Analysis and Design of Bituminous Pavements

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Lecture - 30

Climate Consideration in Design Procedures

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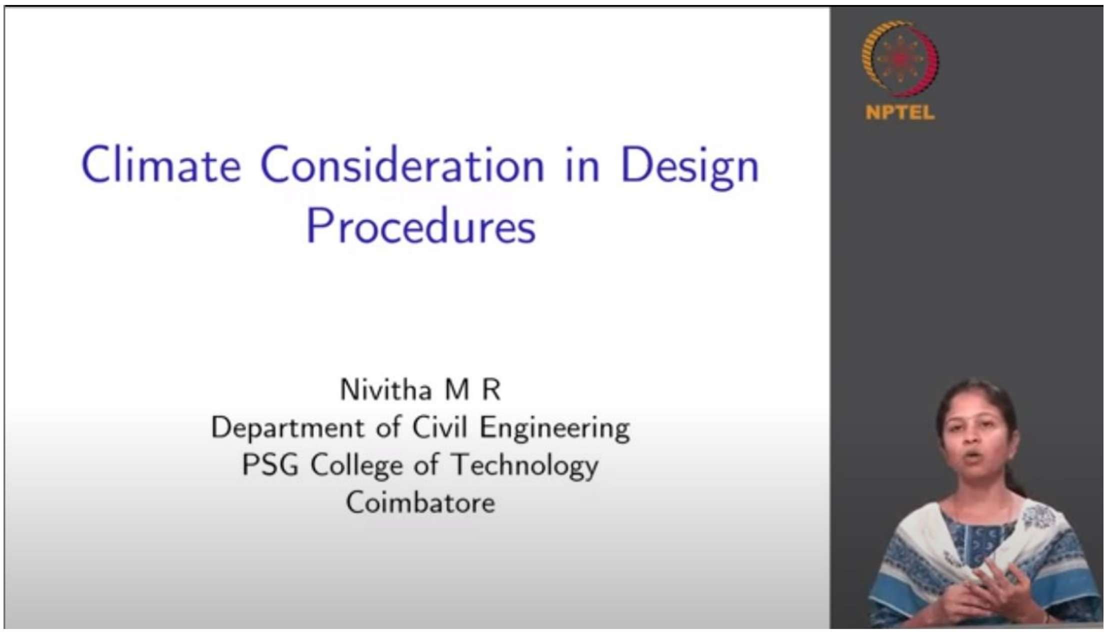

Hello everyone, welcome back. In this lecture, we are going to talk about climate considerations and different design procedures. So far, we have been talking a lot about climate and its effect on material properties. We have seen how material characterization is carried out. We have seen it for granular layers as well as for bituminous layers regarding what is the effect of climate on those material properties. So, we have quantified different climate-based parameters.

We have solar radiation, rainfall, wind speed, air temperature, and many parameters which influence the bituminous layer and then we have water content that is going to influence the granular layer. So, we have discussed the effect and the magnitude of this variation on the material properties. Then we looked into the EICM module, which is an enhanced integrated climate module, and how it takes into account the variations in climate and how it translates into the material property, and how these variations are incorporated into the design procedure. So, in continuation with that, I am going to spend the next few minutes talking about the consideration of all these variabilities related to climate on material properties and how they are taken into account in different design procedures.

So far we have come across different design procedures. To name a few, we have the IRC 37 design procedure which is used in India and we have been commonly referring AASHTO design procedure. In AASHTO also we have a 1993 version and then we have a 2004 version which is MEPDG. Then we have the Austroads design procedure, then we have the South African pavement engineering manual. So, we have different design procedures that are available. We are going to see how to translate the effect of climate on material properties and how it is incorporated into these design procedures. So, here we are going to focus on three different softwares which help us to carry out pavement design and the options available in incorporating the material properties.

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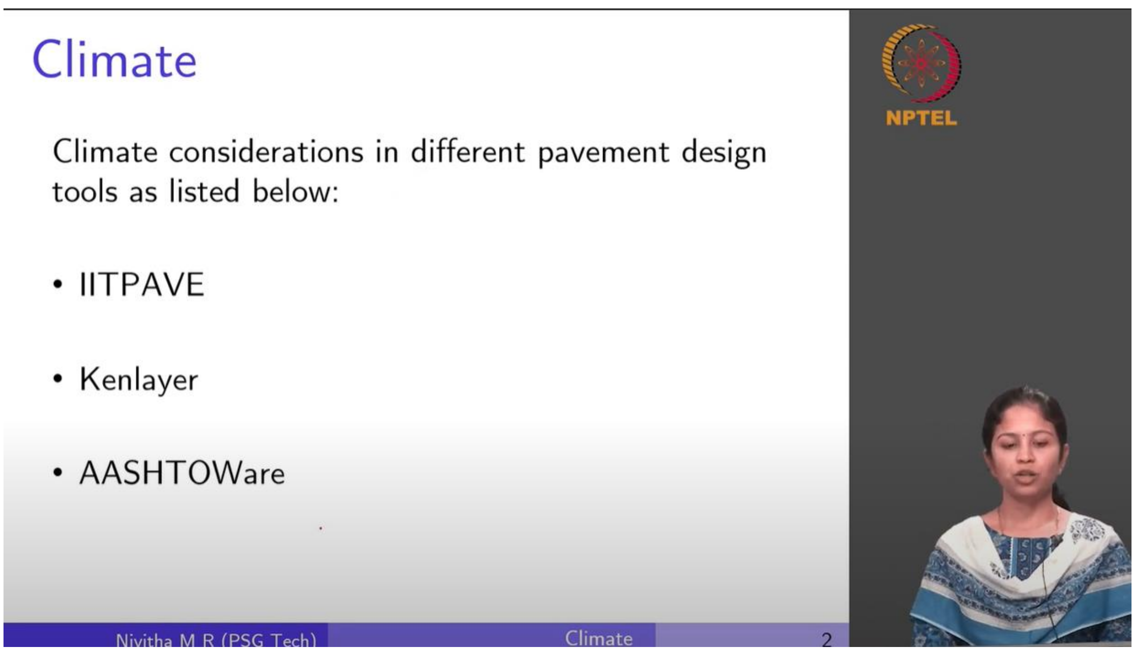

We are going to focus on different tools, one is IITPAVE, the other one is Kenlayer and the third one is AASHTOWare. So, we are going to take these three design software and see how climate is addressed in each of these softwares. So, let us now first look at IITPAVE. I am sure many of you would be familiar with it. Again I am not going to go through the entire design using IITPAVE. You will be hearing about it in the subsequent lectures. So, I am not going to talk about the design procedure using IITPAVE, but I am going to talk about the options available to input material properties and whether there are any considerations in this particular tool to take into account the variability in material properties because of the effect of climate.

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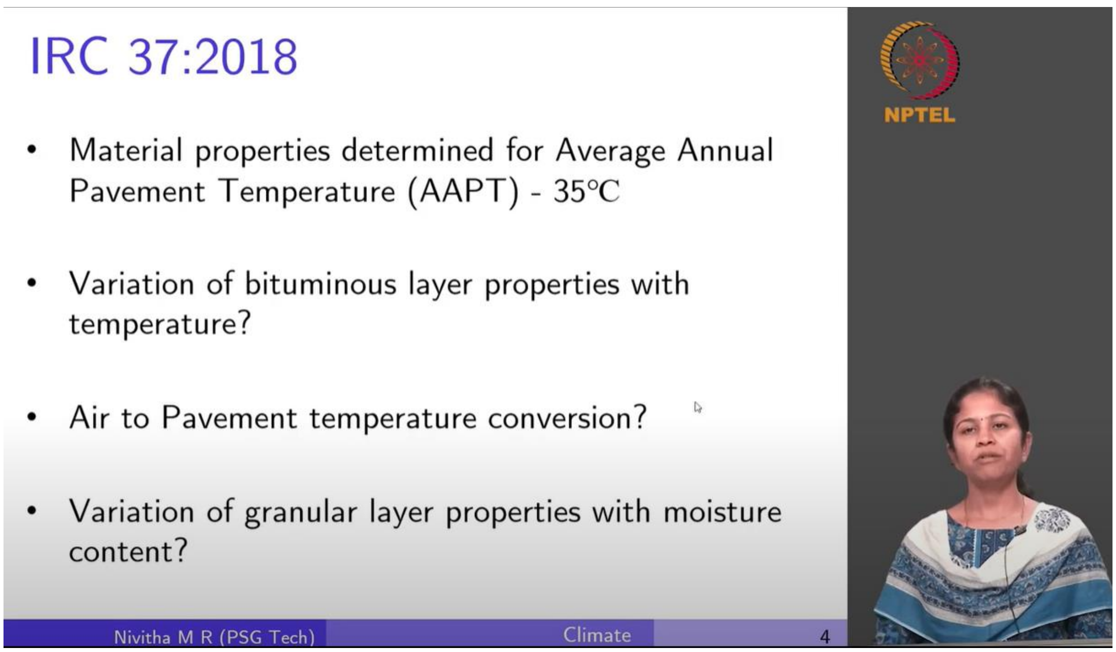

So now if we look at the IRC 37 design procedure, which gives guidelines regarding pavement design, we see that this guideline suggests the design of pavements using an average annual pavement temperature of 35°C. So, if there are deviations from this specified temperature, then the design templates which are suggested in IRC 37 have to be re-evaluated. So, that is the specification with respect to temperature in IRC 37. Now we know that we have bituminous layers and then we have granular layers also which are present in our pavement. The bituminous layers will be subjected to the influence of temperature. In the previous lectures, we have seen that temperature is the major factor that influences the variation of bituminous layer properties and this also varies with the age.

So then how do we determine the pavement temperature? Again what we measure is air temperature. We have to make appropriate correlations to convert air temperature to pavement temperature. Again we have seen that we are using surrogate models which are developed for other locations and other climatic conditions. If we attempt to use the same for Indian conditions, we have seen the amount of variability also. So, air temperature to pavement temperature is another concern that we have to address here.

Then if we look at the granular layers, we have seen that soil moisture content plays a major role in influencing the modulus value of the granular layers. So, we determine what is the moisture content present in the soil, and make appropriate correlations. We have seen the soil water characteristic curve. So, we determine the moisture content and the water retention capability of the soil and then we calculate the appropriate influence on modulus. So, the granular layer properties vary with moisture content.

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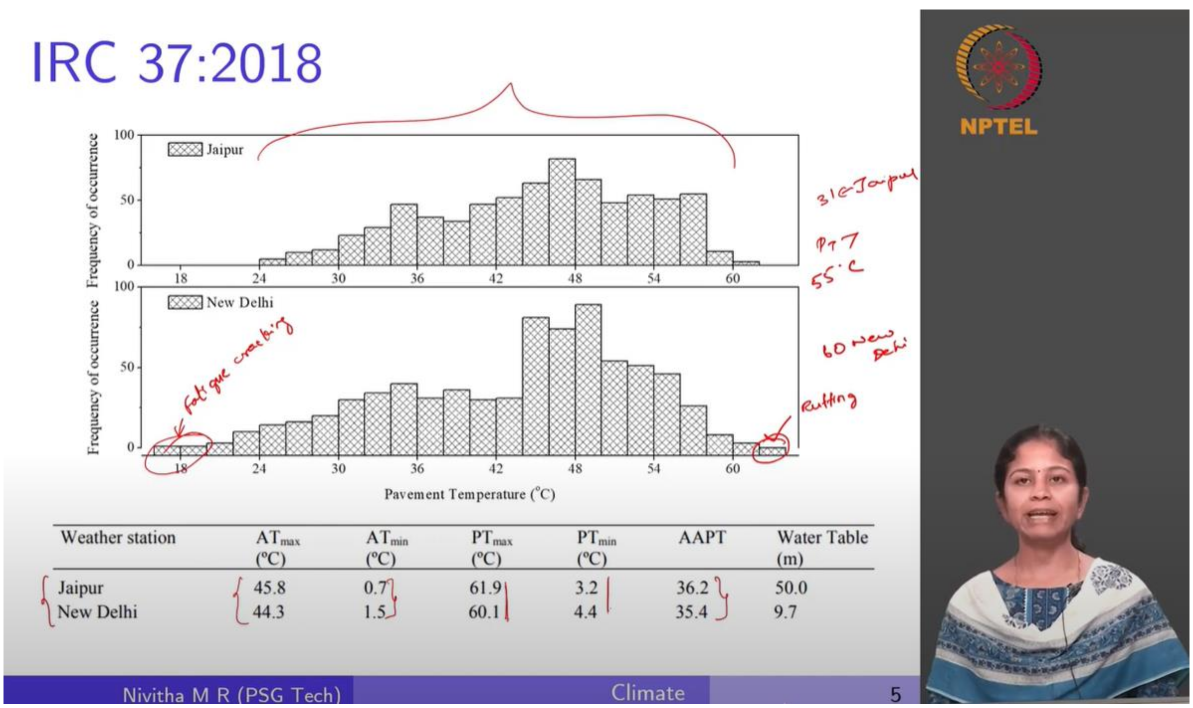

Before we move on to the IITPAVE software, let me show you some data which talks about the variability in temperature distribution for two locations that have identical AAPT values. Let us say we are comparing Jaipur and New Delhi, the maximum air temperature is 45.8 and 44.3, minimum air temperature values are closer.

So, we use these air temperature values in a pavement temperature model and predict the pavement temperature. So, these are the pavement temperature values for these two locations, the maximum pavement temperature, the minimum pavement temperature, and AAPT is also calculated. You can see that the AAPT values are closer. So, now we attempt to plot a distribution of the pavement temperature. In this study, the air temperature data were collected for these two locations for 2 years and an appropriate pavement temperature model was used to convert the air temperature into pavement temperature and then the pavement temperature value was plotted in terms of a histogram.

So, the frequency distribution for individual temperatures is seen here. So, for Jaipur, we can see that it is mostly concentrated in these temperatures, whereas for New Delhi, we see extreme values. We see some values having higher temperatures and some values having lower temperatures as well. High temperature values are going to be critical in terms of rutting and low temperature values are going to be critical in terms of fatigue cracking. Though both of the locations have identical AAPT values, the temperature distribution is different. In fact, when the data were analyzed in detail, it was seen that the number of days in which the pavement temperature is greater than 55°C was about 60 in the case of New Delhi, whereas it was around 31 in the case of Jaipur.

This shows that though locations may have identical AAPT values, their frequency distribution is different, and depending upon the frequency distribution of these pavement temperatures, the distress will also vary. So, we have seen that for highways located in these two locations, the distress prediction was also different. So, this is the influence of the temperature distribution that we observe in a location and why we should take this into consideration in our design.

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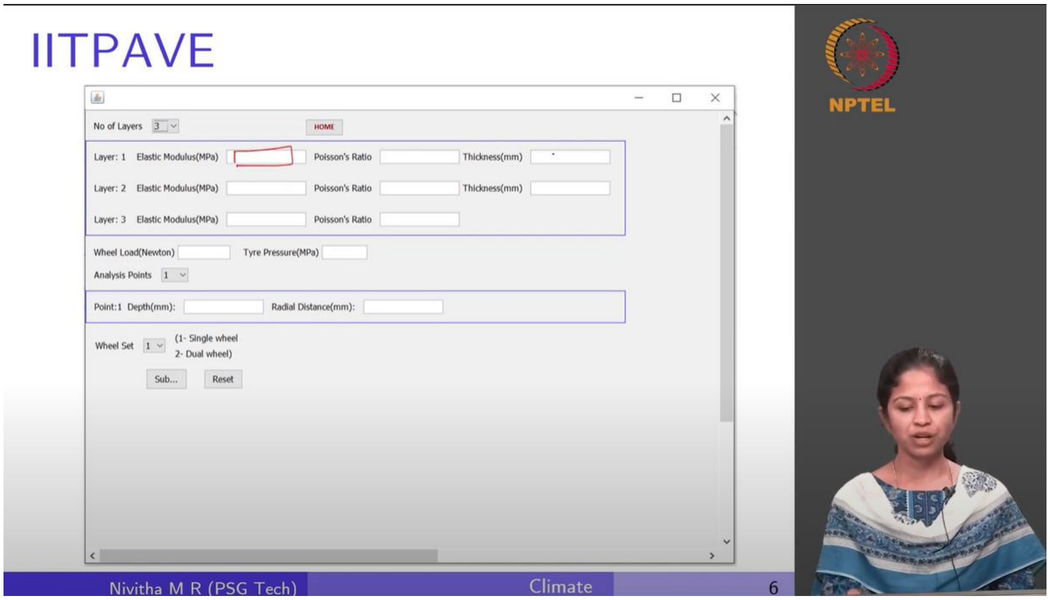

So, now when we move into IITPAVE, this is the screen where we have to input our values. So, we specify the number of layers, you can see that for each layer, we have a box wherein we can input our modulus value, Poisson's ratio and thickness. So, there is one value that we can input for layer 1, one value for layer 2 and one value for layer 3. So, this is the only provision available to input the layer modulus and we do not have any provision to adjust these modulus values depending on the effect of climatic conditions. So, this is with IITPAVE.

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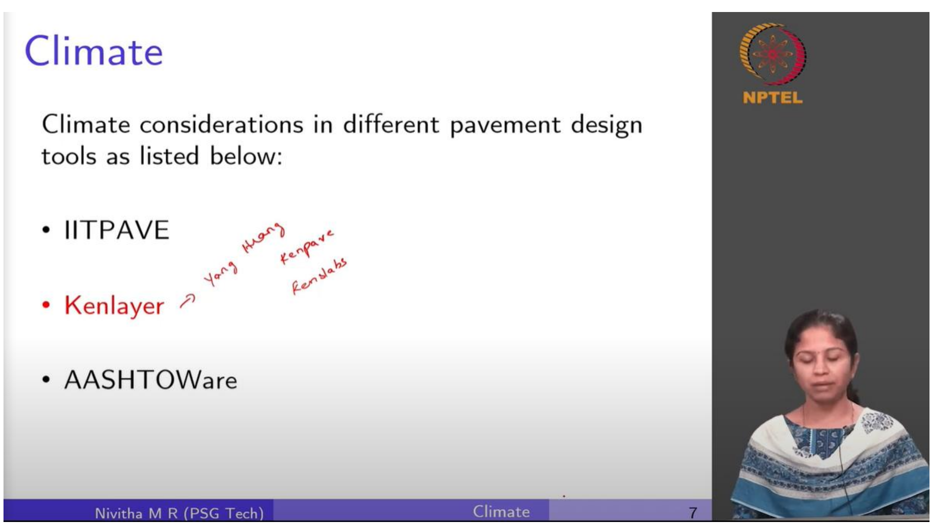

Next, I am going to introduce another software to you that many of you may not be quite familiar with, it is called Kenayer. So, this software was proposed by Huang. He authored one of the famous books on pavement design. He has proposed this software. We have 2 modules namely, KENPAVE for flexible pavement and KENSLAB for rigid pavement. So, let me show you what this software has in terms of incorporation of material properties and whether climate-related effects can be taken into account in this software.

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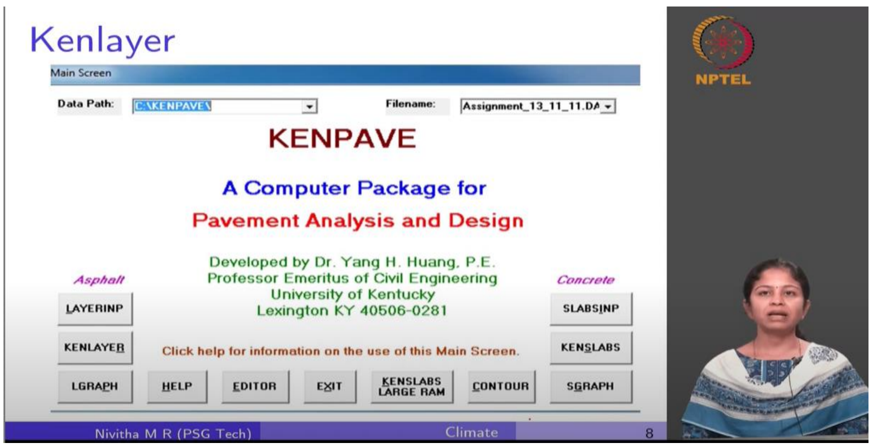

This is the main screen of this software. We have a place wherein we can give input for each layer. So, once you click this layer input, these are the options.

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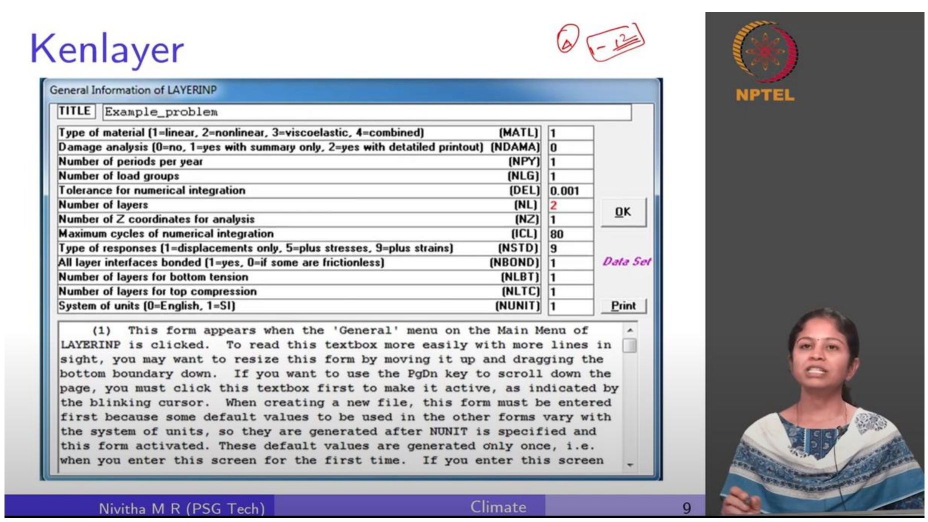

So, just for the sake of completeness, let me go through the options. One is the type of material. So, we can say whether it is going to exhibit a linear response, nonlinear, viscoelastic, or combined response. But most probably we will be using a linear layered elastic analysis, but if you want other considerations also, we can give in this software. The second is about damage analysis, let me skip this. The third one is the number of periods per year which we are interested in. So, what this software does is, we will be able to split the design period into different seasons for a given year. At maximum, we will be able to give up to 12 periods in a given year. What this software does is, it collects different modulus values for each of these design periods. If I give period 1, it allocates a proportion of axle loads during period 1, and that particular modulus is used for the computation of strains. So, like that for each period, the appropriate modulus value is used for design. So, by default, we just use 1 single value like we had seen before in IRC 37.

The maximum that you can give is 12. Sometimes we can also divide it into 4 considering the 4 seasons that we might experience. We can give values anywhere between 1 and 12 for this option. So, this is where the variability and material property is going to be taken into account. So, we have all other parameters, I will skip all of them. I will just show you the material property input window alone.

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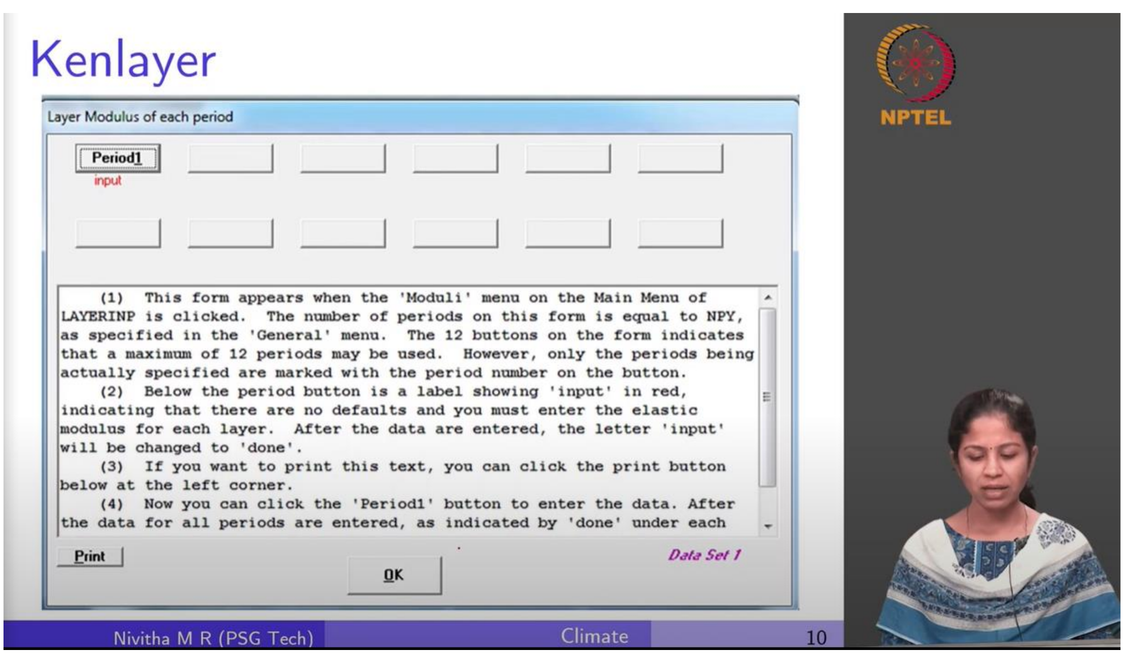

When you want to give this layer modulus, since we have given only one period in the previous case, we have given the number of periods per year as 1. Since we have given it as 1, we are seeing only 1 tab which is enabled. The maximum is 12. If you give 12, all these tabs that you see here will be enabled and we will be able to give material properties.

So, you can see for period 1, we are required to give an input value. So, the appropriate values we can give for each layer. So, if it is a particular month, season 1, we can identify the expected temperature during that period, and the corresponding variation in modulus. Similarly, the expected moisture content in the soil and the corresponding variation in modulus for the granular layer.

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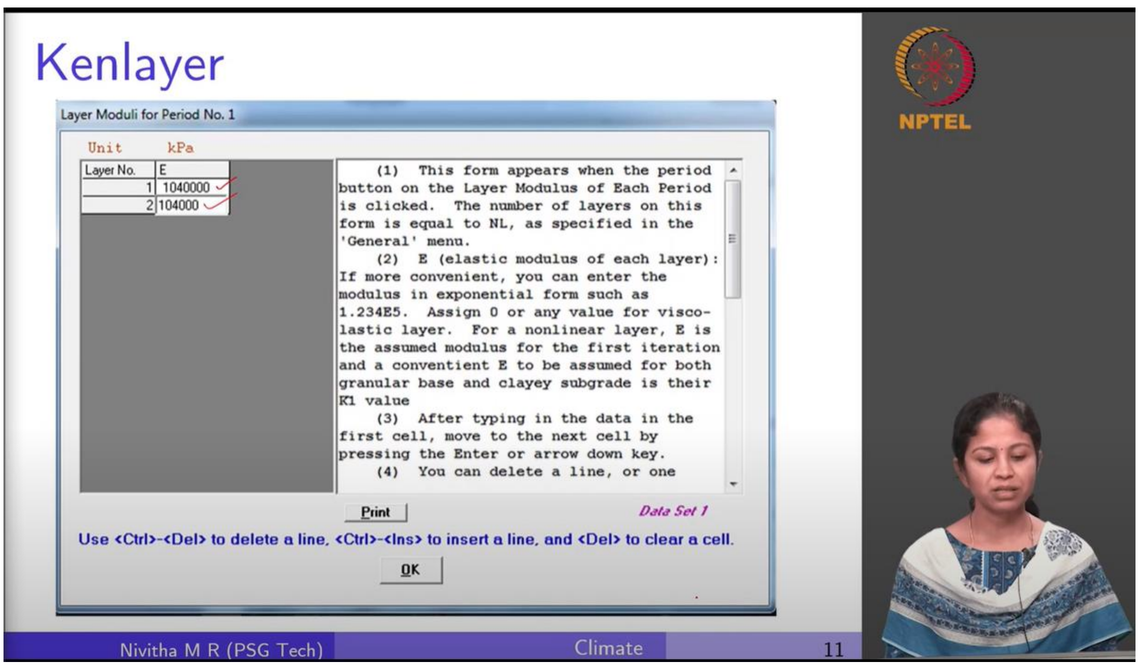

Now if you see here for layer 1, the modulus value is 1040000. For layer 2, the modulus value is 104000. I have just given some arbitrary numbers to illustrate, but we can give the appropriate value for layer 1 and layer 2 depending upon the climatic condition prevalent in that particular season. This is for period number 1. If you have 12 periods, we will have 12 windows like this and for each period, we have to input the layer modulus for each layer. So, this is a slightly advanced, slightly better consideration I would say over the other design methodologies wherein a single-point measurement is used. So, at least here, we are able to divide the period, divide the calendar year into different seasons and then take into account those in design. This is about Kenlayer.

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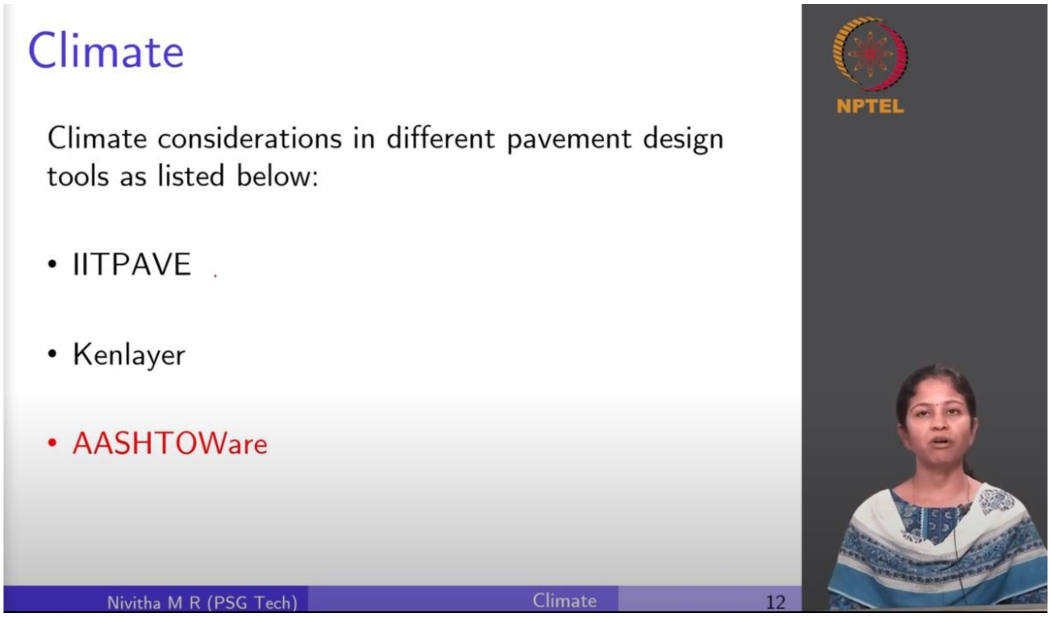

Next, I will talk about AASHTOWare, which is a comprehensive software that takes into account a lot of variables and tries to quantify its effect on material properties. So, previously I was discussing the enhanced integrated climatic model (EICM) and I was saying that this model is inbuilt into the AASHTOWare software. Once we give certain input parameters regarding climate, the software appropriately addresses the modulus of different layers and then uses it for design. So, let us see how these values are input into the software and what are the outputs that we get from the EICM.

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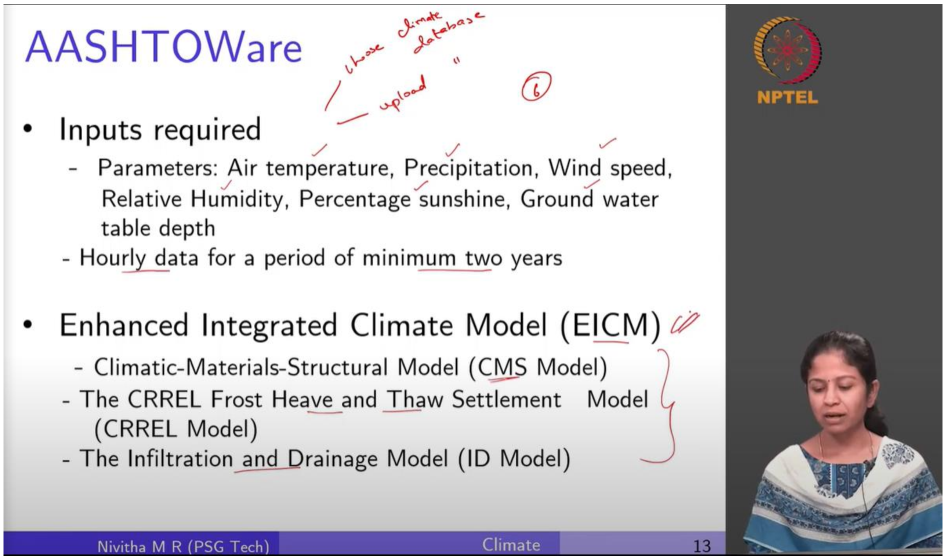

For the inputs required for the climate data file, there is a separate climate database that we have to enter. For the locations that are present in the US, there is a default list of weather stations. So, if you pull down the option there, the stations for which the climate database is available will be listed. We can either choose locations from that or we can upload our own climate database.

The parameters that will be present in the climate database are air pressure, precipitation, wind speed, relative humidity, percentage of sunshine, and groundwater table depth. We need all these 6 parameters to be input in the climate database, and hourly data is required for a period of a minimum of 2 years. More details about this we had already seen in the EICM module. So, then what this EICM does? We have seen that there is a climate material structural model, which translates the effect of climate onto the variation in material properties and the structural response that we observe. Then we have a CRREL model, which is used for heave and thaw settlement.

Again all this we had seen and we have an infiltration and drainage model, which takes into account the rainfall that we have observed and converts that into the moisture content that is present in the soil. These are the modules that are present in EICM, which is inbuilt into this particular software. So, as a user, we will be required to choose the climate database or we have to upload the climate database. If we create one, we have to upload this. All these things are already inbuilt into the software.

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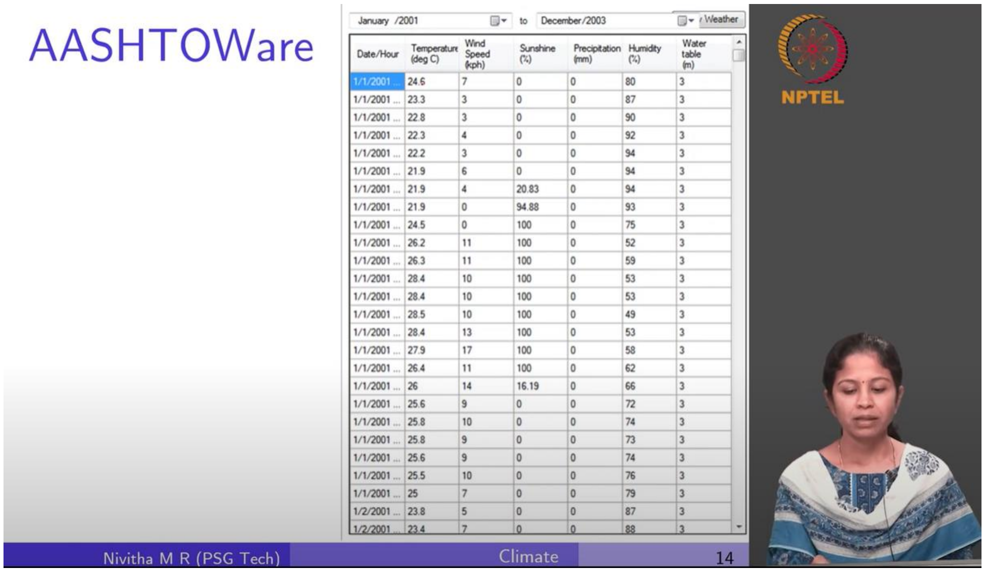

So, once we do this, this is how the database will look. You can see this is day 1, first hour, the temperature, wind speed, sunshine, precipitation, humidity, and water table is given. This is how the climate database will look like. So, like that we give for 24 hours, you can see here, we will be having data of 24 data points before we move on to the second day, which is the 2nd of January. For each hour, we have to give all these input parameters. Now, if I want to use software like AASHTOWare and carry out pavement design, I will be able to update our climate information into AASHTOWare.

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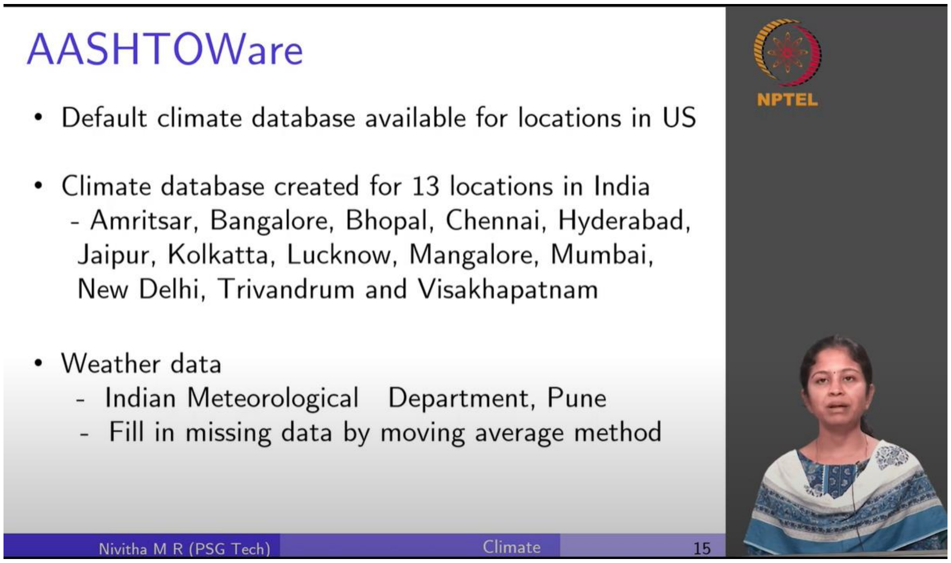

So, here we have created a climate database for 13 locations in India. So, these are the locations for which we have created the climate database in the appropriate format, and collected information about all these parameters from the Indian Meteorological Department (IMD). And each of these data was having a lot of missing points and errors. So, all this data was corrected and there is a template in which it has to be arranged to be uploaded into the software. So, it is arranged in that specific manner and the climate database is ready. In India, we have the information for about 13 locations spread across the country. Now, we can use these climate database files, if we want to carry out pavement design for India using AASHTOWare. So, this consideration of the realistic climate conditions could be done if we want to use AASHTOWare software. So, the missing data were filled in by a moving average method, and a lot of pre-processing was done before this data was used in the climate file. So, this is with regard to the weather data.

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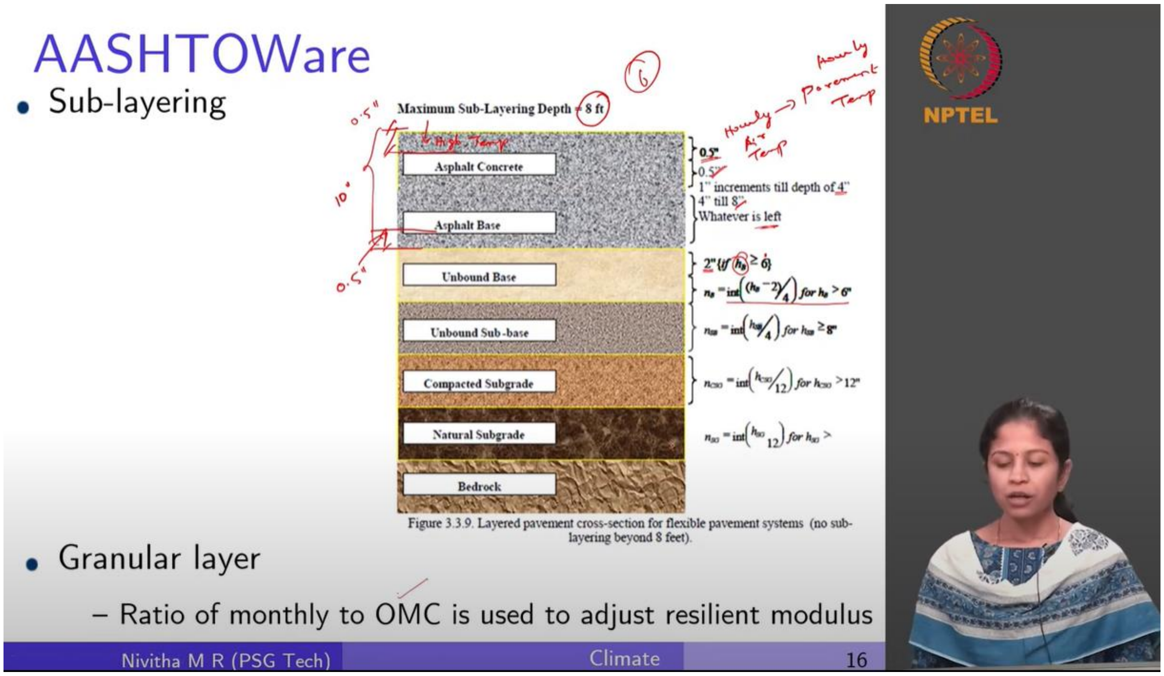

Now, let us look at how the sub-layering is carried out in AASHTOWare. What is the sub-layering? We might have one particular layer. As this is given in feet and inches just to illustrate, let me stick to the same units which are given in this plot. So, the maximum sub-layering depth that will be used is 8 feet, and each layer will be sub-layered in a different manner. Let us say this is the bedrock, the next layer is a natural subgrade, then we have a compacted subgrade, then we have an unbound subbase lying over it, then we have an unbound base, asphalt base, and asphalt concrete. So, these are the layers that are present in a pavement which is taken here for example. These are the sub-layering options. For the asphalt concrete layer, the top 0.5 inches is one sublayer and the next 0.5 inches is another sublayer. After that, it is taken in 1-inch increments till a depth of 4 inches. Then 4-inch increment till a depth of 8 inches and the remaining whatever is left is taken as one block. This is how the asphalt layer is sub-layered.

Now, why do we have to carry out this sub-layering? We can see here, let us say this is 10 inches. It is not appropriate to use the same modulus value for all 10 inches of this particular layer. The top surface will be subjected to high temperatures and thus the modulus will be relatively lower compared to a layer that is present in the bottommost portion. So, if I take the top 0.5 inches, the modulus of this layer is going to be relatively lower than the bottommost 0.5 inches of this asphalt base.

So, to take into account this variability and to use the appropriate value rather than using an average value for the whole layer, the sub-layering concept is used. Similarly, for the granular layer also. So, the layer that is close to the water table will have more moisture content and therefore lesser modulus compared to another layer. They have different sub-layering options. If you look at the unbound base, it is 2 inches if the thickness of the base layer is greater than 6. For all others, they have an interval in which this is 6 inches for all other layers they have a manner in which it could be sub-layered.

So, you can see this for an unbound base, unbound subbase, compacted subgrade, natural subgrade and all layers. So, they are sub-layered and the sub-layer thickness varies from layer to layer. For each sub-layer, individual modulus values are assigned and when the pavement design is carried out, instead of let us say, this is 1, 2, 3, 4, 5, instead of 6 layers, right, all the sub-layers will be considered and the pavement design will be carried out. The stresses and strains will be computed for all the individual sub-layers. Appropriately the modulus value for the sub-layers will be taken into account. For the granular layer, the ratio of monthly to optimum moisture content is used to adjust the resilient modulus.

So, from all the soil water characteristics curves and other soil properties, we will be able to get the moisture content that is present in the soil. Over the entire month whatever the moisture content present in the soil, the ratio of that to the optimum moisture content is taken and the resilient modulus is adjusted accordingly. This is the sub-layering and the appropriate material property that is used in AASHTOware. Then how does it take temperature into account? So, we have seen that we have hourly data for each location. For each of this sub-layer, the hourly data will be used and the hourly air temperature will be converted to hourly pavement temperature.

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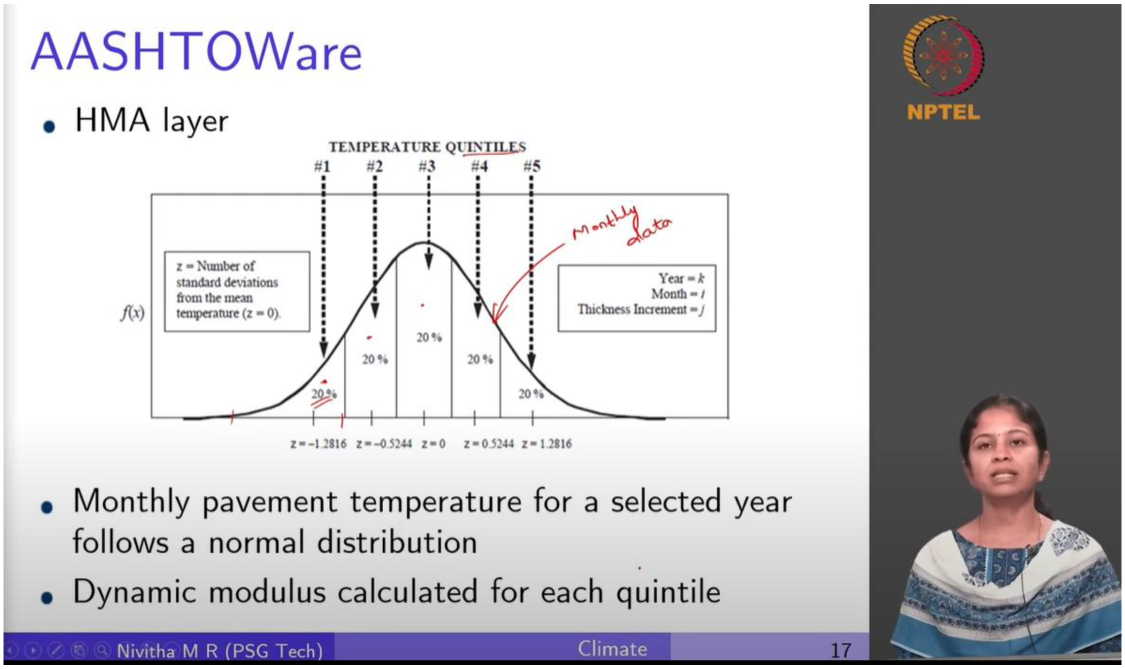

This pavement temperature is taken here and it is fitted with the normal distribution. So, this is for monthly data. This kind of distribution is fit for the data collected every month. For this monthly pavement temperature data, a distribution is fit and it is divided into 5 equal portions, each representing 20% of the data. So, they are called temperature quintiles. Now each quintile is taken and one average value is taken for this quintile because you can see that the variability and temperature within a quintile will be very less. So, one representative value can be taken for this particular quintile rather than taking it for the entire temperature for that month. So, in the first quintile, one representative temperature value will be taken and that will be used as the material property in the calculation of the strains. Then it is done similarly for the second quintile, third quintile, and so on. Again, this is done for every sublayer which we have seen earlier for the asphalt layer.

So, the monthly pavement temperature for the selected year is considered to follow a normal distribution, and the dynamic modulus is calculated individually for each quintile. We have an asphalt layer, we have given the temperature and we have given the pavement temperature. The pavement temperature distribution along the depth is also calculated. So, from that, the appropriate dynamic modulus will be calculated for each temperature quintile. This is the consideration of material property and its variability with respect to temperature.

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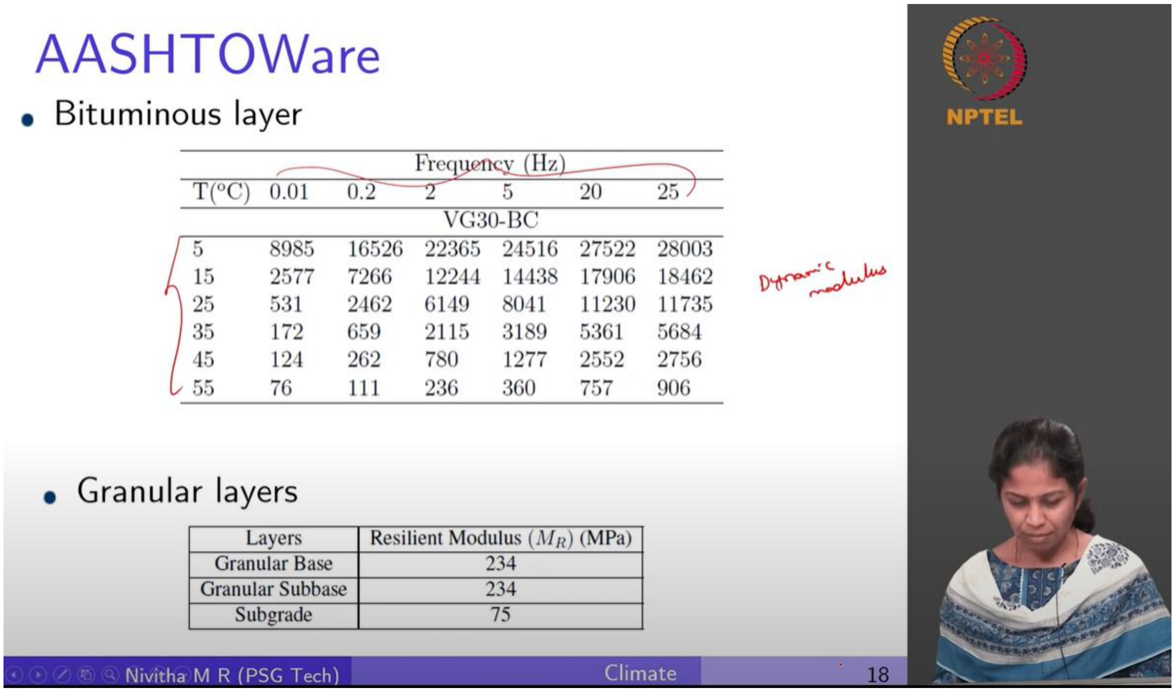

Now we can see here for the bituminous layer, it is if you use a level 1 kind of input, again I will tell you what level 1 is. Level 1 kind of input is a very precise input that is measured for that particular material property, the material that is going to be used in the site. So, there are no assumptions here, there are no empirical equations that are used to predict the material property. For the bituminous layer at different frequencies, you can see here the frequency range is 0.01 to 25 Hz. For different frequencies and different temperatures, the bituminous layer modulus is measured. This is the dynamic modulus. The dynamic modulus value is measured for different temperatures and frequencies. This value is input here and it is used to construct a master curve. How does a master curve look like?

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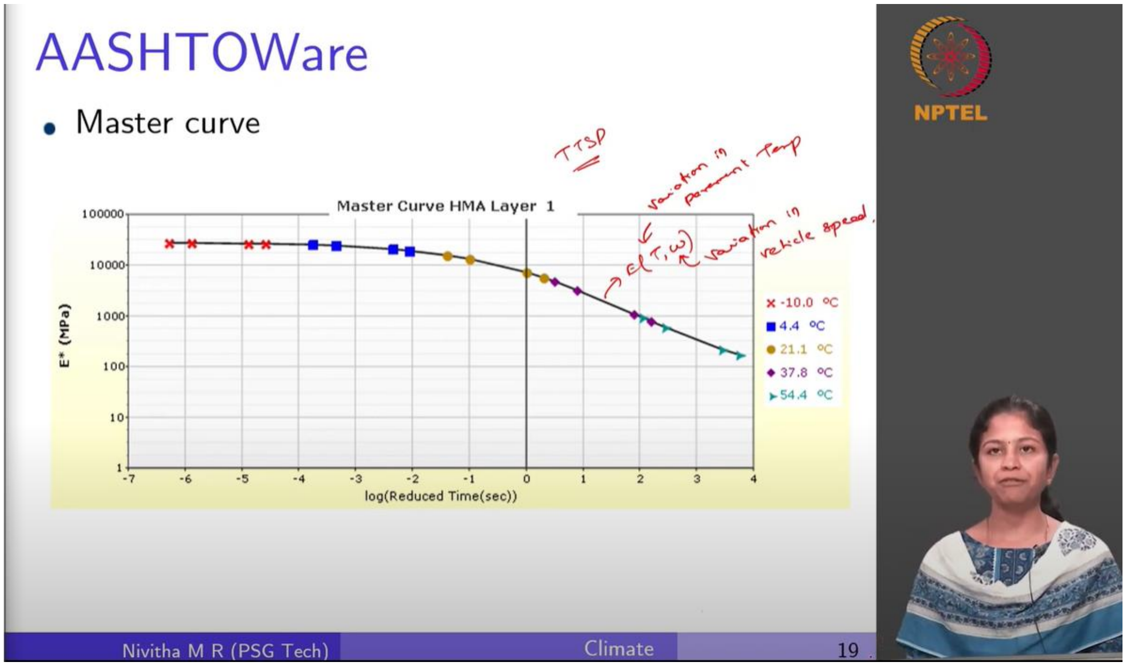

This is how a master curve will look for a bituminous layer. It is based on the time-temperature superposition principle. Again, you should have been briefed about this in one of the previous lectures. So, we use this and construct a master curve. This is how the master curve will look like. It is constructed for a specific reference temperature, but from this master curve, we will be able to take the modulus value for any given temperature and any given frequency. This accounts for the variation in pavement temperature and this accounts for the variation in vehicle speed. It will be taken from the master curve and appropriately the stresses and strains will be computed.

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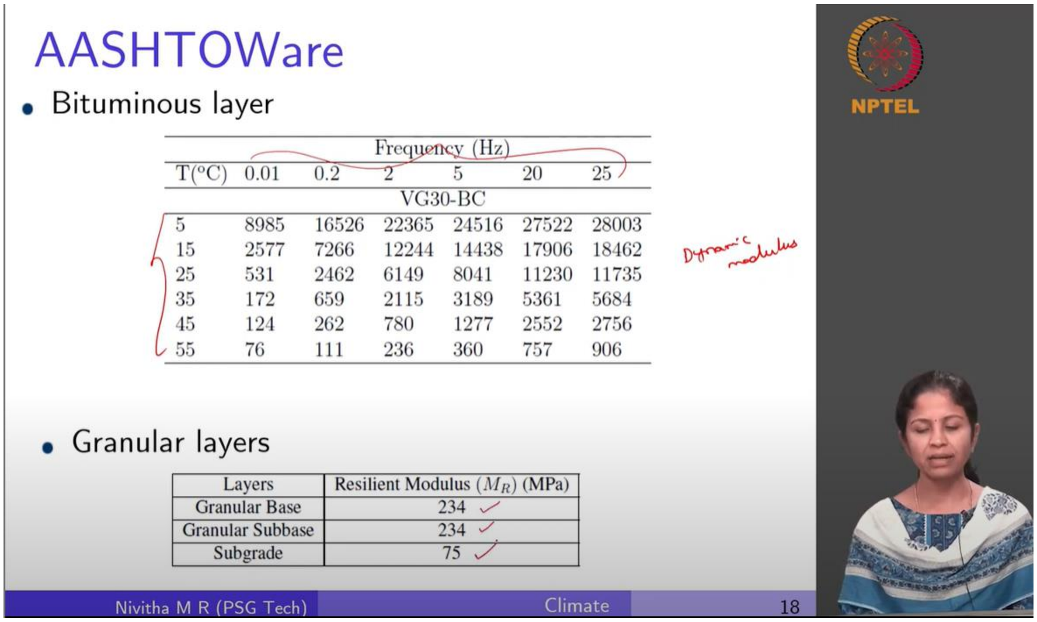

Alternatively, for granular layers, we have the resilient modulus which is used. We have a value for the granular base, granular sub-base and subgrade layers. So, these are the material properties that will be input into the AASHTOWare software.

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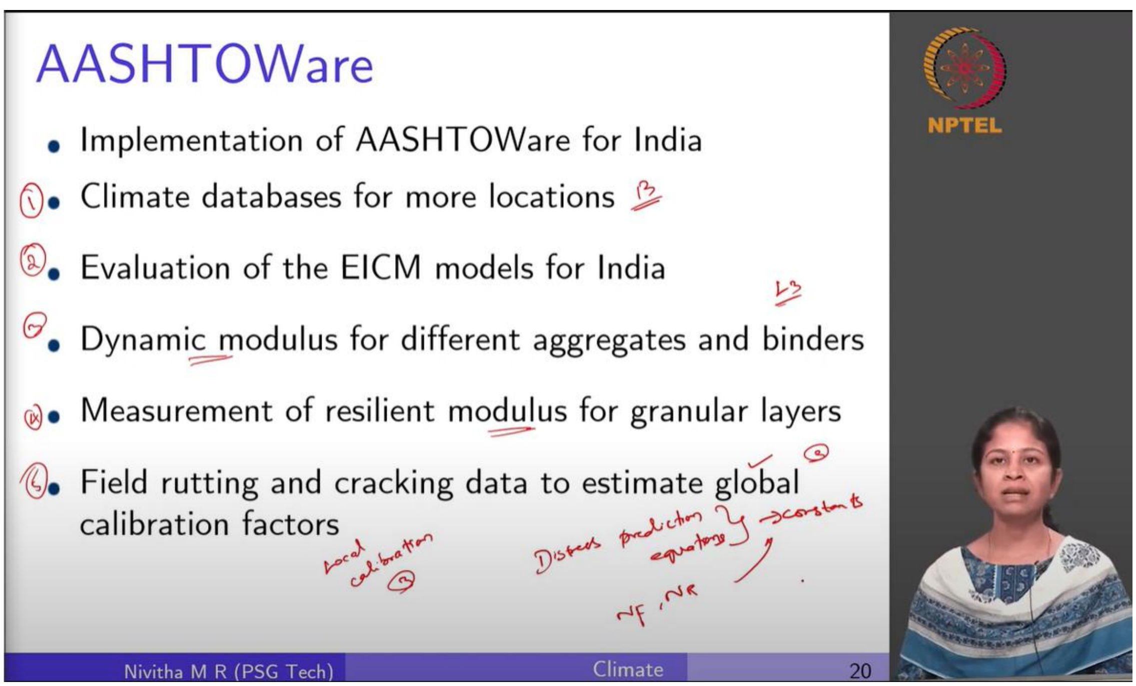

If we have to use the AASHTOWare software for India, let us say, what additional data has to be collected. We have seen that there are a number of empirical equations and climate modules that are used in the software. So, the data corresponding to all these things have been collected, calibrated and validated for US conditions. If we have to use this software in India for computation of the distresses for locations in India, we have to collect additional data or make suitable modifications to the available data. So, what kind of modifications we will be making? The first one is the climate database. We have seen that we have a climate database for Indian conditions for about 13 locations in India. But if we want the climate database for a particular location, which is closer to the site where we are constructing, then we have to have more climate databases so that we can be as close as possible.

So, this is the first information that we want. The second information is the evaluation of EICM model for India. Again, we have seen that all the sub-modules, the CMS model or the CRREL model, infiltration drainage model. So, all these models have been developed, calibrated and validated for the climatic conditions prevalent in the US. So, we have different correlations, air temperature to pavement temperature, the influence of wind speed on it, the radiation and the amount of radiation falling. All of them have been calibrated for US conditions. We have to develop a similar kind of model or we have to make suitable amendments to the EICM model to be able to use it for Indian conditions.

The third one is the dynamic modulus value for different aggregates and binders. Again, if we are using a level 3 kind of input, which is more related to the default values available in the software, we do not have the modulus values for the type of mixes that we use in India. So, we need to collect more amount of data related to dynamic modulus for different aggregates and binders and then we should be able to use it in the software. Then the measurement of resilient modulus also has to be carried out for granular layers. Only if the resilient modulus value is measured and used, then appropriate modifications to the value can be made to consider the effect of moisture content. And finally, this is the fourth one. So, the final one is related to field rutting and cracking data.

We have distress prediction equations. In these distress prediction equations, we have constants like the constants that we have in fatigue (N_f) and rutting (N_r) equations. We have similar kinds of constants in the distress prediction model in AASHTOWare also. Again, these constants have been calibrated for the specific conditions in the US. If a particular strain is given, what is the corresponding rutting or fatigue cracking, or any other distress? Again, we have to calibrate the constants in the model for the conditions present in a given location.

They have two kinds of values that are specified. One is the global calibration factor. We also have another calibration factor called the local calibration factor. So, this global calibration factor is to take into account the global variation and mixed properties. And this local calibration factor takes into account the variability between laboratory and field data. There are 3 local calibration constants and 3 global calibration constants.

Once we identify this for a specific location, then we will be able to more accurately predict the distresses for the selected location. These are the different parameters or different kinds of information that we have to collect and use in the AASHTOWare software if we have to use a similar kind of tool for Indian conditions. So, this is an overview of the consideration of the effect of climate on material properties in different design tools. I thank you for your time here.