. This is the fourth parameter. The parameters are solar radiation, wind speed, atmospheric long wave radiation and back radiation put together and one more is precipitation. There are also other parameters.

One, we can say that as the cloud cover. Let us say there is a given amount of solar radiation. What percentage of the solar radiation reaches the pavement surface? That again is influenced by the cloud cover. If we have a higher cloud cover, this proportion is going to be less. So, cloud cover is another parameter.

Similarly, we can also use another parameter which is sunshine, instead of using the solar radiation parameter. What is the percentage of sunshine that we experience on a given day? That is an indirect way of quantifying the effect of cloud cover. Like this, there are many parameters which we will be using and quantifying the effect of environment. So, now there are three processes that happen in a pavement. Again, there are many processes that happen. We are interested in identifying the effect of three processes. The first one is convection, second one is evaporation and the third one is conduction.

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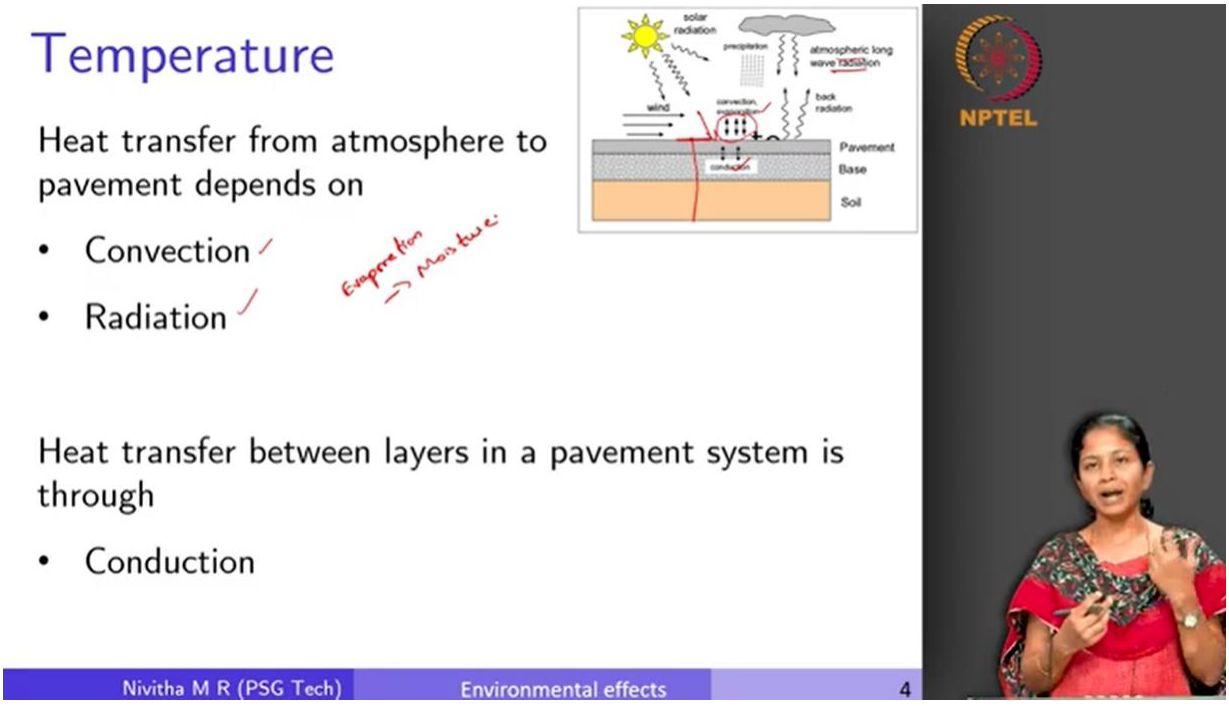

Convection is nothing but the heat transfer from atmosphere to pavement. This heat transfer from atmosphere to pavement depends on convection and radiation. We said there are this back wave radiation and atmospheric long wave radiation. These radiation effects are going to influence the heat transfer from atmosphere to pavement and back from pavement to atmosphere. So, we have

convection and we have radiation and there is also heat transfer between layers in a pavement. From the atmosphere, the amount of heat that falls onto the surface of my pavement and how much of heat is actually reflected back and it is transferred from pavement to air is through convection and radiation. Whereas, once I have a given temperature on the surface of the pavement, what is the temperature gradient that I observe along the depth of the pavement? So, that is governed by these conduction phenomena, which mostly depends on the thermal conductivity properties of the individual layers. So, these are the 3 phenomena.

In addition, we have evaporation. Once we have water on the surface and if there is some amount of heat that the ambience is experiencing, so there will be evaporation because of the heat conditions. So, convection, radiation is for heat transfer and heat transfer between layers is through conduction. We also have evaporation, which is mostly for the moisture aspect in the pavement. These are the factors which help to quantify the influence of environmental factors onto the pavement system.

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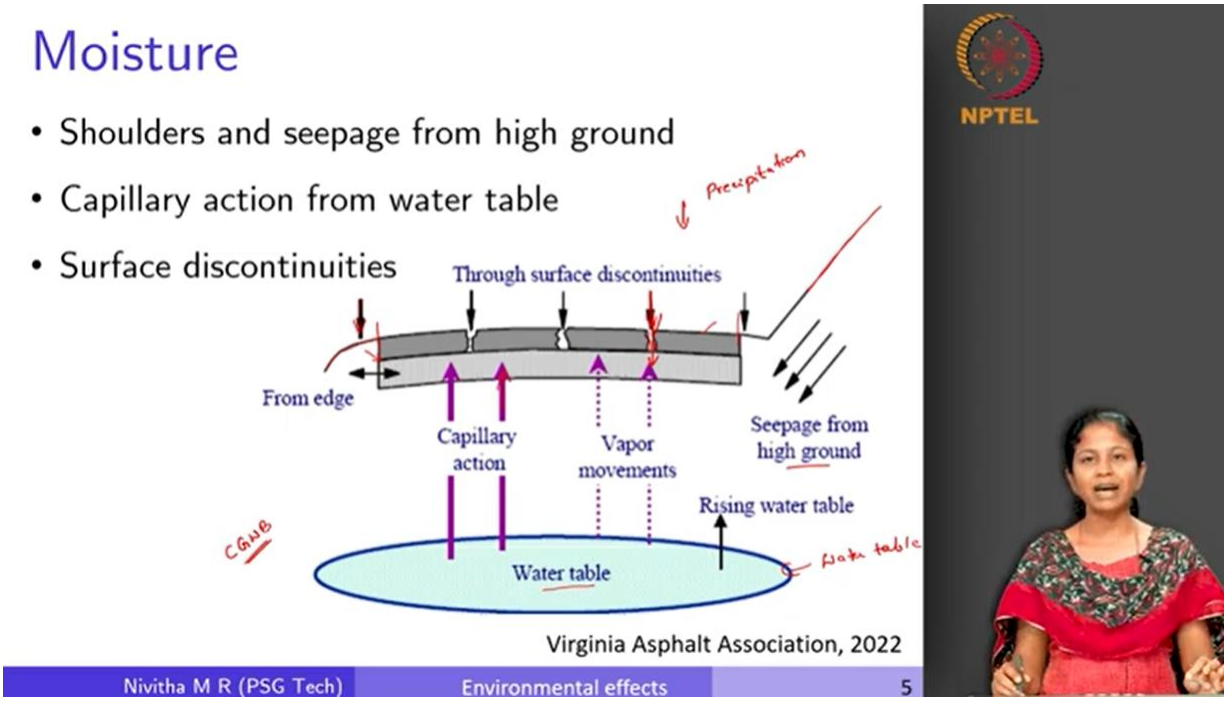

This is moisture. We can now see how moisture influences the pavement system. What are the sources of moisture in a given pavement? Now, this is our pavement system. There are 2 sources

of water. One is from precipitation or rainfall, the other is from the groundwater table. This precipitation moisture content will enter into the pavement either through the discontinuities that are seen in the surface. Let us say that we have cracks on the surface of the pavement. This crack is not only acting as initiation point for the damage, but it is also paving way as an entry point of moisture into the pavement system. This rainwater will enter into these cracks and then enter into the bottom layers. We have seen earlier even in one of our previous lectures that, among the many roles played by the surface course, one of the major function is to provide an impermeable surface. So, if it is a dense graded mix, it is going to provide an impermeable surface and if it is an open graded mix, it is going to quickly drain water from the bituminous layers into the side drains. So, the discontinuities present if any, it is going to act as a point of entry of moisture into the pavement system.

Then the water will also enter the shoulders on the side. So, these shoulders also should be having some drainage considerations. Let us say that, apart from the edge of the pavement, we have the soil layer which is present here. So, water which enters into this soil layer will also enter laterally into the pavement system. This is another point of entry of moisture into the pavement system. Let us say this is a pavement, we have a high ground nearby. So, there is also going to be seepage from a nearby high ground. This is another source of moisture entry. One is vertical entry and another one is the lateral entry. This is for the rainwater or the because of the precipitation.

The next aspect is water table. There is water table at different depths depending upon the location. Information about water table is commonly available, otherwise maps prepared by a central groundwater board indicate groundwater table at different locations. From these kind of sources also, we will be able to get information on the water table. We have water table because of which there is capillary action. Depending upon the depth of water table, the capillary action may be relevant or may not be relevant. So, this groundwater table may also raise or lower down depending upon the seasonal variations in a given year. So, during rainy season, there is a rise in the groundwater table and during the dry spell there is a reduction. Again, how much it reduces and how much it falls is again governed by the precipitation factor. So, these are the effects of moisture onto the pavement.

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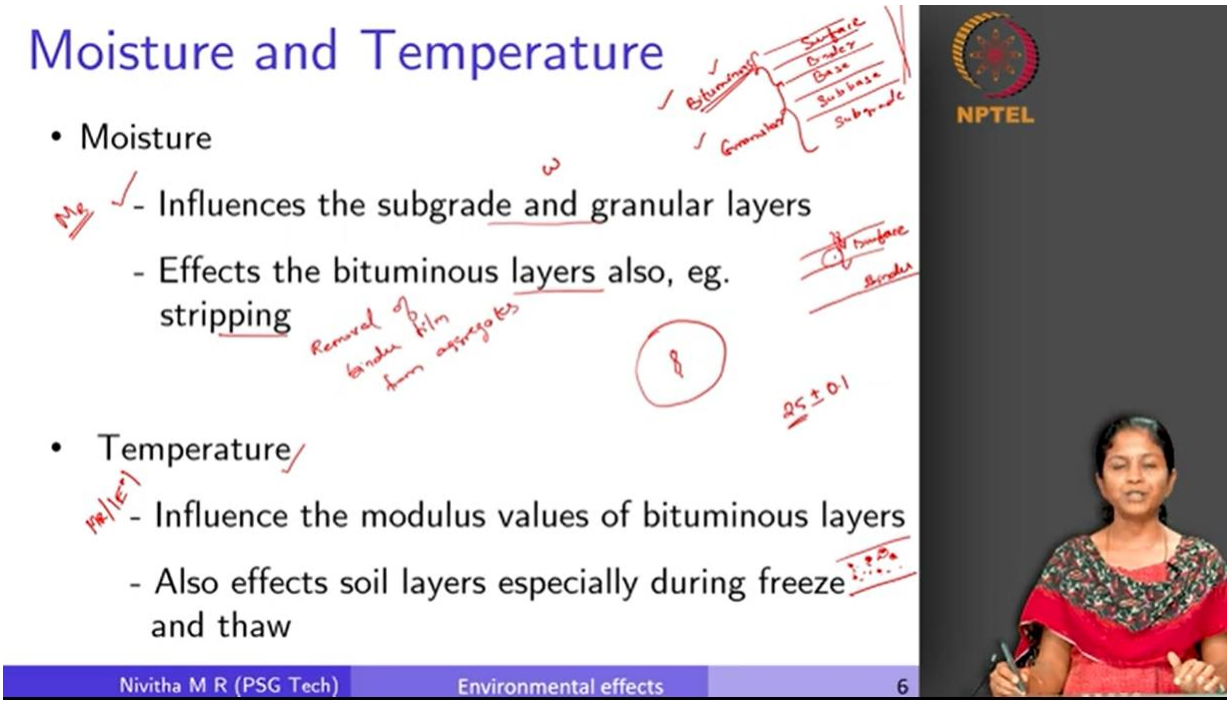

Among these things, we are going to focus on 2 parameters which are moisture and temperature. But is moisture going to affect all the layers in a pavement uniformly? We said that we have different layers in a pavement. We have the subgrade, subbase, base, binder and surface course. The bottom 3 layers are granular and for a typical bituminous pavement, the top two layers are bituminous layers. Now, is moisture going to affect all the layers in a pavement? What kind of influence it has on these 2 kind of materials? In a granular layer, it is directly going to influence the subgrade and granular layers in terms of the water content of the soil. So, we will be seeing subsequently and we have also seen in the experimental procedure that the moisture content plays an important role in determining the strength aspects of the granular layers. So, obviously, once the moisture content increases, the strength is going to reduce. So, it has a direct influence on the granular layers. This is one aspect. There are many other aspects also. It also affects the state of stress that the material undergoes under higher moisture content compared to a dry state. Similarly, it will also influence the freeze and thaw effects in soil. We will be discussing about all these aspects shortly.

We cannot say that moisture has no effect on bituminous layers also. It does have a certain degree of influence on the bituminous layers. What kind of influence? So, once moisture enters into the pavement, let us say this is the surface irregularity and so water enters here.

This is my surface course. Because of the interconnected air voids, it might reach the binder course or it may not reach the binder course. So, once water is present inside the bituminous layer, there is a higher possibility for stripping to happen. Stripping is removal of binder film from aggregates. So, we know that bitumen is the binder which is holding together all the aggregates together in a bituminous mix. So, once water comes into contact with the bituminous mix, it will slowly start ripping away this binder film from the aggregates. Now we will end up having loose aggregates. So, that is why whenever you see a pavement with some cracks on the surface, slowly what will happen is the crack will start expanding. Once particles come out from there, there is more water that is retained on these cracks, it forms kind of a pothole. So, this moisture can enter into the layer, it will rip the binder film from the surrounding aggregates and that is why when we see an initial crack here, it will grow eventually into a large pothole. This stripping effect is a major concern for moisture, but is it going to affect my design? Is it going to affect my modulus? It has a direct influence on the resilient modulus of all the granular layers, that is subgrade, subbase and base layers, but it does not have any significant influence on the modulus of bituminous layer as such. Stripping is only going to influence the distress, it causes a lot of other effects because of which the modulus may reduce, but directly it is not going to influence the modulus.

The next is the effect of temperature. Because of all these radiations, we have a particular temperature on the surface and there is going to be a temperature gradient along the depth. Again, how it varies I will show you because it is not simple to draw a line like this, there are a lot of variabilities that we will see in the temperature gradient along the depth of the pavement. Now this temperature is going to have a significant effect on the bituminous layers. We have seen earlier for testing of bituminous materials, whether it is the resilient modulus or the dynamic modulus test, maintaining a precise test temperature is very, very important. If you see, most of the test procedures will say 25 ± 0.1°C or maximum of 0.1°C variation will be allowed for all the tests on bitumen.

This is because temperature has a significant effect on the modulus parameters such as resilient modulus and dynamic modulus (|E*|) of bituminous mixtures. Is it going to affect the soil layers? Not from the modulus perspective, but yes, it is also going to have some kind of influence on the soil layers.

Let us say this is a soil system. There are voids which are present in the soil system. Depending upon the degree of saturation, there might be some amount of water which is present inside these voids. Once the air temperature reduces below a certain value, let us say that it goes to subzero temperatures. So, once air temperature goes subzero, the water which is present in these voids is going to freeze. Because of this freezing condition, we are going to have ice formation in these voids and the modulus of the layer is going to increase substantially. That is one influence of temperature on the granular layers. So, we can say that temperature actually influences both the bituminous layer and the granular layer, but in different ways. Shortly I will show you when there is moisture increase in the pavement, there is about 20 to 60 times increase in resilient modulus.

So, temperature has an influence on the modulus of bituminous layer and the modulus of granular layer when there is ice formation. If there is no ice formation, let us say in country like India where except for some portions of the northern part where temperatures fall below 0°C, for most of the other parts of the country we rarely experience subzero temperatures and this kind of an ice formation would be a rare phenomenon. In that scenario, we can ignore the influence of temperature on the modulus of granular layers. So, this is with regard to the influence of both these parameters on the pavement.

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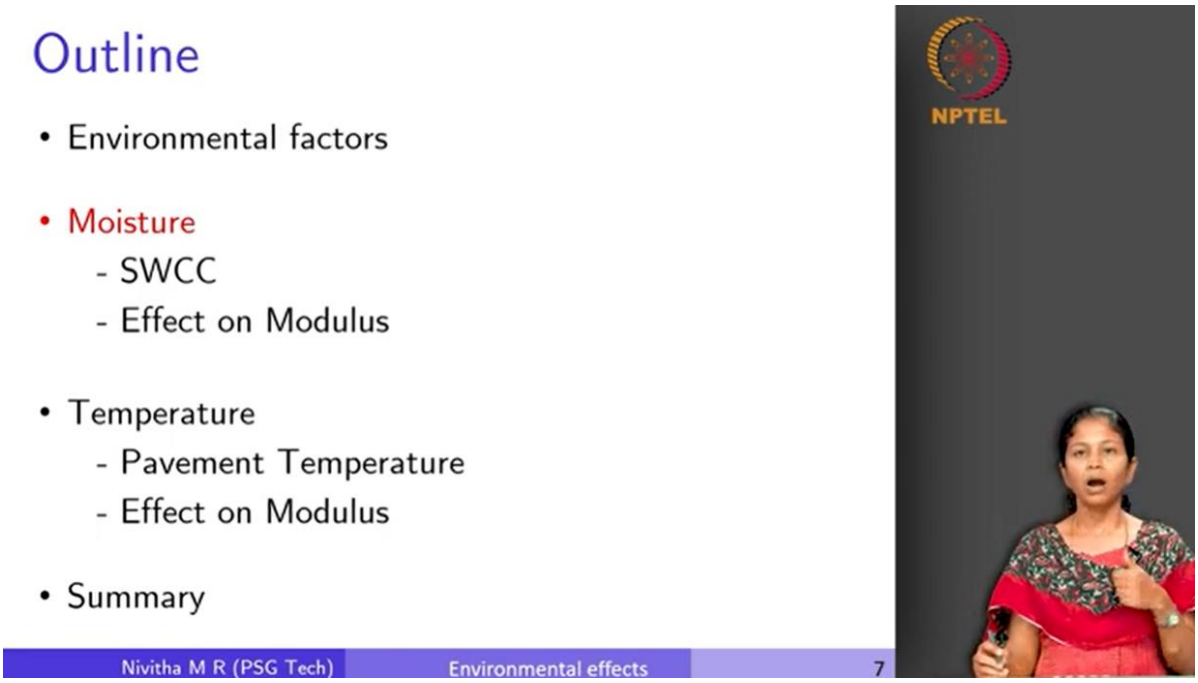

Now let us start talking about moisture in specific. How moisture influences the modulus value, how is it taken into consideration and what is the degree of influence on the modulus parameters?

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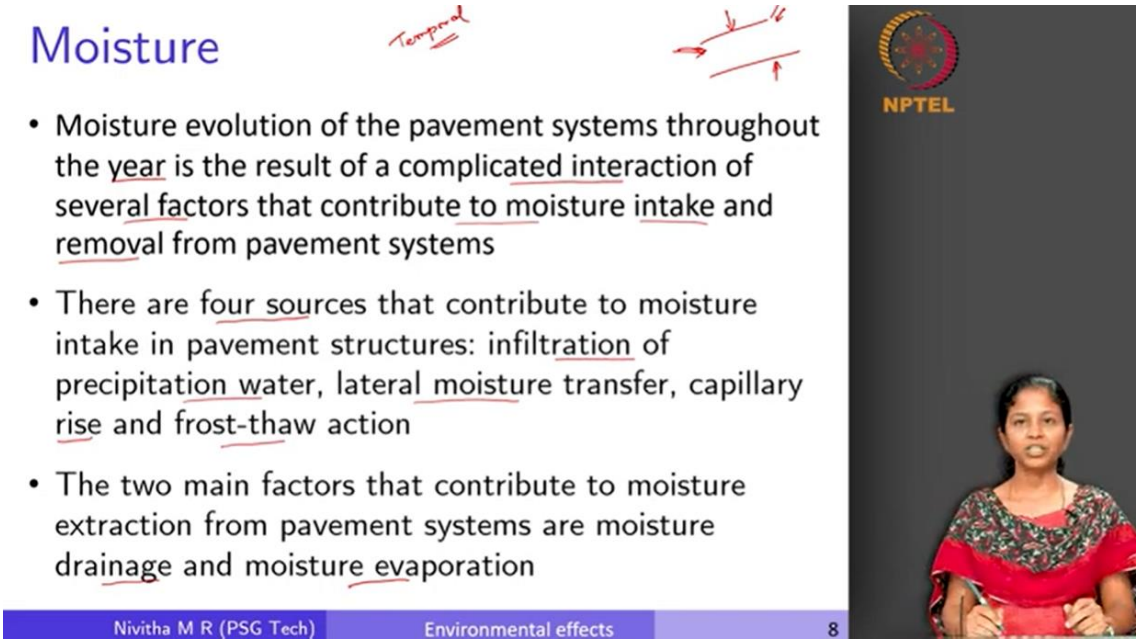

Over a given calendar year depending upon the seasonal aspect that particular location is going to experience, there will be fluctuations in moisture content. So, there will be temporal variations that are variation with time because of these moisture effects. The variation in a year is a result of complicated interaction of several factors which contribute to moisture intake and removal. So, if I have a pavement system, there are 3 factors which are going to cause a moisture influence. One is precipitation, one is lateral drainage and capillary action.

Similarly, there are phenomena through which water will be removed from the pavement system also. Generally, studies define that there are 4 sources that contribute to moisture intake in a pavement structure. What are these 4 factors? One is infiltration of precipitation water like we said earlier, the rainwater which is going to enter into a pavement system because of irregularities in your surface. The second one is lateral moisture transfer from a nearby shoulder or an earthen surface or there could be a high land and because of the seepage. Third one is capillary rise from the groundwater level and the fourth one is frost and thaw action. These are the 4 sources that contribute to moisture. So, once the water freezes, when it is thawing, it is going to release water. So, that is what is through this frost and thaw action. And there are 2 main factors which contribute to moisture extraction from the pavement.

What phenomena remove water from your pavement system? One is moisture drainage like we have a capillary action because of permeability, water is going to also drain off from your pavement system. That is one aspect of removal. The other aspect is moisture evaporation. So, we have seen in the earlier slides also evaporation is one phenomenon which is interaction of the pavement system with the environment. So, because of this evaporation also there would be moisture removal from the pavement system.

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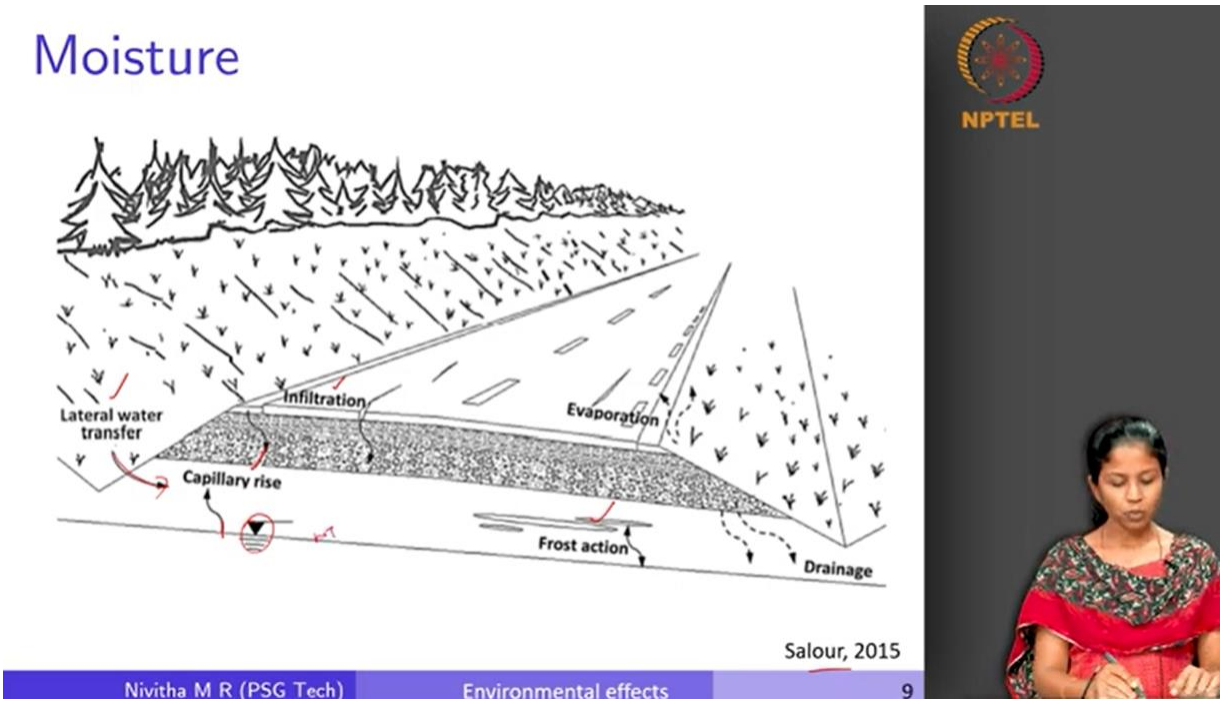

This is nicely indicated in a thesis by Salour. You can see here this is a typical pavement system. So, these are the 4 factors which lead to moisture increase in a system. The infiltration part, the lateral water transfer occurs especially when you have an embankment or a higher area nearby. Even otherwise if you do not have anything, there would be soil nearby and because of the soil, there would be lateral entry of moisture and the granular layers might be more affected because of this lateral water transfer. And then there is this frost action also and capillary rise from this water. This is the water table level. From this water table level there would be capillary action into the bottom most layers of the pavement. And what are the phenomena through which water is drained? One is evaporation and the other one is drainage from the pavement.

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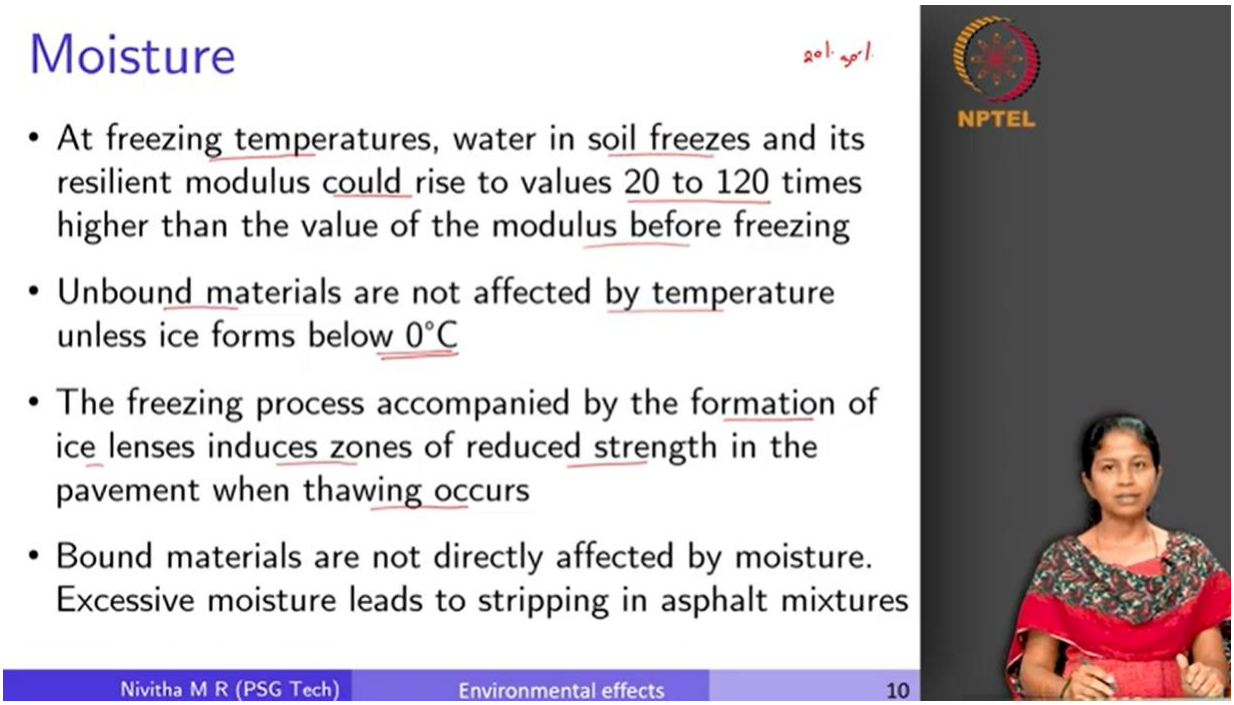

Previously I was talking to you about the influence of temperature on granular layer. So, as temperature reduces as it goes below subzero, water in the soil freezes. So, there would be a natural moisture content which is present in the soil and the water would be present inside the voids. Maybe the saturation content is 20% or it could be 30%. Whatever be the natural moisture content, this moisture content will freeze in the soil. And in the freeze condition, the resilient modulus can rise up from 20 to 120 times higher than the value of the modulus before freezing. There is a substantial increase in modulus because of this freezing effect. However, unbound materials are not affected by temperature until ice forms below 0°C.

That is why I said when we have locations which experience subzero temperature, we have to consider the effect of temperature on resilient modulus of the granular layers. Until we experience subzero temperature, it is not going to be a major factor. This freezing process is accompanied by the formation of ice lenses which induce zone of reduced strength. I will show you what this ice lens formation is. There is formation of ice lens which induces zone of reduced strength in the pavement when thawing occurs.

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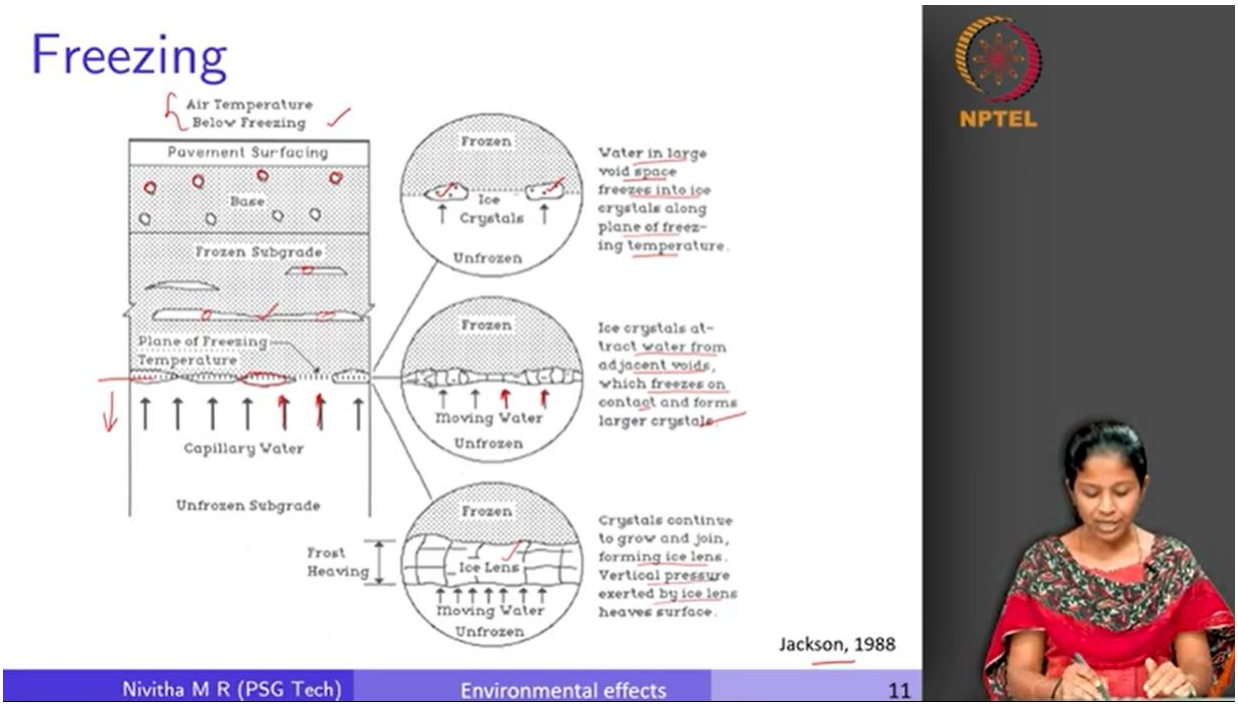

This is a typical pavement system. Let us say that the air temperature is below the freezing temperature. This is the pavement surface. Again, it is not a typical pavement cross section used in India. I have taken it from this particular reference and for them they have a surfacing, a base and a subgrade. This is the composition of the pavement. You can see here, as temperature reduces, we have these voids which were filled with water. Not necessary that all the voids should be completely saturated with water. Depending upon the degree of saturation, a few or certain degree of voids will be filled with water. These voids which are filled with water freeze when the air temperature falls below subzero and also there is subgrade which is also frozen. The water which is present in the voids in subgrade is also frozen. Below a particular point, there is an unfrozen subgrade. So, this subgrade ill still allow capillary water to rise in the pavement because this has not yet reached 0°C. It has not reached the freezing temperature.

The temperature here is slightly higher. Now this will allow capillary action. There will be a plane of freezing. If you look at this, you can see here there are ice crystals which are initially formed. When you have a small void space, there is only small amount of water, the effect is insignificant. You can see they will remain as isolated pockets. When you have a large void

space and it freezes into ice crystals along a plane of freezing temperature, eventually there will be a plane that will be formed wherein more number of air voids is present. These ice crystals will freeze, they will attract water from adjacent voids. So, once you have ice crystal, it will tend to attract water from the adjacent voids which are present. This will also freeze on contact and form larger crystals. So, a small ice crystal which was present initially is attracting water from the adjacent area and it begins to increase in size. Now this ice formation will attract more water from this water table because of capillary action and it will increase. This water is able to move because below this ice lens, there is an unfrozen subgrade. So, your entire subgrade does not freeze. Once there is this ice lens formation, many studies have shown that the temperature is slightly warm below the ice lens and it is an unfrozen subgrade. This will allow movement of more water towards this ice lens and once it reaches here, it will start freezing and the ice lens will grow in size. So, crystals continue to grow and join forming ice lens and there is a vertical pressure exerted by ice lens and it tries to heave the surface. It tries to push the surface upwards. This is the freezing effect.

Once this freezing effect is over and the temperature begins to increase, we will experience the thawing effect. During this thawing effect, what will happen is, this portion which was like completely filled with ice previously will now thaw. The water will all move out. It will be completely filled with water. This will act as a point of reduced strength. It acts as a zone of reduced strength when thawing occurs.

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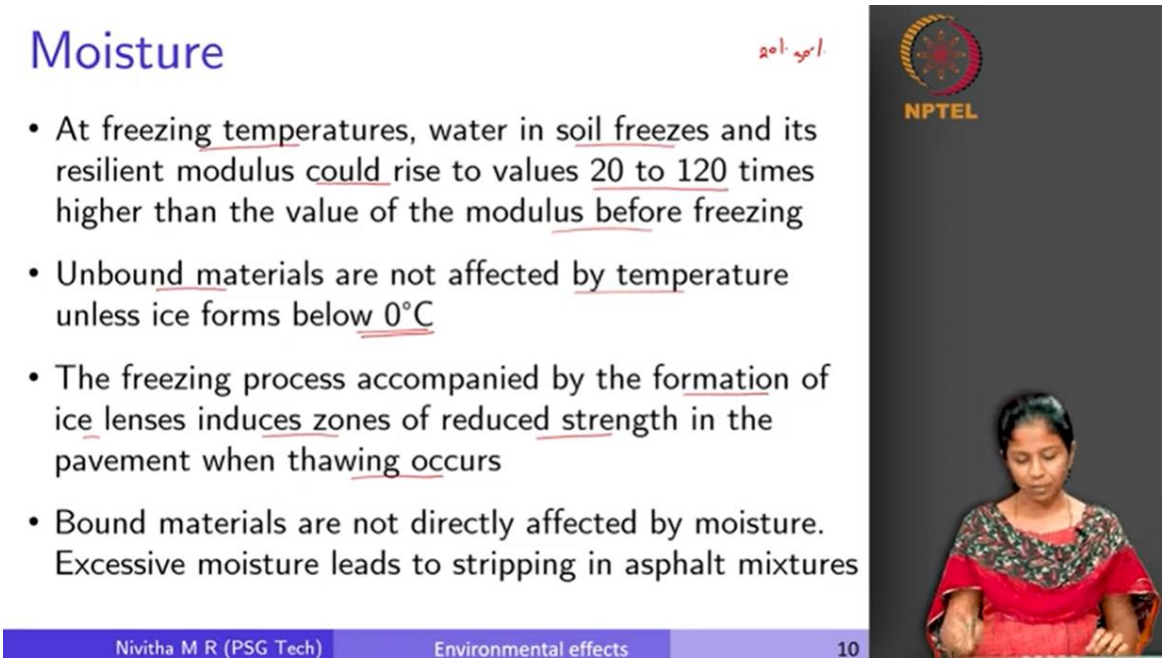

Then the bound materials are not directly affected by moisture. Maybe excessive moisture will only lead to stripping in asphalt mixtures.

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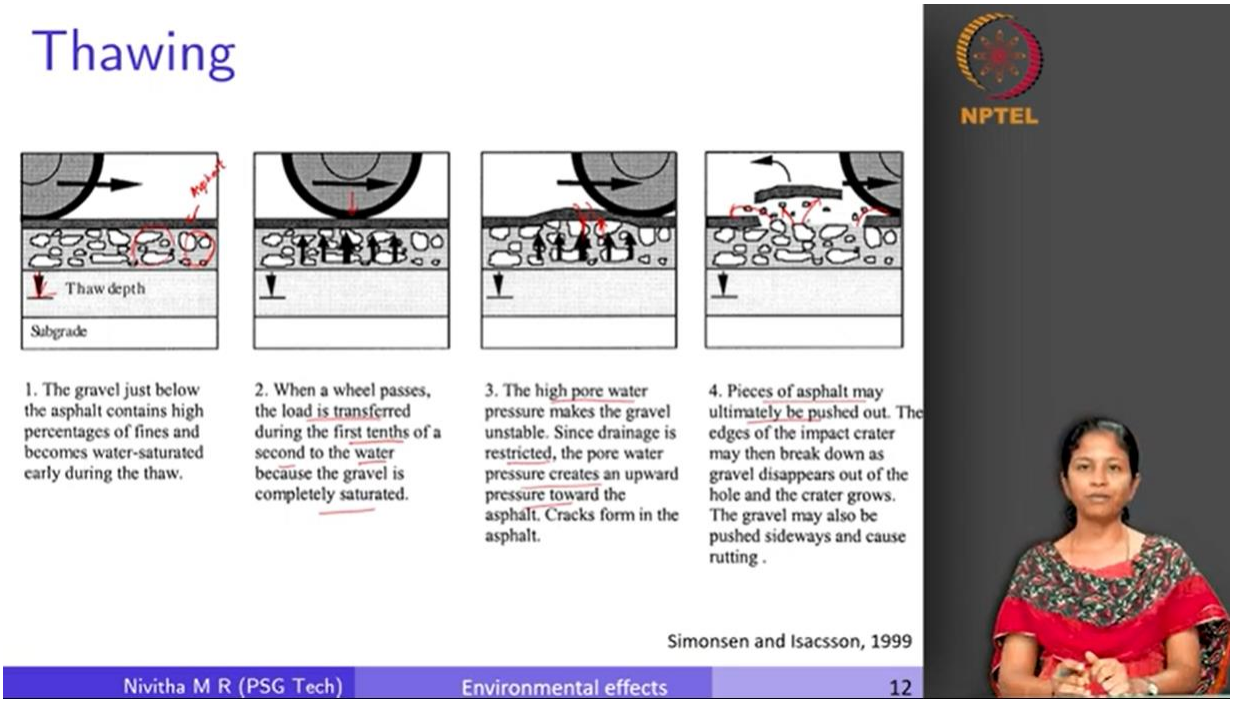

Now, let us see what happens during thawing. Let us again consider a similar kind of pavement system wherein you have a surface course, granular layer and then you have a subgrade. This is a depth up to which there is a thawing effect that we will observe. The gravel below the asphalt will contain high percentage of fines. Again, this is for another composition, another kind of material will have high percentage of fines and the water will become saturated during the early thaw because when there is up to this depth, there is a thawing effect. Because of this thawing, there is more water that is released and so gravel layer will become completely saturated with water. When a wheel passes this particular point at given instance, the entire load is passed on to water since this gravel is completely saturated.

The load is transferred during the first tenths of a second to water because gravel is completely saturated. Once the load is transferred to water, the pore water pressure increases and makes this gravel unstable. Because of this pore water pressure, it is trying to push the soil upwards and we have restricted drainage here. There is no place that it can move and the drainage is also very slow because this layer is kind of more permeable. Since drainage is restricted, the pore water pressure creates an upward pressure towards asphalt. When this force is significant, it starts to form cracks on the surface. Ultimately, depending upon the magnitude of this pressure, pieces of asphalt may also be pushed out. The edges may break and then the gravel will just disappear out of it. It might also be pushed sideways which cause rutting. So, this is the freeze and thaw effect which is observed in a pavement. Again, in India, sparing a very few locations, most of the other locations do not experience this freeze and thaw effect. That is why it hardly finds place in any of our codal provisions also and we will also not be looking into the detailed aspect of this freeze and thaw effect.

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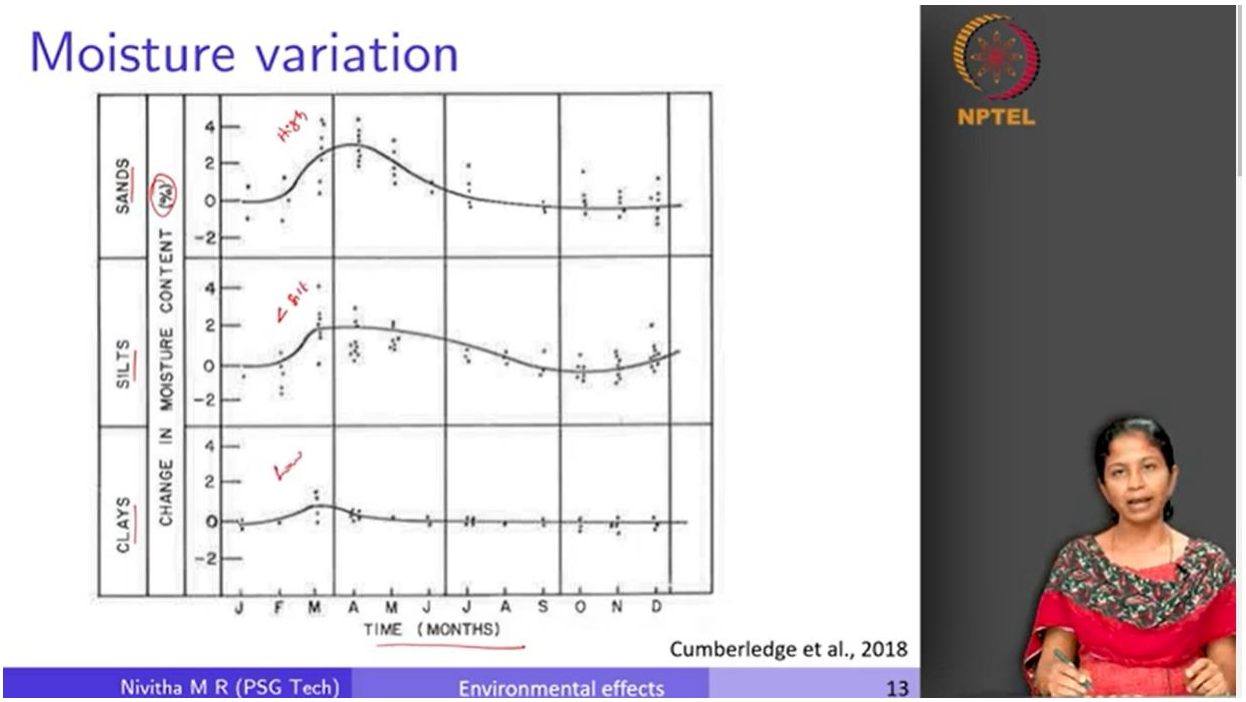

This is a typical curve which shows the moisture variation. Again, this is for a particular location where the variation is given over different months. We can see how the water content varies as a function of the duration for sand, silt and clay. We can see here that the moisture content fluctuation is high in the case of sand, relatively less in the case of silt and low in the case of clay. Again, this is for a specific location. This might tend to vary. It is only the type of soil that is give, the gradation and all the other aspects of the soil is not mentioned here. It is subject to vary, but this is a typical trend that we will see. If you have clay, it has very less change in moisture content. Again, for this location, if you have sand, there is relatively higher variation in moisture content.

Next, we will be looking into the soil water characteristic curve. This is an important parameter which is used in calculation of modulus for granular layers. I will stop this lecture here. In the next part, we will talk about soil water characteristic curve and its effect on modulus.