Analysis and Design of Bituminous Pavements

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Lecture - 12

KENLAYER – 4

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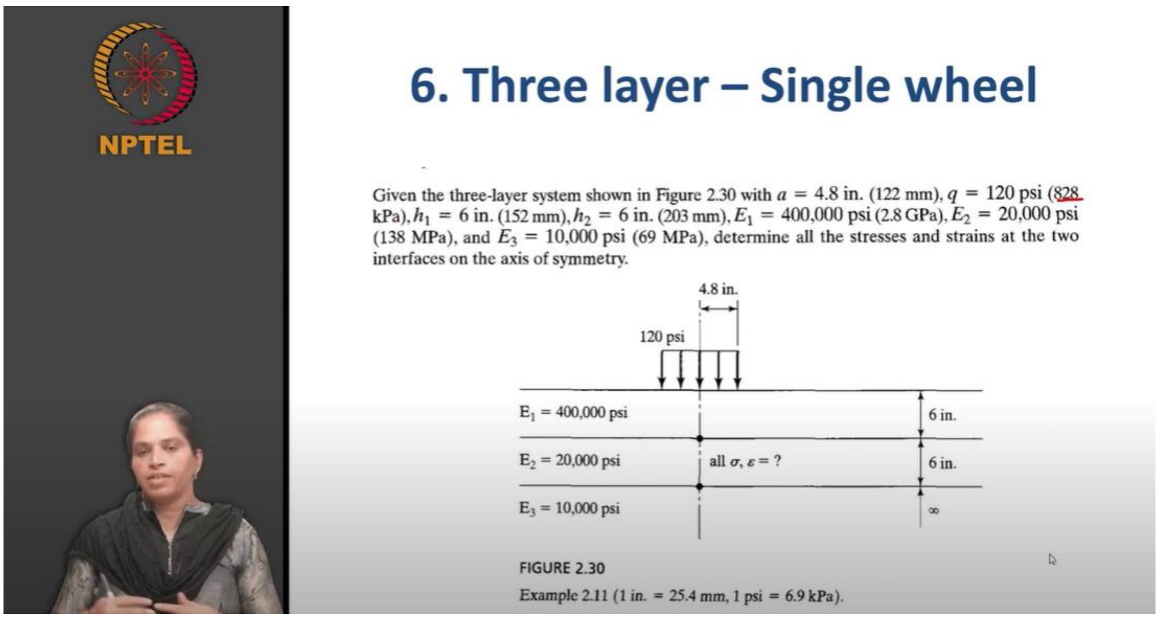

The last lecture was on a two-layered system. Now, we will focus on a three-layered system. So, what we will do is, we will take a three-layered system and solve it in KENPAVE and find out what are the critical stresses and strains at critical locations and at least two different critical locations, one, is at the bottom of the asphalt layer and second one is at the top of the subgrade layer.

So, we will directly move to the numerical. So, you have a three-layered structure something like this. This is subjected to a single wheel load with a contact radius of 122 mm and a contact pressure of 828 kPa. The surface layer has a thickness of 152 mm and base layer has a thickness of again 6 inch which is 152 mm. And the bottom layer is of an infinite thickness. The modulus of each layer is as given here. First layer modulus is 2.8 GPa, second layer modulus is 138 MPa and third layer modulus is 69 MPa. Let us find stresses and strain at two critical locations. One is at the bottom of the asphalt layer and second one is at the top of the subgrade layer. We will find out all the components of stresses and strain and we will see how these values vary.

So, these are the inputs we need to give in the KENLAYER for solving this numerical. In the general information, you have type of material to be linear, no damage analysis, number of periods is 1, load group is 1 which is single axle single wheel. Let us keep the numerical integration tolerance to this as the default value. Here, the number of layers is 3 and number of z coordinates when we are looking for the analysis is 2, one is at the bottom of top layer and second is at the top of the subgrade layer. So, other values we will just keep it as the previous numerical and we will use an SI system here.

So, once you complete your general input, these are the layer thickness and Poisson's ratio properties. Top layer is 6-inch thickness which is 15.2 cm, second layer is also 6-inch thickness 15.2 mm, bottom layer is infinite thickness. So, let us use a Poisson's ratio 0.35 for the surface layer and base layer. If you want you can modify it and check how the values varies. The subgrade Poisson's ratio, I will keep it as 0.5.

We have given two z coordinates. The first z coordinate is going to be 15.2 cm and the second z coordinate is going to be the bottom of the second layer which is going to be 15.2 plus 15.2 that is 30.4 cm. So, with this z coordinates, we will find out stresses and strain at two points.

Now, these are the modulus value for three different layers. You can see that the top layer has a maximum modulus and the subgrade has a minimum modulus.

So, once you complete the modulus input, this is the load information which you have to give, 0 for single axle single wheel, contact radius is 12.2 cm, contact pressure is 828 kPa. Since it is a single axle single wheel, YW and XW values are 0. Let us keep only one radial distance here which is at the center of loading. So, you have RC is 0 at this point.

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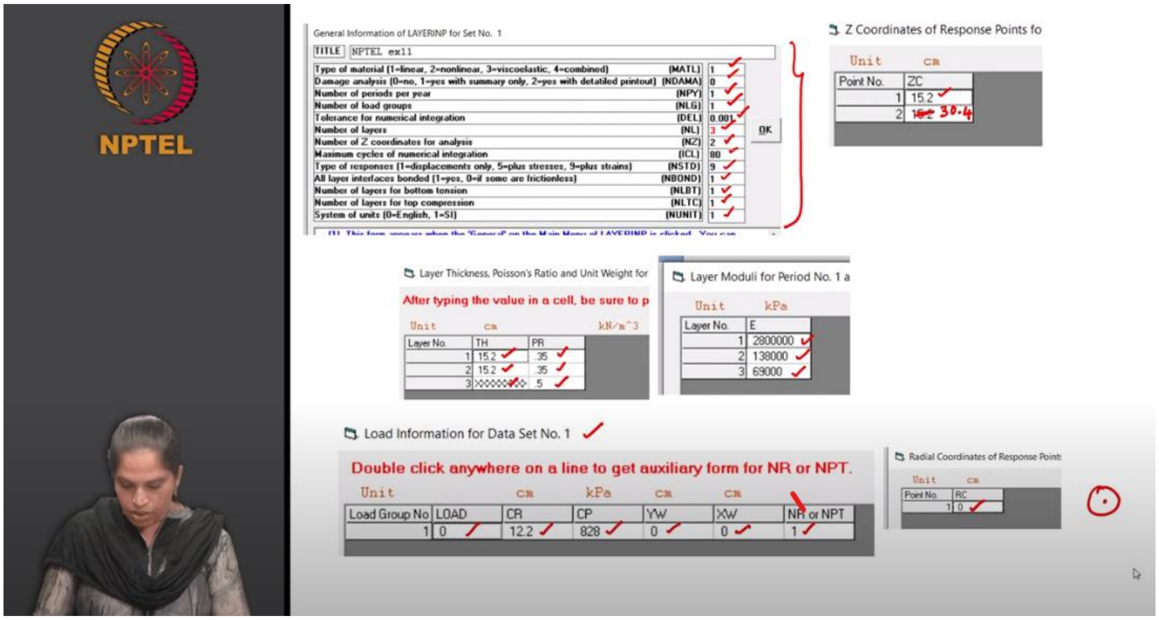

Now, once you give all this input and compile it, this is the result you will get. So, we have given only one radial distance which is exactly at the center of loading and two vertical coordinates which is 15.2 cm and 30.4 cm. So, the first line corresponds to the bottom of an asphalt layer. The second line corresponds to the top of a subgrade layer. These are the critical stresses and strain at two different depths. Now, the vertical stress and strain at the top of a subgrade layer that is at the depth of 30.4 cm from the surface that is 51.065 kPa and 5.466E-4. This is going to govern the rutting in subgrade layer. And, tensile strain maximum which is -3.142E-4 are the corresponding stress are going to influence the fatigue damage in the asphalt layer. So, these are the critical stresses and strains we will be using further in the design.

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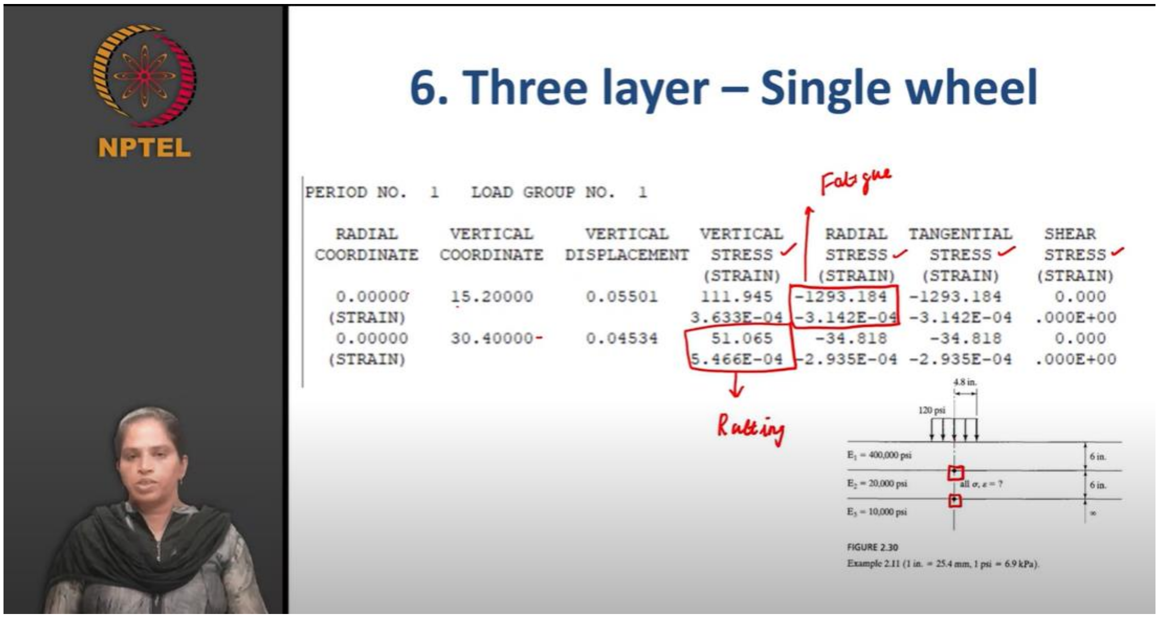

Now, we will see how the thickness of a base course influences tensile strain at the bottom of the asphalt layer. So, for this purpose what we will do is, we will use a base course thickness of 8 inch. In previous case, we used 6 inch now, we will use 8 inch and determine tensile strain at the bottom of the asphalt layer and we will check how the thickness of the base course influences the tensile strain value.

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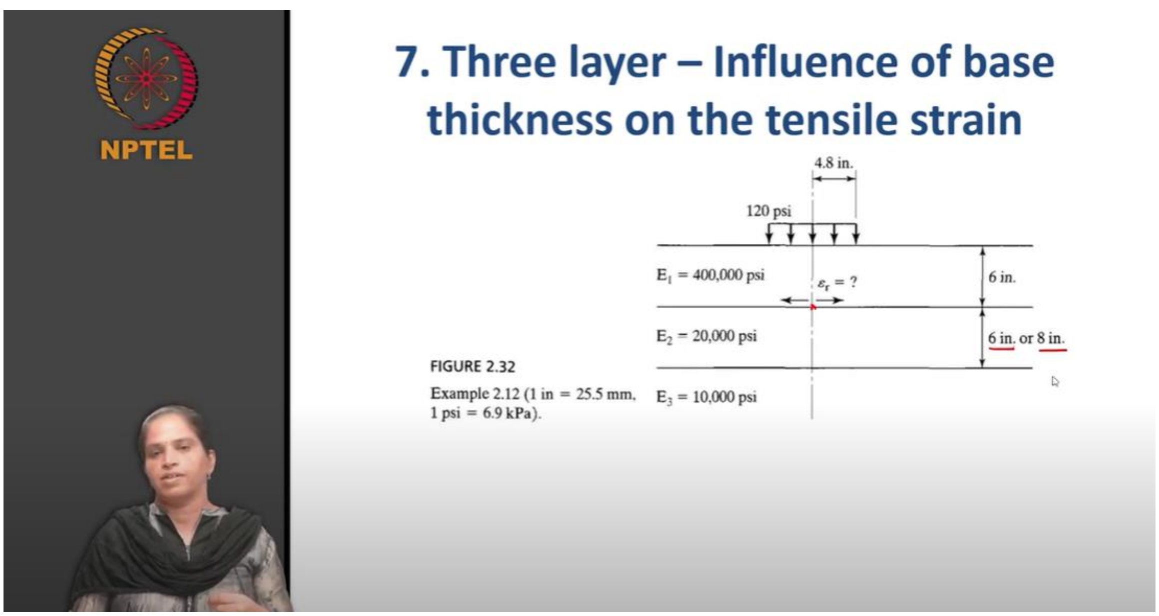

So, we have to solve one more KENLAYER analysis here with the base layer thickness of 8 inch. So, these are the input for that purpose. General information will remain same as our previous information. Modulus value same as our previous information. Load value is also same as our previous numerical here. The only variation is with the layer thickness. First layer is of 6-inch thickness, 15.2 cm, second layer is of 8-inch thickness which is 20.4 cm. The Poisson's ratio value is same as our previous numerical. Since thickness is varying, the interface distance from the surface will also vary that is, the z coordinates. So, first is at the interface of first layer and second layer which is 15.2 cm. Second is at the interface of second and third layer. So, it is 15.2+20.4 which is 35.6 cm.

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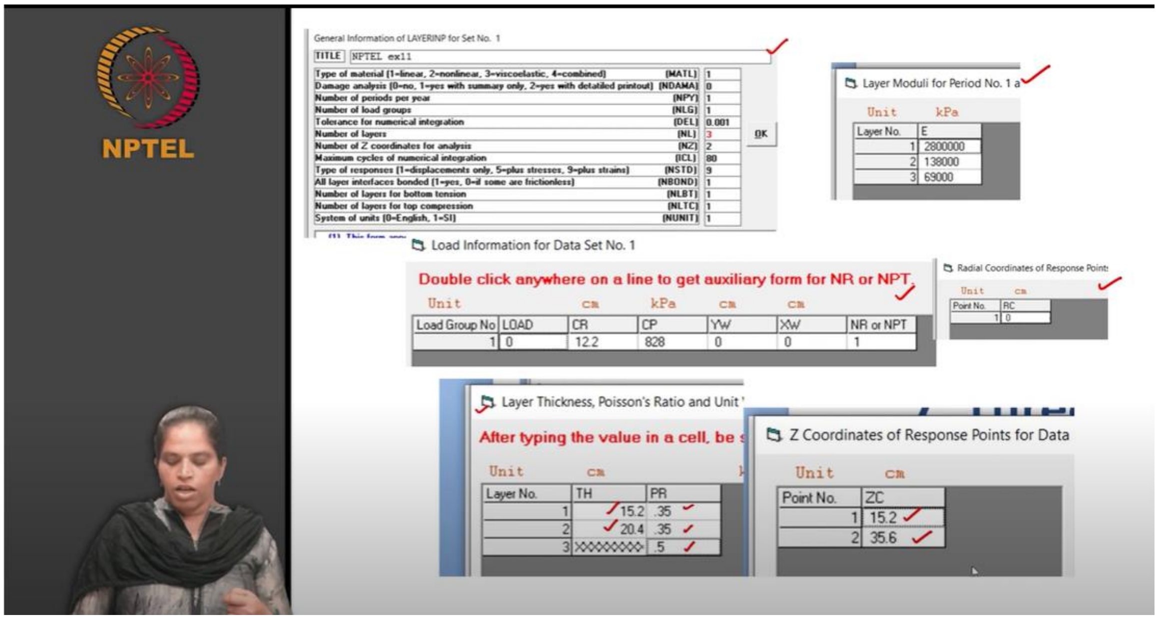

Now, we will give this as an input and compile the KENLAYER program and this is the result which you will get for 35.6 cm z-coordinate. So, we are interested in finding what is the tensile strain at the bottom of asphalt layer and when you compare the values with that of the previous numerical, the values are nearly the same. So, it says that increasing the thickness of the base layer do not much vary the tensile strain at the bottom of the asphalt layer. You can see the difference in the vertical strain and stress here at the top of a subgrade layer. So, in this case the vertical strain at the top of a subgrade layer is 5.466E-4. In the second case, it has reduced to a considerable extent. So, if you increase the thickness of the base course, you can reduce the vertical compressive strain at the top of the subgrade layer.

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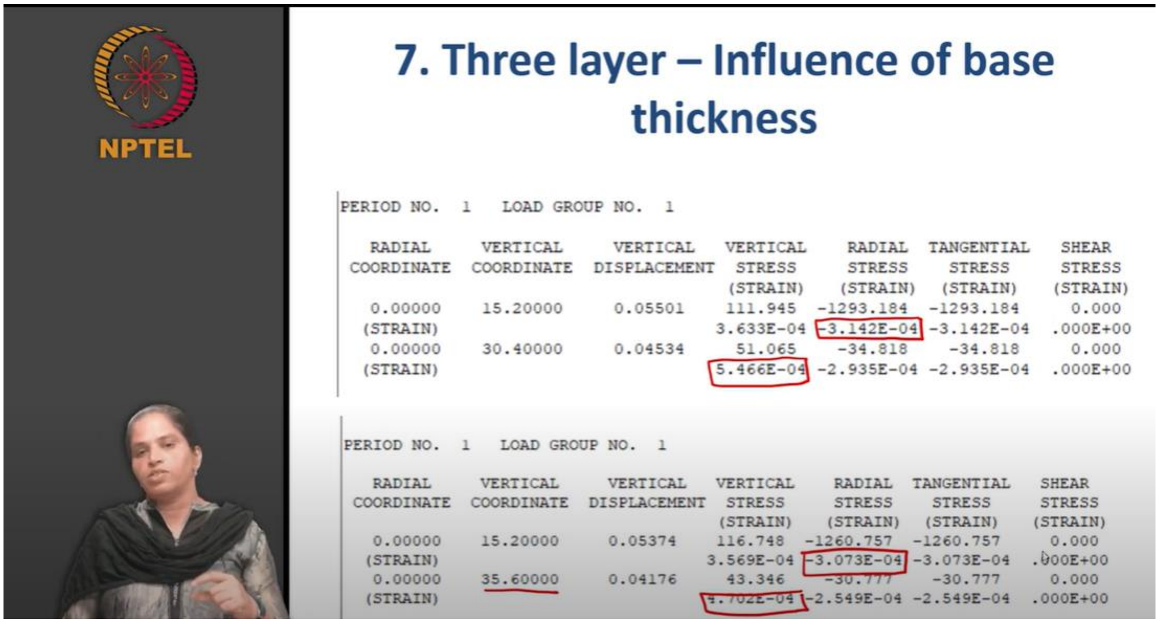

We have solved two-layered system and three-layered system using a KENLAYER software and understood how the thickness of different layers, modulus of different layers or different axle configuration influences stresses and strain at critical locations. We also know now that there are at least two critical locations in a bituminous layer. One is at the top of the subgrade layer where the vertical compressive strain induces rutting in the subgrade layer. The second one is at the bottom of the HMA layer where the tensile strain at the bottom of the HMA layer induces fatigue damage. So, these are the two critical locations for rutting and fatigue damage. We also understood that axle type or axle configurations, thickness of surface layer and base layer and modulus of three different layers influences these critical strains. Now, we will see how these critical stresses and strain vary when you vary these parameters.

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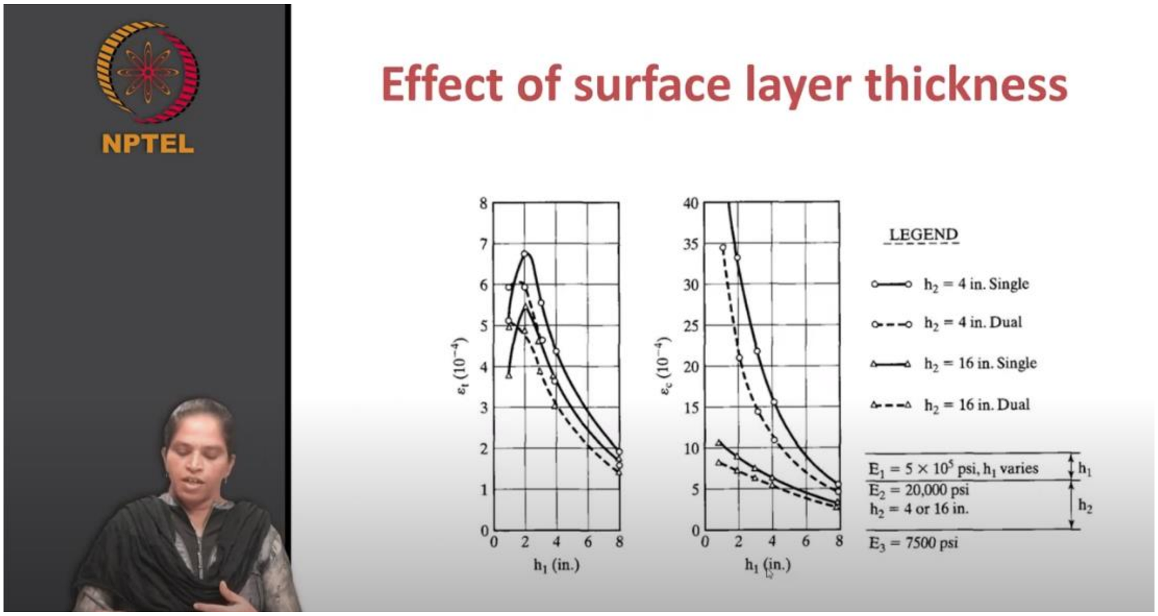

First, we will see the effect of surface layer thickness variations on the critical tensile strain and compressive strain. So, critical tensile strain at the bottom of this HMA layer is considered as ε_t. Critical compressive strain at the top of subgrade layer is considered as ε_c. So, we are going to see how these two stresses vary for different axle loads that is with a single wheel or with a dual wheel and we will also see for two different thickness of base course. One is with a 4-inch thickness and other is with a 16-inch thickness that is where you have a thin base and thick base. So, with the single axle dual wheel and with a thin base and thick base system if you vary the thickness of the surface layer how is this tensile strain and compressive strain going to vary with the thickness of the top surface. So that is what we are going to see now. So, you have a simulation this is for different cases with the modulus of E_1 to be this value, E_2, E_3 modulus values are given here and h_1. For different depth of h_1 you have a simulation, this is here. Let us focus on horizontal tensile strain at the bottom of the asphalt layer which is this case. We have four cases here. The first one corresponds to a pavement that has a thin base of 4 inch and we use the single axle single load configurations. The second one corresponds to a pavement with a thin base and dual wheel load. Third one corresponds to a pavement with a thick base of 16 inch thickness and single wheel. Fourth one corresponds to a thick base pavement with the dual wheel. Now comparing these four cases we will understand the influence of ε_t on the thickness of asphalt layer. So we can see that there is a critical value for only the single wheel load cases, that is 1 and 3. So when the asphalt layer is less than 2 inch, so when you increase the asphalt layer thickness from 0 to 2 inch you can see there is an increase in ε_t, but this case occurs only for a single wheel load and not for the dual wheel load. So when the thickness of asphalt layer is above 2 inch on increasing the thickness of the asphalt layer, you can see that there is a considerable decrease in ε_t. And you can also see that ε_t value is lesser for a dual wheel case compared to the single wheel case. So this is as far as ε_t is concerned. Now you can see the influence of vertical compressive strain at the top of the subgrade by varying the thickness of top surface. So, here again you have four cases 1, 2, 3 and 4 cases. Now, the first and second case here corresponds to thin base. So, you can see that increasing the thickness of asphalt layer is more effective in reducing the vertical compressive strain only if the base is thin. So, you have a drastic reduction in case of 1 and 2. If you have a thick base 3 and 4, you do not find that much of drastic reduction as in the cases of 1 and 2. So increasing the asphalt layer is more effective in decreasing the compressive strain at the top of a subgrade only if the base course is thin. If you provide a a thick base course, h_1 does not much influence. And here again you can see that ε_c is higher consistently for a single wheel load compared to a dual wheel load.

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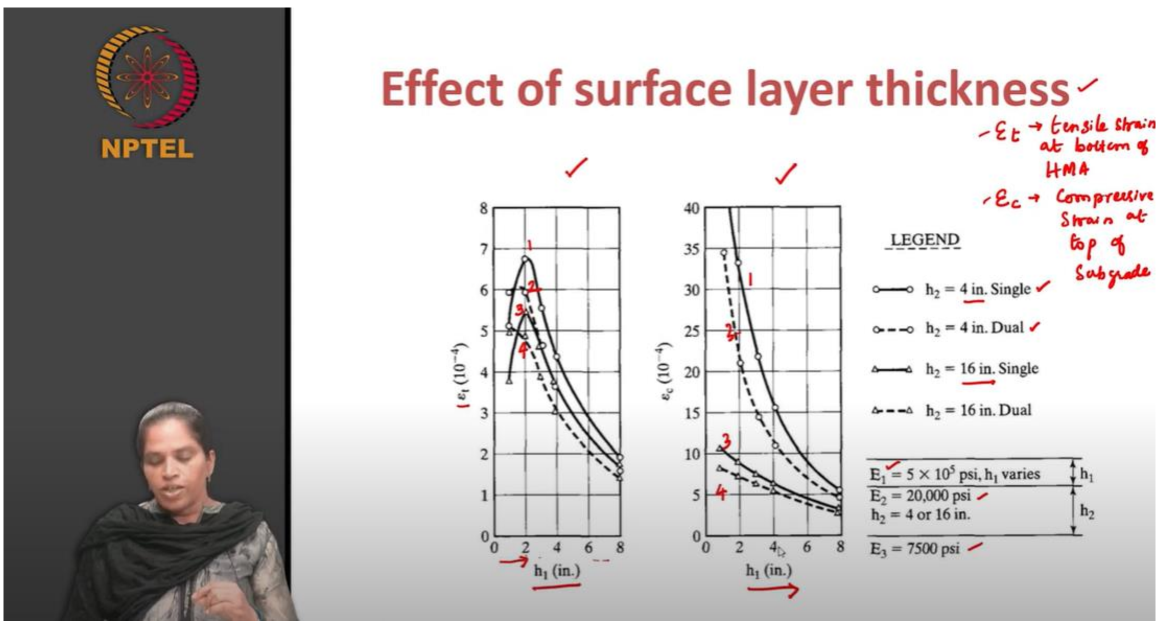

Now let us understand the effect of base layer thickness variation on ε_t and ε_c. So now let us focus on ε_t first. You can see that the influence of dual wheel is pronouncing. Dual wheel has lesser tensile strain compared to the single wheel cases. And h_2 increase, that is base layer thickness increase does not have much influence in ε_t. This you can see the graph to be flat across different h_2. So h_2, increase in base layer thickness do not much influence ε_t value. But this case, in case of ε_c, you can see that when you increase the thickness of base layer the vertical compressive strain drastically reduces for asphalt thickness of 2 inch. But 8 inch, you see a smaller reduction compared to 2 inch thickness. So increase in h_2 does not influence ε_t in much way but it influences ε_c, especially when you provide a thin surface when compared to thick surface.

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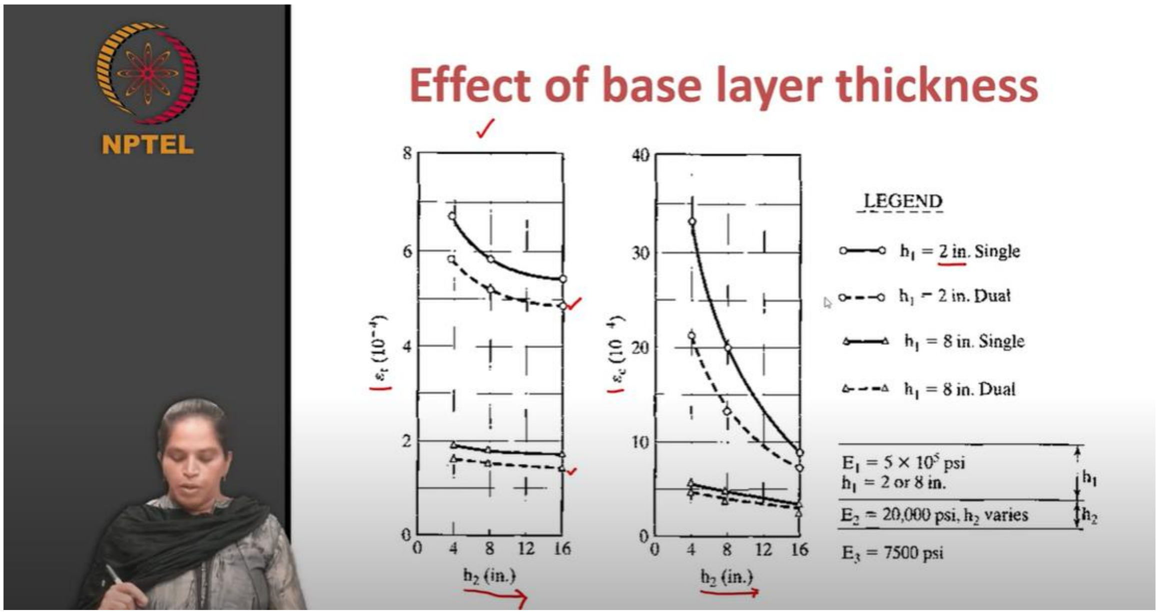

Now, we will see the effect of base layer modulus variations in ε_c and ε_t. So, this is the ε_t variation for different modulus variation of a base layer. So, this simulation was run for an E_1 value of 2×10^5psi and 10^6 psi, that is, asphalt layer having a small modulus and a larger modulus with single and dual wheel. So you have 4 cases here and thickness of the asphalt layer was kept as 4 inch and base layer thickness was kept as 8 inch for all the simulations. Now, if you see the cases here or increasing the base layer thickness, ε_t reduces only when the asphalt modulus is lesser, 2×10^5. When you provide an asphalt layer with high modulus value, you do not see much.

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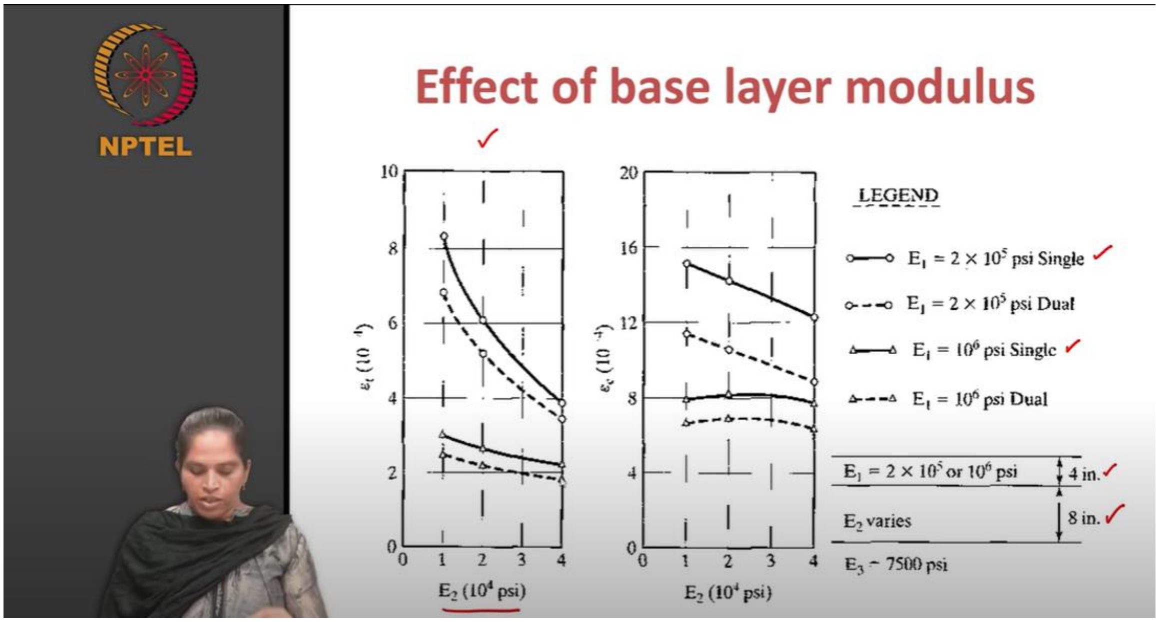

Now, let us focus on the influence of subgrade modulus on ε_t and ε_c value. The analysis is run for this structure here. The structure has an asphalt layer thickness of 4 inch, base course thickness of 8 inch. The modulus of base layer is 2×10^4 psi. The analysis was run for 2 different modulus of asphalt layer, one is 2×10^5 psi and the second one is 10^6 psi. Also, the analysis was run for 2 different loading conditions, one is with a single wheel and second one is with a dual wheel. So, with this structure the modulus of the subgrade layer is varied and ε_t and ε_c were determined for different cases. Now let us focus on ε_t values. So ε_t versus E_3 value is nearly a flatter curve for all 4 cases. This indicates that variation in the modulus of a subgrade value does not much influence the ε_t value. We see quite an opposite trend when we read ε_c value here. So, you can see that by increasing the E_3 value, ε_c decreases considerably and the curve is almost parallel for all cases which says that increase in subgrade modulus value decreases ε_c irrespective of whatever the base asphalt layer modulus is, whatever the axle configuration is. So, if you want to reduce vertical compressive strain at the top of a subgrade layer one way is to increase the subgrade modulus.

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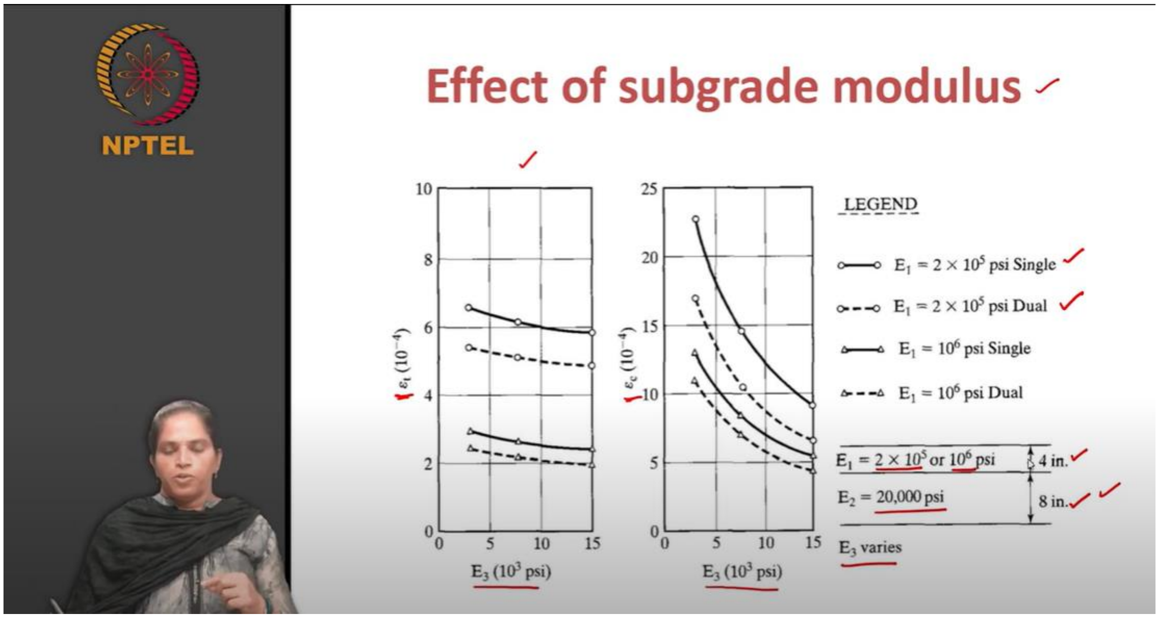

So, we have learnt 2 layer system and 3 layer system analysis and we saw what are the critical stresses and how the factors like axle configurations, thickness of a layer and modulus of a layer influences the critical stresses. Just to consolidate, in short we saw that ε_t which is the critical tensile strain at the bottom of the asphalt layer is much influenced by the surface layer thickness and surface layer modulus. So, base course thickness and modulus have lesser effect on ε_t. We also saw that vertical compressive strain on the top of the subgrade layer is much influenced by the base layer property and subgrade modulus. So, let us keep this in mind when we do a design. So, what next in the KENLAYER is we will do a damage analysis but we will come back and do a damage analysis once you learn the basic concept of damage analysis.