Analysis and Design of Bituminous Pavements

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Lecture – 43

Pavement design with Granular Base

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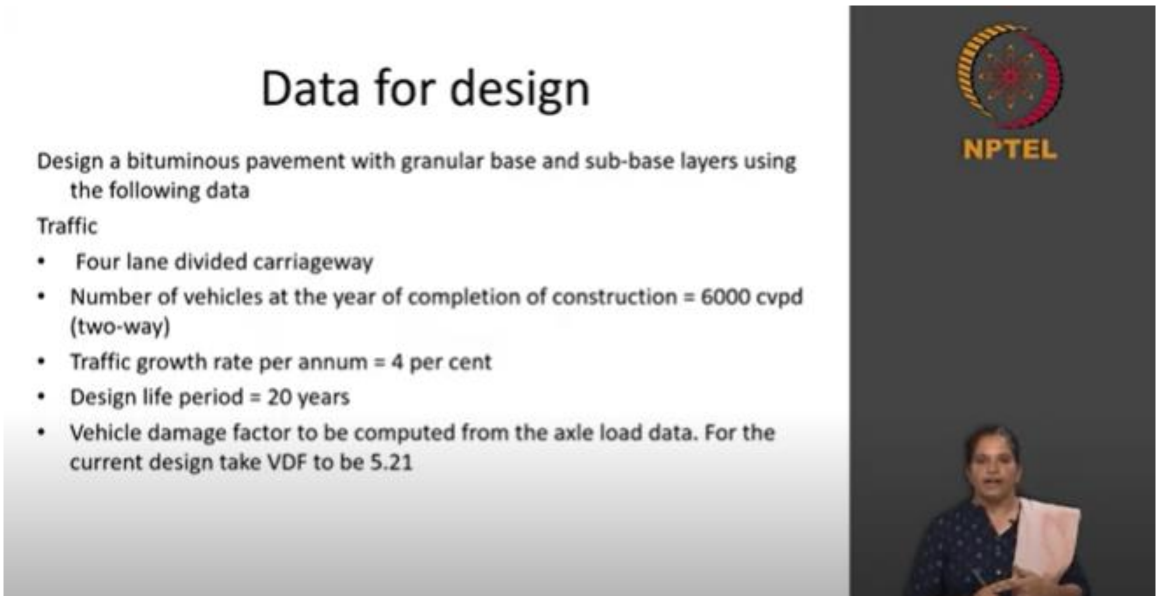

So, now we know how to compute the stresses and strain using an IITPAVE software. If you do not have an access to an IITPAVE software, you can very well use a KENLAYER software and compute the stresses and strain and use in this design approach. So, now we will see design of bituminous pavement with granular base course. So, these are the data for the design available. Now with this data, we will design a bituminous pavement with granular base and subbase layer. So, design a bituminous pavement with granular base and subbase layer for a traffic data of which has a 4-lane divided carriageway, number of vehicles at the year of completion of construction is 6000 commercial vehicles per day. So, this is including a 2-way traffic. So, it is a divided traffic. So, one-way traffic will be 3000 commercial vehicles per day. Traffic growth rate per annum is considered to be 4% and for the design period of 20 years and we also need a vehicle damage factor here.

So, you know how to compute a vehicle damage factor from the axial load data. Prof Neethu has already explained in detail about this. So, I will take the same value that was computed by Neethu here as a VDF value which is 5.21 for the computation of number of repetitions of standard axial load. But keep in mind that this vehicle damage factor has to come from the axial load data. So, that is related to traffic.

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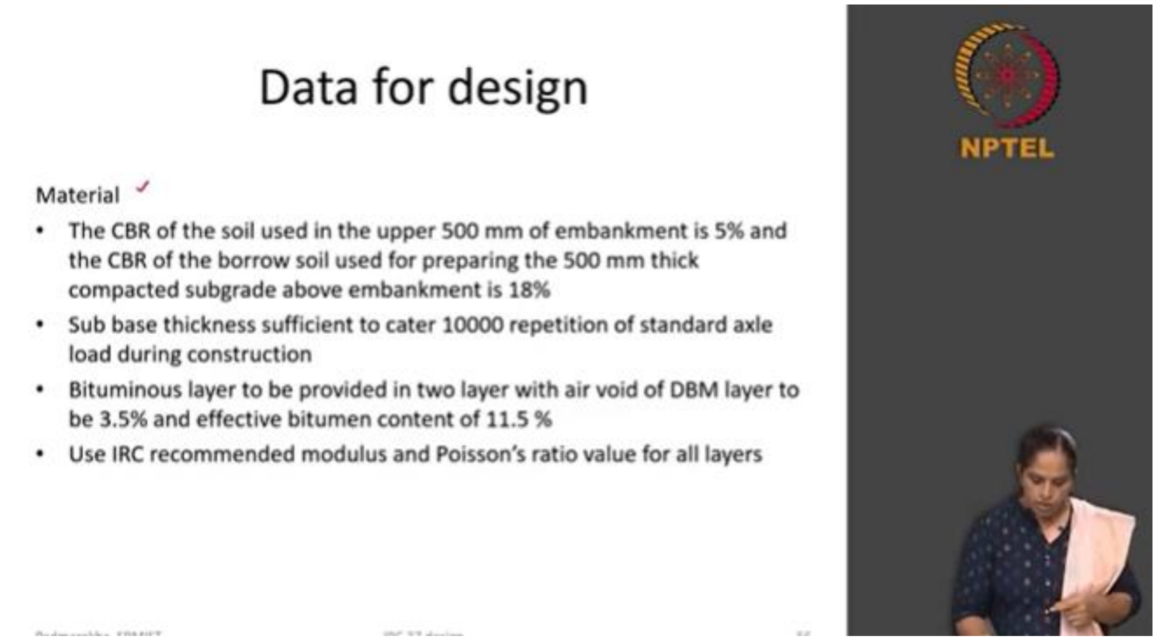

Now what are the material inputs we need? So, we have a CBR of a soil used in the upper 500 mm of embankment is 5% and CBR of a borrow soil used for the preparation of 500 mm thick compacted subgrade above the embankment is 18%. That is, you have a subgrade in 2 structures. One is you have an embankment and the embankment this CBR value is 5% and the compacted subgrade has a CBR value of 18%. And subbase thickness should be sufficient enough to cater 10,000 repetitions of standard axial load during constructions. So, and we have a bituminous layer to be provided in a top 2 layer and it has an air void of 3.5% and effective bitumen content of 11.5% by volume. So, we use IRC recommendations for modulus and Poisson's ratio value and we will design a pavement here.

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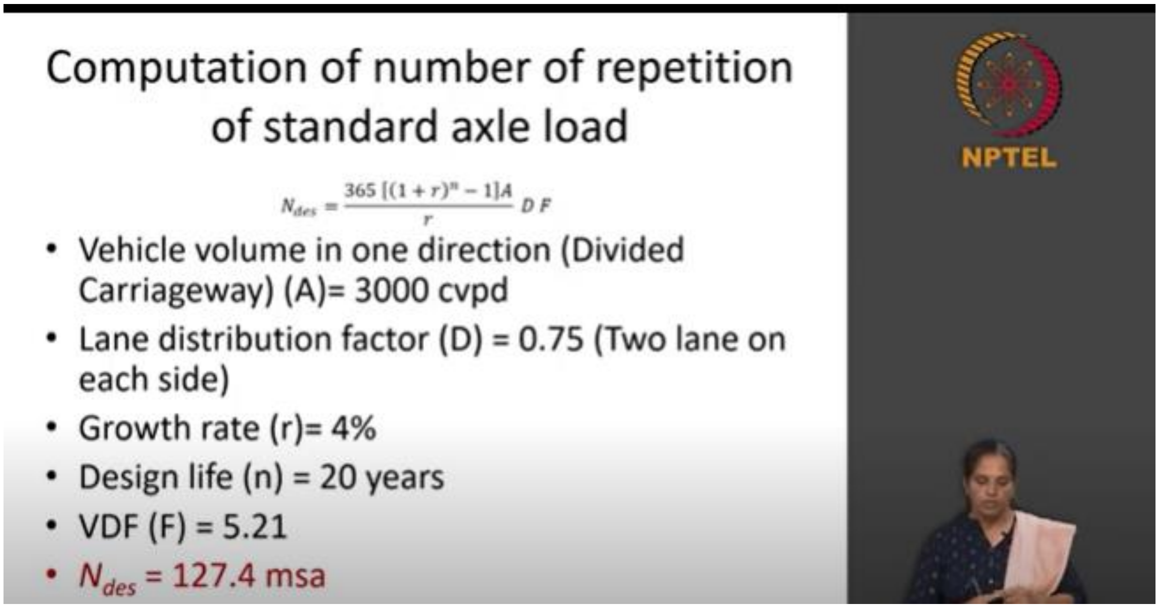

So, first we will compute number of repetitions of a standard axial load. So, we know this N_{des} equation here.

$$N_{des} = \frac{365[(1+r)^n - 1]A}{r} DF$$

So, here A value is 6000/2 which is nothing but 3000 commercial vehicles per day and lane distribution factor for 2 lanes that is 4 lane divided highway 2 lane on each sides. So, it will be 0.75. Growth rate R is given as 4%. Design life of 20 years for a VDF of 5.21 when you substitute all the numbers here you will get N_{des} to be 127.4×10^6 or 127.4 msa. So, whatever pavement thickness you provide should cater to 127.4 msa for 20 years of pavement life.

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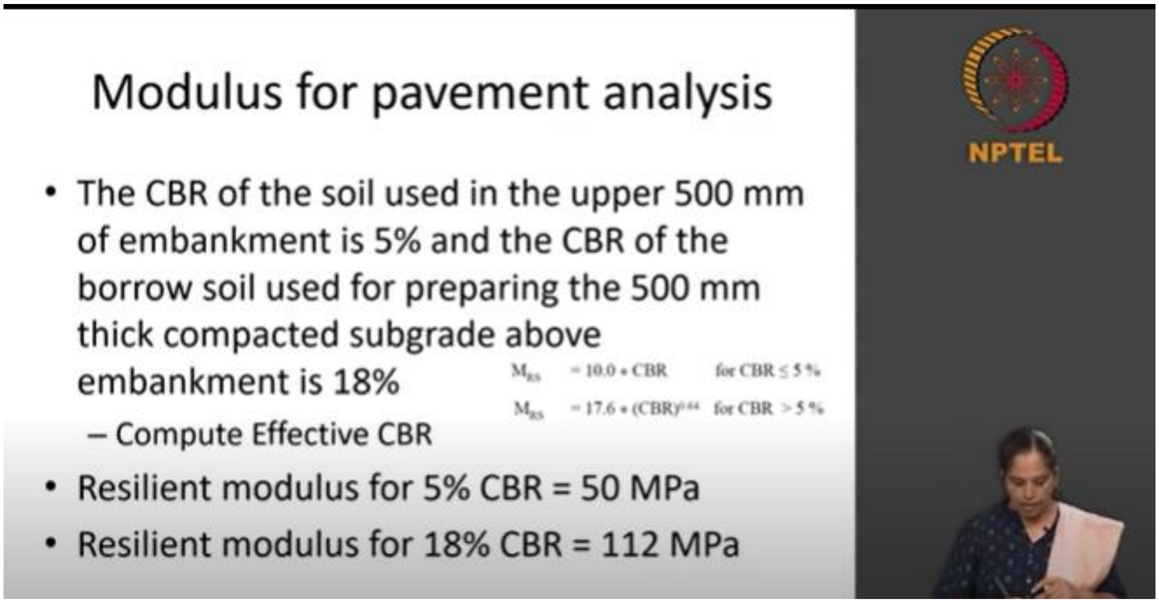

So, now we will see one by one modulus value that we need to consider for the design here. So, we have a subgrade layer to be considered as a 2 layers. So, bottom layer will have a CBR of 5% and the top compacted layer will have a CBR of 18%. Now, in such case what will be the effective modulus to be used in the design here? So, first we will compute the effective modulus here. We will convert the CBR directly to a resilient modulus value using an empirical equation suggested by IRC 37 here.

$$M_{RS} = 10 \times CBR \qquad \text{(for CBR} \leq 5\%)$$

$$M_{RS} = 17.6 \times (CBR)^{0.64} \qquad \text{(for CBR} \geq 5\%)$$

So, if the CBR value is equal to or less than 5 it is just direct multiplication of 10. So, 10 × 5 here gives 50 MPa. So, this layer will have a resilient modulus of 50 MPa and the top layer will have a resilient modulus value of 112 MPa and this is computed using this second this equation here. So, once you have a resilient modulus value, we will give this input to an IITPAVE software and compute the surface deflection here.

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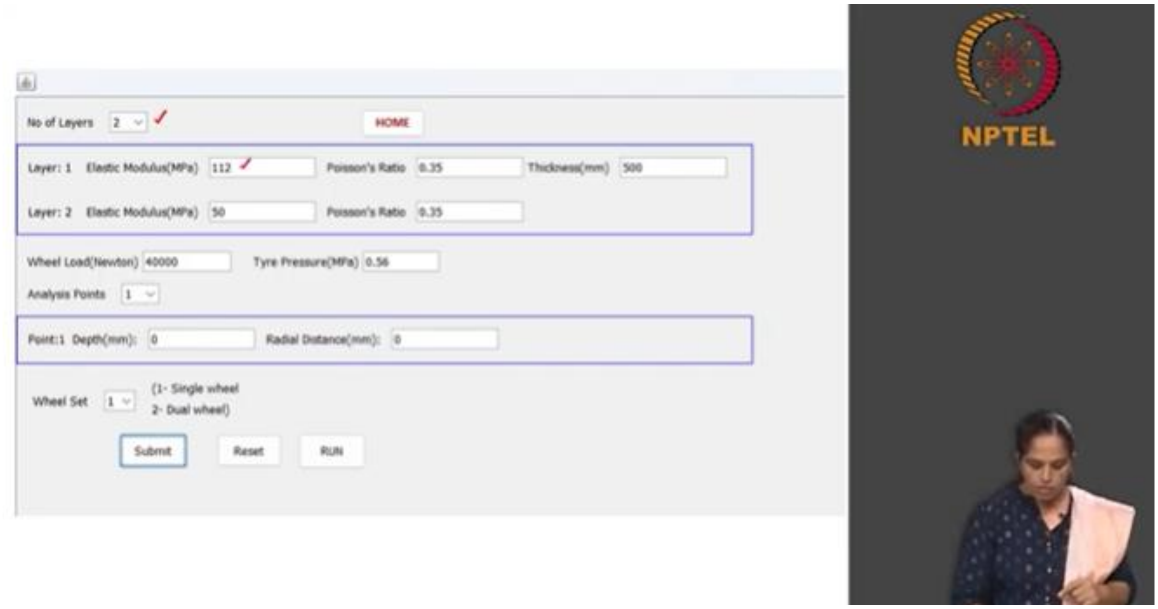

So, this is the screen of IITPAVE software. So, we have 2 layers. The first layer has an elastic modulus of 112, second layer has an elastic modulus of 50 MPa. Poisson's ratio we will take it as 0.35 for both the layers, the top layer is 500 mm thick. So, we use a single wheel of 40 kN with a contact pressure of 0.56 MPa and we are interested in finding only the surface deflection. So, I will keep analysis point to be 1. So, the depth at which we need the deflection is at the surface, so it is 0 and the radial distance also 0 and we will use a single wheel of 40.

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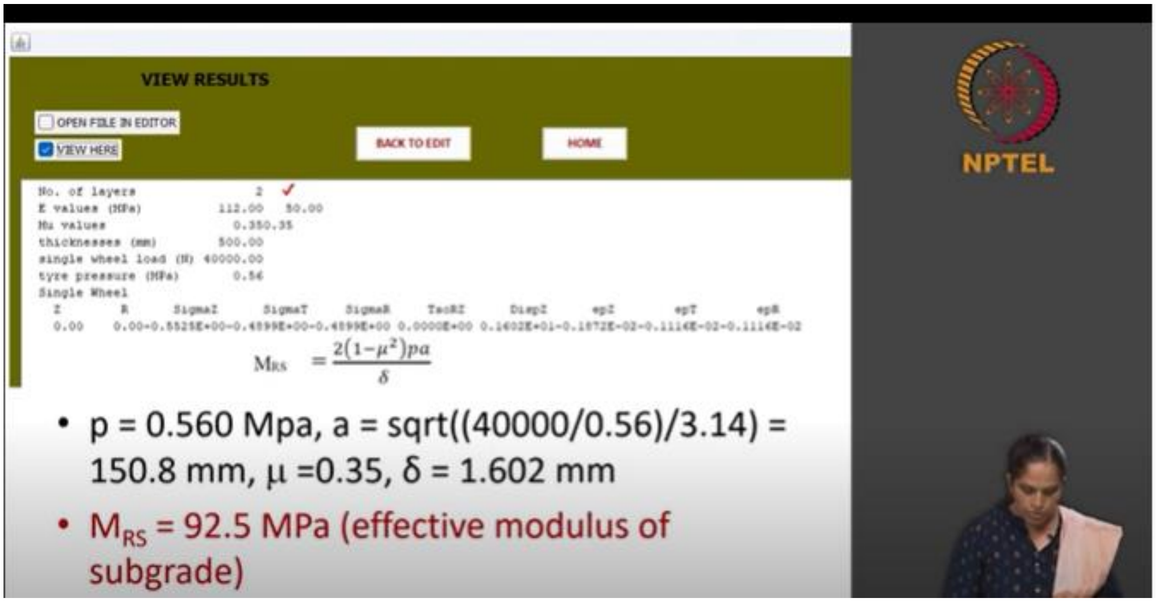

With this input when you submit it, you will get the output results to be like this. So, for a number of layers of 2, for any given other inputs, you see that the surface deflection value to be equal to 1.602 mm. So, again, the negative sign given here in the in this IITPAVE software indicates that the strain is compression and positive sign indicates that strain is tension, it is just quite opposite to the KENLAYER what we used. So, for a pressure of 0.56 MPa and the contact radius of 150.8 mm and for the Poisson's ratio of 0.35, when you substitute all these number here, you will get the equivalent modulus to be 92.5. So, we will use this as an effective modulus for the subgrade. So, here on we are going to consider the subgrade as a single layer with a modulus value equal to 92.5 MPa.

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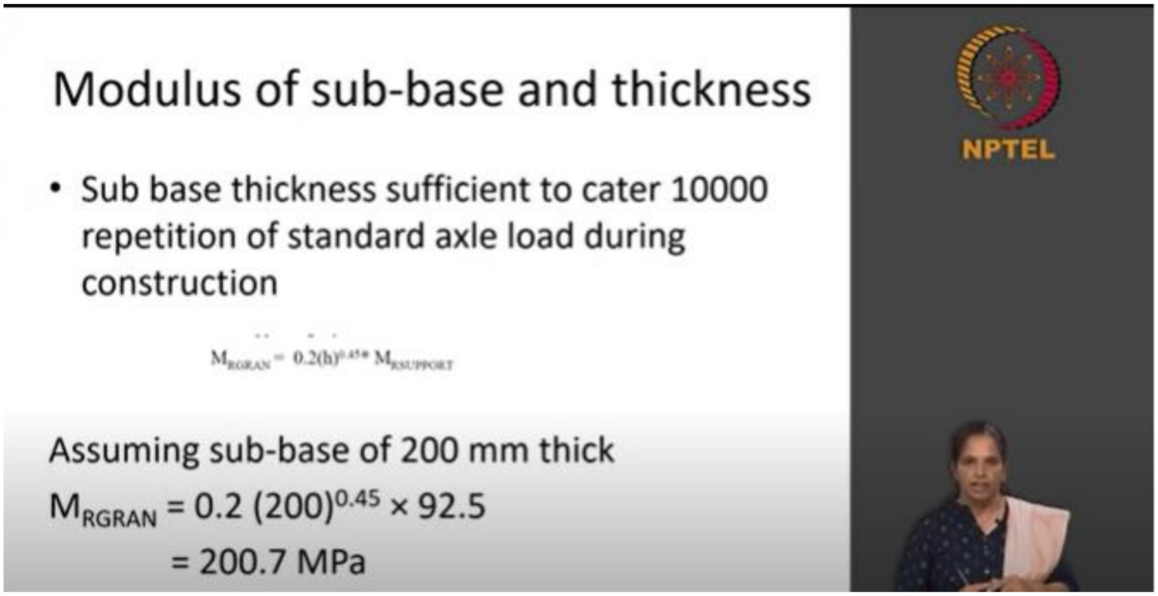

So, the next is a modulus of subbase course and its thickness, we know that the modulus of a subbase course or any granular layer is going to depend on the thickness here and we have to make sure that there should be a minimum thickness for a base layer to cater to 10,000 repetitions of a standard axial load that occurs during construction process so that we protect the subgrade from rutting. So, you have this equation empirical equations from IRC 37.

$$M_{RGRAN} = 0.2(h)^{0.45} \times M_{RSUPPORT}$$

So, let us first assume that the base layer of a thickness of 200 mm. For an assumed base layer thickness, we will check whether the subgrade rutting is safe here. So, for an assumed thickness of 200 mm, you get the modulus of a subgrade to be computed to be 200.7 MPa. So, we will use this modulus and use it in a IITPAVE software and compute what is the vertical compressive strain on this upgrade soil.

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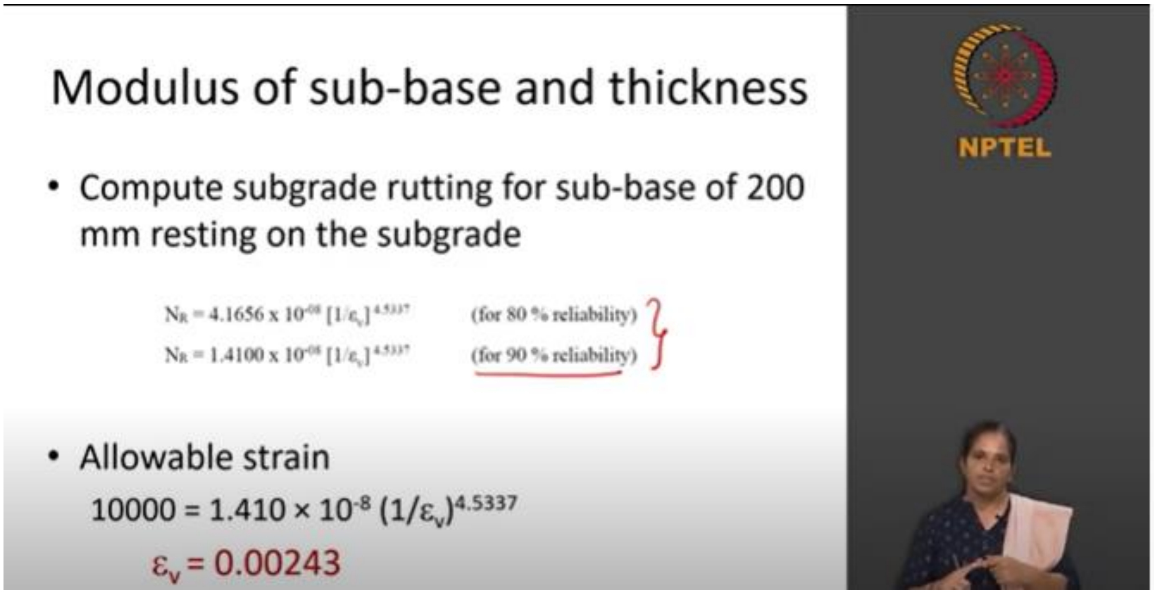

So, before computing, we will also use this reliability equation, we will stick to 90% reliability and find out what is the allowable strain for subgrade rutting.

$$N_R = 4.1656 \times 10^{-08} \left[\frac{1}{\varepsilon_v}\right]^{4.5337} \qquad \text{(for 80\% reliability)}$$

$$N_R = 1.4100 \times 10^{-08} \left[\frac{1}{\varepsilon_v}\right]^{4.5337} \qquad \text{(for 90\% reliability)}$$

So, now N_R which is nothing but 10,000 number of repetitions of a standard axial load with a 90% reliability equations, when you compute this ε_v, you get the ε_v value to be this 0.00243. So, what is this ε_v exactly represents is for a rutting for a pavement subgrade soil to fail in rutting, the strain value is should exceed 0.00243. So, that means you can allow a strain up to 0.00243 before the pavement or a subgrade fails in rutting.

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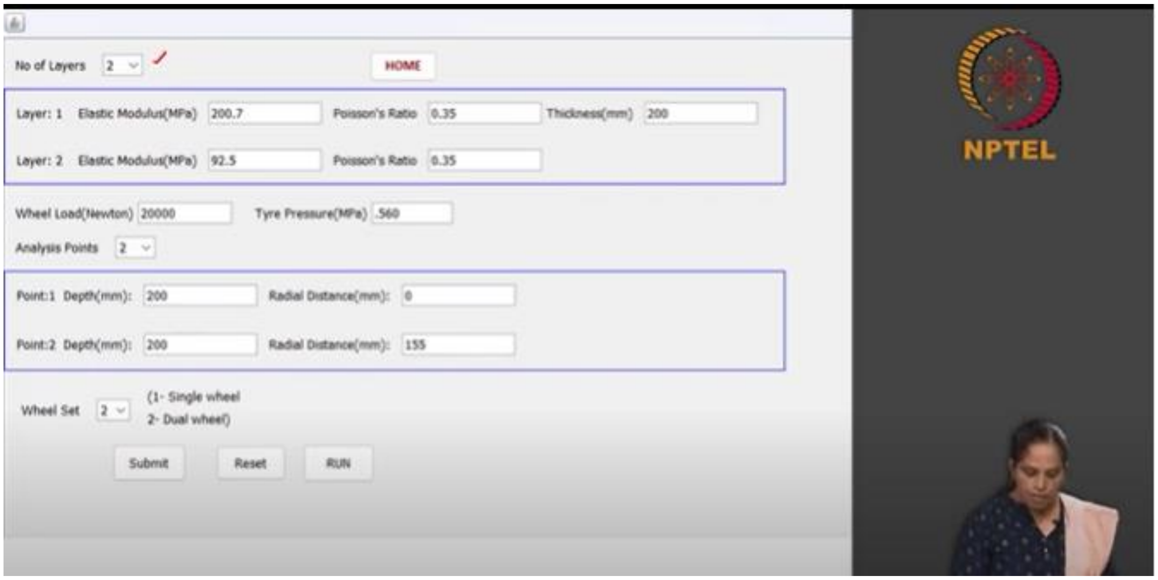

So, now when you open a IITPAVE software, you can give an input number of layers to be 2 subgrades, 1 subgrade and 1 base layer. Base layer has an elastic modulus that we computed to be 200.7 MPa, subgrade effective modulus is 92.5 MPa. So, let us use that effective modulus here and Poisson's ratio both this 0.35 and we have assumed the thickness of a sub base layer to be 200 mm. So, now for this layered structure, it is subjected to the wheel load of 20 kN that is standard axial load and tyre pressure of 0.56 MPa. Let us find out the stresses and strain values at 2 point but at the interface of a subbase and the subgrade layer. So, at the interface the depth is 200 mm, one is at the radial distance and other is 155. It means 2 wheels are spaced exactly at the distance of 310 mm. So, the center point is 310 divided by 2 that is 155 mm. So, we use a dual wheel load when you submit and compile that you will get the results to be like this.

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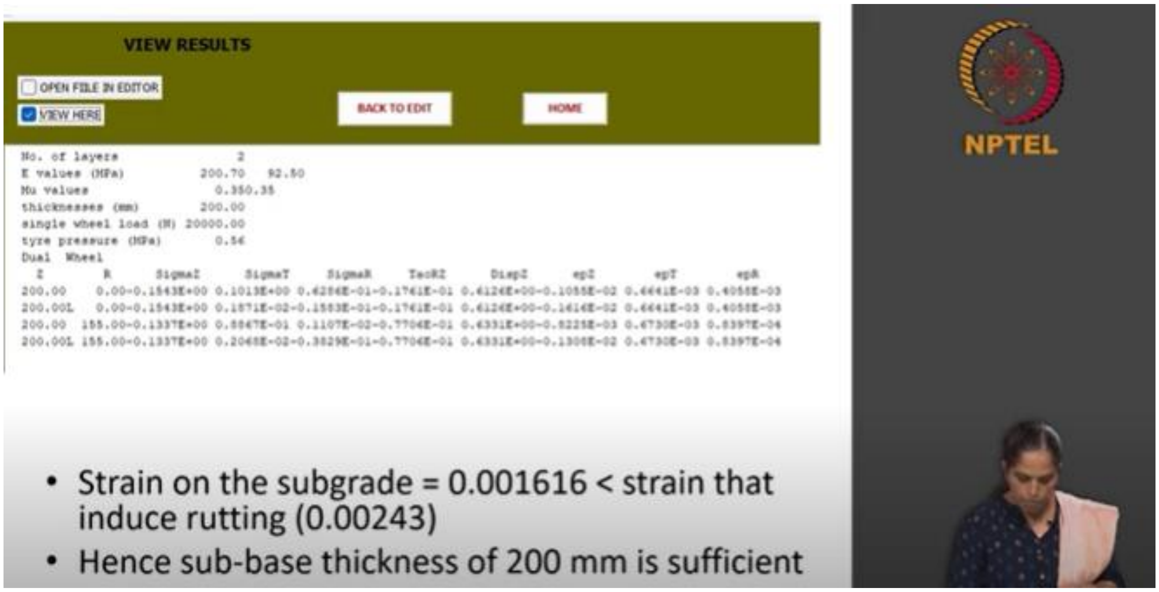

So, for the input what we have given, the strain that induces the subgrade rutting as a vertical compressive strain that is this value, you need to find out which is the maximum value here. The vertical compressive strain at the top of a subgrade layer maximum is found to be this number, negative sign indicates that the nature is compressive. So, now you can see that this strain value is much less than the allowable strain which we have computed from a 10,000 repetitions of a standard axial load that is 0.00243. So, we can provide a base course thickness of 20 mm or base course stiffness of 20 mm is sufficient enough to take the traffic that is acting on the pavement during a construction process.

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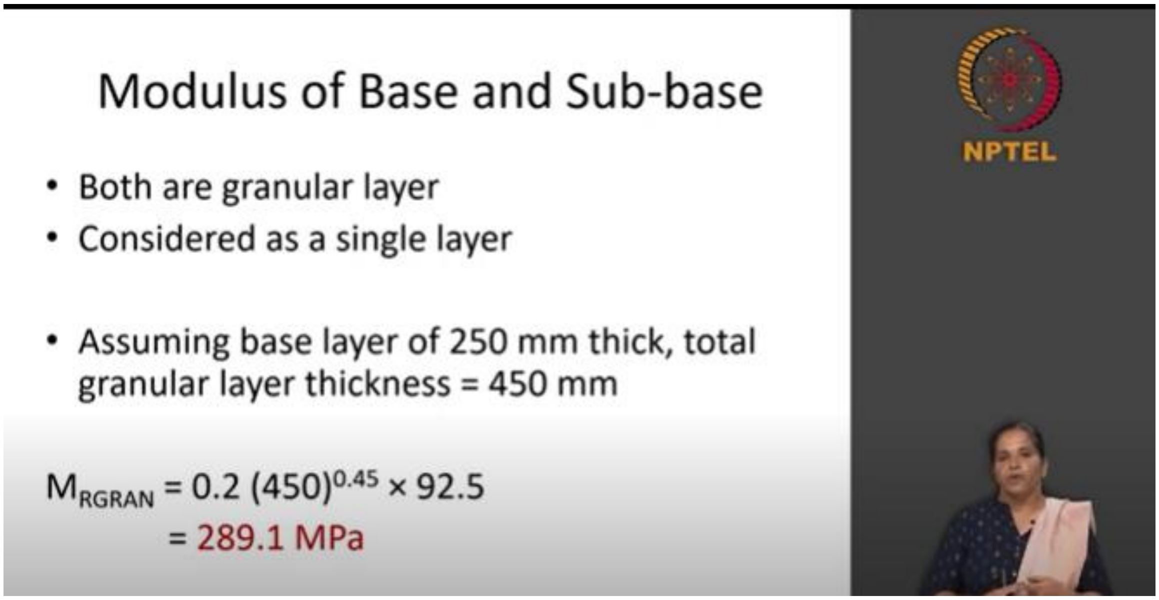

Now, we will see what is the modulus of a base course and a subbase course layer for considered for the design purpose. See both base course and subbase course are a granular layer. So, we can consider both base and subbase together as a single layer for the design purpose. We have taken subbase layer thickness to be 200 mm and we have verified that the 200 mm thickness of subbase is sufficient enough to prevent rutting during constructions. Now, we will assume a base layer thickness of 250 mm. So, the combined base and subbase thickness will be 200 + 250 which is 450 mm thickness. So, if you provide 450 mm thick granular layer, the combined one single modulus for the granular layer can be computed with the same empirical equations which depends on the thickness of a layer H and the modulus of a support which is 92.5 modulus of subgrade here. So, that modulus of a granular layer computed is 289.1 MPa. So, we will use this modulus for the design.

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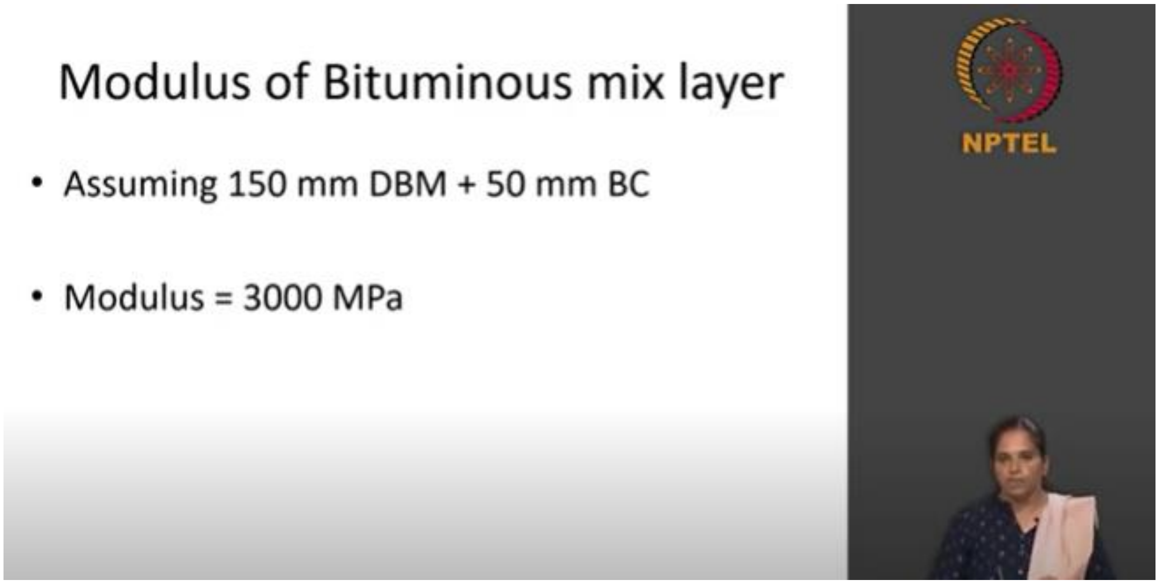

Now modulus of a bituminous mix. So, we will assume a bituminous layer to be as a 2 layer, one is a binder course of 150 mm DBM and 50 mm BC at the top layer. So, as per an indicative number given in the table, so we select the modulus corresponding to 35^{o}C and we will use the modulus of 3000 MPa for the computation of stresses and strains.

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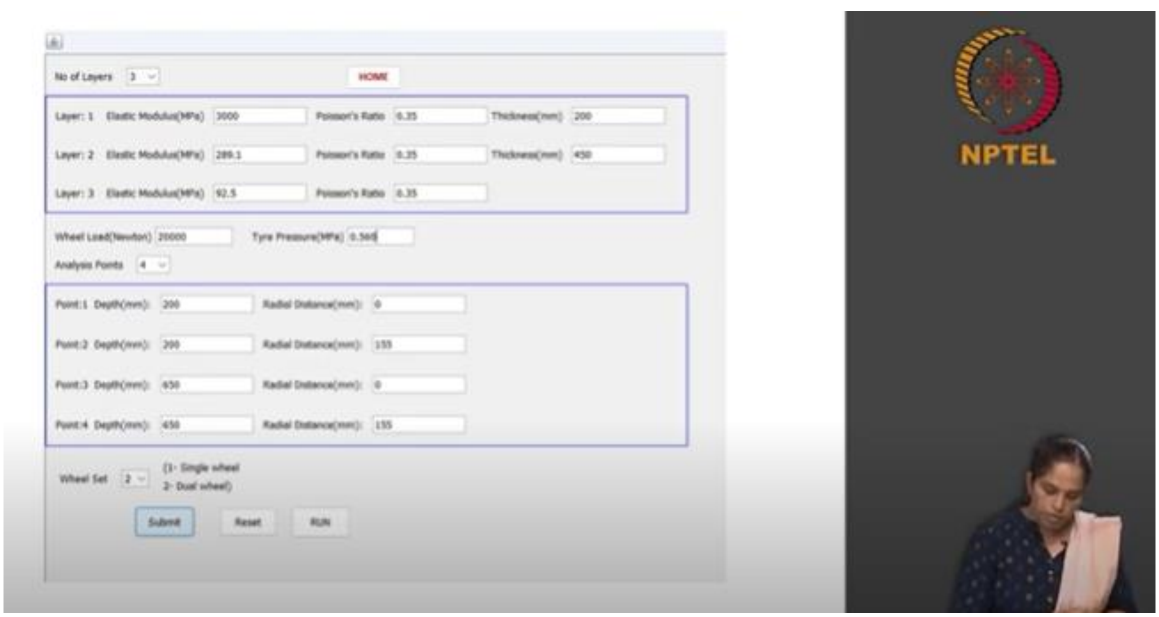

So, once we decide upon a modulus, let us give all this input in the IITPAVE software. So, you can also use a KENPAVE software for this purpose. So, number of layers was defined as 3, because we clubbed BC layer and DBM layer as a single layer and we use 1 modulus and we clubbed base course and subbase course as 1 granular layer and we give 1 modulus here. So, we just have 3 moduli here, one bituminous course, the second one is granular layer and both these rest on the subgrade. So, the elastic modulus of a bituminous layer is 3000 MPa, elastic modulus of granular layer is computed to be 289.1 MPa and this is an effective elastic modulus of a subgrade layer. So, these are the Poisson's ratio value, we will keep it as 0.35. So, we have assumed a thickness of 150 + 50 as a bituminous layer thickness. So, total is 200 and total thickness of subbase and base course is 450 here. Now, this structure is subjected to 20 kN wheel load that is a dual wheel type with a tyre pressure of 0.56. And if that is the case, we need stresses and strain at 4 different locations that is at 2 interfaces, one at the first interface and other at the second interface and one is exactly at the center of loading that is one-wheel center of one wheel and other is a center between 2 wheels. When you summit and run this program, this is a result you will get it.

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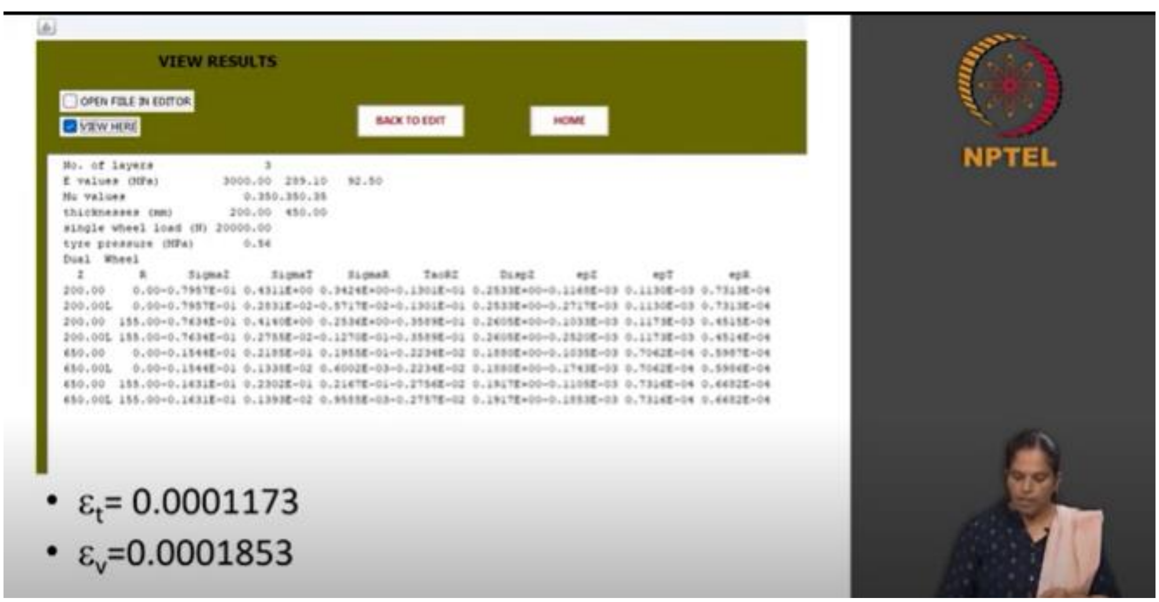

Now, the fatigue damage in the asphalt layer is induced due to horizontal tensile strain at the first interface. Now, when you see these 4 results corresponds to first interface and negative positive value here indicates the tensile strain value and the maximum value here you can see the maximum tensile strain to be 0.1173×E-4. So, this is the one that is going to induce fatigue damage in the HMA layer and rutting occurs in the subgrade layer and that is at the second interface.

In the second interface ε_t or compressive strain which is given in the negative value, so maximum among this 4 value to be considered for rutting. So, the maximum value is 0.1853×E-3, which is the vertical compressive strain that induce rutting in the subgrade layer.

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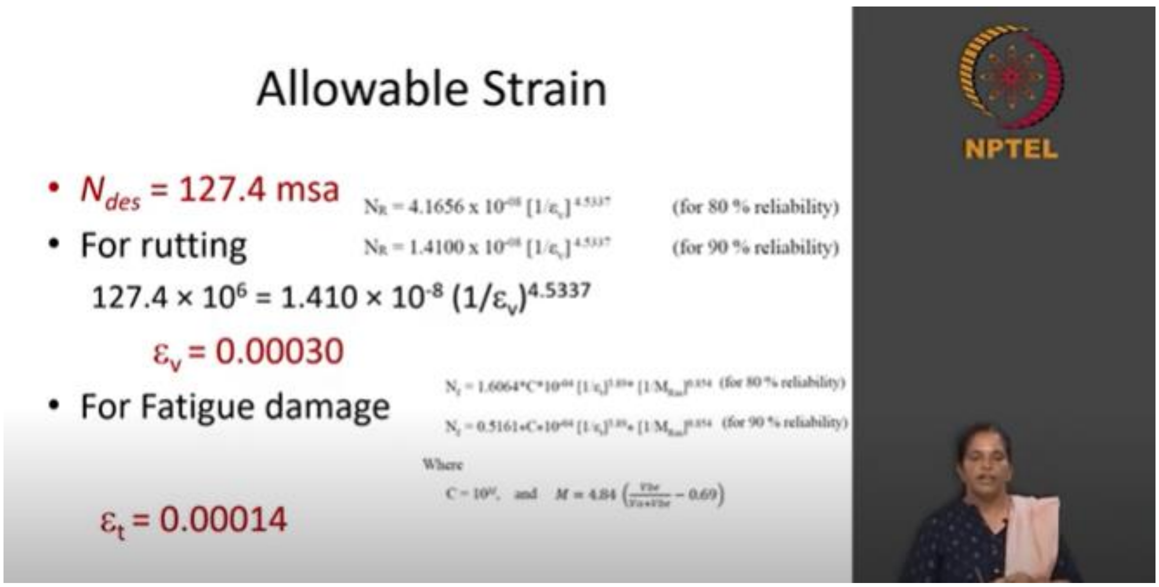

So, now we will use this in the transfer function and we will check what is the allowable strain and what is this exact strain in the structure. So, the allowable strain is computed from the number of repetitions of a standard axial load.

$$N_R = 4.1656 \times 10^{-08} \left[\frac{1}{\varepsilon_v}\right]^{4.5337} \qquad \text{(for 80\% reliability)}$$

$$N_R = 1.4100 \times 10^{-08} \left[\frac{1}{\varepsilon_v}\right]^{4.5337} \qquad \text{(for 90\% reliability)}$$

$$N_f = 1.6064 \times C \times 10^{-04} \left[\frac{1}{\varepsilon_t}\right]^{3.89} \left[\frac{1}{M_{Rm}}\right]^{0.854} \qquad \text{(for 80\% reliability)}$$

$$N_f = 0.5161 \times C \times 10^{-04} \left[\frac{1}{\varepsilon_t}\right]^{3.89} \left[\frac{1}{M_{Rm}}\right]^{0.854} \quad \text{(for 90\% reliability)}$$

Where,

$C = 10^M$ and $M = 4.84\left(\frac{Vbe}{Va+Vbe} - 0.69\right)$

So, you have number of repetition of a standard axial load to be computed to be this, when you use that 90% reliability equation, you find that strain value to be 0.00034. So, this is a maximum strain that is allowable in the pavement means you need a pavement thickness so that the strain value in this will not exceed 0.0003. For a fatigue damage when you use a 90% reliability equations, you get ε_t to be 0.00014. So, this is the allowable value computed from the traffic, but the value what we got is this. So, you can see that ε_v which is 0.0001853 which is very much less than this, so it is safe in rutting. Now, ε_t which is 0.0001173 is also less than this so, which is safe in tensile strain. So, we can see that the strain that is computed from the stress strain analysis is less than the allowable value here.

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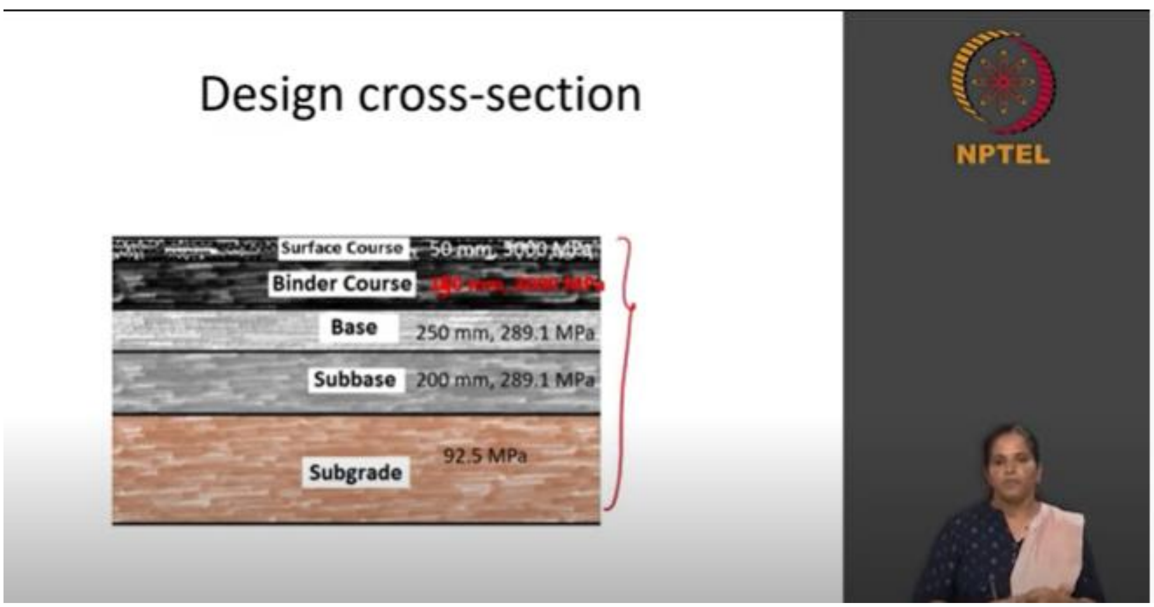

So, whatever thickness we assumed will take care of rutting on the subgrade layer and fatigue damage in the HMA layer and this is the structure what we assumed. So, in case if your requirement is not meeting out or if the strain in the layers are way too high to meet a fatigue damage criterion, you can increase the thickness of a binder course and check with the design again. In case if you are not meeting with the rutting criteria, you can either increase the base course thickness or this surface course thickness.