Analysis and Design of Bituminous Pavements

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Lecture – 45

Pavement design with RAP Base

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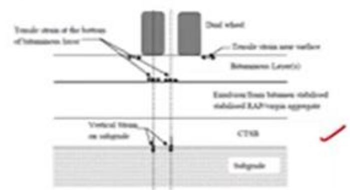
Pavement cross-section with RAP stabilized base

- Traffic – 150 msa



Layer	Modulus (Mpa)	Poisson's ratio	Thickness (mm)
BC	3000	0.35	40
DBM	3000	0.35	80
Base (RAP)	800	0.35	200
CTSB	600	0.25	250
Subgrade	70	0.35	-

So, in this lecture, we will see design of bituminous pavement with a RAP stabilized base and the pavement cross section details for a long life pavement. So, we will design a pavement cross sections with RAP stabilized base and to take a traffic of 150 million standard axles. So, this is a typical cross section, the pavement cross section may consist of 4 or 5 layers in which 1 or 2 layers can be a HMA layer and HMA layer resting on a RAP stabilized base. So, the RAP stabilized base course is considered here as a granular layer. So, you need to determine the resilient modulus of a RAP stabilized base assuming it to be a granular layer and use that as an input here to determine critical stresses and strain. So, we will use a cement treated base layer again it is resting on a subgrade. So, we will assume a trial section and find out whether the assumed trial section can take 150 msa traffic.

So, let us assume a 5 layered structure with 2 HMA layer BC and DBM of 40 and 80 mm thickness, we will use a modulus of BC and DBM layer to be 300 MPa. So, now the base course is used to here is a RAP stabilized base. So, we will assume a thickness of 200 mm with modulus of 800 MPa. This base is resting on a cement treated subbase with a modulus of 600 MPa and with a thickness of 250 mm. So, we will use an effective modulus of a subgrade to be 70 MPa. So, the Poisson's ratio value for a cement treated subbase alone is taken as 0.25 and all other layers it is taken as 0.35.

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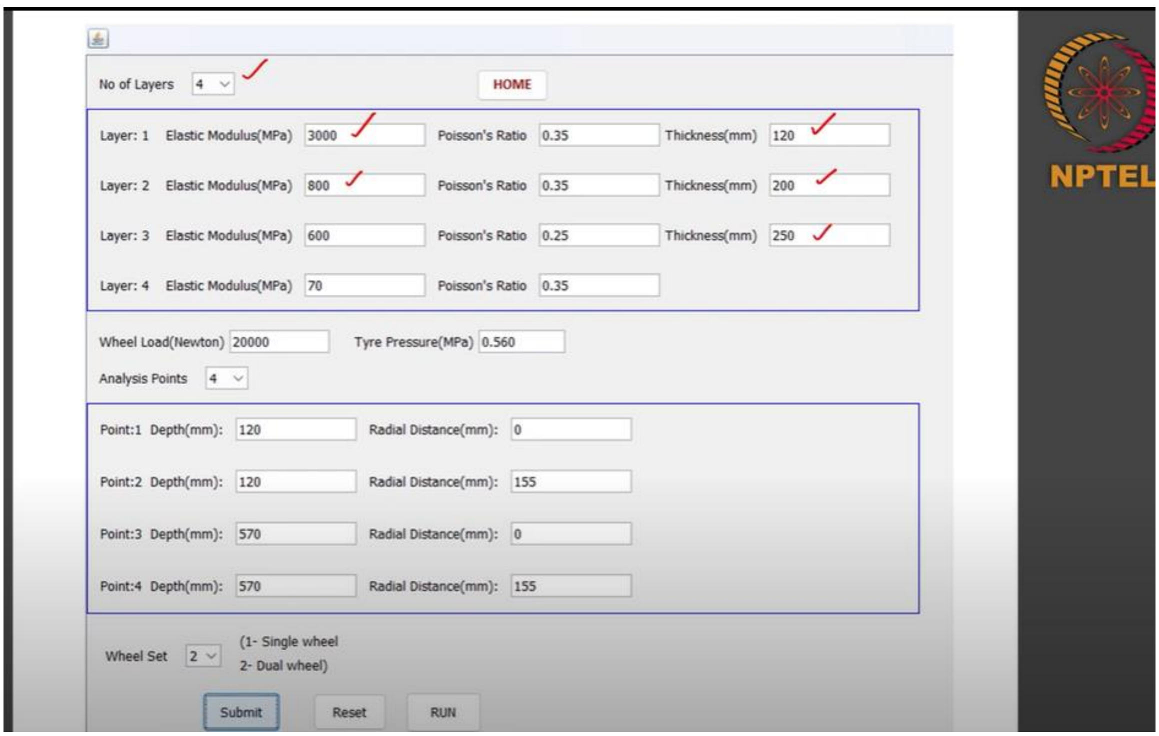

So, now when you give this as an input in an IITPAVE, the software the screen looks something like this. So, we have though it is a 5 layered structures we will club BC and DBM as a single layer. So, you will have a total of 4 layers here. So, BC DBM clubbed together will have a thickness of 120 mm with a Poisson's ratio of 3000 MPa. BC DBM clubbed together will have a thickness of 120 mm with an elastic modulus of 3000 MPa. The base course thickness what we assumed is 200 mm with an elastic modulus of 800

MPa. Cement treated subbase is the thickness of 250 mm with an elastic modulus of 600 MPa. So, we have assumed an elastic modulus of a subgrade to be 70 MPa. Now in this Poisson's ratio cement treated subbase alone is taken as 0.25 other values are taken as 0.35 here. So, this structure is subjected to a standard axle load and with a wheel load of 20 kN and with a tire pressure of 0.56. So, we will determine stresses and strain at 2 interfaces one is at the interface of a HMA layer and the base layer and second is at an interface of a subbase layer and the subgrade layer. So, the first interface is at the depth of 120 mm. So, and we need stresses and strain at a radial distance of 0 and 155 mm that is if you take a dual wheel load one point is exactly at the center of one first one wheel and 155 is exactly at the middle of two wheels.

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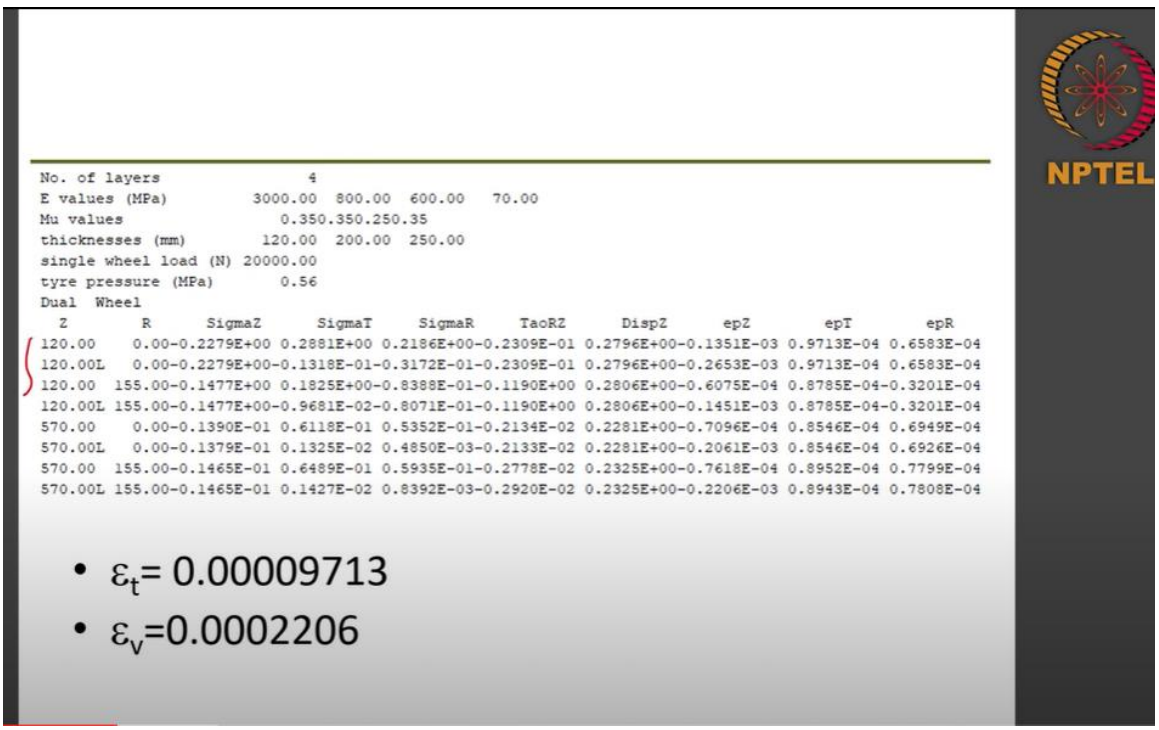

Now if now the second interface is at the depth of 570 mm. So, we will measure the strain value at the radial distance of 0 and 155 mm. Now this is the result you get it now at the first interface that is 120 mm here the critical strain that induces fatigue damage in HMA layer can be obtained from the maximum of this 4 value. So, you get the value to be 0.00009713 that is ε_t and ε_v is at the second interface and ε_v is found to be from the maximum of this value and we get it to be 0.0002206. Now we will find out what is the number of repetitions corresponding to this ε_t and ε_v.

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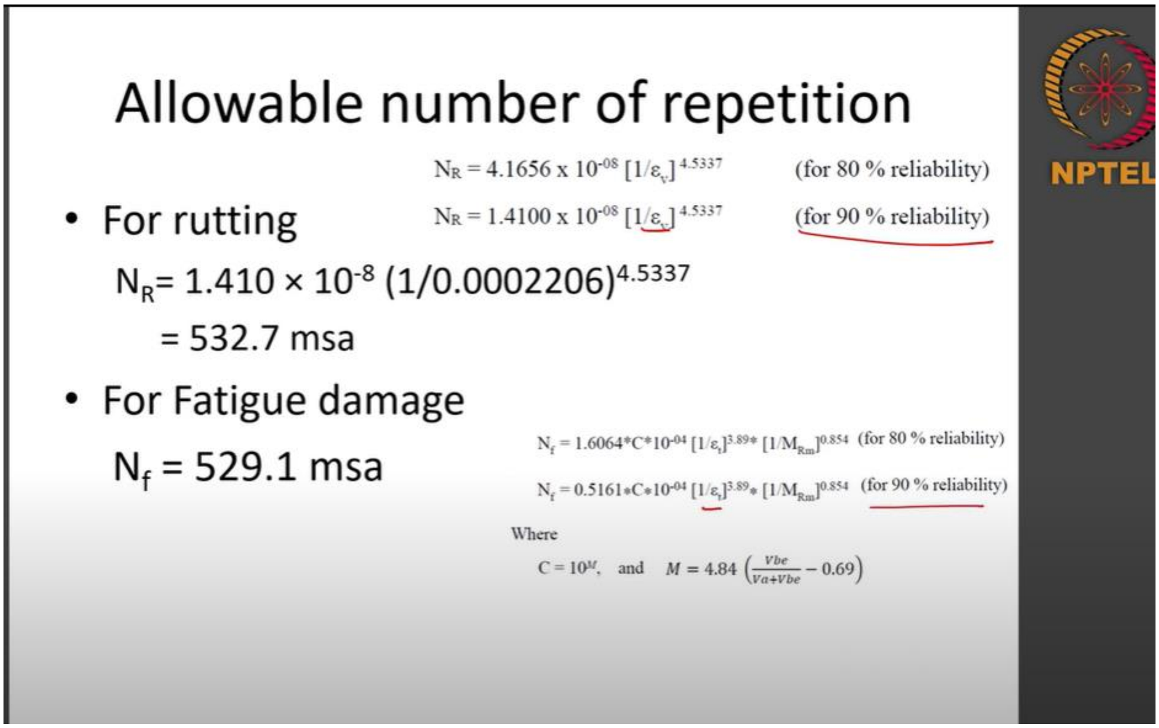

$$N_R = 4.1656 \times 10^{-08} \left[\frac{1}{\varepsilon_v}\right]^{4.5337} \qquad \text{(for 80\% reliability)}$$

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

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

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

Where,

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

So, we will use a 90% reliability equations for this and substitute an ε_v and $\varepsilon_t$in the 90% reliability equations corresponding to rutting and a fatigue damage and we will see what is the allowable number of repetitions of a standard axle load. So, when you substitute ε_v here the number of repetitions of a standard axle load before the subgrade can fail in rutting comes out to be 532.7 msa. For the strain corresponding to the fatigue damage the number of repetitions of standard axle load N_f comes out to be 529.1 msa. So, we need a pavement cross section to take a traffic of 150 msa. Now we see that the pavement cross section what we provided can take higher than 500 msa. So, we can make it more economical by reducing the thickness of different layer. So, this is the thickness we used it for determining the stresses and strain.

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- Try with the following cross-section

Layer	Modulus (Mpa)	Poisson's ratio	Thickness (mm)
BC	3000	0.35	40
DBM	3000	0.35	60
Base (RAP)	800	0.35	185
CTSB	600	0.25	200
Subgrade	70	0.35	-

Now we will go for a next trial sections by reducing the thickness of each layer and we will try out with this cross section. We will take a BC layer which is of a minimum thickness of 40 mm, DBM layer of a reduced thickness from 80 we will reduce it to 60 mm, base course again is of a reduced thickness we will reduce it to 185 mm, cement treated subbase also will go with a reduced thickness of 200 mm and we will see what is the critical stresses and strain.

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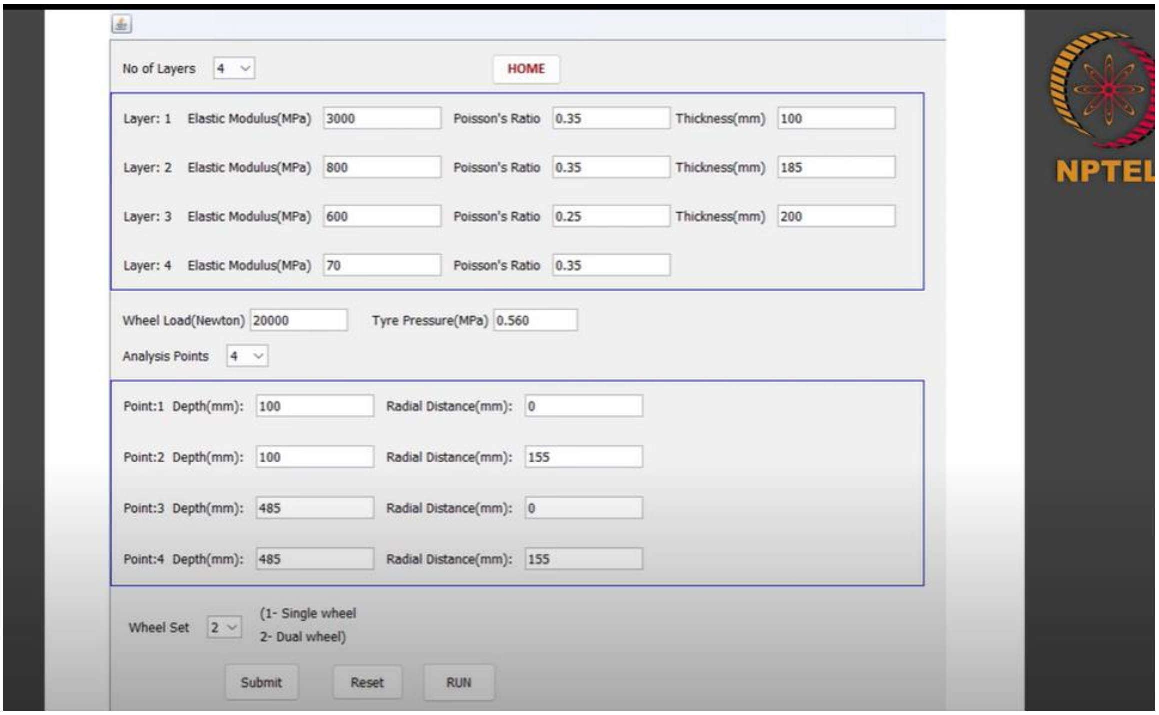

So, this is the corresponding input for the new trial sections. So, you can see the thickness of all the layers are reduced since thickness is reduced the interface thickness will also reduce here and when you compute the stresses and strain at different locations you see this results.

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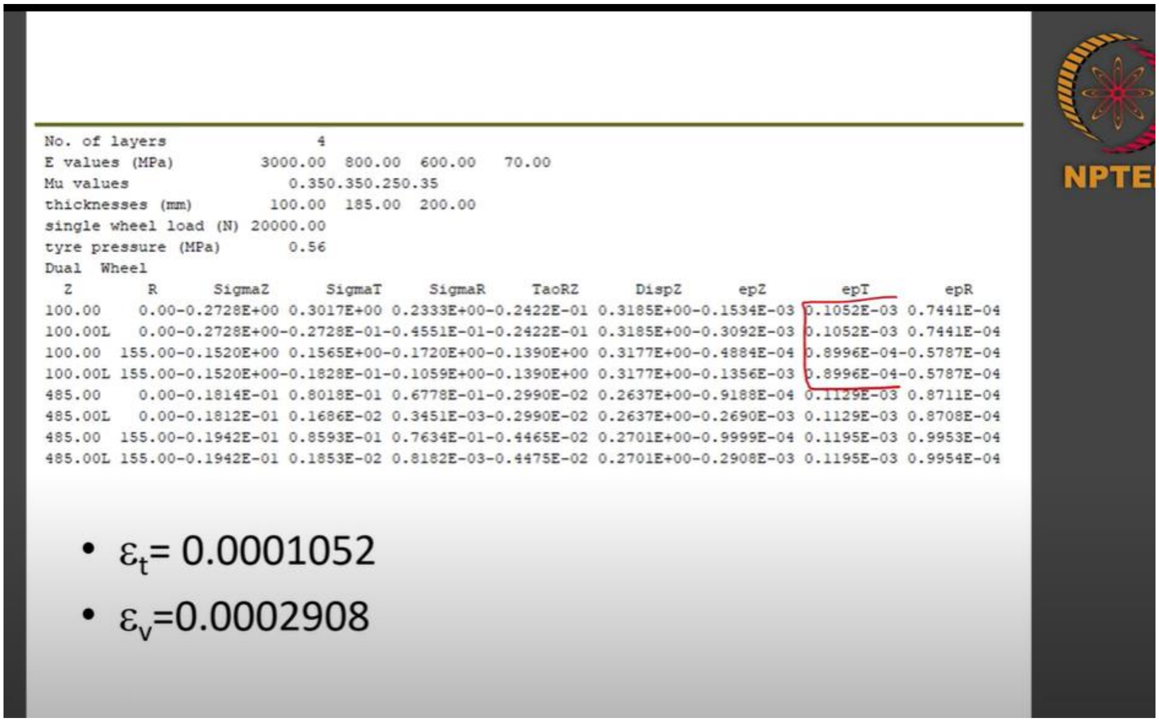

So, at the first interface the strain value which is a maximum from this 4 value is computed to be 0.0001052. Now ε_v value which is computed from the maximum of this value was found to be 0.0002908. Now for this corresponding strain we will again use a 90% reliability equations and get what is the number of repetitions of a standard axle load.

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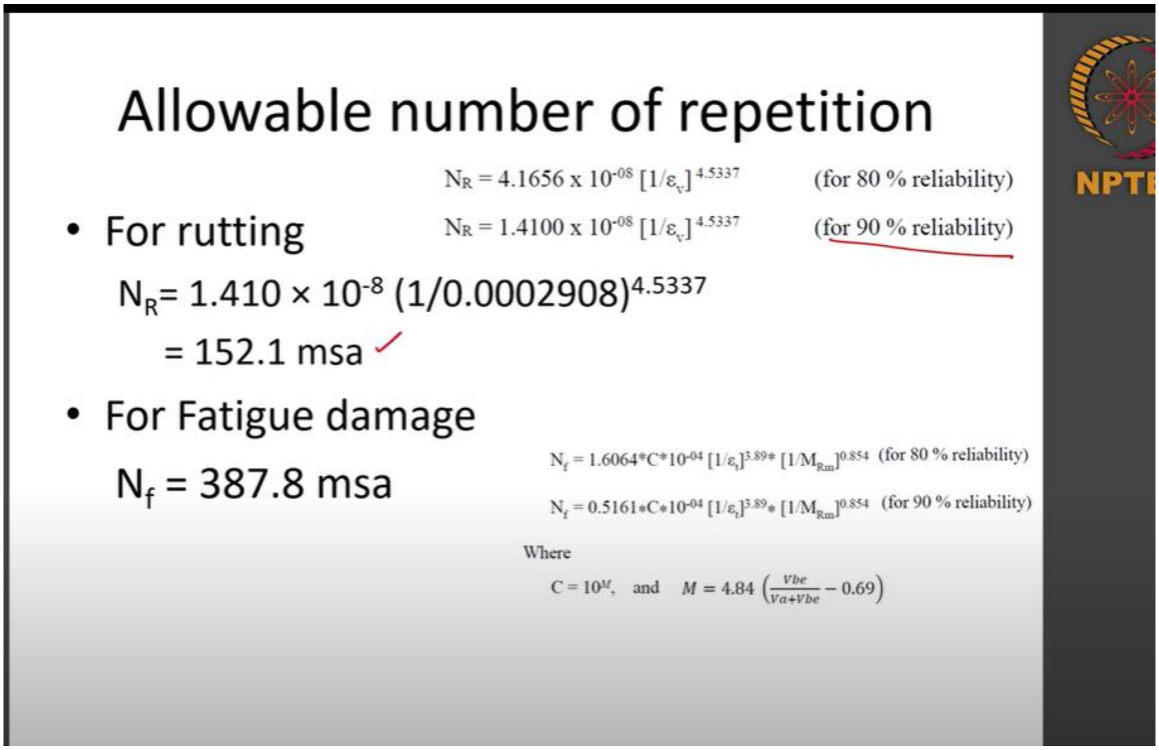

$$N_R = 4.1656 \times 10^{-08} \left[\frac{1}{\varepsilon_v}\right]^{4.5337} \qquad \text{(for 80\% reliability)}$$

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Where,

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

So, you get for a rutting the number of repetitions was found to be 152.1 msa and for fatigue damage it is found out to be 387.8 msa. So, all these fatigue damage analysis or damage equations are computed for a volume of effective binder content to be 11.5%, this is a volume basis 11.5% and volume of air voids to be 3.5%. So, this is a mixture property that we assume for computation of number of repetitions of standard axle load corresponding to fatigue damage. So, we see that the pavement critical failure is in rutting and it is slightly higher than what it is expected that is 150 msa here. So, we now we can say that the pavement with this cross section takes the 150 msa traffic here.

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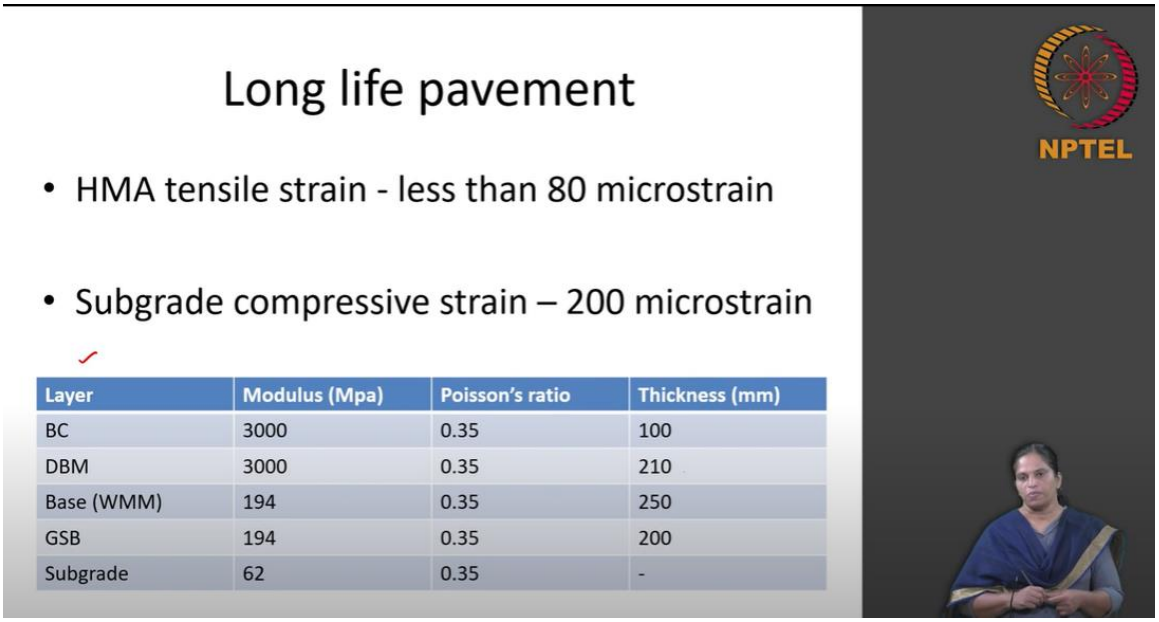

Layer	Modulus (Mpa)	Poisson's ratio	Thickness (mm)
BC	3000	0.35	100
DBM	3000	0.35	210
Base (WMM)	194	0.35	250
GSB	194	0.35	200
Subgrade	62	0.35	-

Now the next design is a long life pavement. IRC defines a pavement as a long life pavement based on the critical strain at different locations. So, if the tensile strain at the bottom of a HMA layer is less than 80 micro strains and if the vertical compressive strain at the top of a subgrade layer is less than 200 micro strain, the pavement is said to have a longer life without any distresses. So, there can be a different combinations of layers with a different modulus and different thickness to exhibit a long life. One such cross section is given here.

So, this is a conventional cross section of the pavement with 2 HMA layer and base and subgrade layer to be a granular layer resting on a subgrade layer and the modulus property what we have is also a conventional material property with a 2 HMA layer to have a modulus of 3000 MPa, base and granular base course having a modulus of 192 MPa. So, this modulus may vary based on an assumed thickness. So, for an assumed thickness you can compute the modulus here, here base and subbase course are assumed as a one single layer and the modulus was computed here and this effective subgrade to have a modulus of 62 MPa. So, for this material property let us assume a thickness of BC and DBM layer together to be 310 mm. So, this 310 mm again it is considered as a one single layer with a modulus of 3000 MPa. Now, base and subbase thickness we will assume it to be 250 mm and 200 mm. Now we will see what is the critical stresses and strain for this assumed section.

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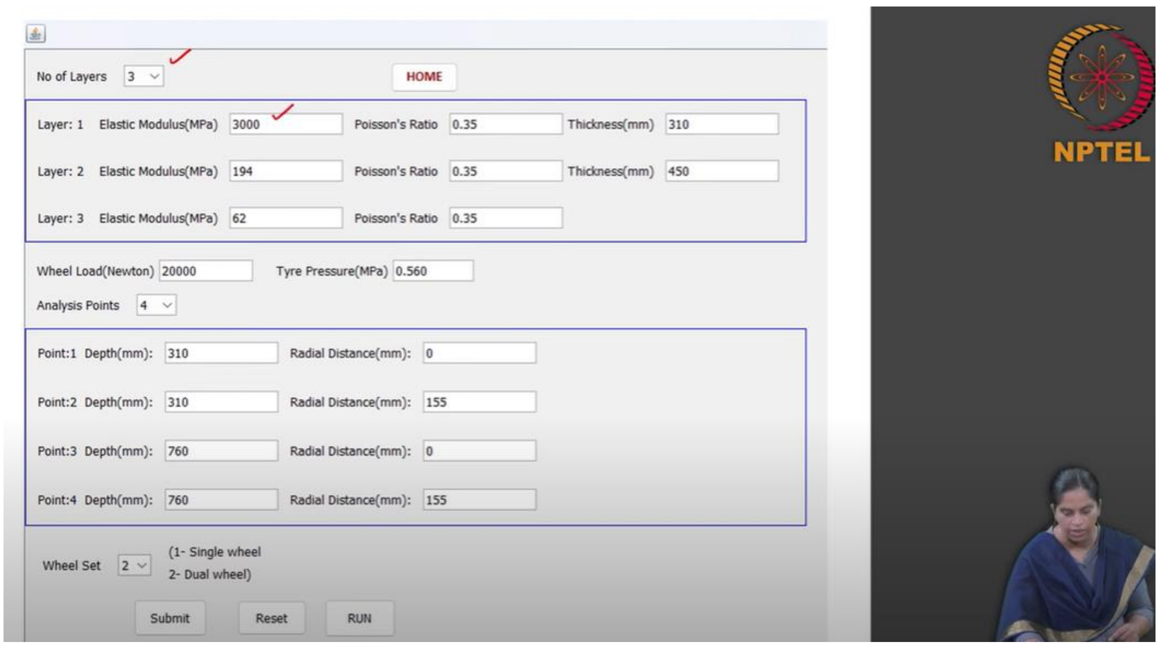

So it is assumed as a three layered sections with the elastic modulus of each layer HMA layer to be 3000 MPa, base layer or granular base layer to be 194 and effective modulus of a subgrade to be 62. So, the Poisson's ratio for all these layers is 0.35 and we have a thickness of base BC and DBM together as a 310 mm and base and subbase combined together as a 450 mm. So, we will subject this pavement to a 20 kN wheel load with a tyre pressure of 0.56 and we will see what are the critical stresses at the interfaces. So, the first interface is at a depth of 310 mm. So, we will find out the stress value at the two locations, one is at the 0 radial distance and other is at a 155 mm radial distance. So, the second interface that is just above the subgrade layer is 760 mm from the top.

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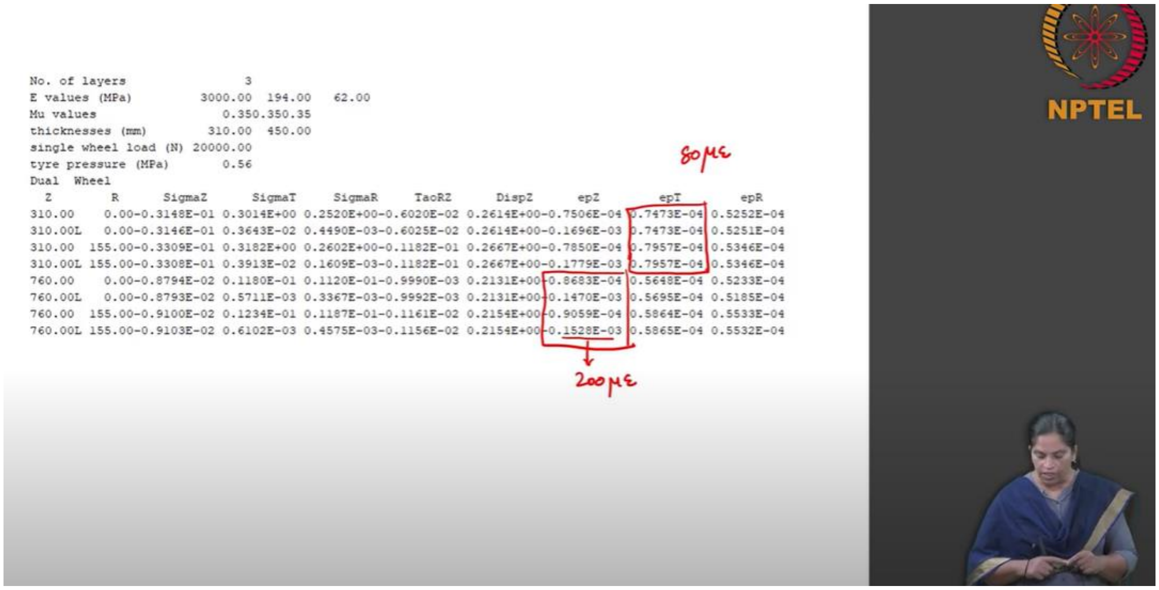

So, now when you see the critical stresses and strain value, the epsilon t what you get is maximum from this 4 value here and we find it to be less than 80 micro strain here. Likewise, ε_v value above the subgrade layer was found to be maximum that is 152 micro strain which is less than 200 micro strain. So, the strain values here are less than the value of 80 and 200 micro strains. So, we say that the pavement cross sections what we assume to have a longer life with no distresses.

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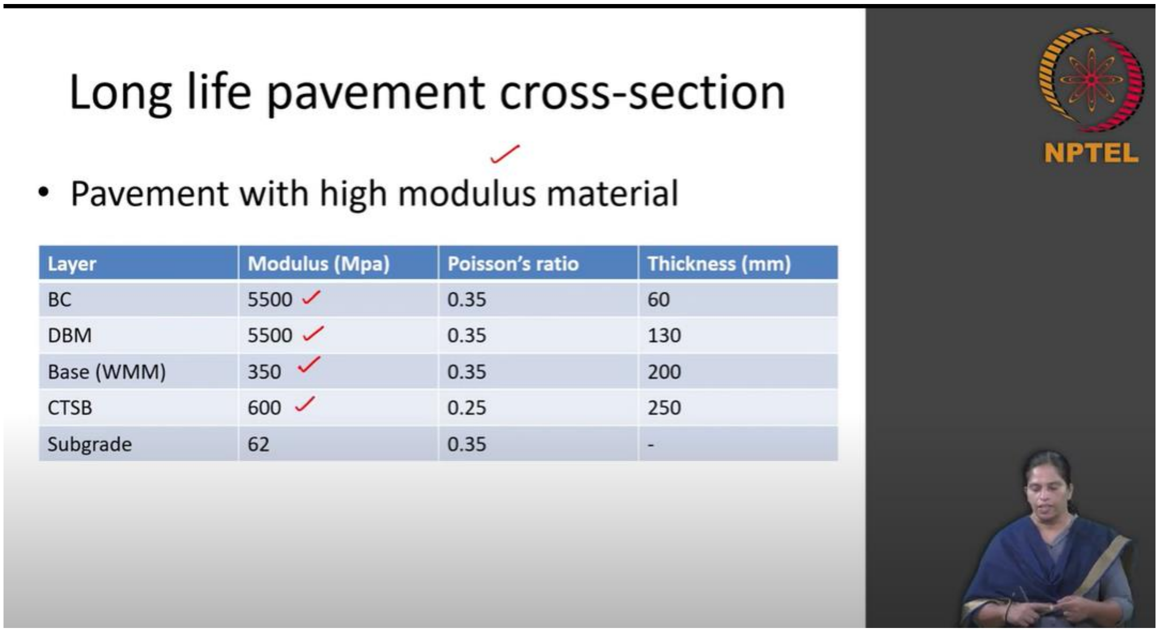

Layer	Modulus (Mpa)	Poisson's ratio	Thickness (mm)
BC	5500	0.35	60
DBM	5500	0.35	130
Base (WMM)	350	0.35	200
CTSB	600	0.25	250
Subgrade	62	0.35	-

Now the second cross sections which we will check is the cross section with a high modulus value. So, we will have a BC and DBM layer that is a hot mix asphalt for layer with a higher modulus. So, you can have a high modulus value by using a high modulus bitumen here. So, let us use the modulus value here to be 5500 MPa here. The base course is resting on a cement treated subbase. So, when the granular layer is resting on a cement treated subbase the modulus of a crushed aggregate above the cement treated subbase can be considered as 350 MPa. So, if you use a cement treated subbase the modulus value here is considered as 600 MPa and subgrade has a modulus of 62 MPa here. Now except a cement treated base all other layer has a Poisson's ratio of 0.35 and cement treated base has a Poisson's ratio of 0.25. Now we will reduce the thickness from as that considered from the previous case because we are providing a high modulus material here. So, let us use a BC and DBM combined thickness to be 190 mm in a previous case it is 310 mm. We will use a base layer of 200 mm and cement treated subbase layer of 250 mm. So, this is typically a 5 layered structures. Now for an analysis we combine BC and DBM together and we will analyze this as a 4 layered structure. Before we see the analysis result we will recollect the material properties recommended by a standard here.

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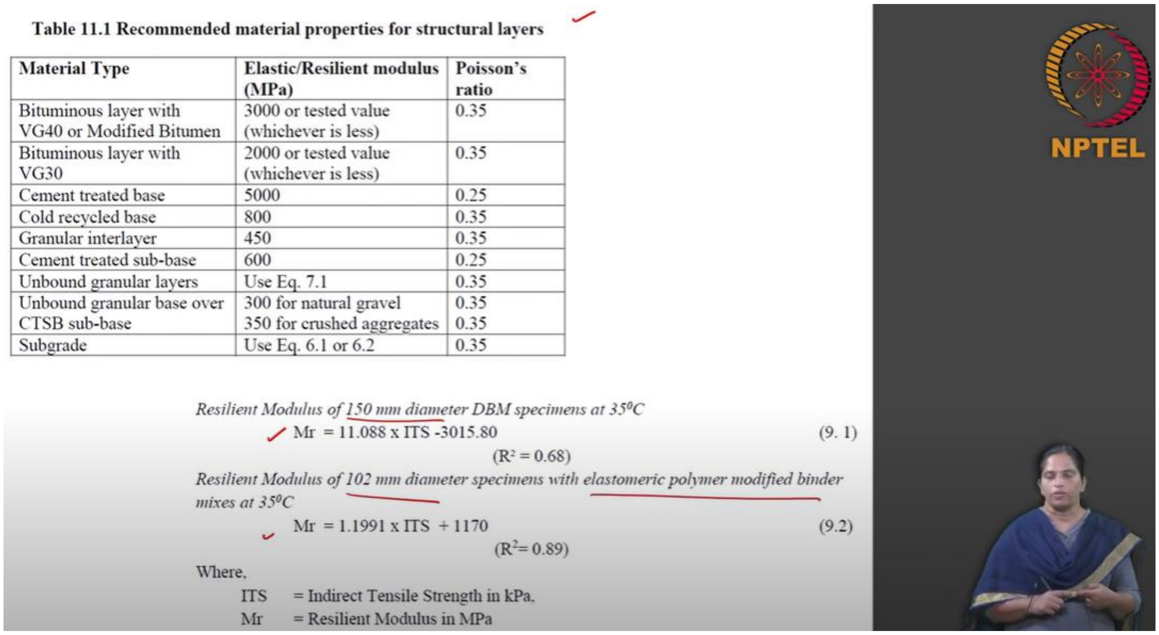

Resilient Modulus of 150 mm diameter DBM specimens at 35⁰C

$$Mr = 11.088 \times ITS - 3015.80 \qquad (R^2 = 0.68)$$

Resilient Modulus of 102 mm diameter specimens with elastomeric polymer modified binder mixes at 35⁰C

$$Mr = 1.1991 \times ITS + 1170 \qquad (R^2 = 0.89)$$

Where,

ITS = Indirect Tensile Strength in kPa,

Mr = Resilient Modulus in MPa

So, this is the table which you already seen here. The first 2 row corresponds to a bituminous material. The bituminous layer with VG40 bitumen or a modified bitumen will have a modulus value of 3000 MPa or lab tested value whichever is a lower value is considered here. Now the bituminous layer with VG30 material has a modulus of 2000 MPa or lab tested value again whichever is a lower value is considered here. So, we need a lab testing here to compute the resilient modulus value and a standard recommends to follow an ASTM procedure to determine the resilient modulus of bituminous mixture.

So, if you do not follow an ASTM procedure for computing a resilient modulus value you can also use a resilient modulus relation here to compute a resilient modulus from an ITS value. So, you have 2 different moduli for a different sample size we use and for a different modulus binder we use here. So, you can compute the resilient modulus and use it here. Now you can see that modulus values are in the range of 2000 to 3000 MPa. This is a conventional modulus value which we use.

So, now in this particular cross section we are going to consider a high modulus HMA layer with a modulus of 5500 MPa. Again we are using granular layer above a cement treated subbase. So, when you use a granular layer above a cement treated subbase you can consider the modulus to be 300 for a natural gravel or 350 for a crushed aggregate. We will use a modulus of 350 MPa for the design purpose.

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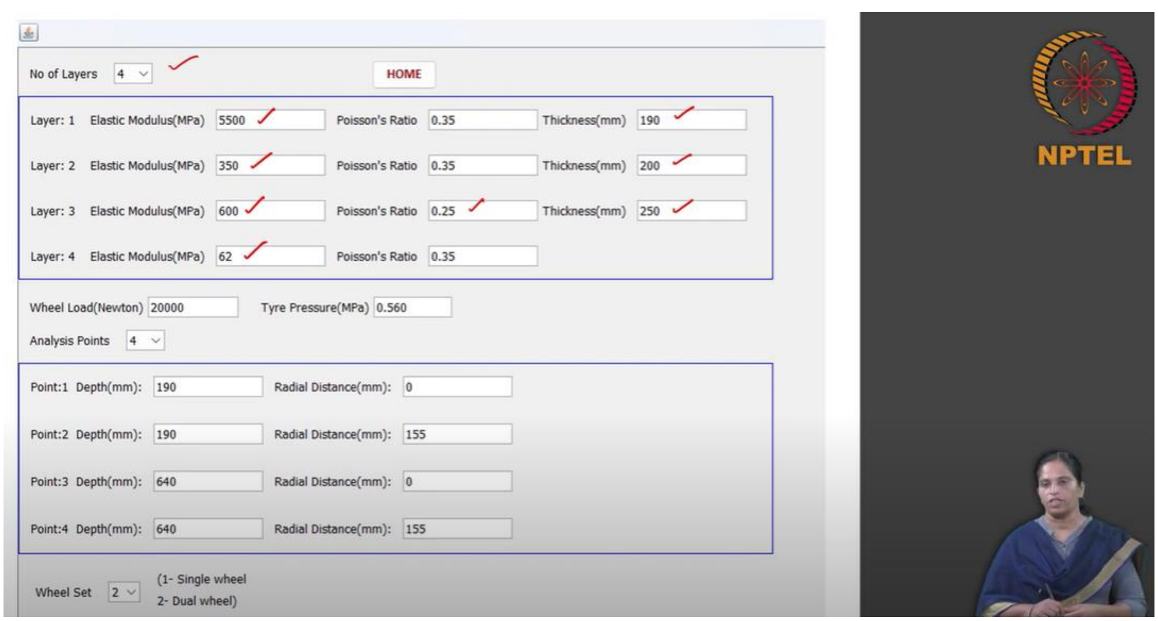

So, we consider it to be a 4 layered structure with 1 layer as a HMA layer of modulus 550 and thickness is 190 mm. Now granular layers of base go 350 MPa with a thickness of 200 and subbase layer is a cement treated layer with a modulus of 600 MPa with a Poisson's ratio of 0.25 and the thickness of 250 mm. So, this rest on a sub grade that is having an effective subgrade modulus of 62 MPa.

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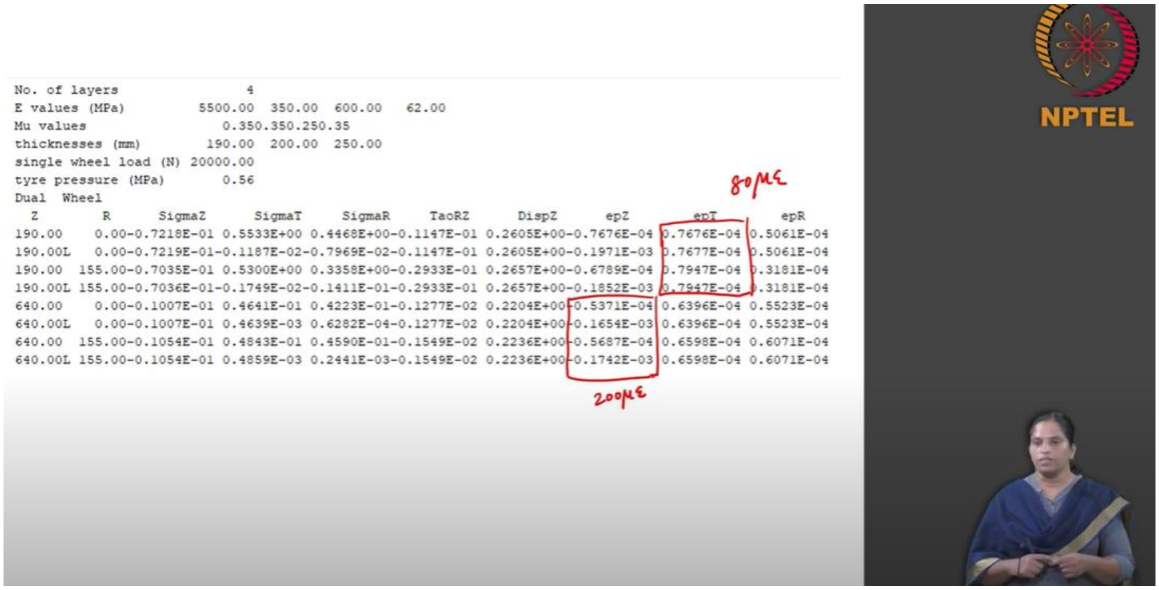

Now if you do this analysis and compute the critical stresses and strain at the interfaces you can see that the tensile strain that induces fatigue damage in a HMA layer to be less than 80 micro strains, vertical compressive strain that induces rutting on the subgrade to be less than 200 micro strain. So, since the strains are within the specified limit for a long life pavement you can call this pavement cross section to be a long life pavement cross section.

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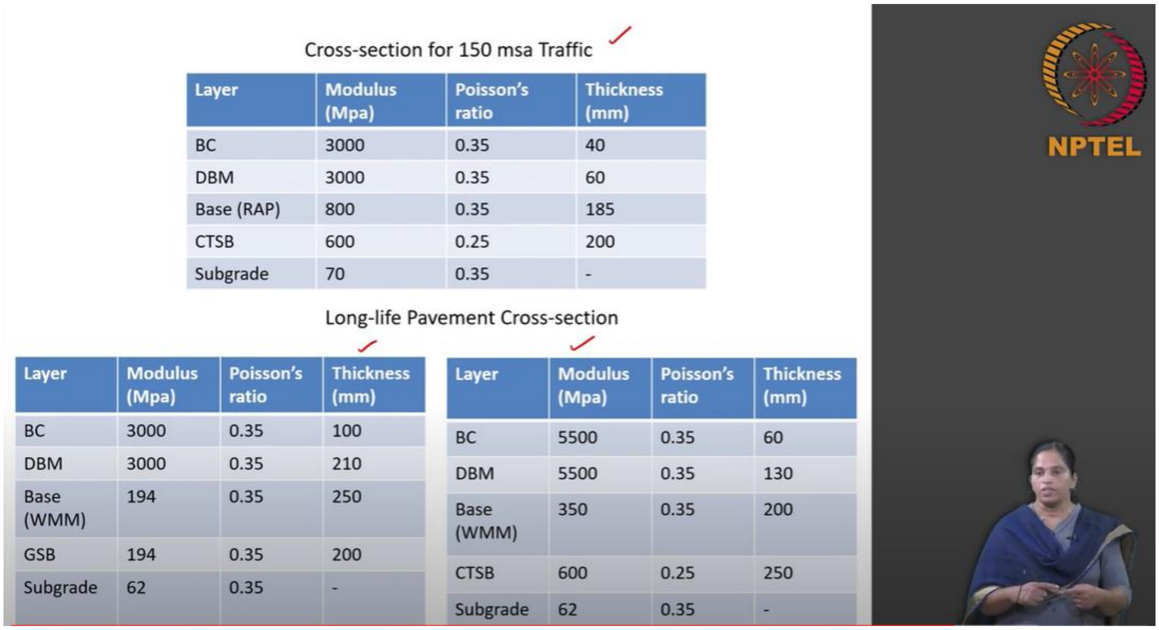

Cross-section for 150 msa Traffic

Layer	Modulus (Mpa)	Poisson's ratio	Thickness (mm)
BC	3000	0.35	40
DBM	3000	0.35	60
Base (RAP)	800	0.35	185
CTSB	600	0.25	200
Subgrade	70	0.35	-

Long-life Pavement Cross-section

Layer	Modulus (Mpa)	Poisson's ratio	Thickness (mm)
BC	3000	0.35	100
DBM	3000	0.35	210
Base (WMM)	194	0.35	250
GSB	194	0.35	200
Subgrade	62	0.35	-

Layer	Modulus (Mpa)	Poisson's ratio	Thickness (mm)
BC	5500	0.35	60
DBM	5500	0.35	130
Base (WMM)	350	0.35	200
CTSB	600	0.25	250
Subgrade	62	0.35	-

This is a 3 different pavement cross sections that we worked out today, one corresponding to 150 msa traffic and other 2 corresponds to long life pavement cross section. So, you can see that the modulus value plays a critical role in the design. So, it is necessary that the modulus value during construction here is to be met when you do a design.

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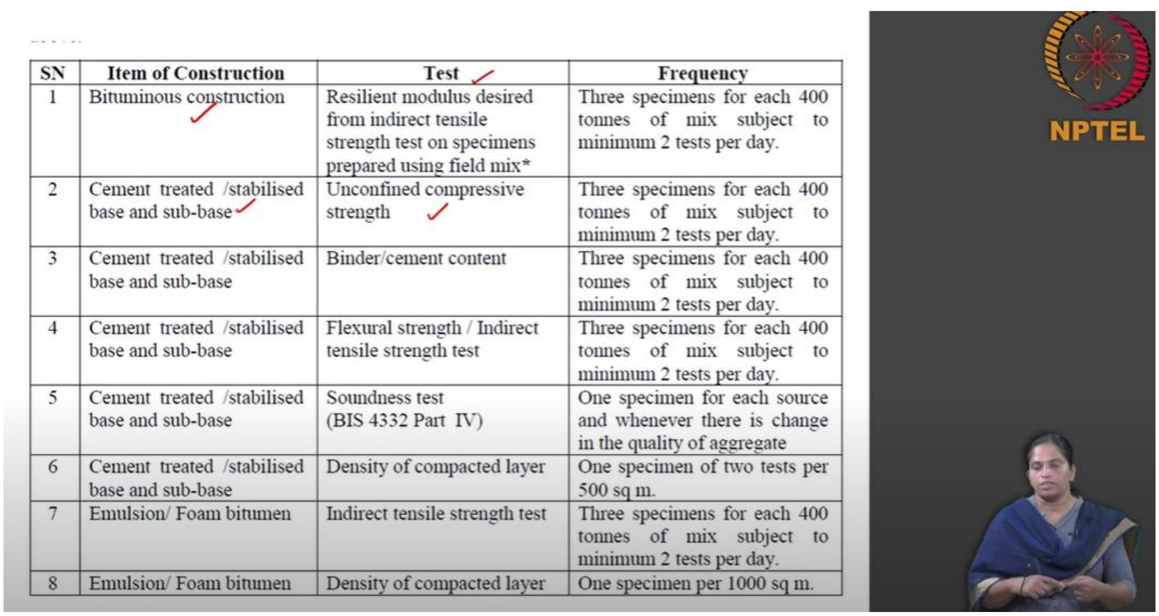

SN	Item of Construction	Test	Frequency
1	Bituminous construction	Resilient modulus desired from indirect tensile strength test on specimens prepared using field mix*	Three specimens for each 400 tonnes of mix subject to minimum 2 tests per day.
2	Cement treated /stabilised base and sub-base	Unconfined compressive strength	Three specimens for each 400 tonnes of mix subject to minimum 2 tests per day.
3	Cement treated /stabilised base and sub-base	Binder/cement content	Three specimens for each 400 tonnes of mix subject to minimum 2 tests per day.
4	Cement treated /stabilised base and sub-base	Flexural strength / Indirect tensile strength test	Three specimens for each 400 tonnes of mix subject to minimum 2 tests per day.
5	Cement treated /stabilised base and sub-base	Soundness test (BIS 4332 Part IV)	One specimen for each source and whenever there is change in the quality of aggregate
6	Cement treated /stabilised base and sub-base	Density of compacted layer	One specimen of two tests per 500 sq m.
7	Emulsion/ Foam bitumen	Indirect tensile strength test	Three specimens for each 400 tonnes of mix subject to minimum 2 tests per day.
8	Emulsion/ Foam bitumen	Density of compacted layer	One specimen per 1000 sq m.

So, IRC suggests a few quality control measures for this. So, like you need to collect the sample during construction and test the modulus value to ensure that the modulus what is transferred to the field is meeting all the design modulus here. So, for a bituminous concrete material, so you collect the specimen that is 3 specimens for each 400 tons of a mix that we use and test the resilient modulus value from the indirect tensile strength test and check whether the field mix is meeting out the design resilient modulus value. In case if you use a cement treated material or any stabilized base course and subbase course, so we need to find out what is an unconfined compressive strength test and check whether this meets the design requirement. So, you have a different test here recommended as a quality control measures to check with what we have a design requirement.

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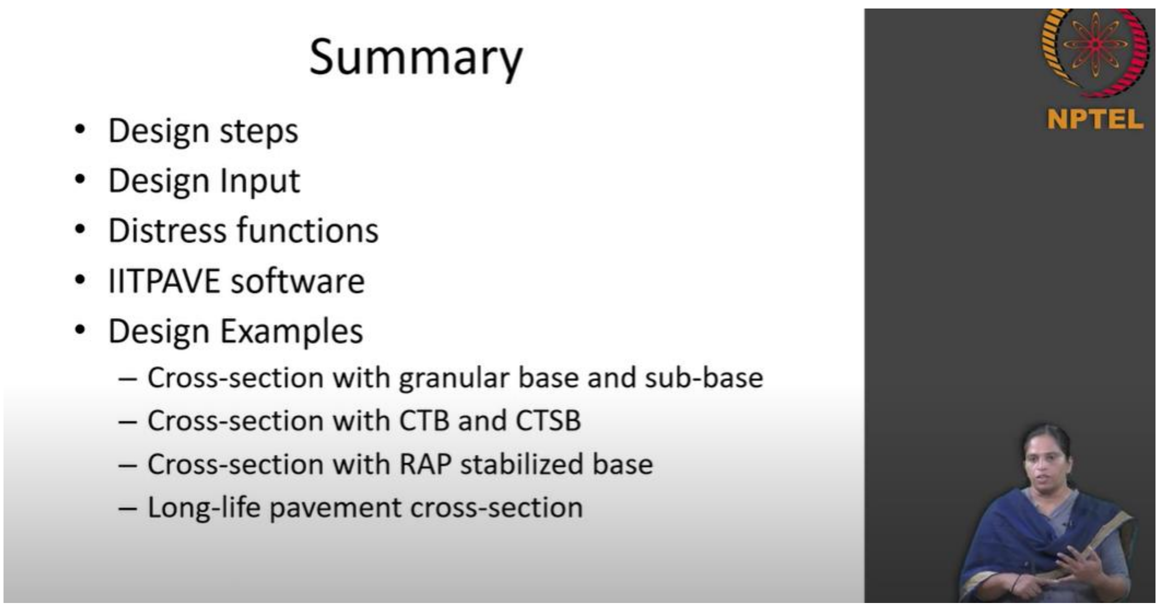

So, now let us summarize what we have seen with an IRC pavement design here. So, we have seen different design steps involved in the design of pavement and we have seen different inputs that goes as a pavement design and we have seen different distress transfer functions that includes distress transfer function corresponding to fatigue damage, rutting and other cement treated base distress.

So, we have seen a demo on an IITPAVE software and we solved a design example for a pavement cross section with a granular base and subbase course. We have seen a cross section with a cement treated base and cement treated subbase course and we have also solved a pavement cross section with a RAP stabilized base binder for 150 msa traffic and we have seen a long life pavement cross sections.

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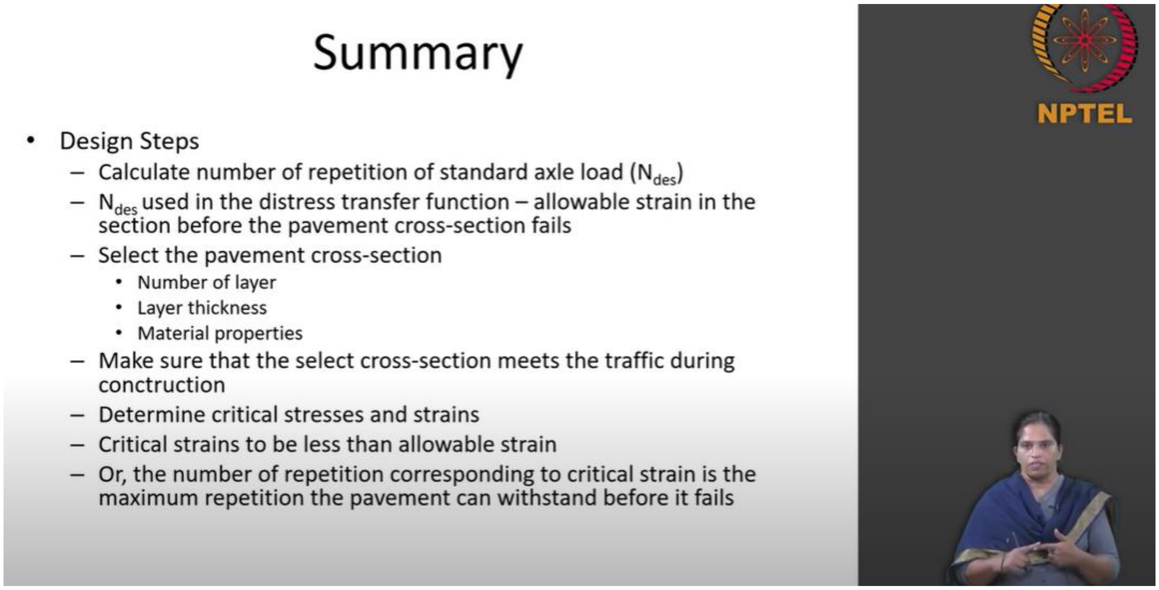

This is the summary of the design step. So, first with the traffic data you calculate the number of repetitions of a standard axle load, IRC designates this as a N_{des} value. This N_{des} value has to be used in the distress transfer function and compute the allowable strain in the section. So, this is the maximum strain up to which we can go for the current given traffic value. Now after working with the traffic data you select the pavement cross section here. The pavement cross section selection includes the number of layer, what should be the layer thickness and what is the material property we give in here. Now when you select these factor you have to make sure that the selected cross section meets the traffic requirement during constructions. So that the sub grade will not fail in rutting or a subbase or a cement treated layer will not fail in fatigue damage during constructions.

So after selecting this layer you find out what is critical stresses and strain using an IITPAVE software and use this critical stresses and strain and check the with the allowable strain value. So the critical strains to be computed should be less than your allowable strain or in other words the number of repetitions corresponding to the critical strain computed is the maximum repetitions the pavement can withstand before the pavement fails. Thank you so much.