**Analysis and Design of Bituminous Pavements**

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**Lecture – 28**

**Enhanced Integrated Climatic Model - Part 01**

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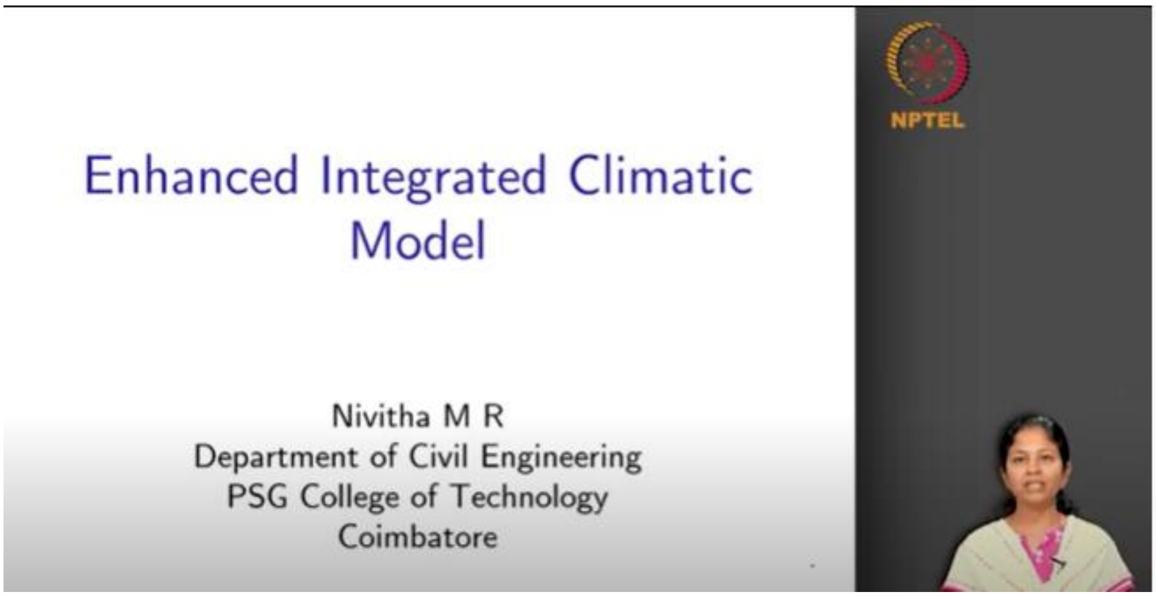


Hello everyone, welcome back. In this lecture, we are going to talk about the enhanced integrated climatic model (EICM). So, first let me tell you what is this enhanced integrated climatic model. So far, we have been talking about different influences of environmental factors on the design input parameters, primarily the modulus. So, we had seen how the moisture affects the subgrade modulus, how moisture affects the freeze and thaw in the pavement, how the temperature profile affects the modulus value of the bituminous layers and how it is contributing to again freeze and thaw in the pavement. It is all these effects we had seen and we had also seen the sensitivity of modulus to all these parameters.

Now, how do we translate that or how do we incorporate that into the design procedure? Typically, in a conventional IRC design procedure, we have again I am drawing this, we have the subgrade, we have the subbase, we have the base course, we have the binder course and we have the surface course. So, for each of these layers, we are going to give thickness value, modulus value and Poisson's ratio value. So, if you look into IRC 37 design procedure, that small tool which is available to compute the strains for a given set of input parameters, we will see that once we apply the load and we have these modulus parameters, we will get the strain response. But in this, we only have the option to provide one value for E and one value for $\nu$. But we have seen that this E value is a variable with respect to the temperature or moisture. And then it is a function of frequency in case of bituminous layers and it varies with time. So, the air temperature has a tendency to vary with time. The pavement temperature will also vary accordingly.

Similarly, the moisture content depending upon the precipitation and the variation in the water table, the moisture content will also vary with time. So, for both these cases, time is one variable and the other one is depth. We also saw that the variation of these parameters at a given time, at a given temperature, frequency, all these things is a variable with respect to the depth. So, how to incorporate the variability of the modulus with respect to all these parameters into the design procedure. So, the currently available design procedures in followed in most of the countries except for this MEPDG, which is followed in the United States have very little scope for consideration of this kind of variability into the design procedure.

So, if you look into some design tools or some design procedures, at the least they have an option to vary it periodically. So, 1 year will be divided into 12 periods or so and for each period you can give an input value. So, this is one possibility. Later in the next lecture, I will show you how to do this for different design procedures. We will take 2 or 3 design procedures and we will see how to incorporate all of this.

But as of now we can recollect that there is very little scope for incorporation of this kind of a variability into the design procedure. But MEPDG has come up with this enhanced integrated climatic model, which to a larger extent takes into consideration the influence of all these parameters. So, how does it take into consideration? What are the different subcomponents available? What is the role associated with all these subcomponents that we are going to see in the, in this and maybe in the subsequent lecture? Again there are lot of equations, lot of models which are used in these calculations. We will not get into the entire depth of this enhanced integrated climatic model. Instead at the outset I will tell you what are the functions of it and how this computation of or how this variation of modulus with respect to all these parameters is typically done.

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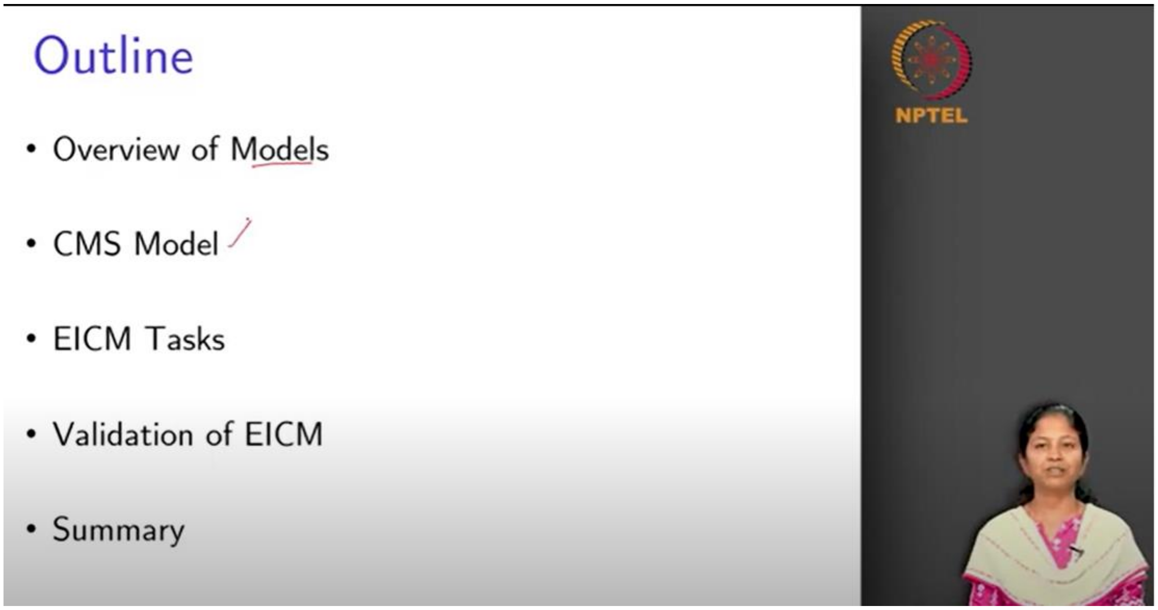


So, having said that this is the outline for this topic. So, initially we will talk about the models which are available in EICM. So, EICM is an integrated model. So, we as the name says it is an integrated climatic model which has lot of subtasks or sub models. And to a larger extent we will see about the CMS model in specific because it is the model which is going to give us the material properties as a function of all these climate inputs.

Then we will split this EIM into subtasks. What are the tasks that this EICM is going to perform? And then we will see some results from field wherein people have tried to validate the EICM model. So, we said we are going to predict moisture content, we are going to predict temperature. What if I measure the actual temperature and see how much is the variability? And then finally we will summarize. So, this is the outline for this particular topic.

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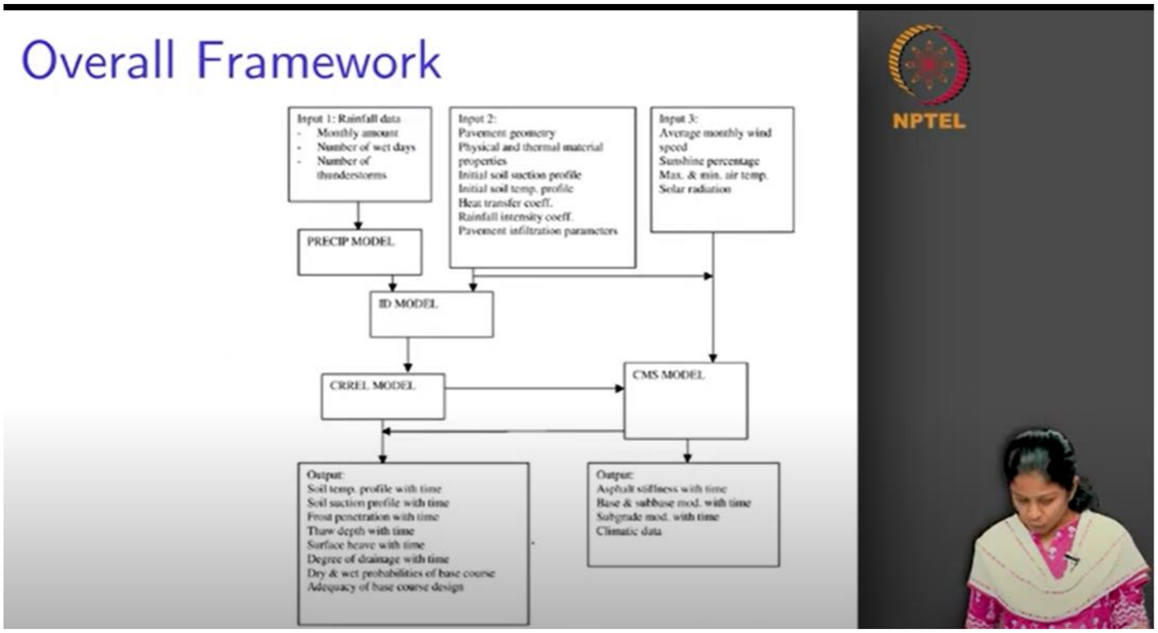


Let me start with the overview of the model. So, this is the overall framework. So, this picture gives the overall framework for this EICM model. So, if you look at this, there are four sub models involved in this. The first one is a precipitation model. The second one is an infiltration and drainage model. The third one is a CRREL model, Cold Regions Research and Engineering Laboratory. It is by US Army Corps. So, they have developed this model. It is specifically for cold regions. And the fourth one is CMS model, Climate Material Structure model.

So, these are the four models that we will be using in this integrated EICM framework. Now, what are the input parameters that we have to give this model? And what are the output parameters that we will be getting in a nutshell? So, the first input that we will be giving here is the rainfall data. So, we said that once we have a certain degree of precipitation, water is going to infiltrate. So, infiltration will happen on the irregularities present in the surface or it can happen as a lateral seepage. So, we are going to collect rainfall data. In rainfall data, we will see what is the monthly amount of rainfall, number of wet days present in a year and number of thunderstorms which are present. These are the input parameters that we will require for the rainfall data. So, these input parameters go into this precipitation model. Again, in brief, I will talk about all these models individually. But now let us just focus on this overall framework. So, we just see that it goes as an input into the precipitation model.

Next, we have another set of input, which is pavement geometry, physical and thermal material properties. So, the first thing what we need is the cross section and then in a given cross section, what are the different layers? What is the thermal properties? Basically, the conductivity, the heat capacity properties of individual layers. Then we need soil suction profile and then we need the initial soil temperature profile heat transfer coefficient, similarly, rainfall intensity coefficient and pavement infiltration parameters. So, these are all this heat transfer coefficient is used for calculating the variation of temperature along the depth. This rainfall intensity coefficient calculates how much infiltration can happen for a given rainfall and so on. So, like that each parameter has, is used in some computation with regard to the infiltration process.

The third input parameter that we will be using is average monthly wind speed, the sunshine percentage and maximum and minimum air temperature solar radiation. So, we have seen in one of the previous lectures, how the air temperature and the other parameters like solar radiation, sunshine and the wind speed influences the pavement temperature. So, we need all these input parameters, it is not only the air temperature, we have seen the relation between air temperature and pavement temperature depends on all the other three parameters. We had already seen that in detail.

So, we need all of them also as input. Now, this information goes into the precipitation model. This model calculates how much of rainfall you can expect over the design period or over the analysis period. Then it is transferred into the infiltration and drainage model. Now, given this much amount of rainfall reaches the surface of the pavement, how much actually enters into the pavement, how much of this rainfall infiltrates into the pavement. And similarly, once the water content infiltrates into the pavement, how much it is able to drain off, how much time it is taking to drain off. So, both are calculated in the infiltration and drainage model. So, for that, we need all these input parameters. So, once we get this, it is transferred into the CRREL model, which calculates the frost and heave, frost and heave associated also the thaw process that is associated with the presence of moisture and soil. Again, we have seen earlier how the freeze and thaw works in a pavement. So, now all of them are input into the CMS model. So, this CMS model in iteration with the CRREL model is going to give us the following output parameters.

What is the variation of soil temperature profile with time? So, we have seen that how the temperature variation in soil is also important for studying the freeze and thaw effects. So, how soil temperature varies with time. Then the soil suction profile with time. Yesterday, we saw the soil water characteristics curve, wherein we saw that depending upon the suction capacity, the relation between suction capacity and the water content present in the soil. So, this suction profile will be obtained from which we can get the water content in soil.

Similarly, how much is the frost penetration? We have seen the formation of ice lenses also here. Similarly, the thaw depth and then how much there is a heave in the surface and what is the degree of drainage with time, the dry and wet probabilities of base course and then finally the adequacy of base design. So, all of them will be the output parameters that we will get. Similarly, from the CMS model alone, we will be able to get the variation in asphalt stiffness with time, the base and subbase modulus with time, the subgrade modulus with time and also some information on the climatic data. So, these are the inputs into the 4 models that will be used and these inputs will be incorporated in the model and translated into these following output parameters. Now, let us see all of these models in detail.

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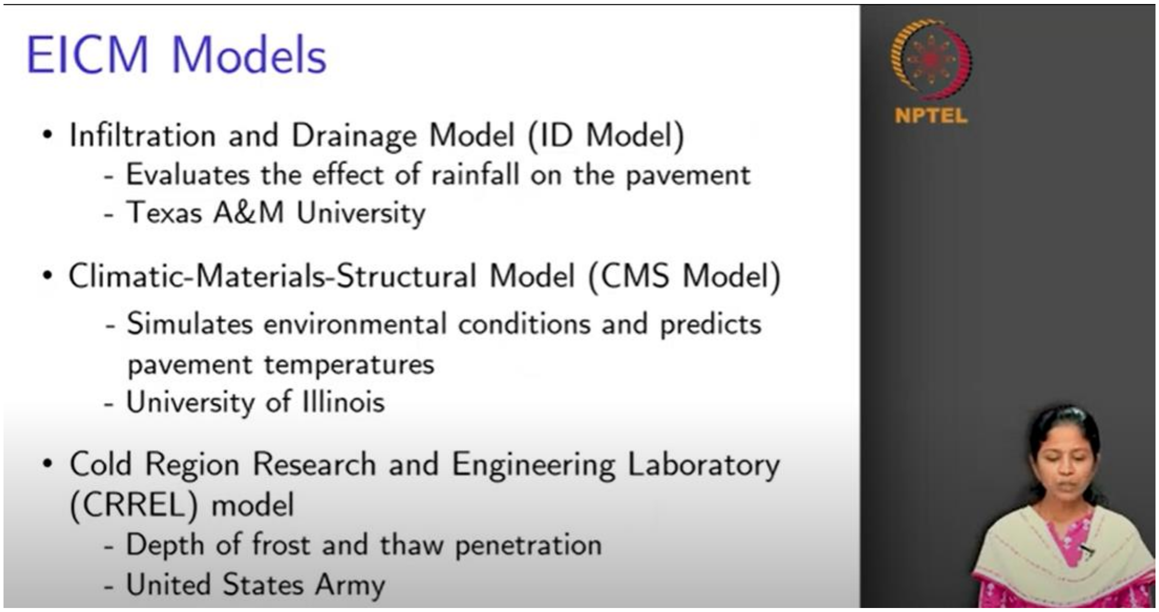


The first one is the infiltration and drainage model. It basically evaluates the effect of rainfall on the pavement. So, this was developed at Texas A&M University. Similarly, the climatic materials and structures model which we call a CMS model, it simulates environmental conditions and predicts pavement temperature. So, we said that we have air temperature, other parameters depending on that the pavement temperature is going to vary. So, to what degree the pavement temperature varies that is predicted by the CMS model. It was developed at University of Illinois. And then we have the CRREL model. This model is specifically used for the frost and thaw process. So, it calculates the depth of frost and then the thaw penetration. So, when the thaw happened to what depth the effect of thaw is observed in your pavement and it was developed by the US Army Corps of Engineers.

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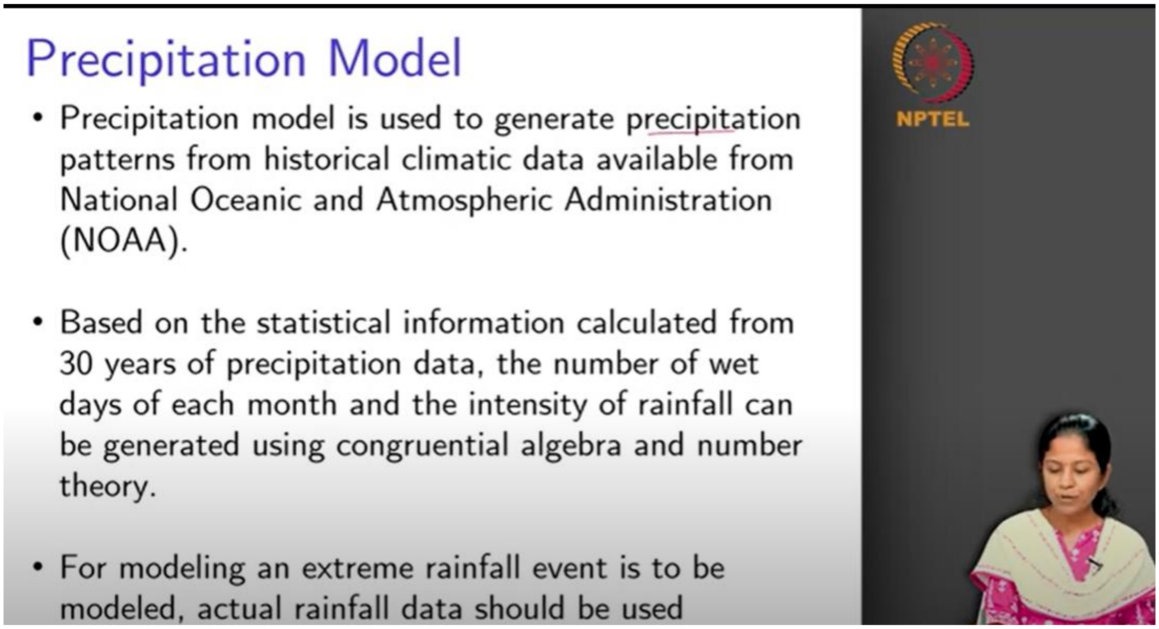


Now, let us look at these models one by one. The precipitation model is used to generate precipitation patterns like probably when you will expect a rainfall and what will be the amount of rainfall that we will experience from historical climatic data available from NOAA. So, they use this and try to predict the rainfall. In the last lecture we had seen that we wanted to predict air temperature for a design period and we were talking about use of artificial neural network or other techniques to do that. Similarly, here we will be using the precipitation model to predict the rainfall data over the design period. Then based on statistical information which is calculated from 30 years of precipitation data, so we need a large database. Even in the case of air temperature prediction we need a large database. If you have to train your artificial neural network, you have to validate it. For all those processes we need large dataset. So, at least 30 years of precipitation data is used here in the precipitation model. So, the number of wet days of each month and the intensity of rainfall can be calculated. So, in a given year how many days we will experience rainfall and what is the intensity of rainfall in those durations. So, that will be obtained. They also caution that if you are using this model it is only for average conditions. So, only for a small range of variation from the average value this model will be working efficiently. If you have extreme rainfalls like very high rainfall, then maybe this model may not work.

So, for extreme rainfall event they say that the actual rainfall data should be used rather than getting the data through the precipitation model.

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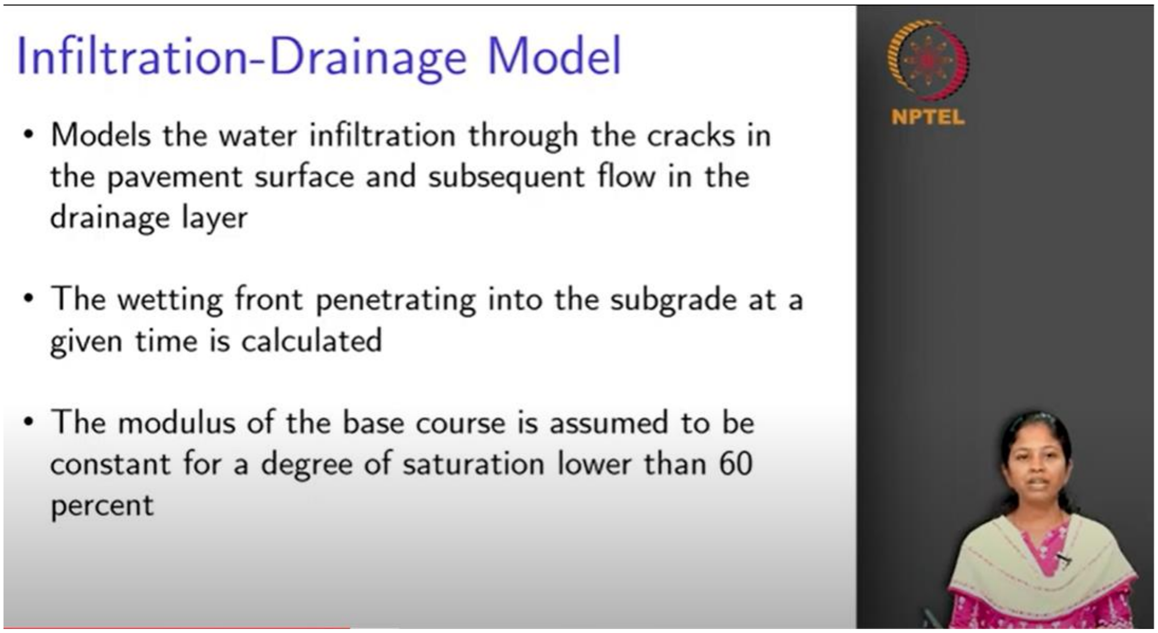


Next we will move on to the infiltration and drainage model. So, this particular model captures the water infiltration through cracks in the pavement surface. So, that is what we said. So, when there is rainfall water enters through the cracks that are present on the surface of the pavement and it also calculates subsequent flow in the drainage layer. So, we have drainage layers in the pavement which are the granular layers that are present beneath the asphalt material. So, this layer tries to drain off water from the pavement surface. So, how much of water let us say this is my pavement system, this is my bituminous courses and this is my granular layers. So, water enters inside it is drained off here. Before it reaches the granular layer it is drained off here. So, how much water precipitates inside, how much is the drainage capacity of these layers. So, both of it is calculated from this model.

The wetting front that is the amount of water penetrating into the subgrade at a given time is also calculated. If it is not properly drained off or even in this case how much of water can penetrate into the subgrade that is also calculated. So, the modulus of base course is assumed to be constant for a degree of saturation lower than 60%. In the last lecture we saw the variation of $MR/MR_{optimum}$, $S/S_{optimum}$. So, we saw that it was constant for some time and then it began to reduce. So, for beyond a certain percentage when it is like more than 30% we saw that it is going to remain as a constant.

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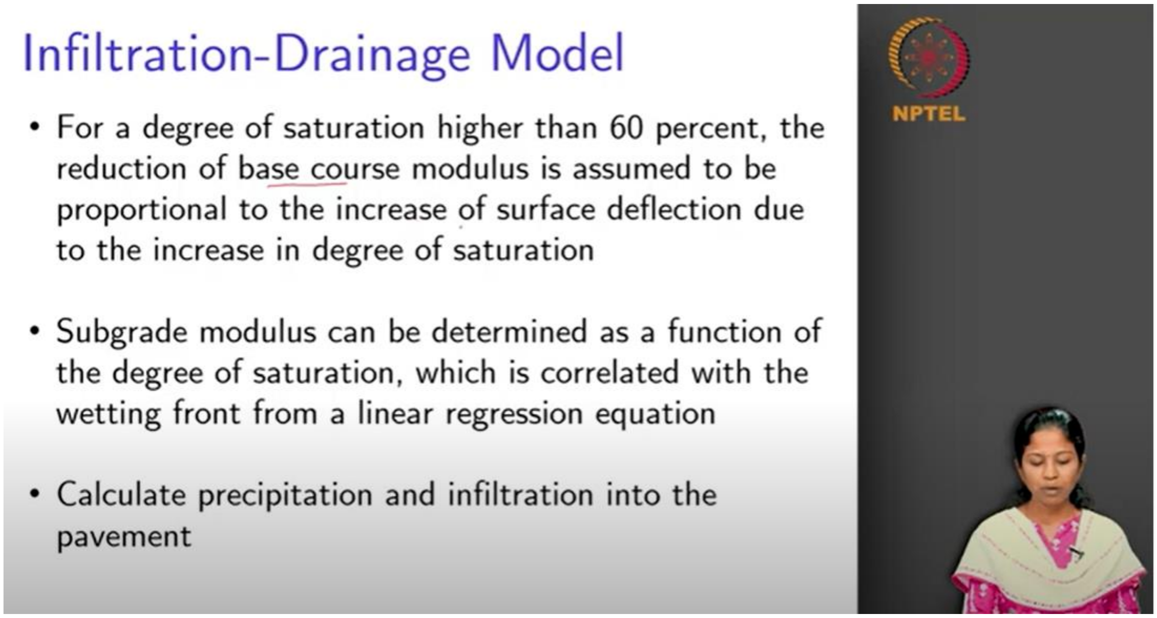


So, here also the modulus of base course is assumed to be constant for a degree of saturation lower than 60%. So, when the degree of saturation is greater than 60% the reduction of base course modulus is assumed to be proportional to increase of surface deflection because of the saturation effect that is present. So, only for a saturation content above 60% the variation in modulus is calculated in this model. The subgrade modulus can be determined as a function of the degree of saturation. So, depending upon the water content present in the soil the modulus is adjusted and we had seen the equations in the previous lecture. Now we can calculate precipitation and infiltration into the pavement.

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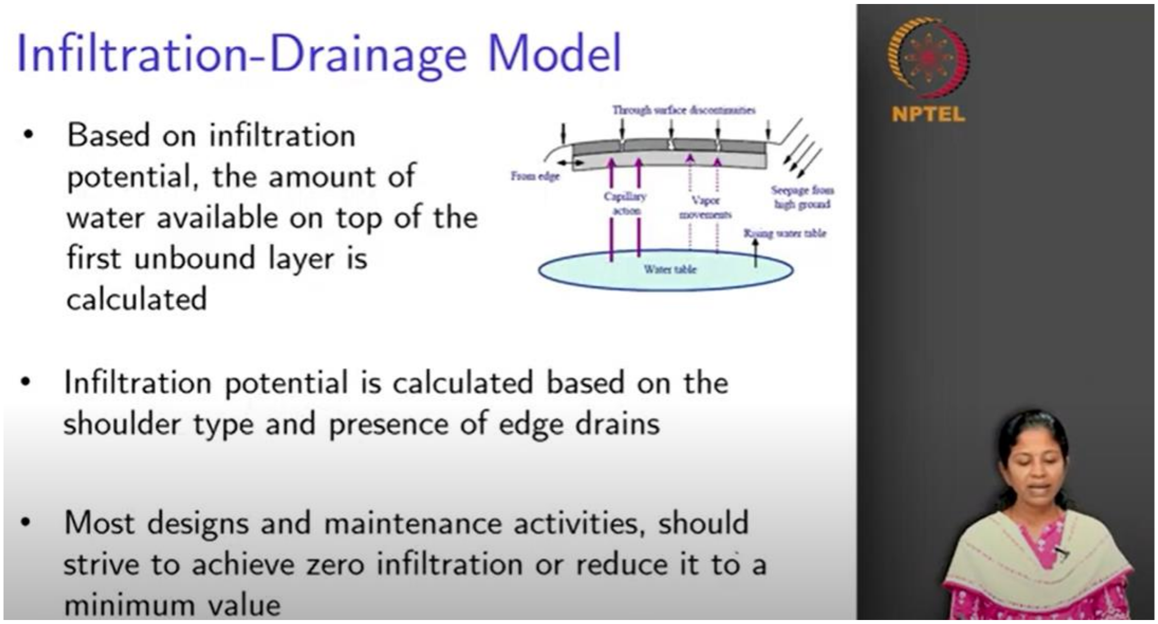


So, this is based on the infiltration potential. So, we had seen here that it can infiltrate from here through the cracks. So, how much is the infiltration potential depending upon that the water available at the top of the first unbound layer is calculated. Again we said that it is not going to influence our bituminous layers. It is only going to influence the granular layers. So, based on this the water available at the top of the first unbound layer. The first unbound layer is the in our Indian context will be the base course. So, the infiltration potential is used to calculate the water content available at the top of the base course.

Now what is this infiltration potential? It is a function of the shoulder type and the presence of edge drains. Because depending upon the shoulder if it is covered with soil the infiltration potential will be higher. If it is covered with the concrete surface or any other material which can drain off water and not let it infiltrate inside the infiltration potential will be low. Similarly, if there is presence of edge drains the water can drain off quickly. So, this potential is calculated based on these two parameters.

Again if you look into the details of EICM model they have equations as to how these things are computed. And then they also say that most design and maintenance activity should achieve zero infiltration. Basically whatever is the water that is falling on the surface of the pavement we should hardly let in any water enter inside the pavement system. We should drain it off on the sides and as quickly as possible. So, most design and maintenance activities should try to achieve zero infiltration or if it is not practically possible reduce it to a minimum value as much as possible. So, this is with regard to the infiltration and drainage model.

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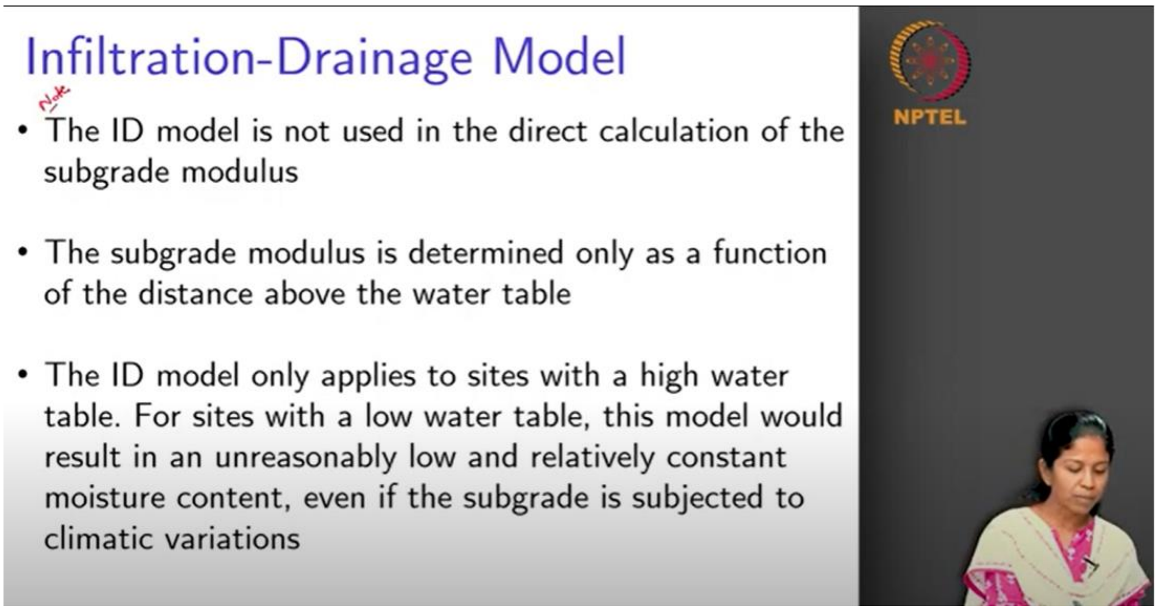


Now there is another note that we have to remember here. This infiltration and drainage model is not used in the direct calculation of subgrade modulus. The subgrade modulus is determined only as a function of the distance above the water table. So, this variation in water table is only expected to affect the subgrade modulus because of the reason that the effect of the water content which infiltrates into a pavement may not when it reaches a subgrade the effect may be very small.

The amount of moisture content will vary in the top for different degree of saturation, but when it reaches a particular depth it was all converging to a closer range. So, because of this variation they did not take into account of the infiltration effect on the subgrade modulus. It was considered to be influenced only by the water table and the capillary action that is present because of the water table. So, this infiltration model thus applies to sites only with a high water table. For sites with low water table this model is considered to result in an unreasonably low and relatively constant moisture content. So, this is valid even if the subgrade is subjected to climatic variations. So, this is something which we have to note about the infiltration drainage model.

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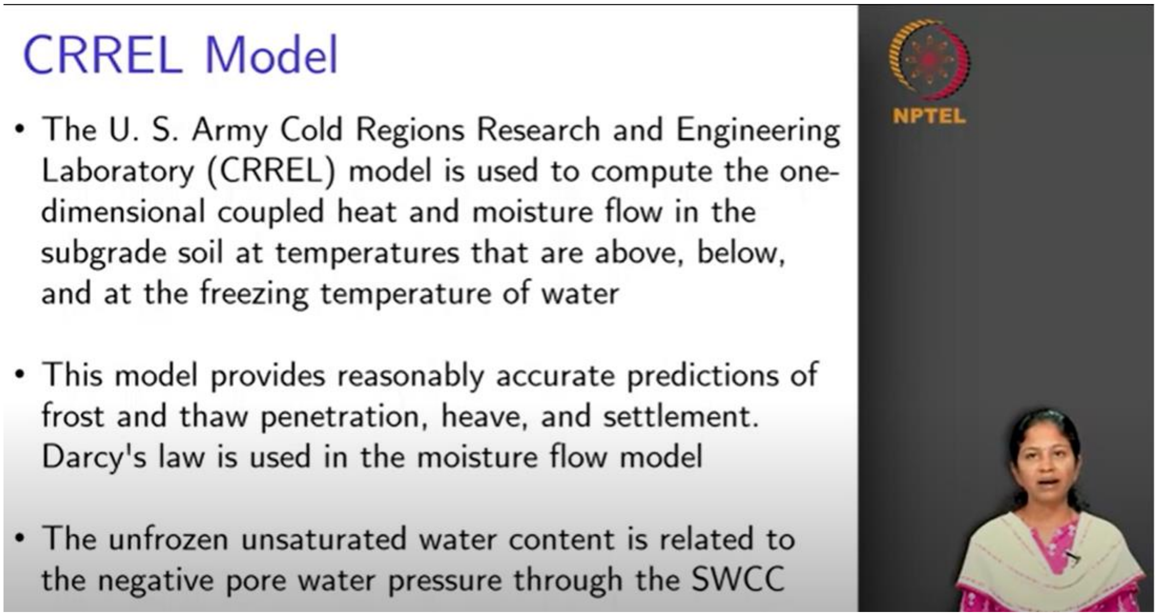


Next we will move on to the CRREL model. So, this US Army cold regions model is used to compute the one-dimensional coupled heat and moisture flow. It is used to calculate the heat and moisture flow in the subgrade soil at temperatures that are above, below and at freezing temperature of water. So, they have different models for different temperature ranges. So, it calculates both the heat and moisture flow because both of them are important to calculate the freeze and thaw effects. So, both are calculated. It provides reasonably accurate predictions of frost and thaw penetration, heave and settlement in the pavement. So, it kind of predicts the entire effect on the pavement. It calculates the heat and moisture at a certain depth and what is the frost and thaw penetration that is available for a given moisture content and temperature combination, what is the heave effect because of this and what is the settlement because of all these phenomena.

So, here Darcy's law is used in the moisture flow model. Here the unfrozen unsaturated water content because we said yesterday when there is ice lens formation, this is the frozen part of subgrade and below the ice lens we have the unfrozen subgrade. So, in the unfrozen unsaturated water content is related to negative pore water pressure through soil water characteristics curve. So, this is a relation that they use in the CRRL model. Also, this model predicts depth of frost and thaw penetration.

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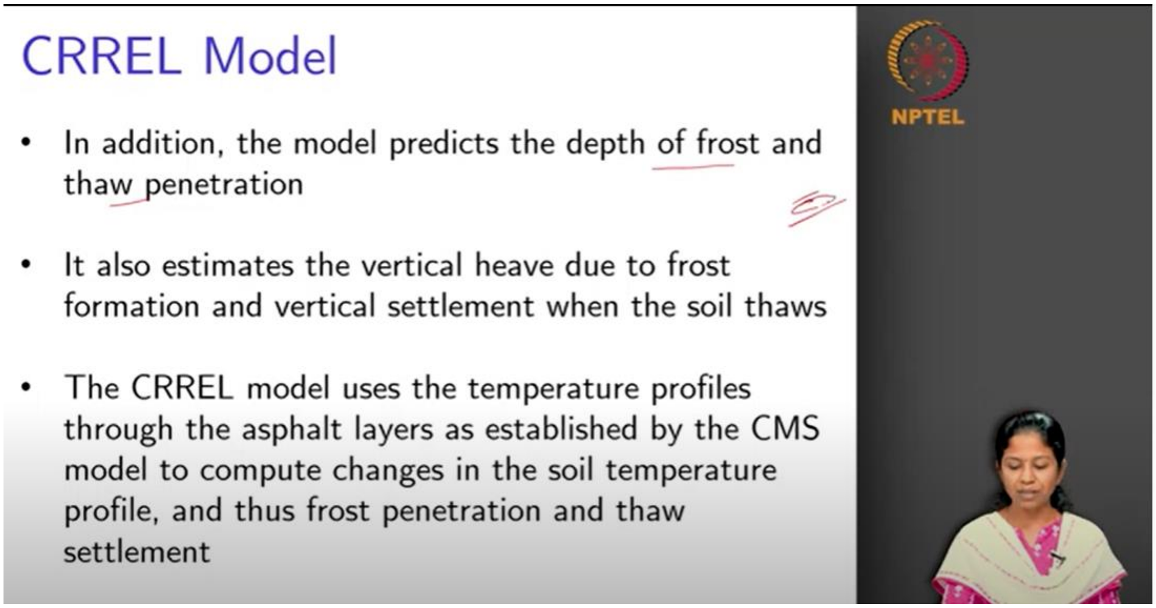


So, to what depth this freezing effect is observed in the pavement and also when it thaws, what is the effect of moisture content and to what depth its influence is observed. And it also estimates the vertical heave because of frost and the settlement when the soil is thawing. So, this also we have seen. The CRREL model uses temperature profiles throughout the asphalt layers as established by your CMS model to compute change in soil temperature profile. So, initially we have the bituminous layer and following that we have the granular layer. So, it uses the temperature profile in bituminous layer which is calculated by the CMS model and then it is used to calculate the temperature in the granular layer subsequently. So, there is an interaction between these two models in the case of temperature calculation.

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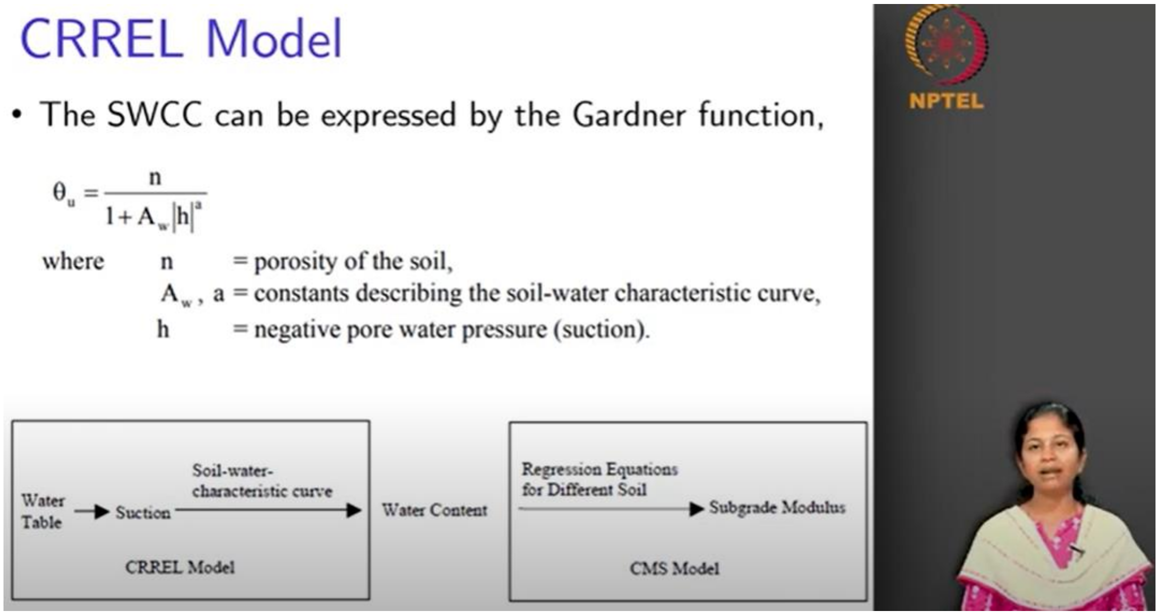


Now this soil water characteristic curve we have seen the trend lines in the previous lecture for different kind of soils. So, this is how the soil water characteristic curve can be explained in the form of an equation.

$$\theta_u = \frac{n}{1 + A_w |h|^a}$$

So, $\theta_u$ is the water content. It is a function of one is the porosity of the soil. There are some constants which describe this and then the negative pore water pressure. So, how do we use that? Say for example, how do we use the interaction between CRREL model, CMS model and quantify the effect of water table on the subgrade modulus. In the previous lecture we have seen that or in this lecture also in the beginning in the input parameters we saw water table is one of the input parameters and we are going to compute how the influence of water table is observed on the subgrade modulus. So, we have water table. Based on the depth of water table we will be able to compute the suction head; the soil suction we will be able to compute from the water table. So, this suction is used in the soil water characteristics curve and the appropriate water content is computed. In the previous lecture we have seen it could be degree of saturation or water content and then this is suction. We call it as metric suction. So, how for a given suction what is the degree of saturation in the soil? So, that we will be able to calculate from this particular curve. So, this soil water characteristics curve is used and then we get the water content.

Now once we know the water content we use it in different regression equations. One regression equation is what we saw in the previous lecture between MR and $MR_{optimum}$. So, once we have $MR_{optimum}$ and know the water content in the soil we will be able to calculate MR. So, that is how the subgrade modulus is calculated for different water table effects. So, this is one small illustration of how the models work in computation of the modulus parameters that we are interested in.

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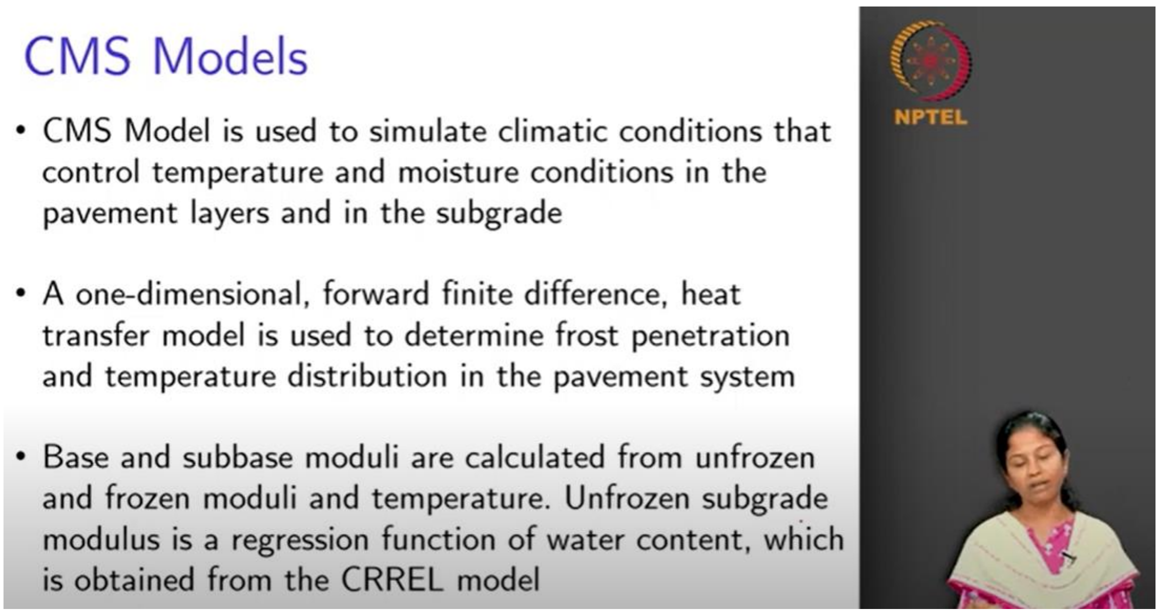


Now let us move on to the other model, the third model which is CMS model or the fourth model in fact. This CMS model is to simulate climatic conditions that control temperature and moisture conditions in pavement layer and subgrade. It is used to compute the climatic effects and then calculate how temperature and moisture varies in a pavement. So, it is a one dimensional forward finite difference heat transfer model. This model is used to calculate the frost penetration and temperature distribution. Basically a finite element model is used, we fix the boundary conditions. Once the values for the boundary conditions are given it can calculate the degree of variation in the underlying in the intermittent thickness layers. So, that is the concept that is used here in the CMS model.

So, let us say the base and subbase moduli are calculated from unfrozen and frozen moduli and temperature. Depending upon the freezing effect in the soil, the modulus is calculated and here we use the CRREL model. So, unfrozen subgrade modulus is a regression function of water content. The subgrade modulus is directly related to the water content which is obtained from CRREL model. The frozen values are calculated from the CMS model whereas the unfrozen subgrade modulus is calculated from the CRREL model that we had seen earlier. So, even for a given layer, the granular layers depending upon whether it is in a frozen condition or unfrozen condition, different models are used to calculate the modulus value.

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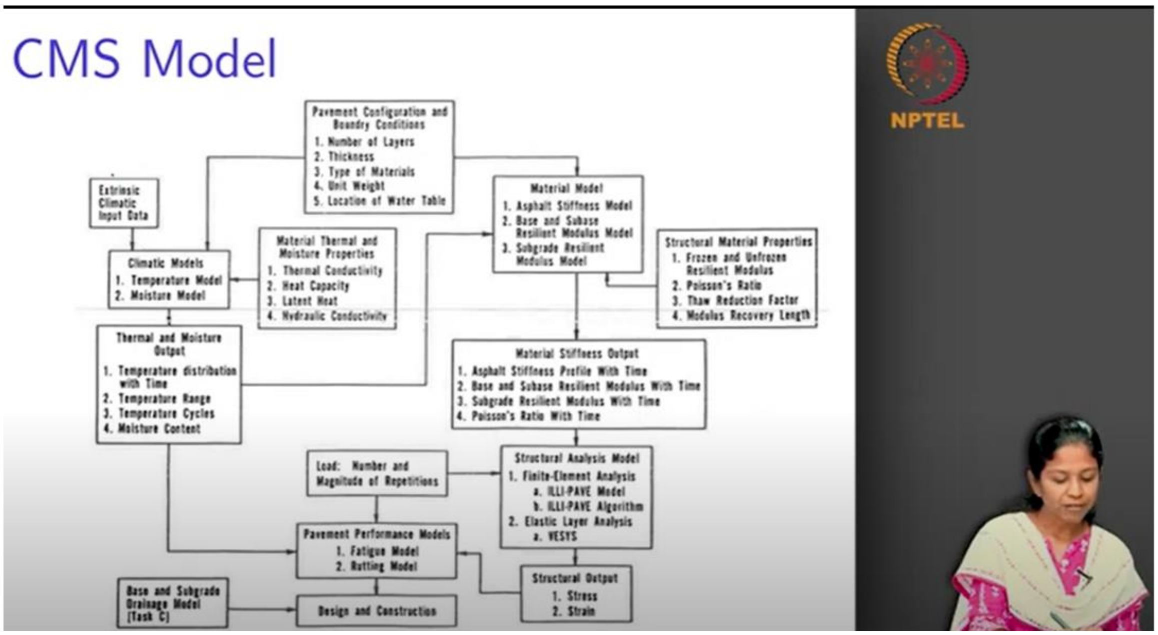


Now, let us see to a little detail about how this CMS model is integrated into the pavement design procedure. So, we have climate data input, climate data that we have to input in the model. This climate data will have air temperature, wind speed, sunshine, water table depth and all other input parameters. Then this data will be input into the climatic model. We have a temperature model; we have a moisture model. Now, we also have to give pavement configuration and boundary conditions. So, we have to first define what is the system that we are interested in analyzing. So, we have to give the number of layers, the thickness of individual layer, type of material, unit weight and where the water table is present. So, all this information about the pavement system we have to provide a prior. Now, we also have to give the material thermal and moisture properties. Like what is the thermal conductivity, heat capacity, I will talk about all these parameters in a few minutes wherein we will be talking about the CMS model in detail.

So, these are the material properties that we have to input to this model. Now, using this we will get thermal and moisture output. So, what are these things? The temperature distribution with time that is one of the things that we are interested in. The temperature ranges to over which range the temperature varies, temperature cycles, how it varies over a given calendar year and what is a moisture content at a given instance in the soil. So, these are the different outputs that we will get from this model.

Now, this goes into the material model. So, given the temperature value, how much is the stiffness in my material, asphalt material. So, given the moisture content, how much is the variation in my subbase and subgrade resilient modulus, all this will be computed here. And then the structural material properties like the frozen and unfrozen resilient modulus, Poisson's ratio, the thaw reduction factor is also input into the model. We get the material stiffness output which is finally the stiffness profile variation with time. You should remember that all these things will be computed at a given instance of time. At a given instance of time, what is the moisture content, what is the temperature distribution and how the stiffness varies. So, ultimately we will be able to get the stiffness profile with time, the subbase and base resilient modulus variation with time, subgrade resilient modulus with time and Poisson's ratio with time. So, all of it we will be able to get. So, this is the whole thing up to here, I am sorry, up to this part is with regard to the material properties that we have to input in the pavement design process. You can see here this whole part, this consideration of material properties itself is an exhaustive exercise. You can see how much of factors we take into account, the different models that we use and the output that we get. So, once we calculate this precisely, we will be able to calculate these strains that we observe at a point in a more precise manner for a given location. Then we have load, the magnitude and number of repetitions, use that in a structural analysis model, compute the strain values. We get the stresses and strains for a given set of material properties, given loading condition, use that in the performance models, compute the rutting and fatigue damage. And then we also have the drainage model which we will cross verify the design and construction process. So, this is how the CMS model is integrated into the pavement analysis and design procedure.

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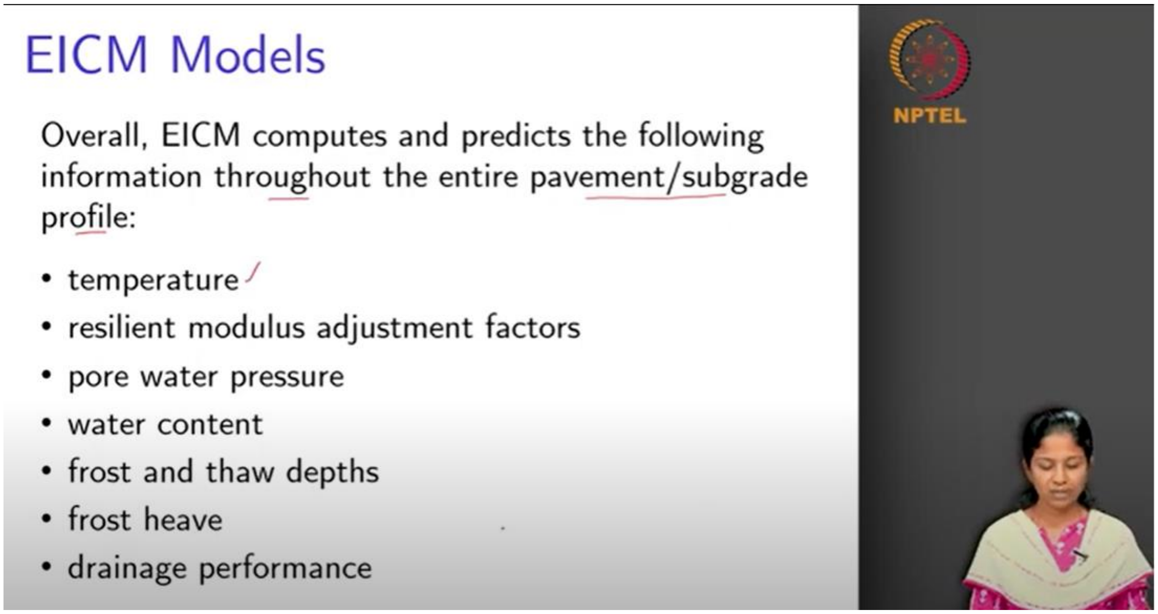


So, in brief, EICM model in an overall, EICM model, the integrated model computes and predicts the following information throughout the entire pavement or subgrade profile. So, what are the things that are computed? One is the temperature profile with time. The second one is resilient modulus adjustment factors in the subgrade because of frozen, in the subgrade because of the unfrozen condition and in the base and subbase layers in the frozen and unfrozen condition. The pore water pressure, the water content, the depth to which the freeze and thaw effects are observed and what is the heave that is observed in the soil because of the frozen condition and what is the drainage performance, the infiltration potential and the drainage capacity of the soil. So, all these things are computed throughout the entire pavement and subgrade profile.

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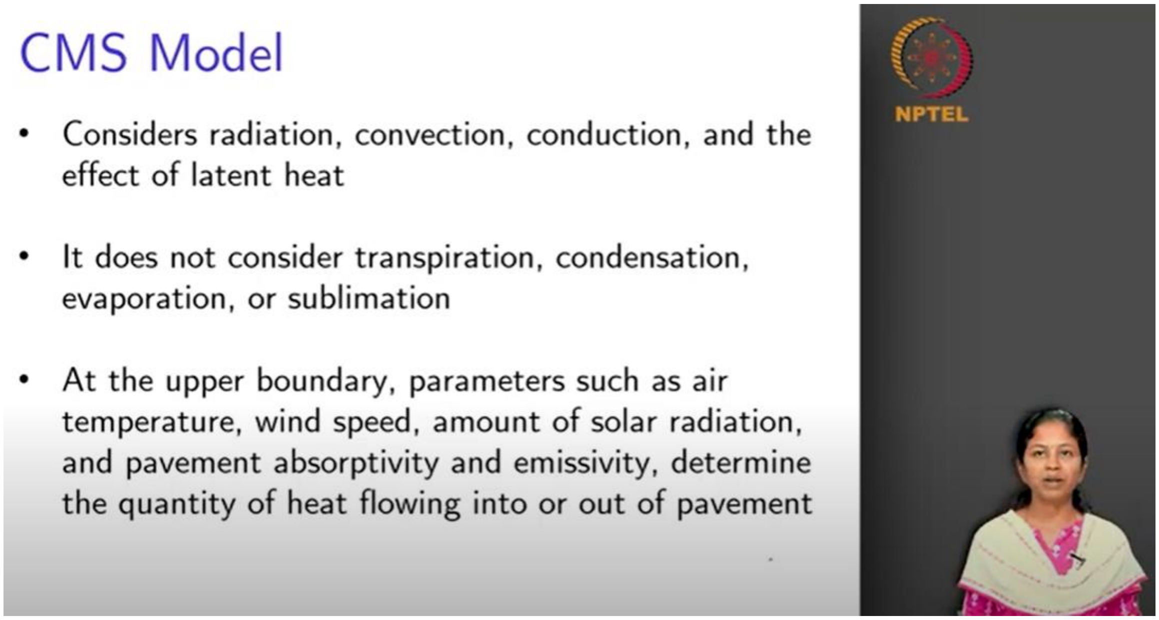


Next we will see about the CMS model in brief. Again, as I said, I am not getting into the much detailed aspect of the CMS model, but again, in a nutshell, we will see about it. This CMS model we said, it converts climatic effect into temperature profile in the, temperature and moisture profile in the soil and bituminous layers. So, this CMS model basically uses the principle of radiation, convection, conduction and the effect of latent heat. In one of the previous lectures, we have seen how a pavement system is subject to influence of different environmental parameters and how radiation, conduction, convection, all these things happen in a pavement.

However, this model does not consider the effect of transpiration, condensation, evaporation or sublimation. It only considers these 4 factors, the factors listed here. So, how does it do? It considers a pavement system. So, the upper boundary, boundary conditions are defined for a finite element analysis. So, we said earlier, we are going to use a finite element analysis. Once we know the values at the boundary conditions, we can interpolate for any given case. So, at the boundary condition, parameters such as air temperature, wind speed, solar radiation and pavement absorptivity and emissivity are used to determine the quantity of heat flowing into the pavement. So, using all these parameters, we determine what is the heat observed at the surface of the pavement. So, this is one boundary condition. It uses an integrated procedure to compute the effect of all these parameters on the correlation between air temperature and pavement temperature.

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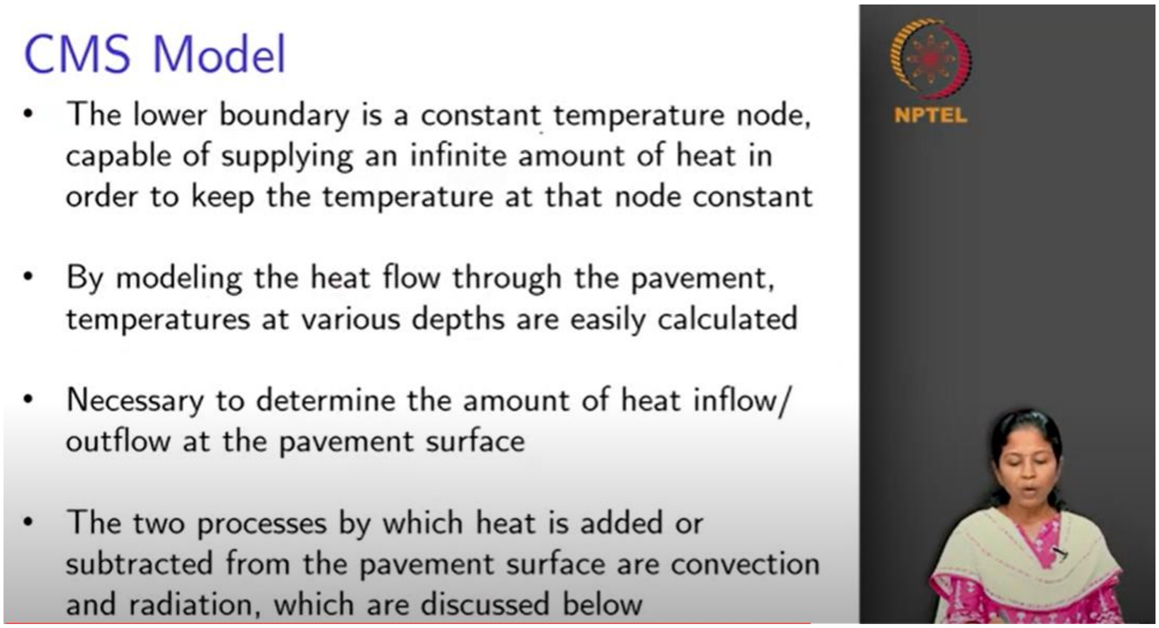


Now, the lower boundary is a constant temperature node capable of supplying an infinite amount of heat in order to keep the temperature at that node constant. So, we assume a constant temperature for the lower node. It is a constant, irrespective of the conditions at the surface, we assume that the temperature at the bottom most layer is going to be a constant. Now, by modeling heat flow through the pavement, temperature at various depth can be calculated.

So, this is how the depth information is calculated by the CMS model. So, it is necessary to determine the amount of heat inflow and outflow at the surface. We said the bottom temperature is a constant. So, only if we calculate the temperature which is received by the top surface or it is emitted by the top surface, we will be able to calculate the profile, the temperature gradient across the depth carefully. So, there are two processes by which heat is added to or subtracted from the pavement, which is convection and radiation. We said conduction happens between layers. So, the interaction between the atmospheric conditions and the surface of the pavement is through convection and radiation only.

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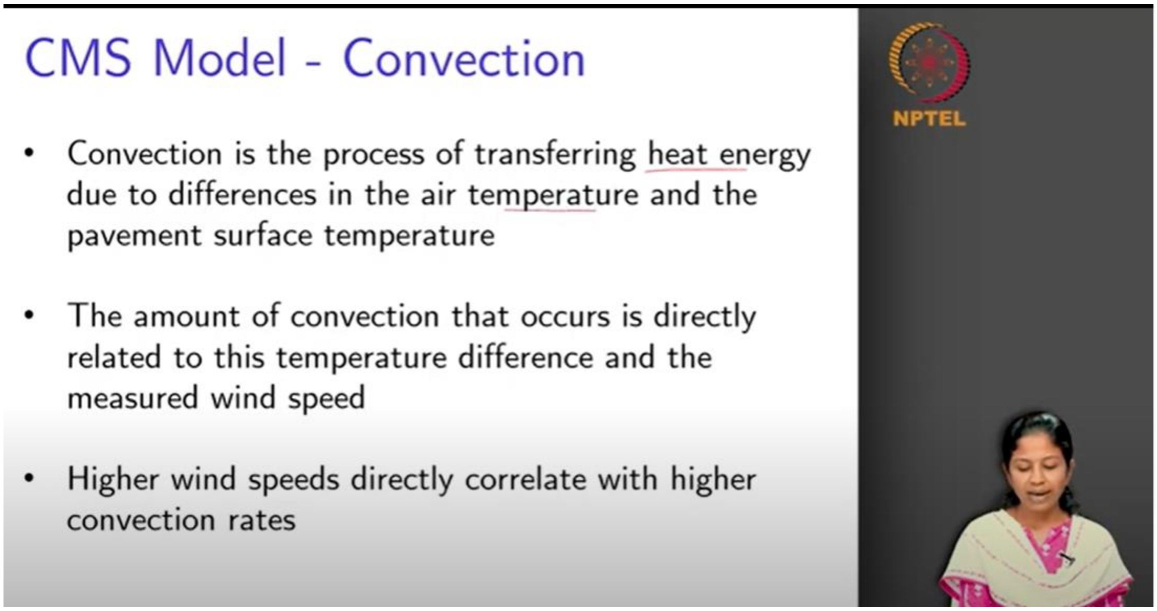


So, what is this convection? It is the process of transferring heat energy due to difference in air temperature and the pavement surface temperature. So, how much heat is transferred from the atmosphere to the surface of the pavement or vice versa that is quantified using the convection process. The amount of convection that occurs is directly related to the temperature difference. What is the difference in temperature between my pavement surface and the air? So, if this temperature difference is large, the convection process will happen rapidly and vice versa. So, it is also influenced by wind speed that we had seen in the previous lecture also. So, higher wind speeds directly correlate with higher convection rates. So, if the wind speed is higher, it enables the removal of heat from the surface at a faster rate.

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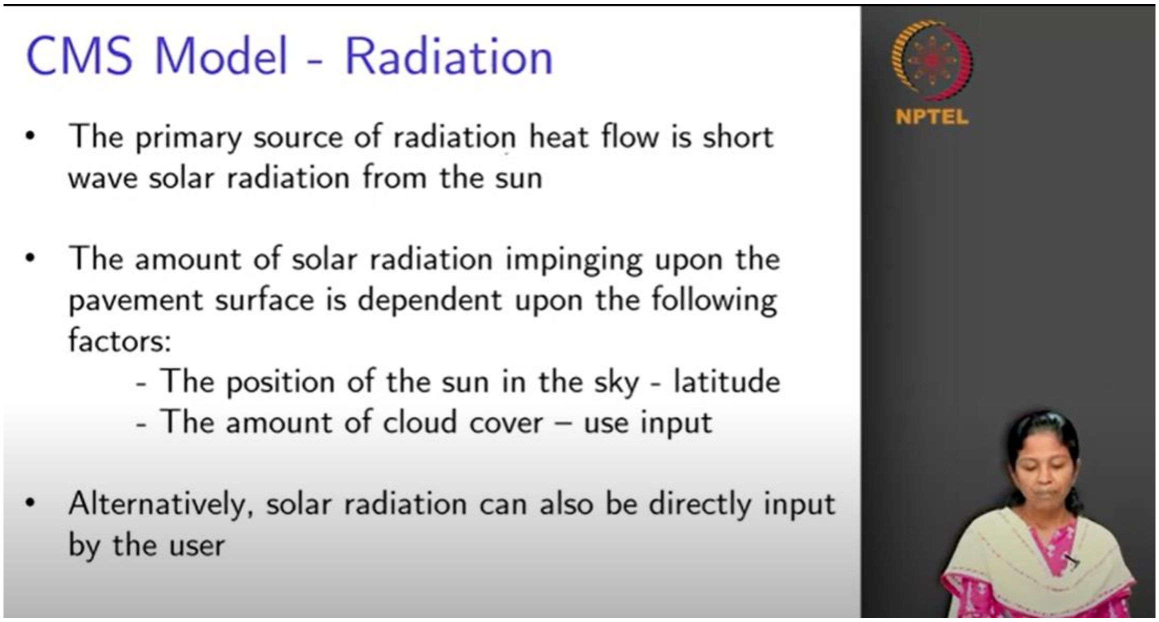


The next factor which contributes to heat in flow to the surface is the radiation process. So, the primary source of radiation heat flow is the shortwave solar radiation from the sun. So, we have the solar radiation that we received from sun that is a shortwave radiation. So, once we receive this shortwave radiation, the amount of radiation impinging on the pavement surface. So, this is a radiation that we received from sun, but how much actually falls onto the pavement surface. Actually depends on two parameters. One is the position of sun in the sky. So, depending upon the angle, the amount of solar radiation will vary. So, this is determined by the latitude. That is why we have seen earlier that latitude is an important parameter in calculation of air temperature and pavement temperature. The second one is amount of cloud cover. How much is the hindrance to the solar radiation when it tries to reach the pavement surface? So, the amount of cloud cover is another input parameter that is used here. This we had quantified using the degree of sunshine. Alternatively, to substitute these two parameters, we can also directly input the solar radiation that is quantified at the surface of the pavement also in the design model.

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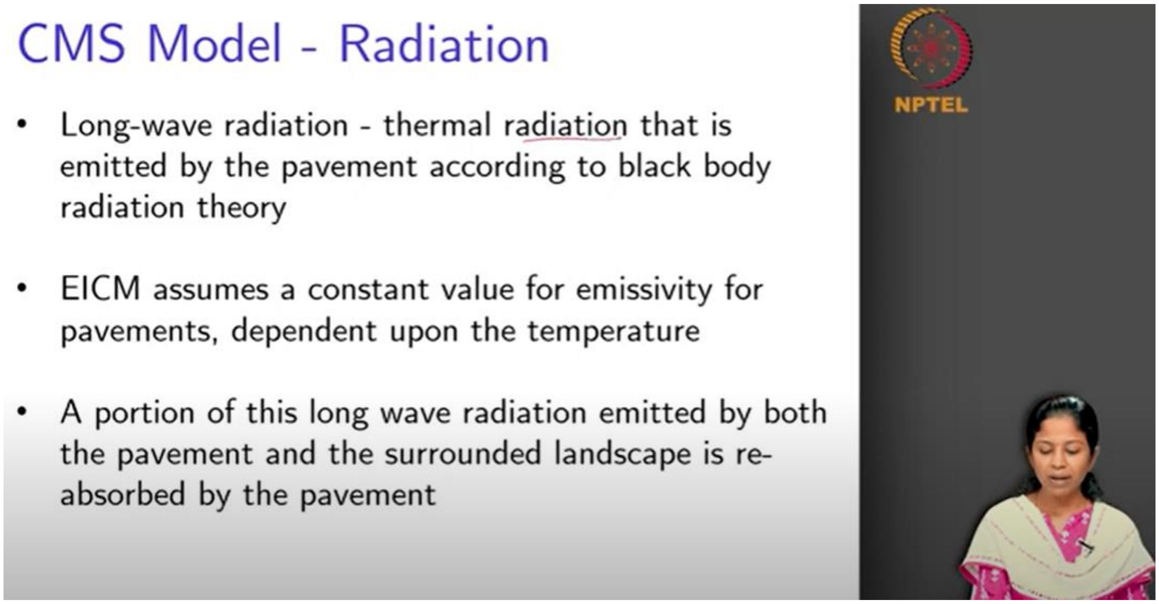


Now let us see the longwave and shortwave radiation. The longwave radiation is nothing but the thermal radiation that is emitted by the pavement according to the blackbody theory. So, let me show you this with an illustration.

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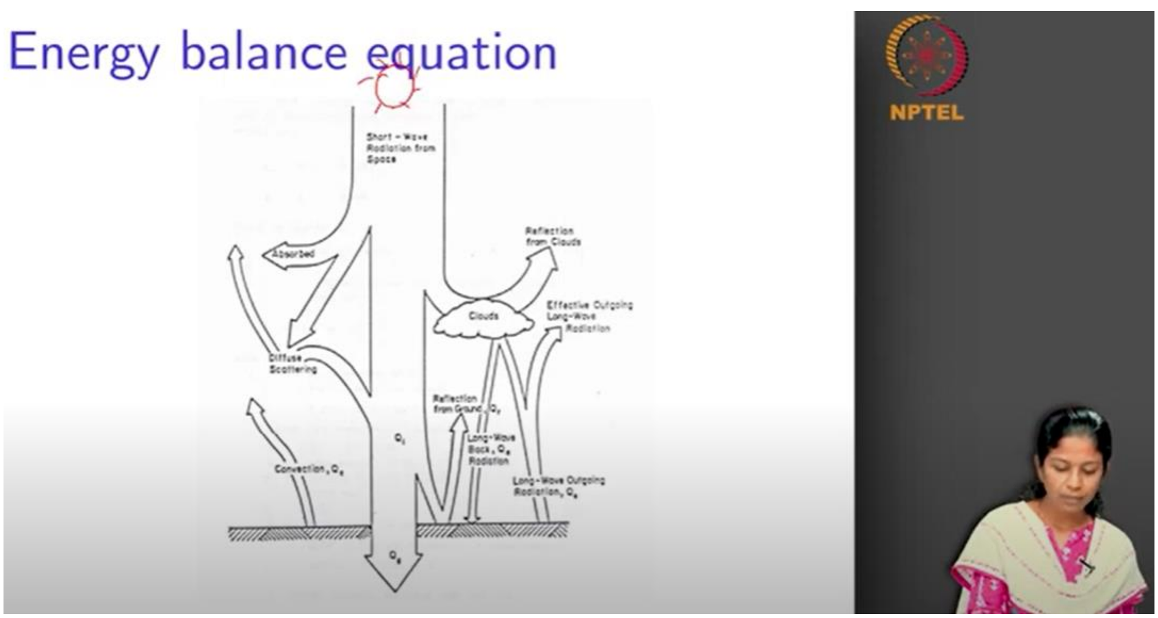

What we get from sun is a shortwave radiation that falls onto the surface. So, this shortwave radiation can directly fall on the surface. Some amount of this radiation might be absorbed by the surrounding conditions also. Now this shortwave radiation once it reaches on the pavement, it is emitted back as longwave radiation. So, this longwave radiation is emitted back to the atmosphere. That is what we had seen in one of the previous lectures as longwave radiation that is another factor in the contributing to the heat supply to the pavement.

So, we also mentioned that it is not the radiation that we receive from sun. It is basically the radiation that is re-emitted by the pavement surface. This longwave radiation could also be reflected back to the pavement. You can see here there is a cloud cover which is reflecting this longwave radiation back. So, these are the radiation aspects that we will receive, that we will observe on the surface of the pavement.

So, this EICM assumes a constant value for emissivity for pavements dependent upon the temperature. So, depending upon the temperature we have the degree of emission that we can observe from the surface of the pavement. So, this portion of this longwave radiation is emitted by the pavement and it is also by the surrounding landscape which is reabsorbed by the pavement. So, that is what we had seen earlier.

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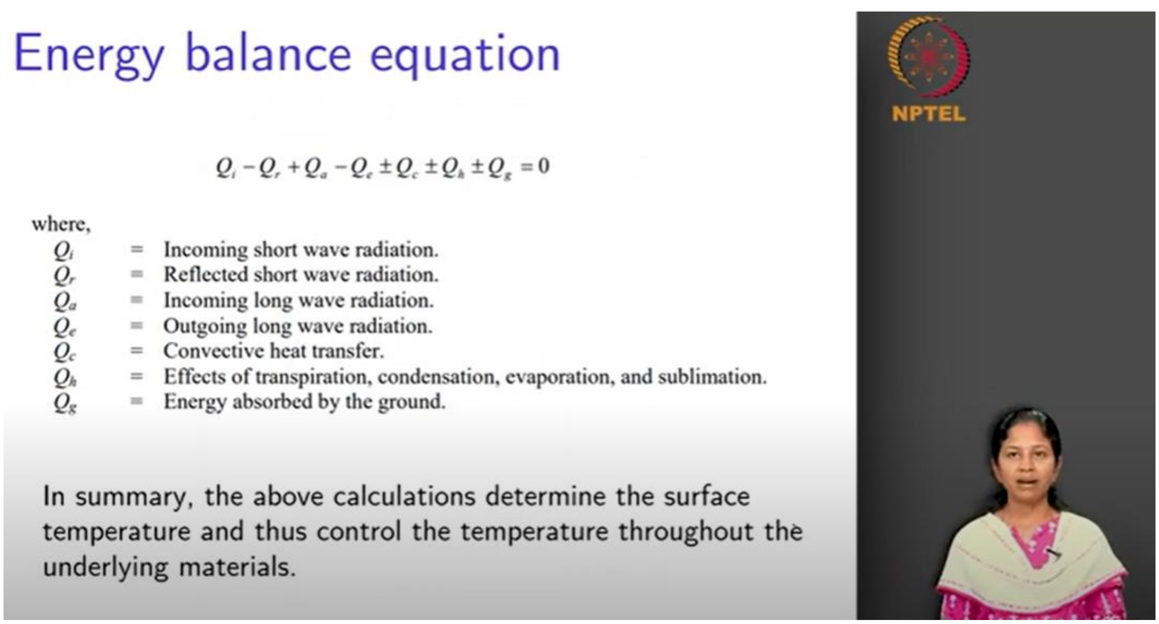

Now we start deriving an energy balance equation. So, we know what are the inputs to the pavement, how the heat is reflected back from the pavement surface. So, we try to see what is the net heat energy that is present on the surface, that is applied to the surface of the pavement. So, we have different radiation parameters that we are using here.

$$Q_i - Q_r + Q_a - Q_e \pm Q_c \pm Q_h \pm Q_g = 0$$

This is the incoming shortwave radiation from sun. It is reflected shortwave radiation. You can see it is taken away from the pavement. That is why it is given with the negative sign. Outgoing longwave radiation, outgoing longwave radiation, convection heat transfer, it could be plus or minus depending upon the temperature. And similarly, we have the transpiration, condensation etc. And we also have the energy absorbed by the ground. So, these are the net heat flow into the pavement. But again, we said we will not be taking into the effect of transpiration. So, this will not be taken into effect by the model. So, in summary, the above calculations determine the surface temperature. And once we determine the surface temperature, we said we are going to use FEM to compute it at any given depth.

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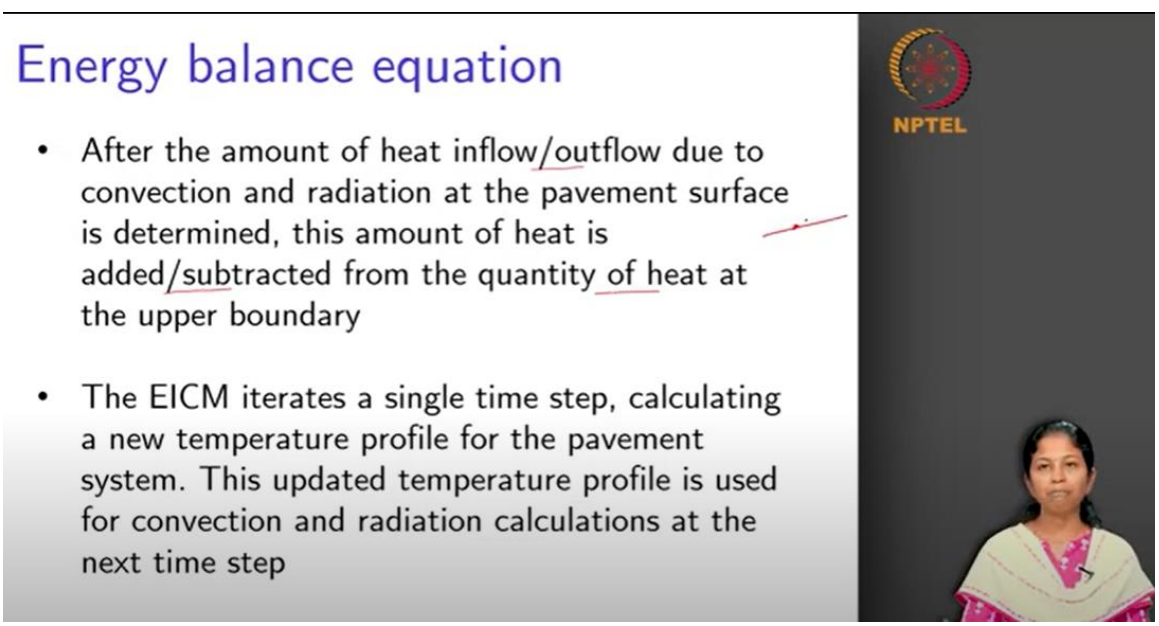

So, after the amount of heat inflow due to convection and radiation is determined, then this is added or subtracted from the quantity of heat, which is already present in the upper boundary. We should remember that at a given instant of time, there is already some temperature which is experienced at the surface. And because of all this, there is some more addition of heat to the surface of the pavement. So, this addition or subtraction will be subsequently calculated to the already available temperature at the surface of the pavement. So, this EICM, this it iterates a single time step. So, at a given time step, it calculates the energy present at the, so one is the temperature at surface that is already present, second one is the net heat input.

So, the sum of these two parameters will give the temperature at the surface at the next time step. So, again at the next time step, the same both these parameters will be recalculated and so on. So, it is done at every time step. So, this updated temperature profile is used for convection and radiation calculations for the next time step. So, subsequently it goes on and that is how the temporal variation of the temporal variation is calculated.

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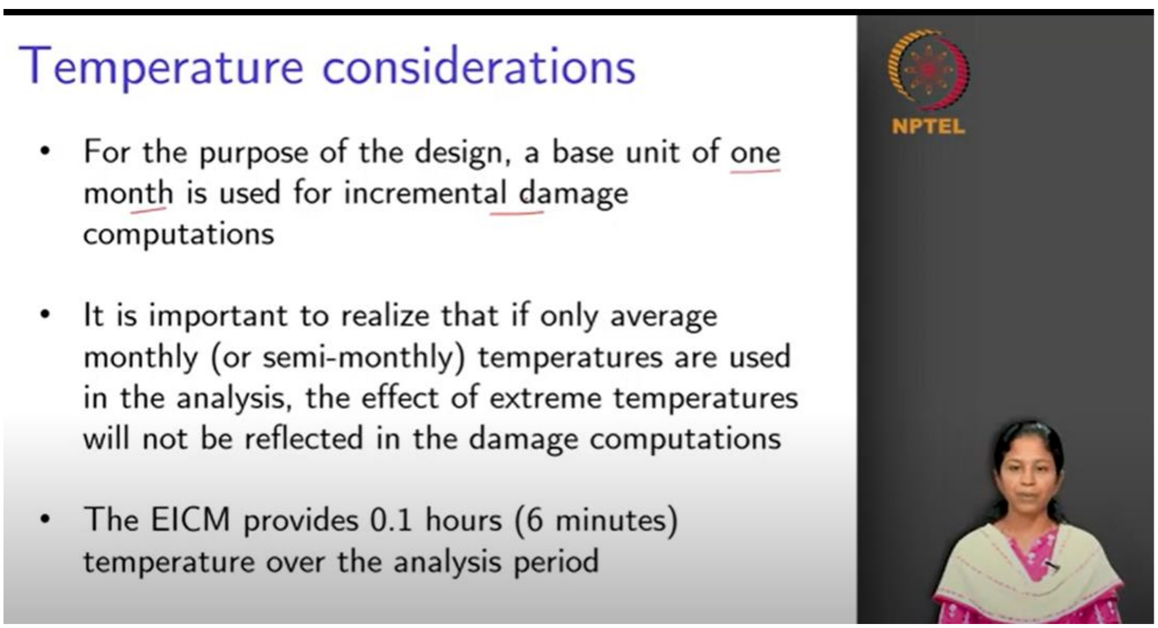


Now, for the purpose of design, a base unit of 1 month is used for incremental damage computation. So, what is this incremental damage? Just hold on. In a few lectures down the line, you will be learning in detail about the incremental damage computation. So, you should remember here that it is calculating the value for 1 month, we are going to compute the damage. So, that is our, the least unit of time which we are going to use for computation of distress.

Now, it is important to note here that the average monthly temperatures are usually used in the analysis. Typically, we will use the monthly average, but if we use the monthly average, let us say this is my average, this is my range over which the temperature varies, this is my average value. Here, we are going to, we are not going to quantify the end effects, the extreme temperature effects, especially the influence of this high temperature here. So, to take into account of this, we are going to do a small analysis on the temperature data. So, this EICM model is able to provide temperature data for every, every sixth minute over the entire analysis period. So, the surface temperature will be calculated for every sixth minute and the corresponding temperature variation along the depth also will be calculated.

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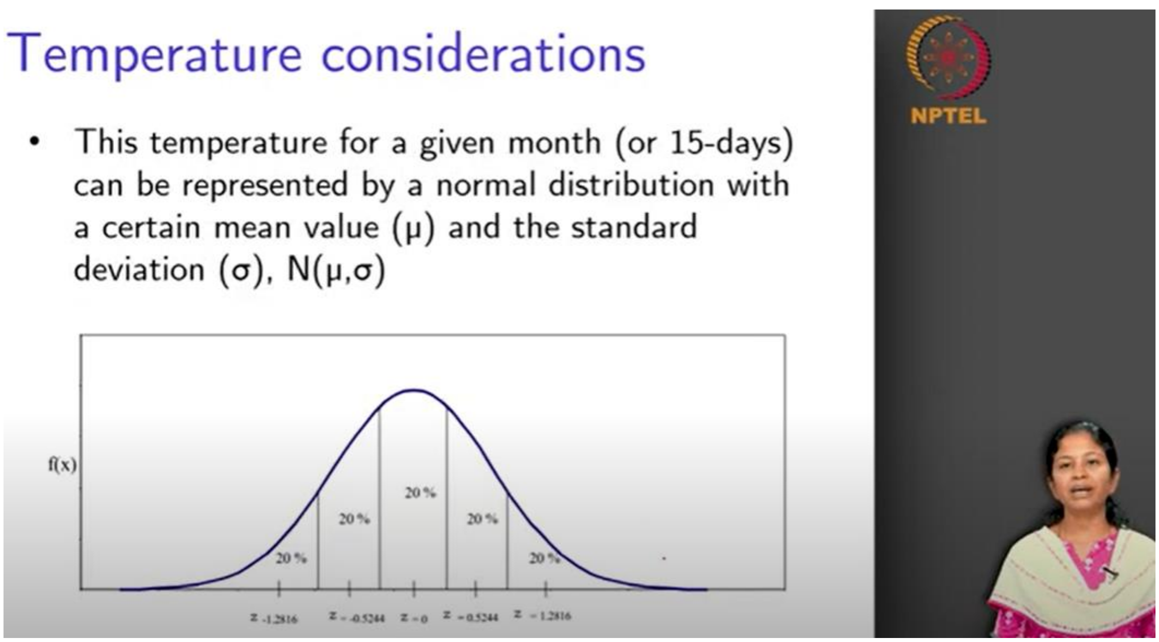


Now, how do we take into account of the extreme effects? So, this temperature which is given for, which is calculated for a given month, in some cases, it could be calculated for 15 days also. For the sake of discussion, let us stick to this monthly variation. It can be represented by a normal distribution with a given mean value and standard deviation. So, for every six minutes, we will be collecting the data. So, let us say that we are able to collect data for 30 days in a month. So, this entire temperature information is drawn in the form of a temperature distribution. And for most of the cases, it has been observed to follow a normal distribution. So, this distribution of temperatures, this is for a month at a given location. We can just say that at a given location, this is for a month. Now, this temperature is divided into 5 quintiles. This each one, they call it as a quintile. So it is divided into 5 quintiles, where each quintile takes into account of 20% of the data. So, once it is divided into 5 quintiles, now this information from each quintile is taken into account for analysis.

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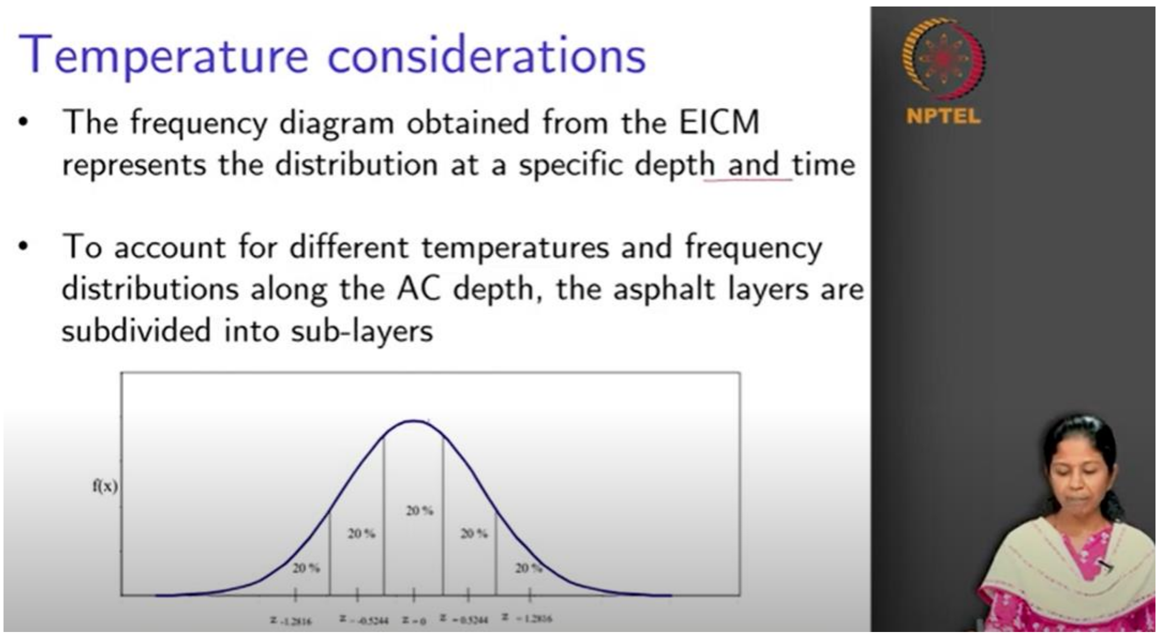


So, the frequency diagram is obtained and then it represents at a specific depth and for a given month over the analysis period. That is why the time effect is given here. So, to account for different temperatures and frequency distribution, they are divided into sub layers. Again, this is something we should remember. The MEPDG model, let us say we have, this is our bituminous layer, 160 mm depth. They have a mechanism; they have a guideline by which this entire thickness is divided into 2 or 3 layers for the purpose of analysis. This is more relevant because for this particular layer, we can use one average temperature value instead of using one value over this entire depth.

We had seen how much it will influence the modulus in one of the previous lectures. Similarly, for granular layer, the sub layering is important because we said the confining conditions are going to be different along the depth of a given layer. So, take into account of that precisely and also to take into account of the moisture variation precisely, they have calculated the, they have subdivided the layers. So, for a given sub layer, this quintile will be calculated. This normal distribution will be calculated for the pavement temperature.

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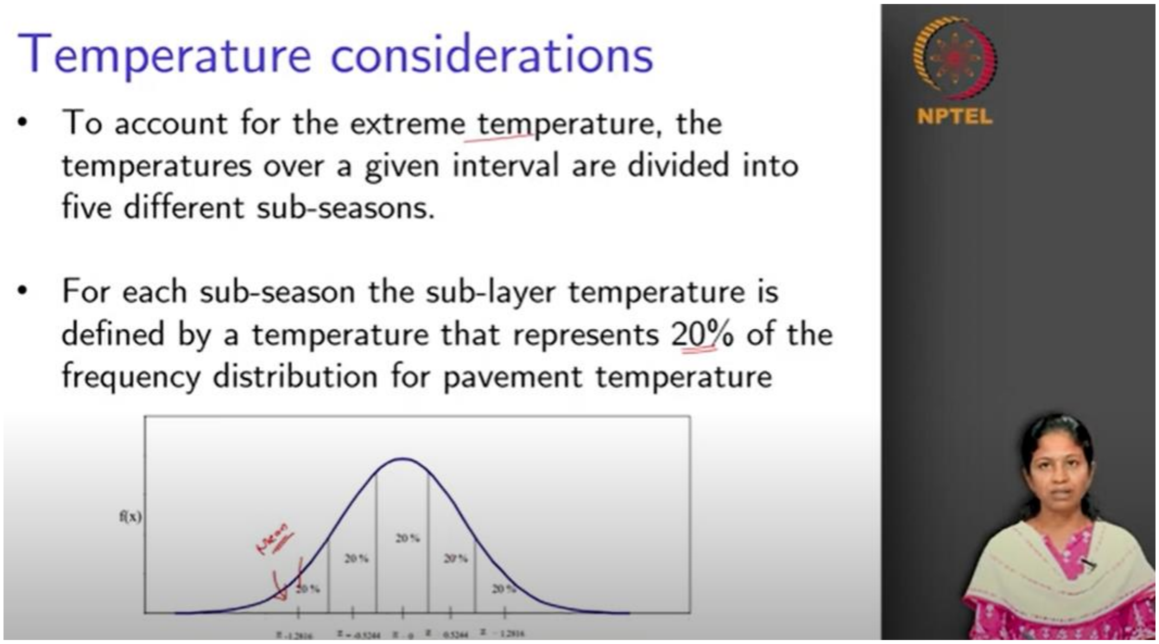


Now, to account for the extreme temperature, it is divided into 5 sub seasons, that is what we said. So, for each sub season, the sub layer temperature is defined as a temperature that represents 20% of the frequency distribution. So, for a given sub layer, we will take this temperature, this 20%, this block here, take the mean value of this block and then for that we will compute the modulus. So, like that it is done. So, again for this block, we will use the mean value and so on.

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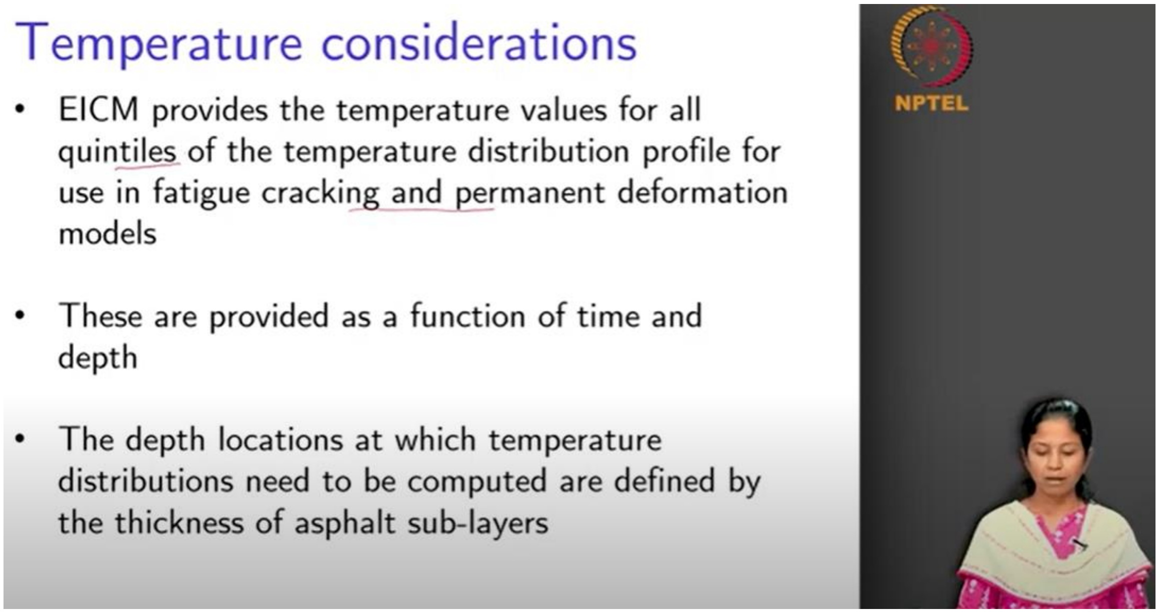


So, you can see here, we will also be taking into account of the extreme values in this case rather than using one mean value as a whole. So, this is the quintile distribution of the temperature, which will be used for the analysis. Now, here it provides value for all the quintiles and then that is used in the fatigue cracking and permanent deformation models when and where the temperature of asphalt layer is required. So, this is provided as a function of time and depth. So, for each sub layer, this is done and it is done continuously over the analysis period.

So, the depth locations at which temperature distribution have to be computed are defined by the thickness of sub base layer. So, like I told you, this MEPDG procedure has a standard guideline how the sub layering will be carried out. So, let me stop this lecture here. We will in the next lecture, we will start talking about the EICM tasks and the validation of EICM, how some field data has been collected to validate the EICM model. Thank you.