Analysis and Design of Bituminous Pavements

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Lecture - 40

Kenlayer - Damage anlysis

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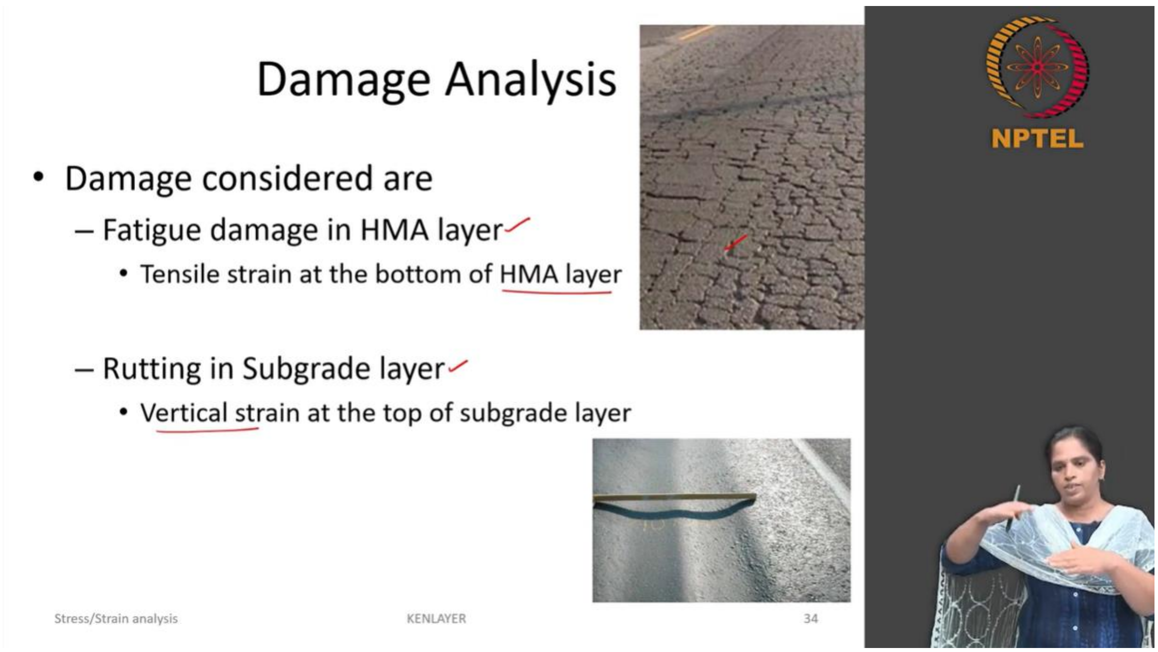

Welcome back, in this lecture, we will see how to do a damage analysis using KENLAYER software. We have already been introduced to a damage analysis here. Damage analysis is carried out for two different damages on the pavement, one is the fatigue damage that occurs in a HMA layer and we can say that the tensile strain at the bottom of an asphalt layer induces this fatigue damage and this is the result of a fatigue damage you can see on the top image. And this second damage analysis is rutting in a subgrade layer and we know that the vertical strain at the top of a subgrade layer induces this rutting. So, this depression is a consequence of a subgrade rutting. You can see the subsequent layer ruts and you will see something like a permanent deformation on the subgrade layer. So, if you want to analyze this damage or how this damage progresses with the number of repetitions, this damage analysis will be helpful for this.

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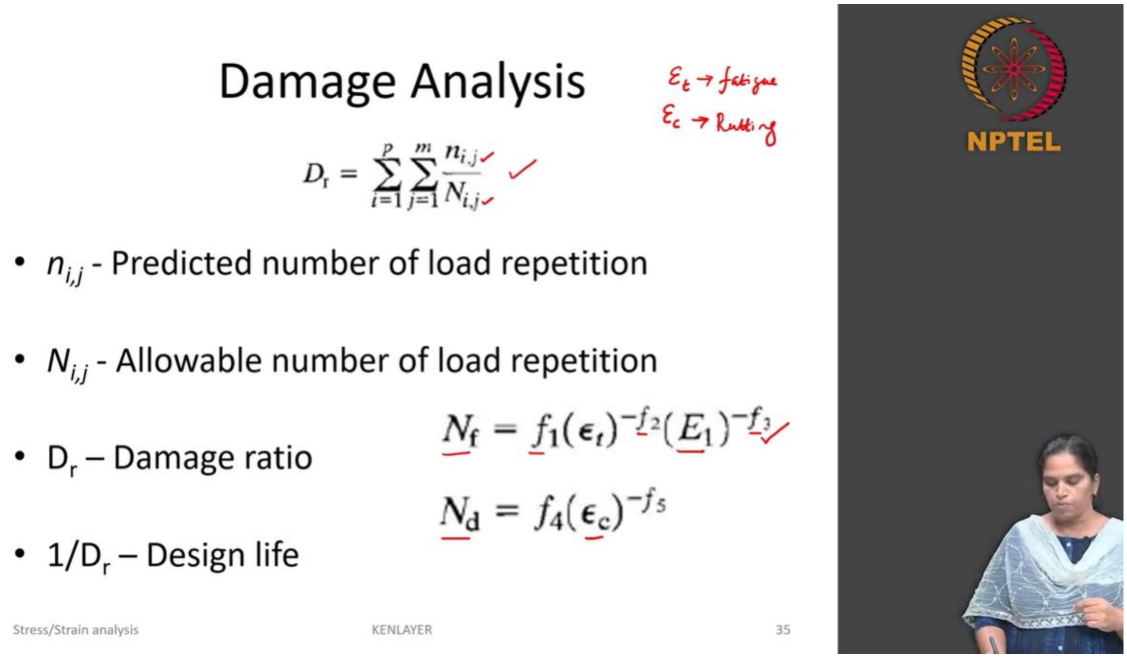

We are familiar with this equation where D_r is a damage ratio, which is nothing but the ratio of a predicted number of load repetitions by the allowable number of load repetitions. So, the predicted number of load repetitions can be grouped for different classes of load, that class can be differentiated based on axle type and load group and different periods. The period can be one month or year or any specific period in which we are interested.

$$D_r = \sum_{i=1}^{p} \sum_{j=1}^{m} \frac{n_{i,j}}{N_{i,j}}$$

So, now this $n_{i,j}$ is computed from the traffic data, and $N_{i,j}$ is computed from the structural capacity here. So, the damage ratio can be computed for any given period and this damage ratio can be used to check how these damages progress with different periods. So, now if let us focus on the denominator value $n_{i,j}$. So, how this $n_{i,j}$ is computed is, we need critical stresses and strain that cause the specific damage and we know that fatigue damage is caused by ε_t which is a tensile strain at the bottom of an asphalt layer, and ε_c with this vertical compressive strain at the top of a subgrade layer induces rutting in the subgrade layer. So, you have two damage analyses performed simultaneously, one is related to fatigue damage and the other is related to rutting. So, the fatigue damage of the HMA layer and rutting of the subgrade layer. So, the strains are related to the number of repetitions.

$$N_f = f_1 (\varepsilon_t)^{-f_2} (E_1)^{-f_3}$$
$$N_d = f_4 (\varepsilon_c)^{-f_5}$$

N_f is a function of ε_t and you have three different constants here f_1, f_2, f_3 and E_1 here is a modulus of a layer. You also know what are the values of f_1, f_2, f_3 for different standards. For example, the asphalt institute method has different values of f_1, f_2, f_3, and I have presented different values of f_1, f_2, f_3 and these values have already been introduced to you by Professor Neethu Roy. So, now N_d which is nothing but the number of repetitions of a standard axle corresponding to ε_c. So, this N_d corresponds to rutting damage.

For any given load value, you can compute ε_c and for any given period, you can compute these N_f and N_d values. Once you know this value, the damage ratio can be computed using these expressions. Knowing the damage ratio value, the inverse of the damage ratio gives you the design life of the pavement.

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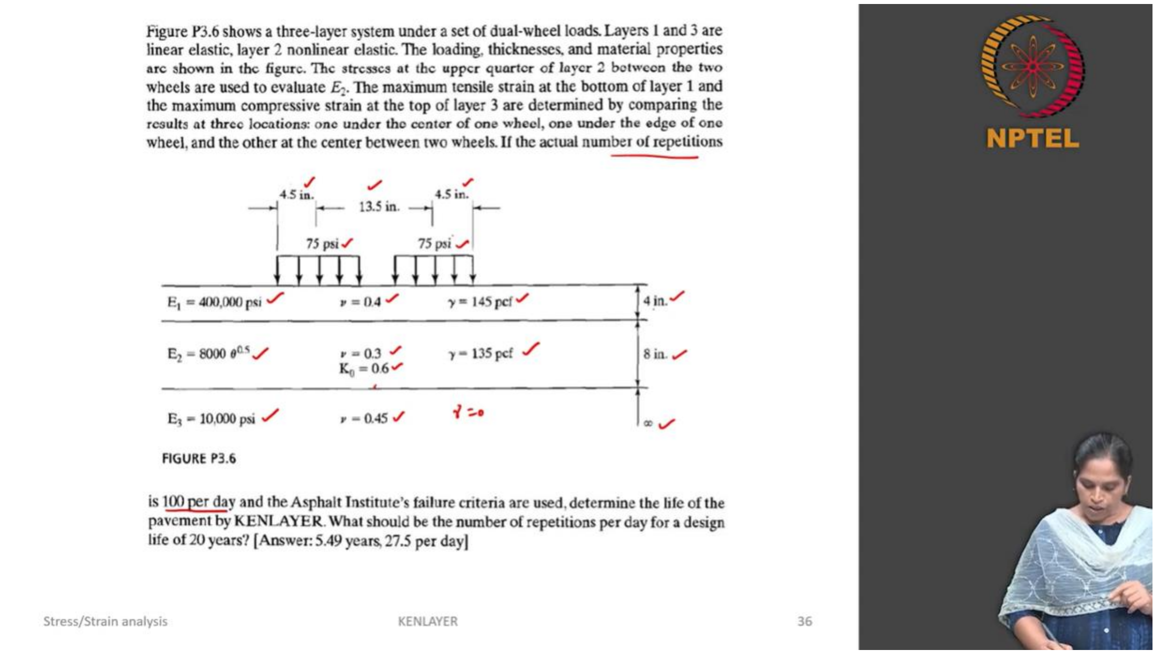

Let us solve this numerical now using kenlayer software. We have a three-layered structure. The layer consists of 4-inch asphalt layer thickness, 8-inch base thickness, and an infinite subgrade thickness. The modulus of the asphalt layer is considered an elastic modulus which is 400000 psi. The base layer is considered a stress-dependent modulus and it is given as k_1 which is 8000 θ^{k2} which is 0.5. The subgrade layer is considered as an elastic modulus which is constant and it is 10,000 psi. Now, Poisson's ratio values are given as 0.4, 0.3 and 0.45 respectively. You also have an earth pressure constant k_0 to be 0.6 for the base layer. So, this will be used in computing γ, self-weight of the material and further the modulus values. So, the γ values for two different layers is given as 145 and 135 psi for first and second layers. We do not need third layer gamma value, because we are not interested in finding any of the stress below this depth. So, self-weight is sufficient up to this point.

Now, you can consider the third value to be 0 when you solve it. So, this structure is subjected to a dual wheel load with a pressure intensity of 75 psi each, and the radius of this is given as 4.5 inches and the center-to-center spacing between the two wheels is given as 13.5 inches. If this is the case, now, the actual number of repetitions of this load applied is it is given as 100 per day.

So, these values are it is very minimal value, but we use this value for learning how to compute a damage ratio. If you really wanted to compute for existing conditions, you can find out what is the number of repetitions of this standard axle load and use the repetitions here and we will use the Asphalt Institute failure criteria for the computation of damage analysis. It means if you are using Asphalt Institute failure criteria, we have this equation. So, the values f_1, f_2, f_3, f_4, f_5 constants, we will consider it from the Asphalt Institute failure criteria here. Now, determine the life of the pavement by kenlayer and we will also find out what should be the number of repetitions of this load for a design life of 20 years.

So, we will first check the life of the pavement, we will check whether we are getting the life of the pavement to be 20 years. If not, if it is less than 20 years, the next question is what is the number of repetitions required for the design life of 20 years.

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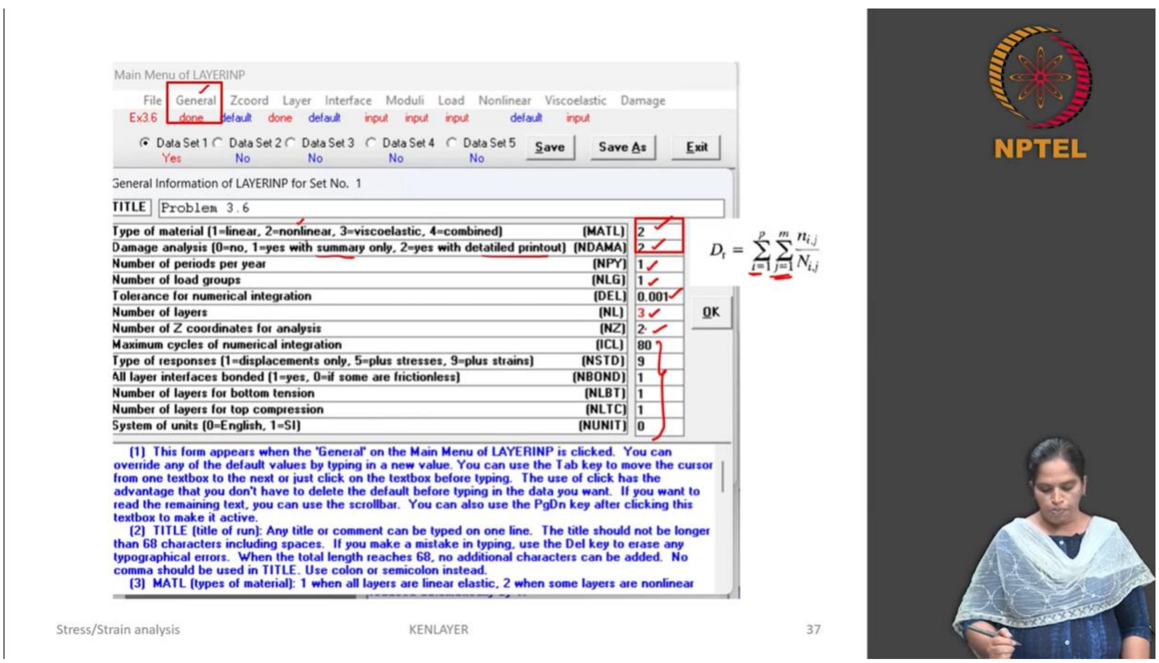

So, now, when you go to kenlayer, when you go to open a new file, you will get a general option. In the general option, you can see that type of material you have a nonlinear analysis. So, we give a nonlinear analysis because the base course is considered a pressure-dependent material modulus.

So, it is 2 here, the damage analysis we are going to perform. So, in previous cases, we get this to be 0. Now, we are not going to keep it as 0, you can either use 1 or 2 depending on whether this is what you need a summary or detailed results. So, I have kept here as a damage analysis 2 and the number of periods per year and number of load groups here is 1, but these numbers can be different here. So, this j value here represents the number of load groups and i value here represents the number of periods here.

If you have other than 1, so, this summation is to be considered here. The tolerance of numerical integration same as our previous default value and the number of layers is 3. The base course is considered as a single layer and the modulus is determined from the single-layer analysis. If you want you can keep this to be 4 and divide a base course into different 2 different layers and compute the modulus. So, I am preferring method 2 here.

So, I kept the number of layers to be 3. The number of z coordinates for the analysis. We need a critical stress and strain one at the interface of the asphalt layer and the base layer and the second at the interface of the base layer and subgrade layer. So, you have 2 here. So, the other numbers here are as same as the previous thing.

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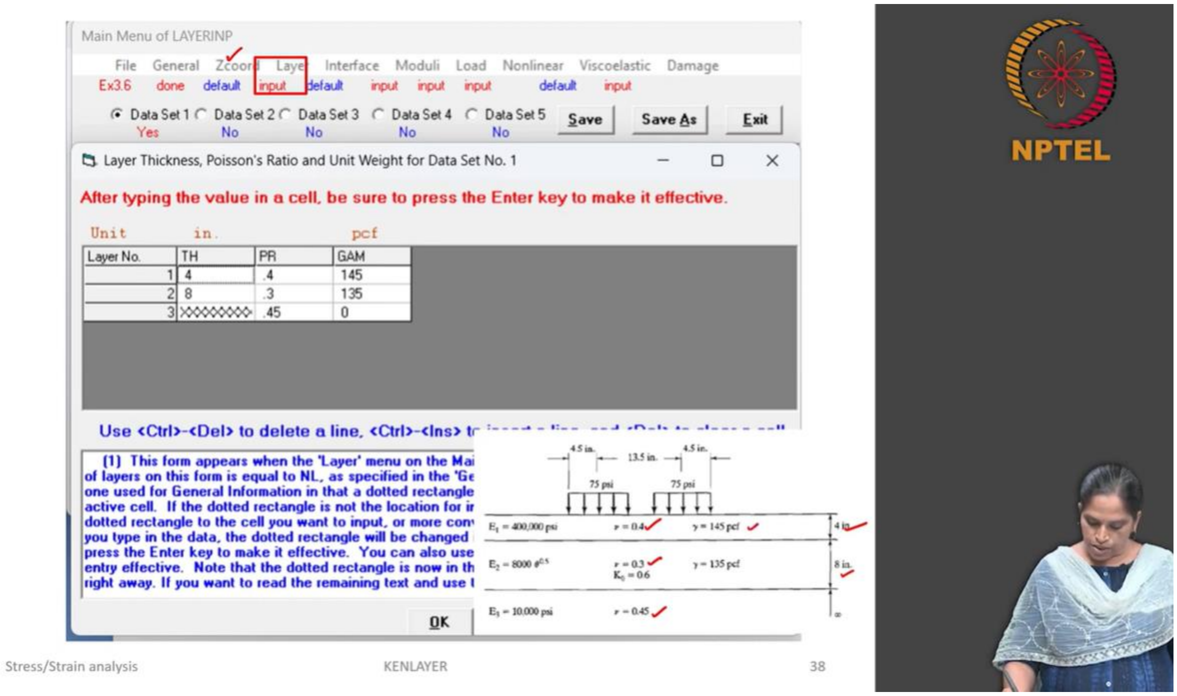

So, once you give this input, the next value is the z coordinate here. Since we are doing a damage analysis, the z coordinate will be selected by default and we do not need to give any number of z coordinates here. So, it is picked. The location at the bottom of an asphalt layer corresponds to fatigue damage analysis and at the top of a subgrade corresponds to rutting analysis and we cannot change the z coordinate here if you perform a damage analysis. Now coming to the layer input, you have the first layer of 4 inch thickness, the second layer of 8 inch thickness, and Poisson's ratio of the first layer is 0.4, the second layer is 0.3 and the third layer is 0.45, gamma value was 145 for the first layer, the second layer is 135 and third layer, I am just assuming it to be 0, that is weightless.

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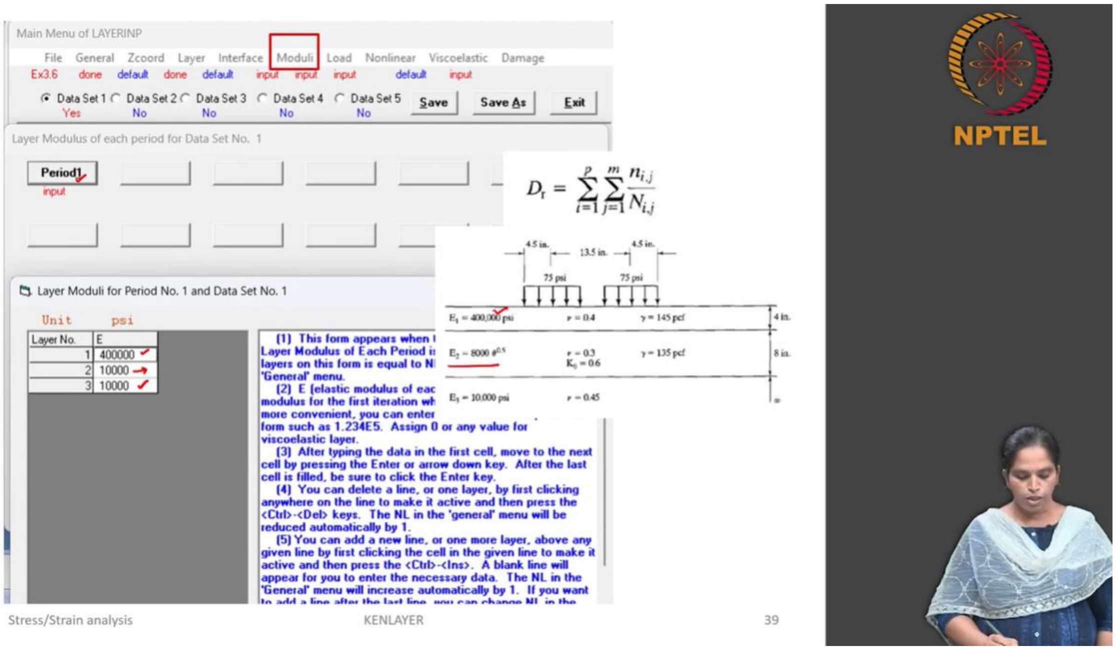

Now when you go to a moduli input, since we have given only 1 period, you will have a modulus for only 1 period, but you can define as many as 12 here for 1 year. So your i value here can be a maximum of 12. You see for 3 different layers, the first modulus is 400000 psi, the second modulus is a seed value which is assumed here because it is a stress-dependent modulus and the third value is also an elastic modulus of 10,000 psi. The same value is given here as an input.

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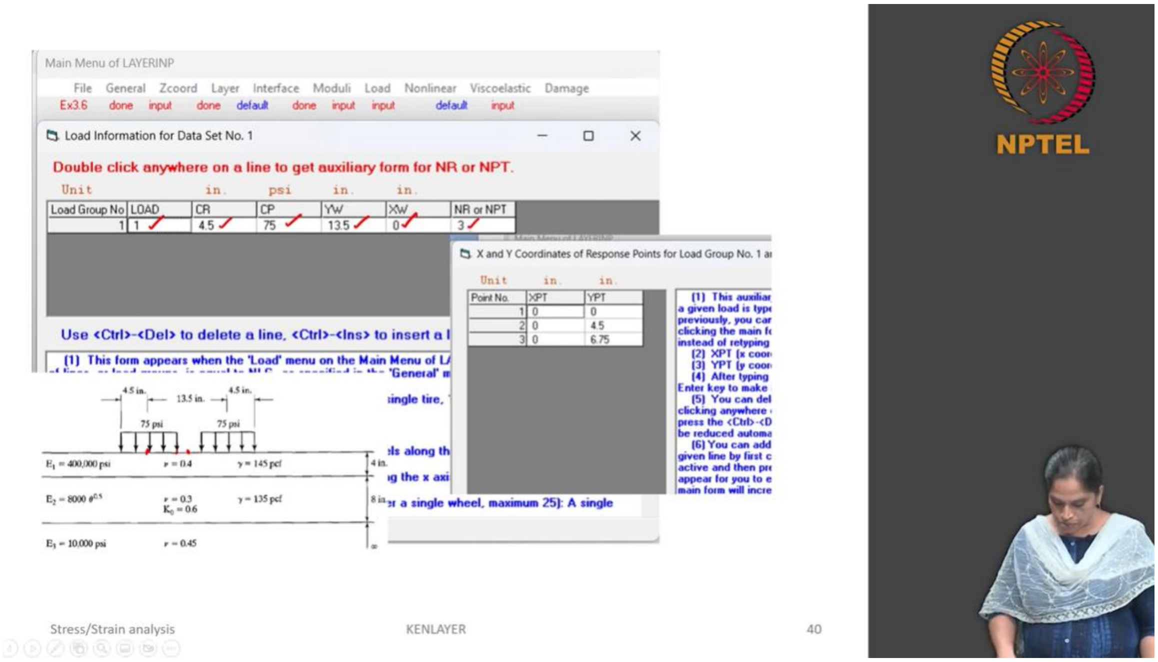

So, once the moduli is done, the next one is the load group. Similar to the modulus value, the load group can also be of many numbers of categories. Here we have only 1 load group, so it is a single axle dual wheel, it is defined as load category 1, the contact radius is 4.5 inches, the contact pressure is 75 psi, the center-to-center distance between the 2 wheels is 13.5 and it is only 1 axle, so xw is 0. So, now let us give a number of point radial contact points as 3 and when you double click on this 3, you have to define what exactly the 3 point is. I have used 0, 0 which is exactly at the center of 1 load as 0.1, 0.4.5 is at this point and 0, 6.5 is at the middle of the loading. So, we cannot define a z point but you can fix the radial point here and determine the point where the stress value is critical.

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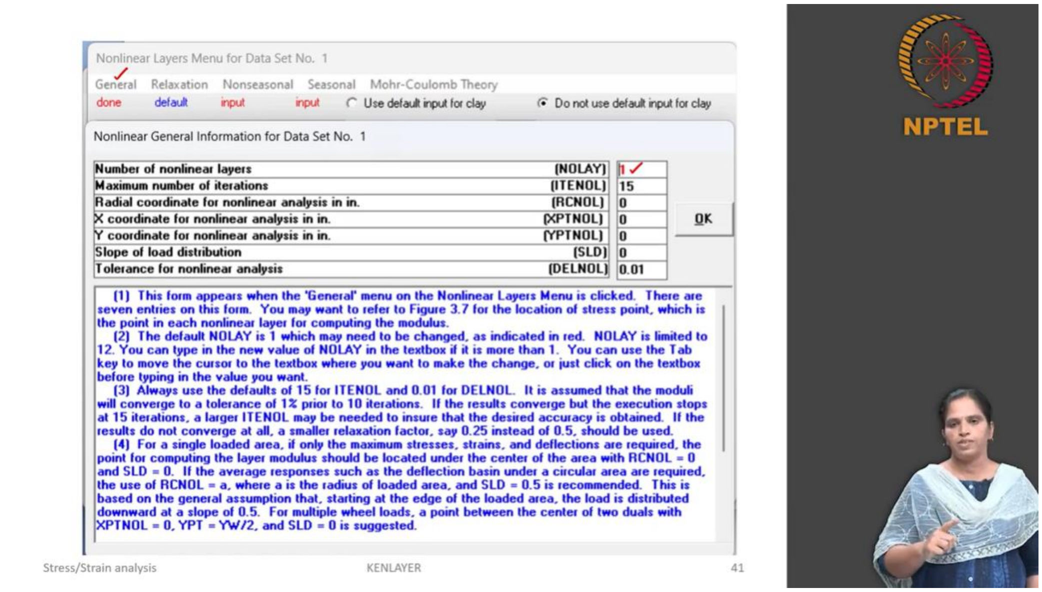

So, once the load input is given, the next input is the non-linear analysis input. So, in the non-linear analysis input for general, so the number of layers for a non-linear analysis is 1, keep in mind the non-linear analysis in the kenlayer represents the stress-dependent modulus value analysis. The number of iterations and other things as explained in the previous case, I just kept it as a default value.

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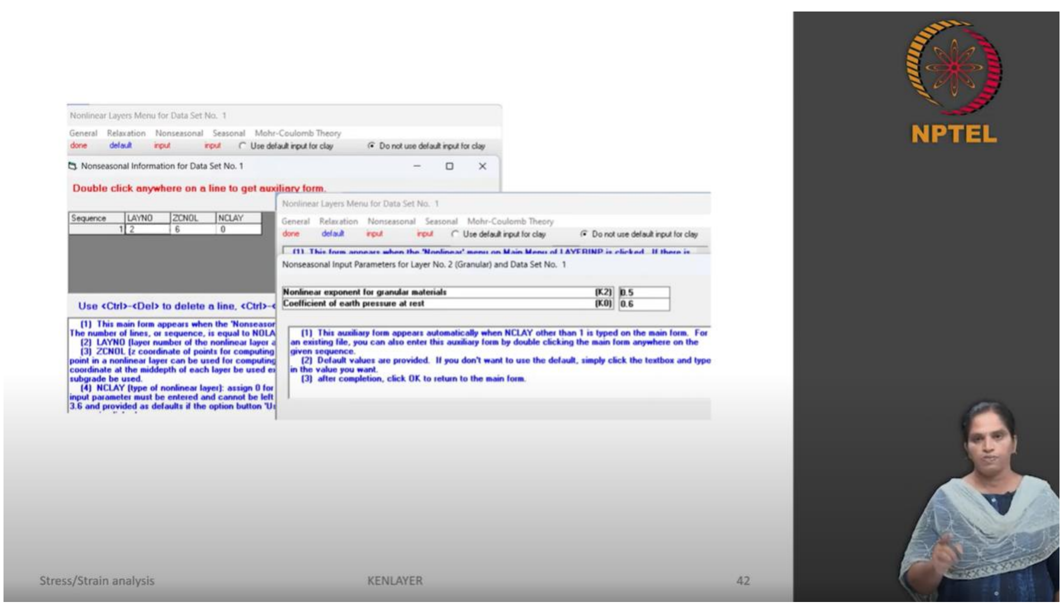

Now the next input is a non-seasonal input which defines whether the layer is a granular layer or a soil layer. So, the second layer is considered as a non-linear layer and the depth exactly what we wanted to do the non-linear analysis is the upper quarter point of the base layer, so 4 plus 2 with the 6 inch thickness from 6 inch depth. This is a granular layer, so you give NCLAY to be 0 and for this granular layer the default value of a K2 value is 0.5 and the coefficient of earth pressure is 0.6 which is given in the question itself.

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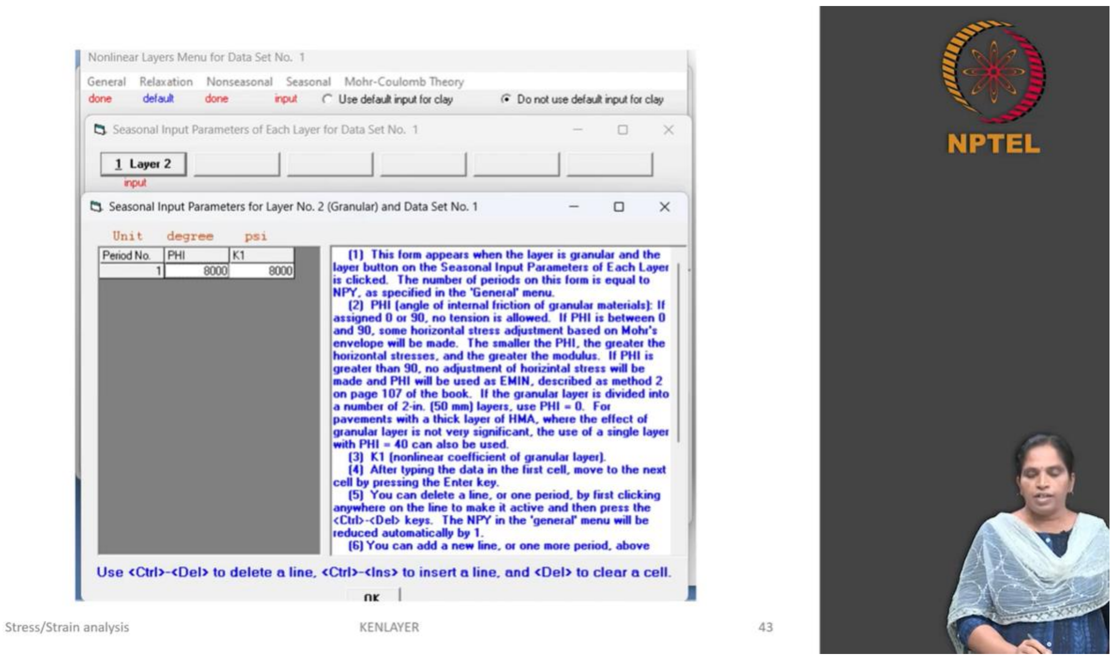

Now, the next input is a seasonal input. We are going to give the value of K1 to be a seasonal. So, it varies with the number of periods which we define. Here we have defined only one number of period. So, for a seasonal input you give the value of K1, K1 here I have used as per the question this is 8000 psi. So, we restrict the K1 minimum value here, so PHI is taken as 8000 psi here. Once the non-linear input is given, the next input is a damage input. When you click on this damage input, you will have 3 options bottom tension, top compression, and volume of traffic.

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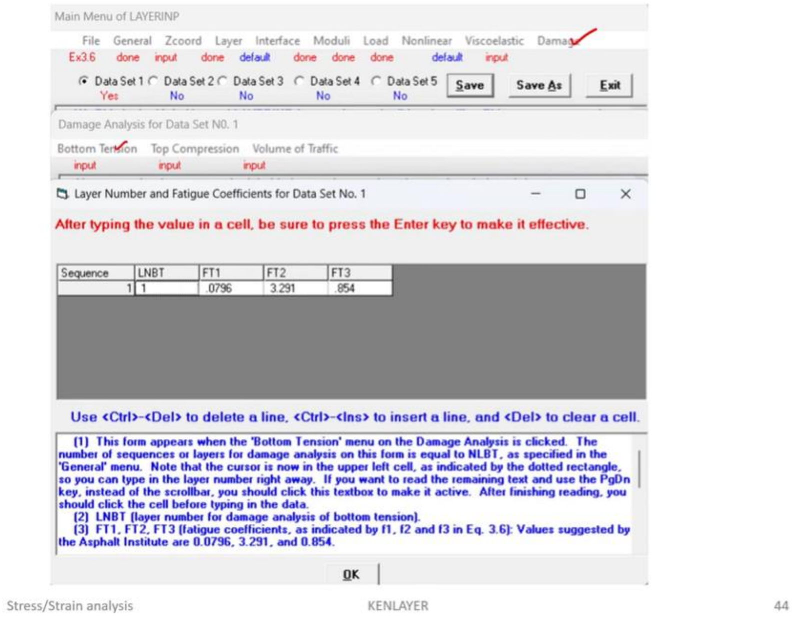

So, in a bottom tension, so you have the number of layers you need to do analysis. So, this is the first layer, layer 1 and FT1, FT2 and FT3 constants. So, these are the default constants as per the Asphalt Institute method. If you have any other constant other than this, you can edit these numbers. So, these numbers are used for computing a damage ratio based on fatigue damage analysis.

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And the second one is a top compression which is at the top of a subgrade. So, it is a third layer and third layer, so you have FT4 and FT5 constant. These constants are based on the Asphalt Institute method, you can edit these constants values if needed.

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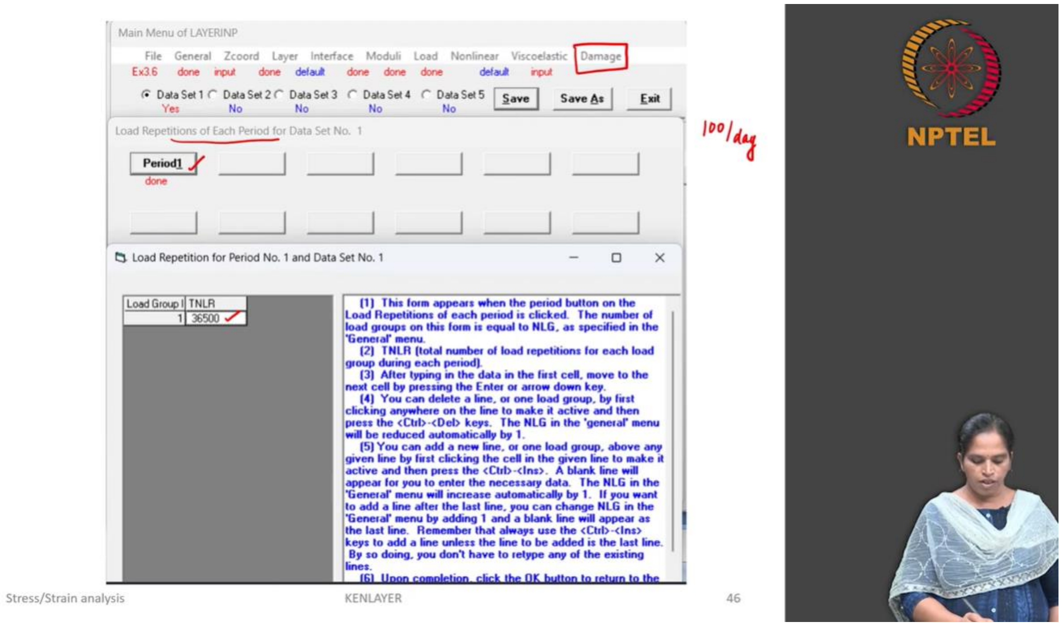

The next input is for the damage analysis. So, when you click on this damage analysis, you will get these load repetitions for each period. So, we have defined only one period here. For a duration of 1 year, now you compute what is the number of repetitions of that specific load group. In the question, it is given that 100 axle repetitions per day. So, if you multiply by 365, you will get 36500 per year. So, this is going to be a number of repetitions of this particular load group in 1 year.

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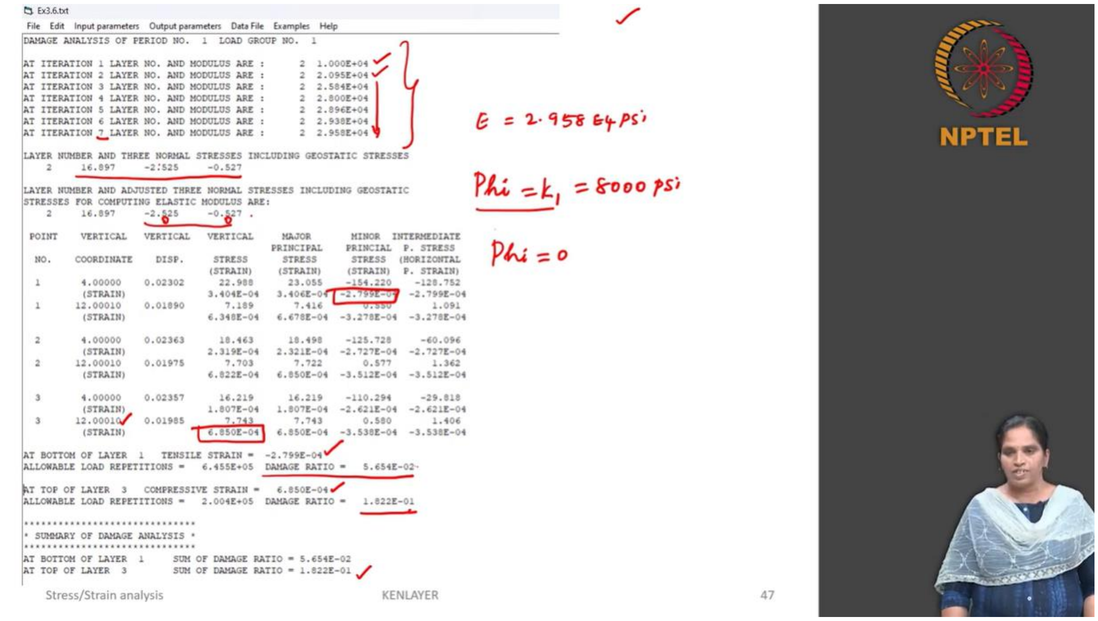

This is the result after compilations. You can see the first result to be the computation of a base layer modulus. So, the initial modulus which we assumed is 10^4 psi. From the initial modulus we compute the stress value, from the calculated stress, we recomputed the modulus value and this process was iterated 7 times so that the results converge and the final modulus of the base layer is 2.958 E4 psi value. So, this modulus was obtained for the 3 normal stresses as indicated here. You can see that out of 3 normal stresses, 2 normal stresses have a negative value. So, the catch here is, in a previous analysis, this normal stress was adjusted to 0, but here it is taken as the same negative value without any adjustment.

This is because we have used a PHI value to be equal to K1 which is equal to 8000 psi. We have defined a minimum value here. There is no adjustment of normal stress to 0, or negative normal stress to 0. In case we used a PHI value to be 0, we have not defined any minimum value here. This stress value has been adjusted to 0 and the modulus computed will be based on this adjusted stress. So, for the computed modulus the critical stresses and strains are determined. So, the strain that induces fatigue damage is -2.799E-4.

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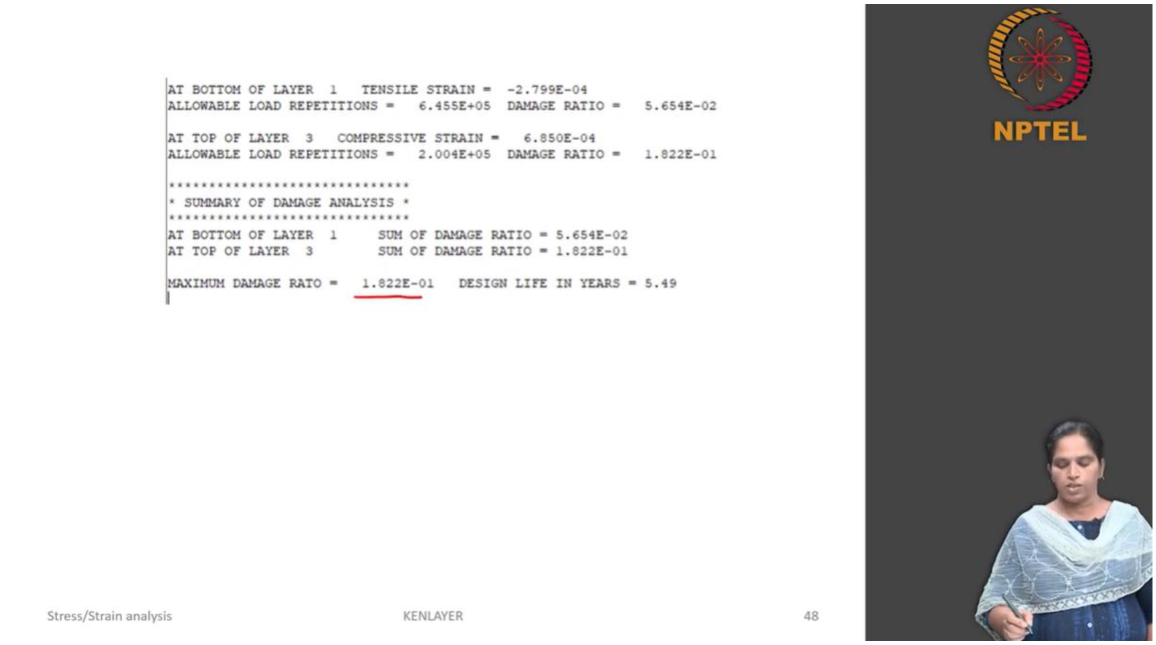

So, it is the tensile strain and from this tensile strain the damage ratio will be computed and the computed damage ratio was found to be 5.654 E-2. And the critical stresses that induce rutting in the asphalt layer are 6.850E-4, which is at a depth of 12.0001 inches and this induces the damage ratio of 1.822 E-1. Now you have two damage ratios, one is for fatigue damage and the other is for rutting. Now whichever is a maximum is considered to be the critical damage ratio. So, the damage ratio corresponding to rutting here is considered as a critical value.

Now if you want to find the design life of the pavement, the design life of the pavement is based on the critical damage ratio, which is rutting in this case. You see that the design life computed from the damage ratio of 1.822E-1 comes out to be 5.49. So, we see that design life is less than 20 years. If you want to bring this design life to 20 years, we need to reduce the number of repetitions to the traffic load.

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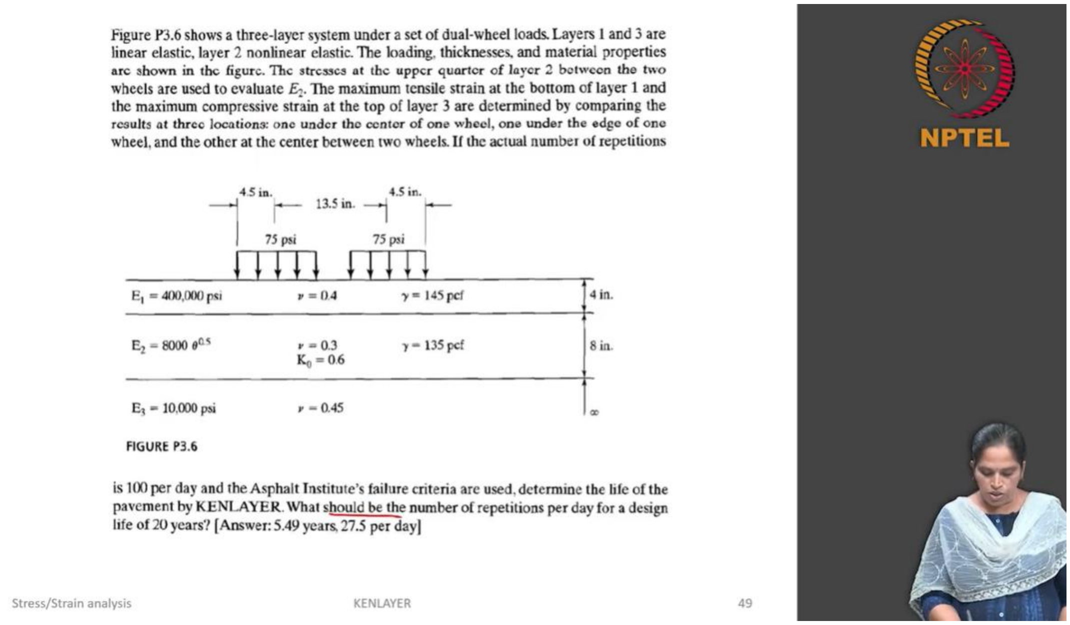

So, now what should be the number of repetitions so as to bring the design life to 20 years? We have to do it only by trial.

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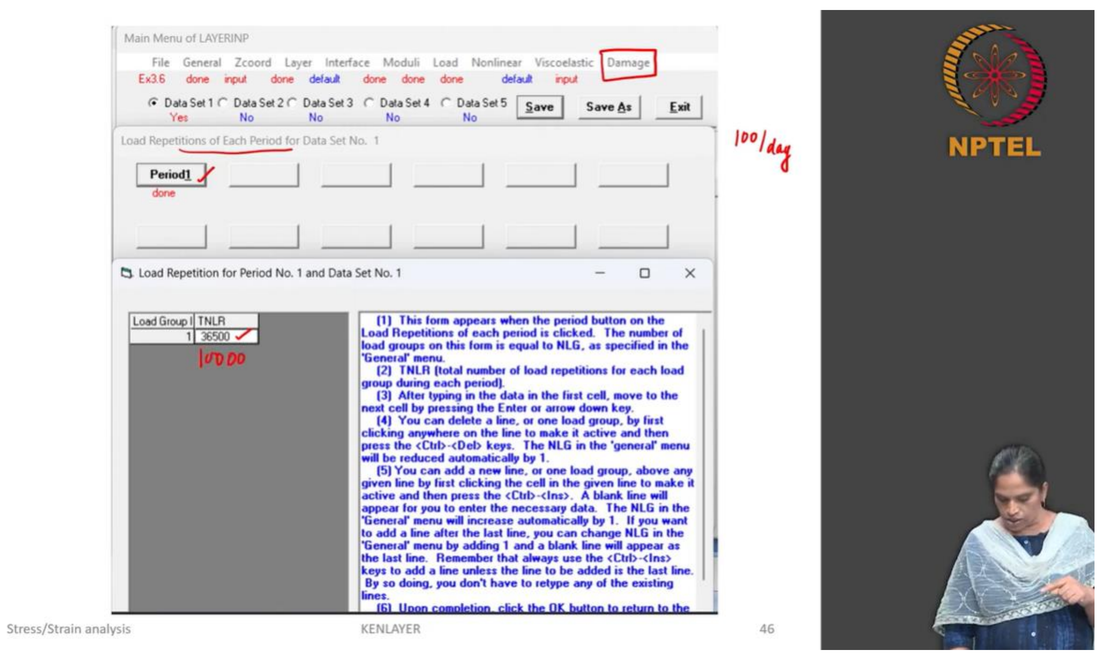

So, now what should be the number of repetitions so as to bring the design life to 20 years? We have to do it only by trials.

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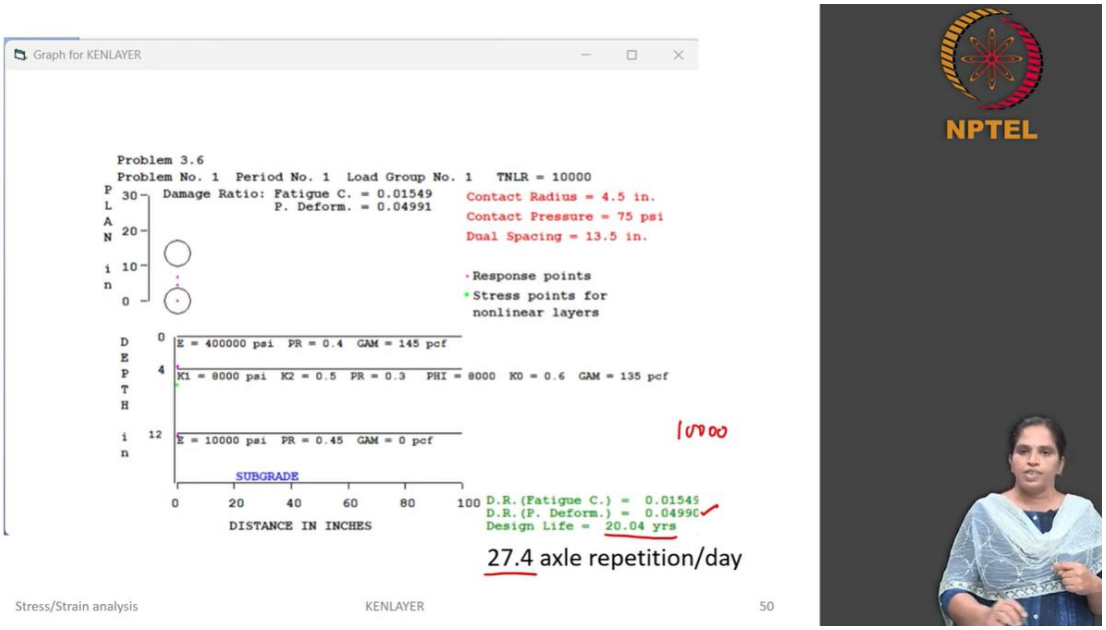

So, all other input parameters remain the same. I just changed the number of repetitions of traffic load per year to 10,000. We need to decide this number only by trials, for the initial trial I kept it to 10,000. When you keep it to 10,000, the damage ratio value computed was found to be 0.01549. So, you see that the second value is critical here from this computed damage ratio, when you compute the design life, the design life was computed to be 20.04 years. So, for bringing the design life to 20.05 years per year, traffic will be 10,000 vehicles. So, per day it will be 10,000 divided by 365, this comes out to be 27.4 axle repetitions. So, to extend your design life to 20 years, the number of repetitions allowed is only 27.4 axles. Notice that this is not the number of vehicles, this is the number of axles here. You will also get a design output in terms of graphical representations in Kenpave.

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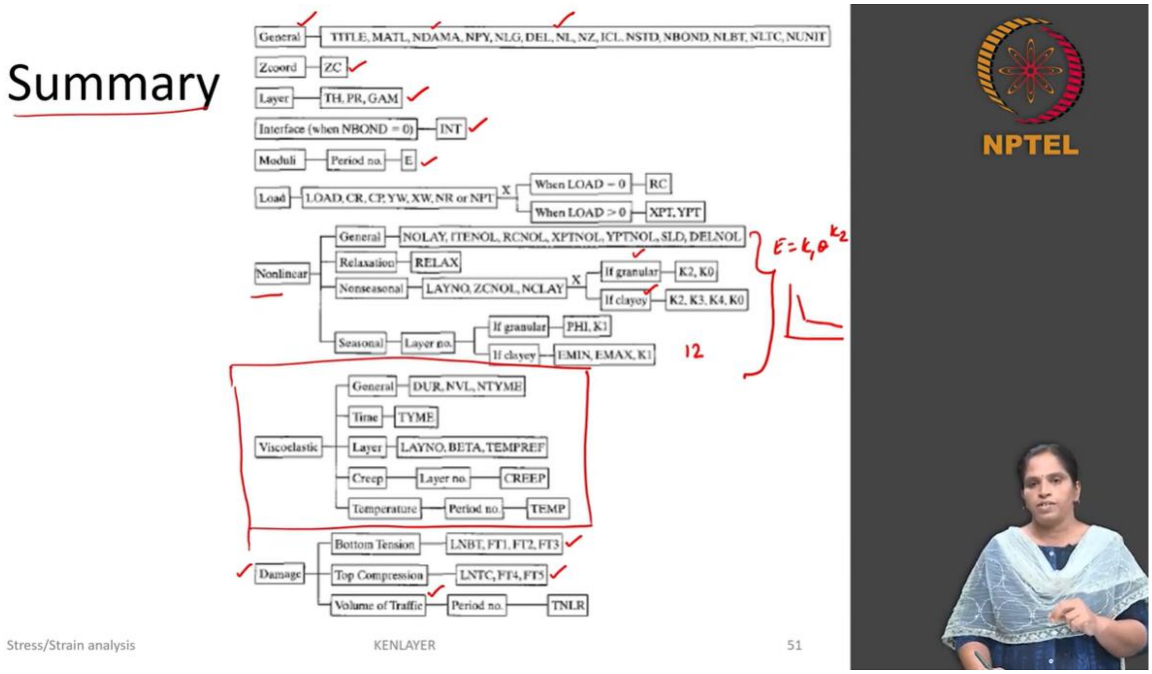

So, this is a graphical representation output. Let us summarize Kenlayer analysis altogether. We gave input in different categories. The first category is a general input, where we define the title, material characteristics, analysis whether we do an elastic analysis, linear analysis, nonlinear analysis, or whether we do a damage analysis or not is defined. In the general tab, number of periods, number of load groups, number of repetitions, and tolerance for integrations are defined as the general input. So, we also give z coordinate, this z indicates the locations where we need stresses and strains. It defines the depth. We define layer thickness, poisson's ratio and gamma value for determining stresses and strain. And we assume layer interface to be a default value and we used a modulus value, this modulus value if it is elastic modulus, we keep it as constant. If it is assumed as nonlinear, the modulus value is going to depend on the stress. For determination of the modulus value at a particular depth, we define whether it is a granular layer or a clay layer. If it is a granular layer, we give the modulus as follows.

$$E = k_1 \theta^{k_2}$$

If it is a clay layer, we assume two slope functions and from the two slope function, we determine the modulus value. You can also consider the seasonal variations in all these analysis by defining number of periods. You can define a maximum 12 number of periods for computation of stresses and strains. And we did not do any viscoelastic analysis and this viscoelastic analysis corresponds to the analysis of HMA layer and this is out of scope here. And we also performed a damage analysis and we computed a design life of a pavement based on the damage analysis. For doing a damage analysis, we considered two damages, one is fatigue damage of a HMA layer and the second one is rutting at the subgrade layer. And for performing a damage analysis, you need to define constants here f_1, f_2, f_3 for fatigue damage analysis.

And these constants are editable, you can either use IRC constants or Asphalt Institute or any other constant obtained from the laboratory test. You need f_4 and f_5 constants for rutting analysis damage analysis. In addition to this, to compute the number of repetitions of a traffic load, you also need the volume of traffic. From these parameters, you compute the damage ratio value and the inverse of damage ratio value will give you the design life. This is what we have seen in the Kenlayer analysis. Thank you so much for your patience and we will get back to you with the IRC design. Thank you so much.