Analysis and Design of Bituminous Pavements

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Lecture – 44

Pavement design with CTB

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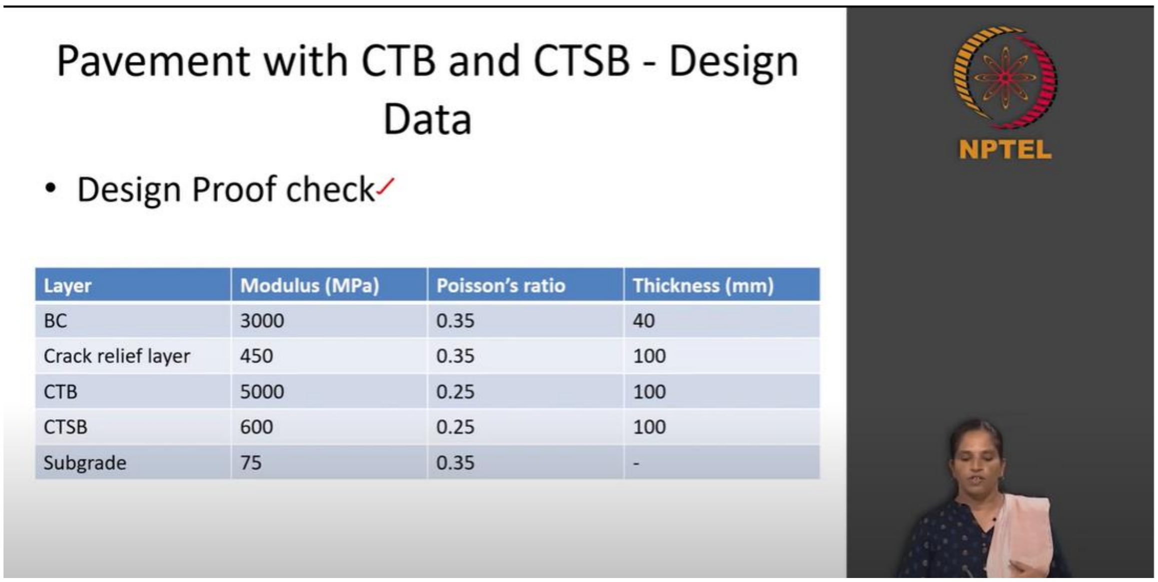

The next design is design of bituminous pavement with cement treated base. So, we will do a design proof check here for an assumed cross section and for any given modulus value here. So, we will assume a pavement cross section with cement treated base and cement treated subbase. So, from bottom if you go, you have a subgrade layer, we will take the modulus of subgrade layer to be 75 MPa. So, above a subgrade layer, we will have a cement treated subbase and modulus of a cement treated subbase using an IRC specification, we will take it as a 600 MPa and cement treated base course, we will take a modulus to be 5000 MPa. So, if you provide a cement treated base course, you need a crack relief layer, there can be 2 types of a crack relief layer, one is a granular crack relief layer or stress absorbent member interface, which is a bituminous mastic prepared using a modified binder and the typical thickness will be about 25 mm.

If you provide stress absorbent member interface that is considered as a non-structural layer. Here we will use granular layer as a crack relief layer. So, the modulus value to be used for the granular layer is 450 MPa. So, we will stick to the IRC specification here. So, above a crack relief layer, we will use one layer of bituminous concrete of modulus 3000 MPa. So, these are the Poisson's ratio value recommended by IRC 37 for different layers. So, let us stick to the same Poisson's ratio value. So, these are the thickness assumed base course of 40 mm thickness, crack relief layer of 100 mm thickness, cement treated base course of again 100 mm thickness, subbase course is 100 mm thickness, subgrade is of an infinite thickness and whatever modulus you have here is an effective modulus.

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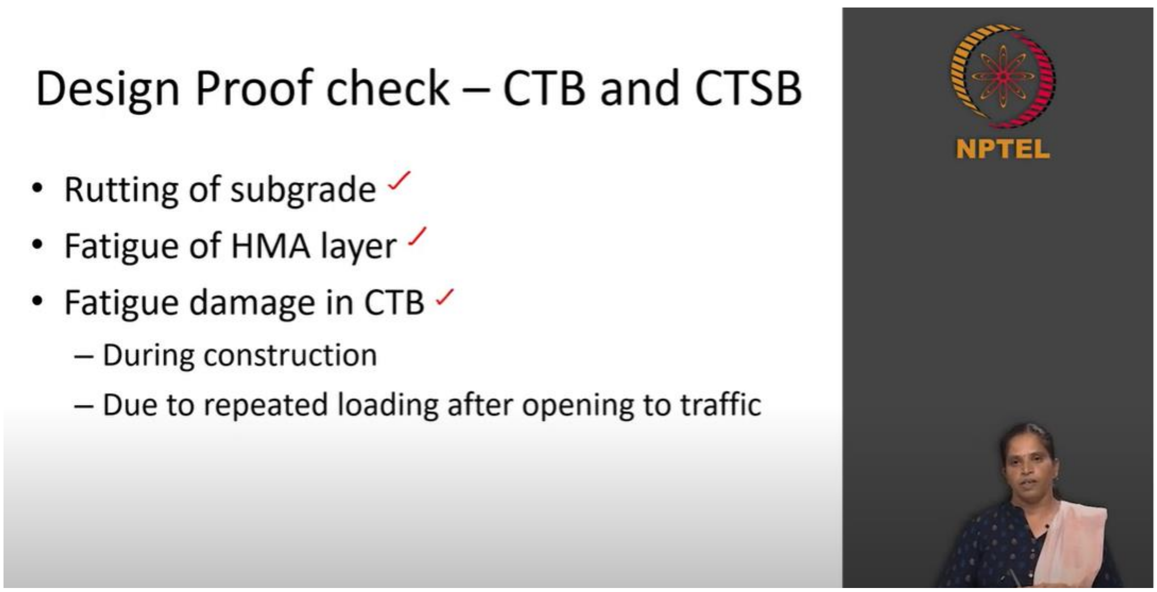

So, now if you do a proof checking for this cross section with that is with a cement treated base and cement treated subbase, you need to check for rutting on the subgrade layer, you need to check for fatigue damage on a HMA layer and you also need to check for a fatigue damage in a cement treated base layer. So, here again, if it is a cement treated base layer, it can damage during construction process itself. So, damage that happens during construction and damage that happens due to repeated loading after opening it to traffic. So, these are the parameters which we need to check. So, we know that rutting on the subgrade layer is induced by vertical compressive strain at the top of a subgrade layer and fatigue damage on a HMA layer is induced due to horizontal tensile strain at the bottom of HMA layer. So, you need to compute these values.

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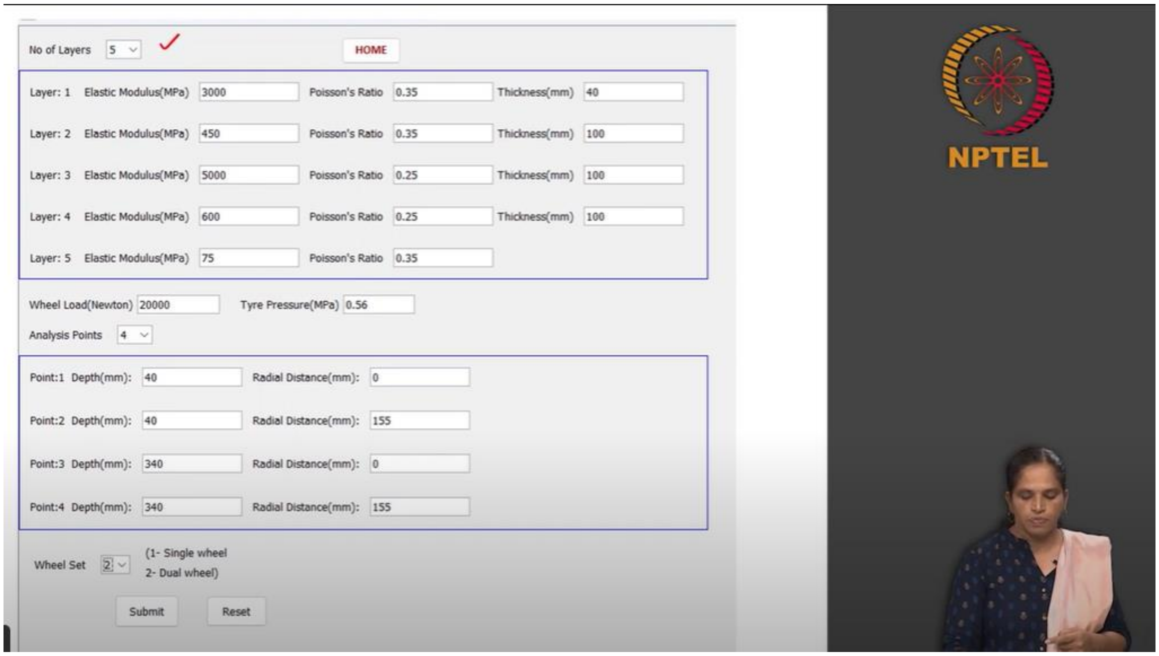

So, this is now typically a 5 layered structure with the top layer as a bituminous concrete layer. So, you have an elastic modulus of 3000 MPa. Second layer is a granular crack relief layer that has a modulus of 450 MPa. So, third layer is a cement treated base course with a modulus of 5000 MPa. Fourth layer is a cement treated subbase course with a modulus of 600 MPa and fifth layer is a subgrade layer with the effective modulus of 75 MPa. So, Poisson's ratio for a cement treated layers are considered to be 0.25, other layers are considered as 0.35. So, we will give the assumed thickness here for each layer and this layer is subjected to a 20 kN load with a tyre pressure of 0.56. Though it is a cement treated base here we are subjecting the loading on the top surface which is flexible here. So, I just considered the tyre pressure to be 0.56 here. So, we will determine strain at 4 points, 2 at interface of bituminous layer and base layer and 2 points at the top of a subgrade layer. So, at the bottom of a bituminous layer 40 mm depth at the radial distance of 0 and at the radial distance of 155 mm. So, at the top of a subgrade layer it is 340 and at the radial distance of 0 and 155 mm. So, we will use a dual wheel load when you submit it and compile it, this is the result you will get it.

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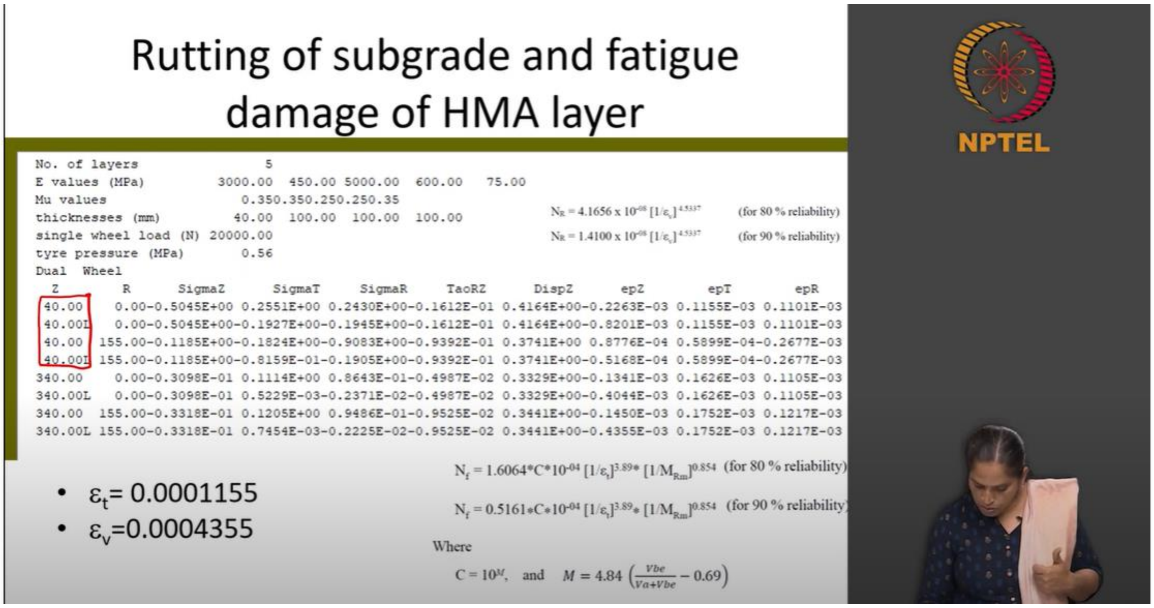

Now we will identify what is tensile strain that causes fatigue damage in a HMA layer. So, HMA layer corresponds to this 2 points, this 4 points and it is a tensile strain. So, it is positive here, now tensile strain positive which corresponds to ε_t. So, a maximum value from this number is considered as ε_t, so which is 0.0001155. So, this is the strain that induces fatigue damage in the asphalt layer.

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

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

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

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

Where,

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

Now the second interface which we used here which is at the top of a subgrade layer, we find out what is a vertical compressive strain on this. So, maximum of these number is ε_v here, so which is 0.0004355. So, we will use a 90% reliability equation here and you can find out what is N_R and N_f.

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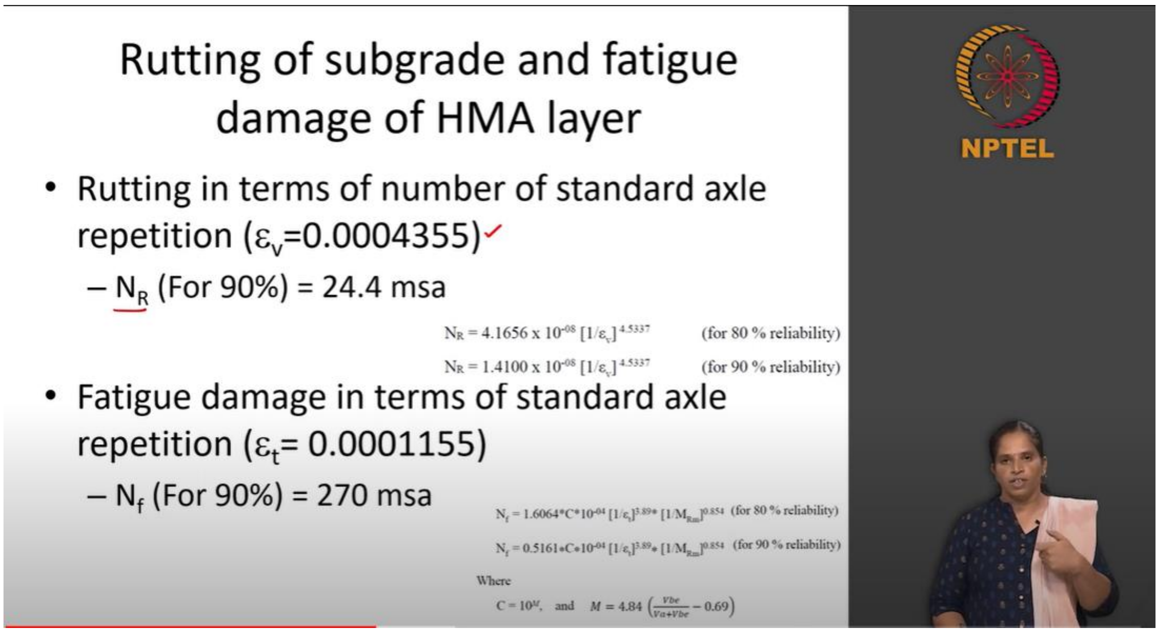

So, if you find a 90% reliability equations based N_r value using this strain at the top of a subgrade layer, you will see N_R to be 24.4 msa. So, what does it mean here is if the pavement subgrade before it fails in rutting it can cater to a traffic of 24.4 msa. So, corresponding to the fatigue damage strain ε_t, the N_f value is computed to be 270 MPa. So, these are corresponding to 90% reliability functions. So, the critical failure here is a rutting subgrade, but it will cater up to the traffic of 24.4 msa.

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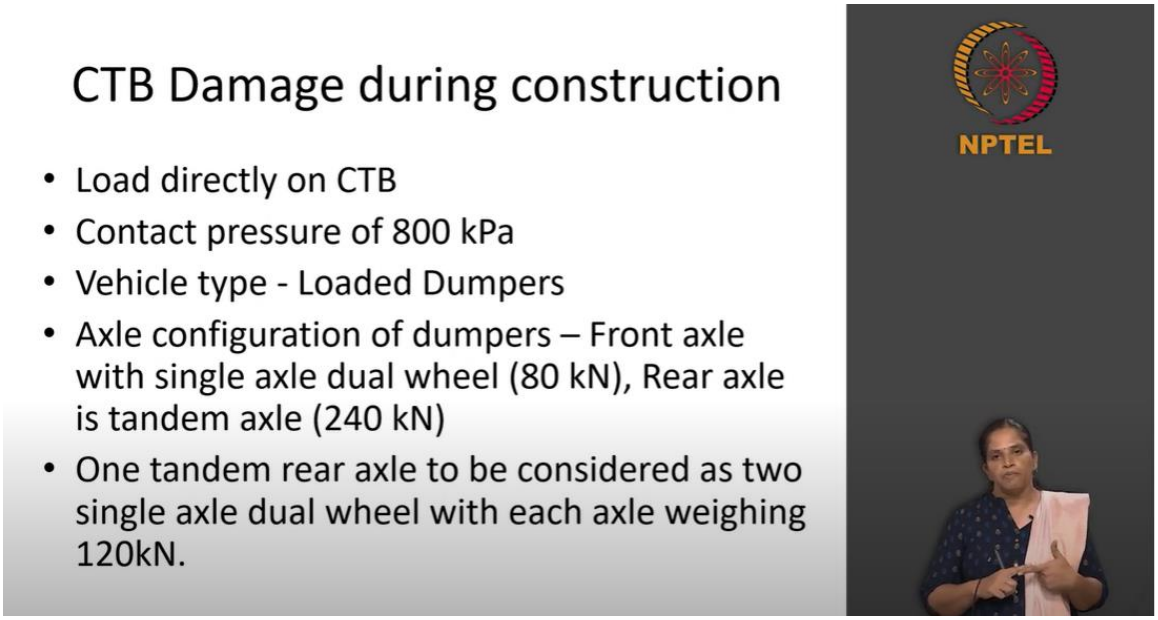

Now the next analysis is cement treated base layer damage analysis that happens during construction process. So, during construction or during the stage of construction, the load is going to directly act upon a cement treated base here and keep in mind that cement treated base is a rigid plate here. So, we use a contact pressure of 800 kPa for the analysis. So, the vehicle type that is going to act on the pavement is it is just a loaded dumper. So, now the axle configurations of this dumpers will be critically a front axle with a single axle single wheel, you can consider it to be 80 kN weight and rear axle is a tandem axle, typically 240 kN weight. As per IRC guidelines, we consider tandem axle to be 2 repetitions of single axle. So that is 2 repetitions of 240 divided by 2 is 120 kN. So, 2 repetitions of single axle weighing 120 kN.

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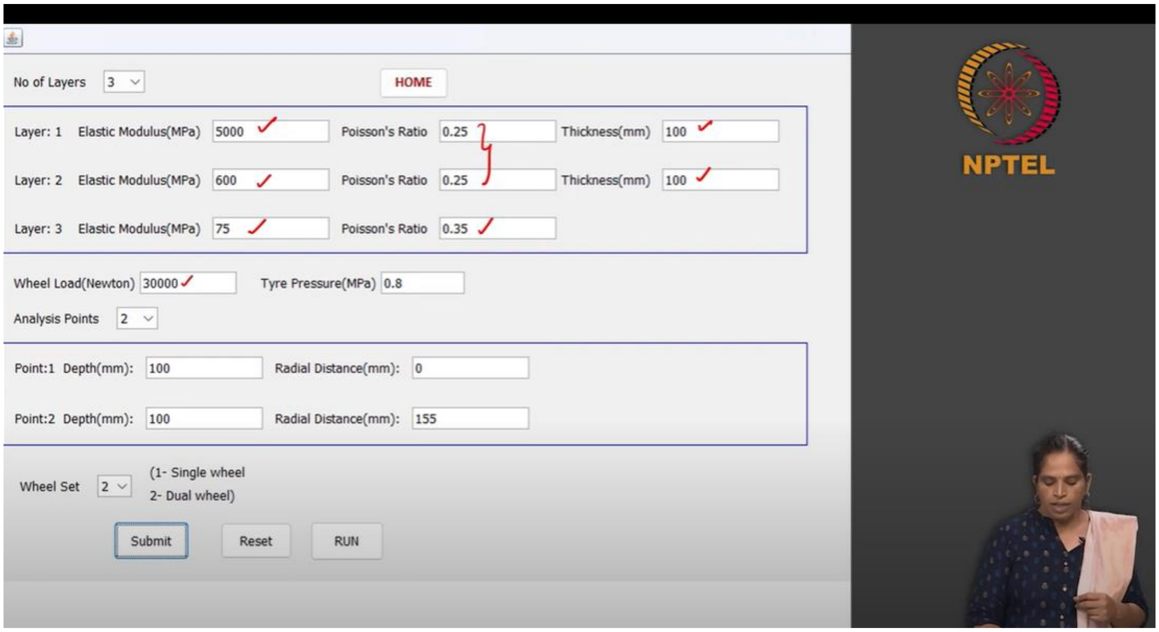

Now, so, we are going to subject this axle on the cement treated base. So, we have only subgrade layer, subbase layer and cement treated layer. So, first layer is going to be a cement treated layer, second layer is subbase layer and the third layer is subgrade layer. So, Poisson's ratio of a cement treated layers are 0.25 granular or subbase layer is 0.35. So, thickness is this is what we have assumed and we are subjecting it to the wheel load of 30 kN. So, this wheel load corresponds to an axle load of 120 kN that we have seen. So, 120 divided by 4 wheels, so that gives you 30 kN each wheel load. So, tyre pressure this being a rigid we consider 800 MPa. Now, we will consider 2 analysis point and exactly at the interface of a base and the subbase layer. So, the depth is 100 mm and we will consider a radial distance of 0, 1 and other is at 155 mm. So, we are going to use a dual wheel here. So, use a number 2 here and once you give all this input submit and run it this is the result you will get it.

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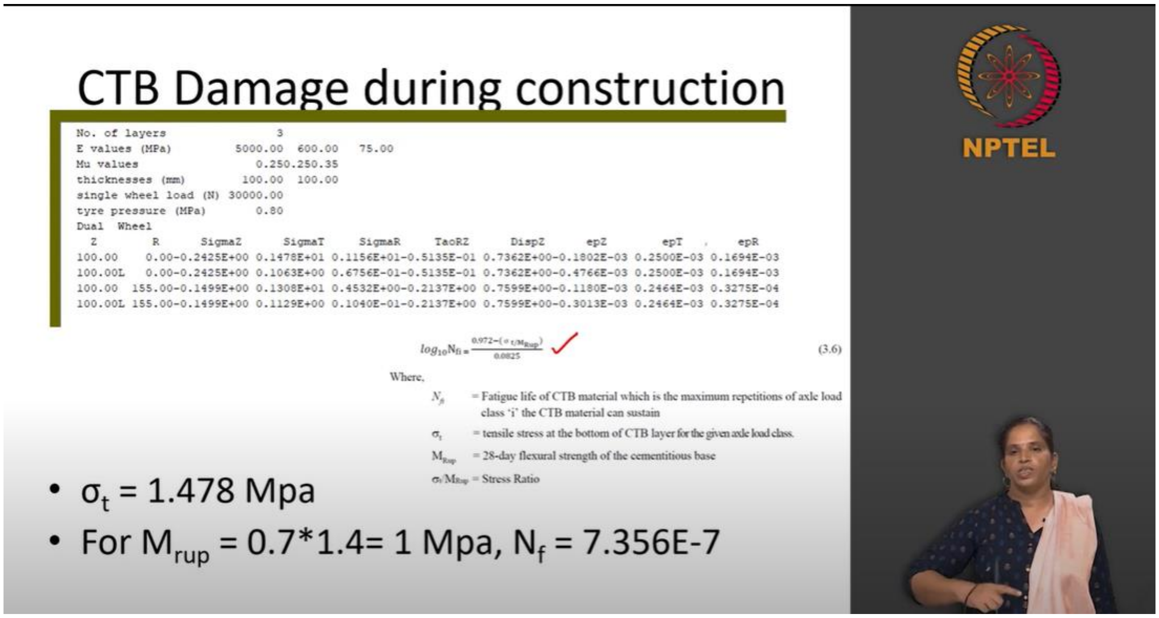

So, we will use a MEPDG expression for the computation of a damage here. And in this MEPDG expression it is a stress dependent and not a strain dependent like previous rutting and HMA fatigue damage.

$$\log_{10} N_{fi} = \frac{0.972 - \left(\sigma_t / Mrup\right)}{0.0825}$$

Where,

N_{fi} = Fatigue life of CTB material which is the maximum repetitions of axle load class 'i' the CTB material can sustain

σ_t = tensile strain at the bottom of the CTB layer for the given axle load class

$Mrup$ = 24-day flexural strength of the cementitious base

$\sigma_t / Mrup$ = stress ratio

So, the tensile stress at the cement treated base layer is going to induce this damage here. So, the tensile stress maximum at the base layer that is maximum out of this 4 here is going to induce a damage. So, the value here is 1.473 MPa. So, this is σ_t value. So, now, I am going to use a σ_t value to be this modulus of rupture as per the equation it is 28 day flexural strength of a cementitious bed, but this is during construction. So, we open it if you open it to a traffic after 7 days of initial curing. So, the modulus of rupture will be 70% of 28-day flexural strength. So, if you take 70% that is 0.7 of 1.4 you will get it to be nearest 1 MPa. So, you can substitute a modulus of rupture to be 1 MPa and for the stress of 1.478 MPa, you will get the number of repetitions of load of 120 kN to be this. So, it is less than 1. So, this is the maximum repetitions that 100 mm cement treated base course can withstand before it fails in fatigue damage.

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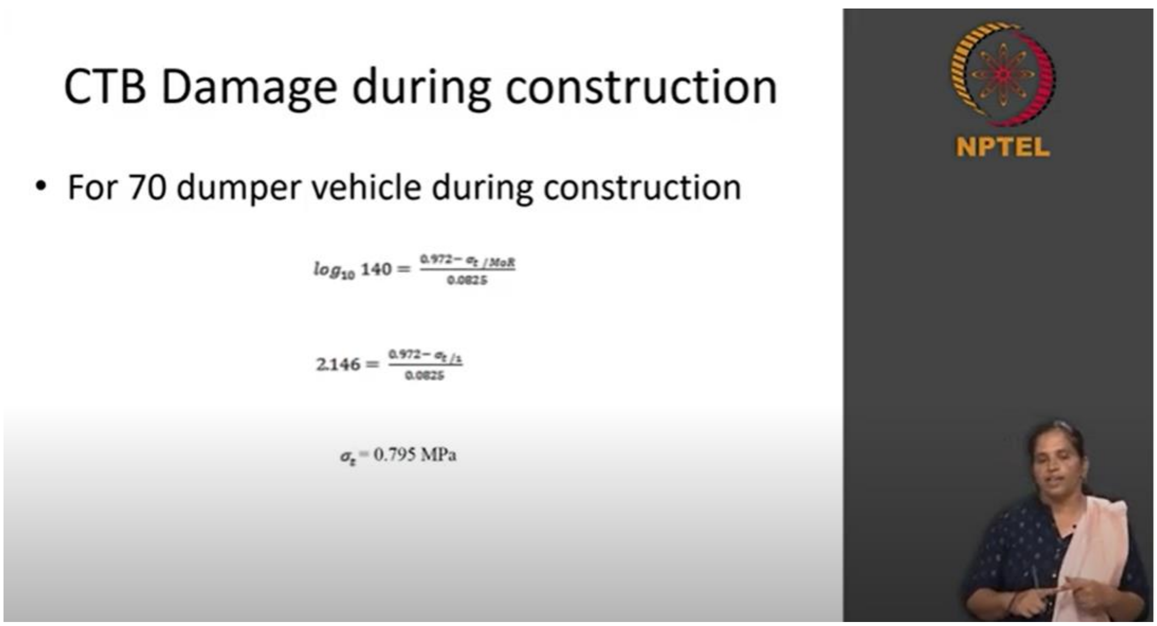

So, if you want to increase these number, generally it will be like nearing 70 repetitions of tandem axle. So, if it is a 70 repetitions of a standard axle, it will be 70×2 that is 140 repetitions of a single axle. Now, if you want to compute this exact stress value for the 140 repetitions of a dumper axle, you can just substitute in this expression and find what is the σ_t value and you find out the σ_t value to be 0.795 MPa. So, if you want a cement treated base to take care of 70 repetitions of a dumper vehicle, you need to restrict the stress at the cement treated base to 0.795 MPa. So, for that what should be the thickness? So, you have to do it only by a trial.

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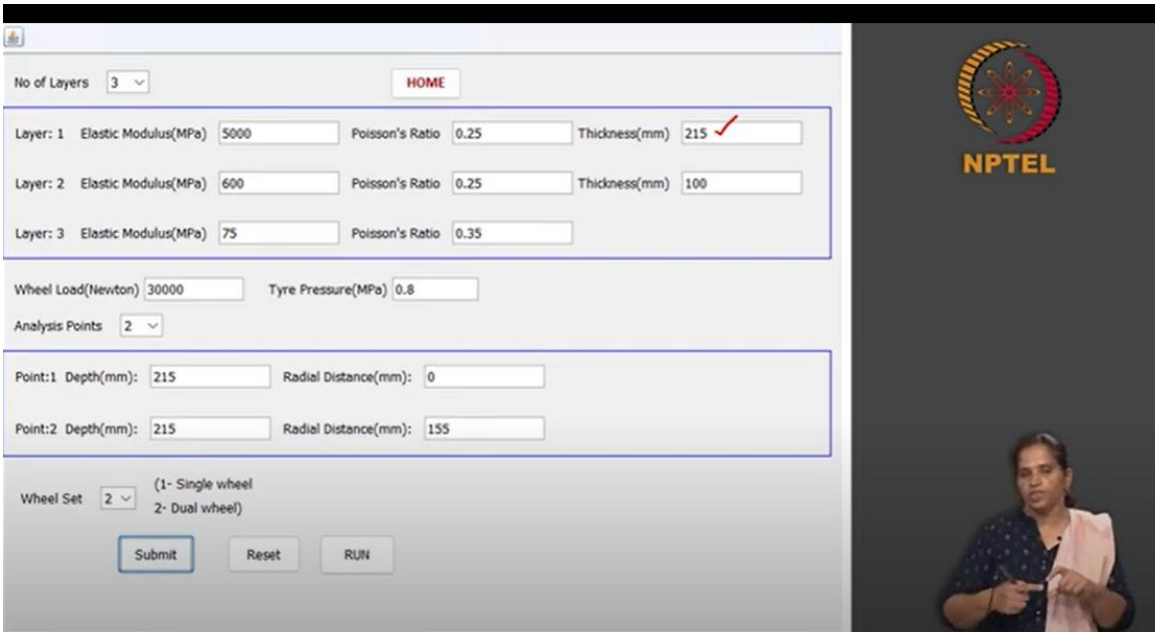

So, I have tried it for a base course of thickness 215 mm. So, other parameter remains the same, the thickness of a base course was increased to 215 mm. So, the depth exactly where we need stress and strain is at the interface that is 215 mm. So, for a 2-wheel load when you submit and run the program, this will be the result you get it.

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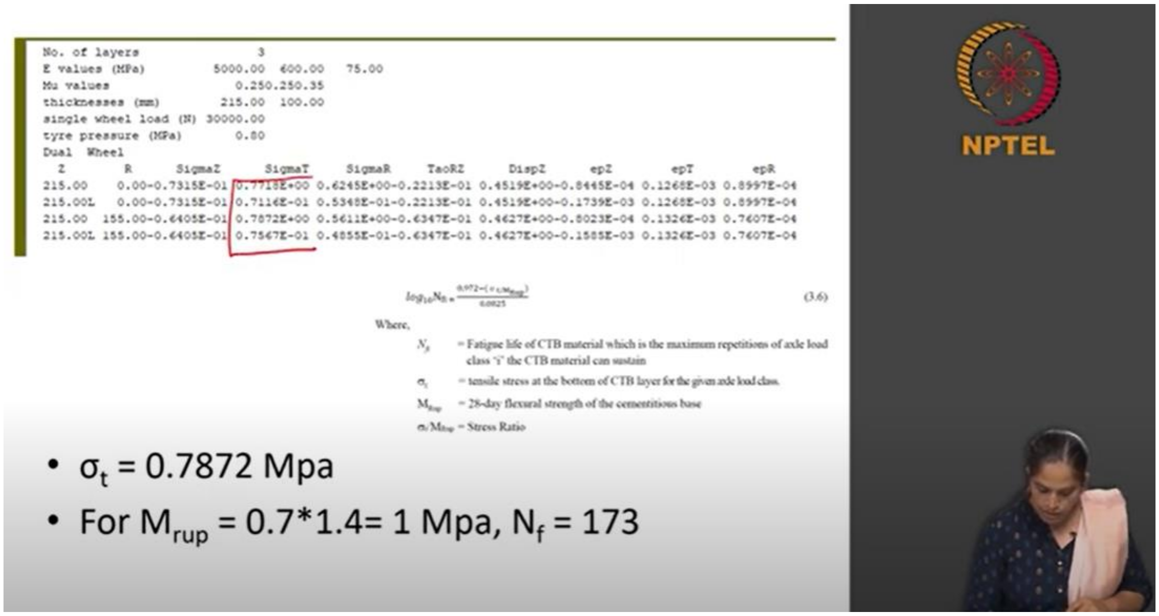

Now σ_t value here you can see to be less than what we needed. So, for this specific σ_t value will cater to a traffic of 173 repetitions of 120 kN load. So, you need a minimum base course thickness of 215 mm.

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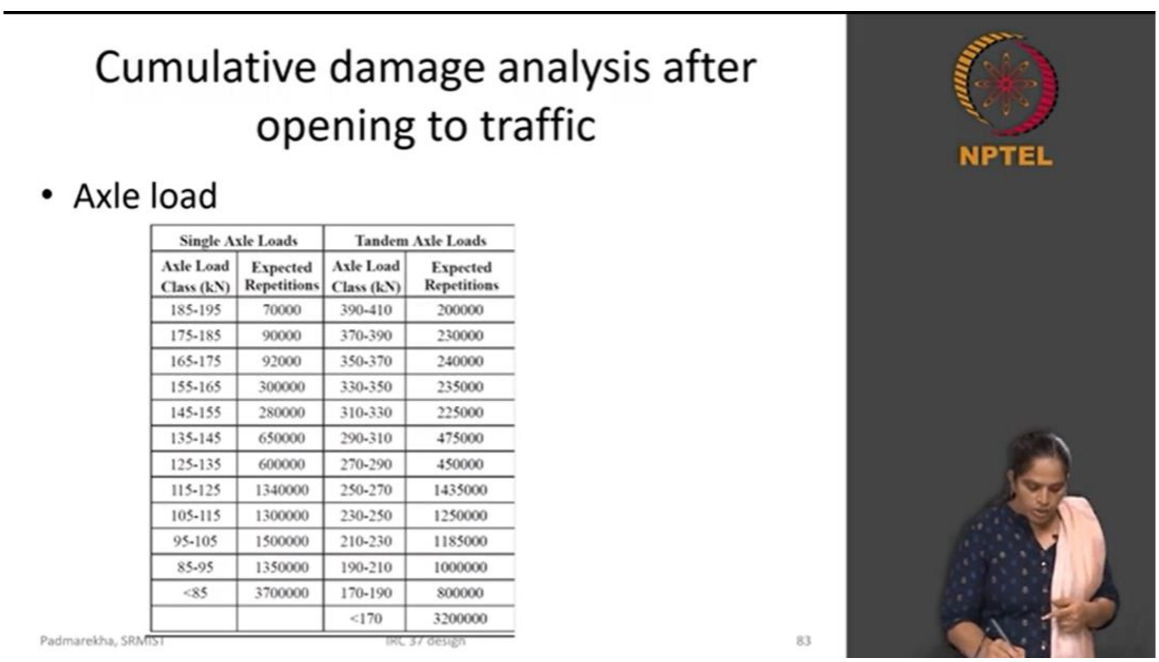

The next analysis is a cumulative damage analysis due to a repeated traffic load repetition. So, for this we need an axle load data, grouped axle load data. Let us use this axle load data to see how to do a cumulative damage analysis. So, now when you closely look into this axle load data, it has only 2 types of axle means I have just considered only 2 types of axle for example, here, it does not mean that the road will not have a tandem axle or we will not consider a tandem axle for the computation of cumulative damage. We consider all type of axle here for the computations.

So, you have a single axle load, you can see that the single axle loads are grouped at the interval of 10 kN and you have a number of repetitions or expected repetitions for each load group of a vehicle. So, you can also see the tandem axle loads are grouped at an interval of 20 kN and you have a number of repetitions of each load group given here. So, we will see how to use this data and calculate the cumulative damage of cement treated base.

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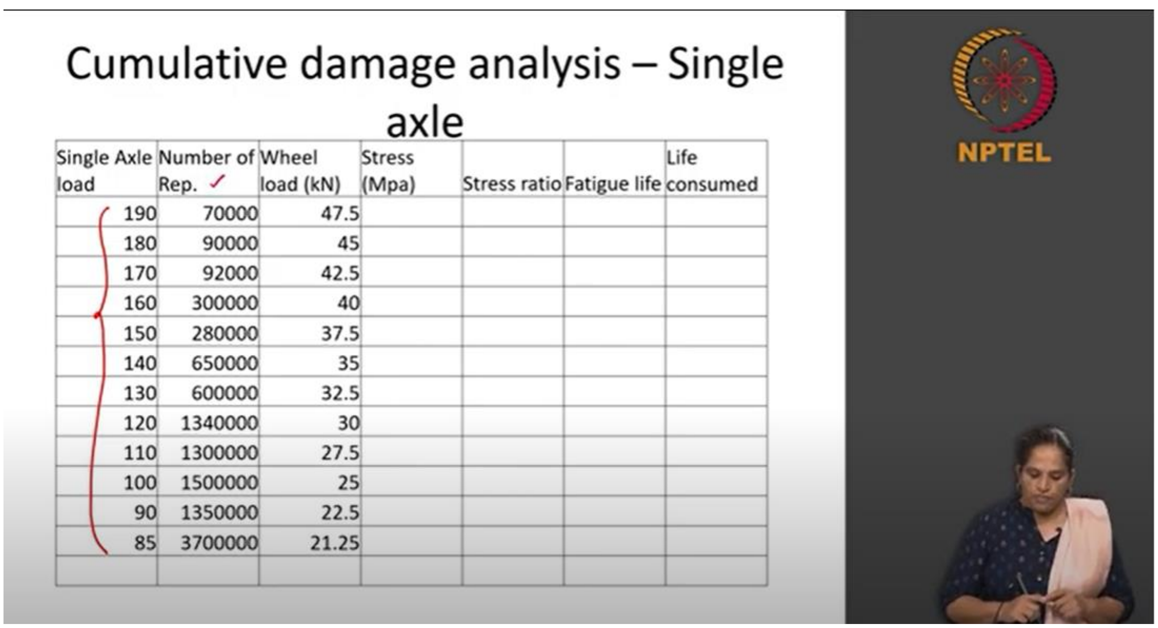

Single Axle load	Number of Rep.	Wheel load (kN)	Stress (Mpa)	Stress ratio	Fatigue life	Life consumed
190	70000	47.5				
180	90000	45				
170	92000	42.5				
160	300000	40				
150	280000	37.5				
140	650000	35				
130	600000	32.5				
120	1340000	30				
110	1300000	27.5				
100	1500000	25				
90	1350000	22.5				
85	3700000	21.25				

So, this is a data just taken a middle value for this strain analysis in the grouped data. From this middle value, the number of repetitions of the single axle value is already given here. So, if this is a single axle dual wheel, if this is a total axle load, so, since it is a dual wheel, it will have 4 wheels, so divided by 4 will give you what is the total wheel load. So, for each of these wheel load, we are going to compute the stress using IITPave software.

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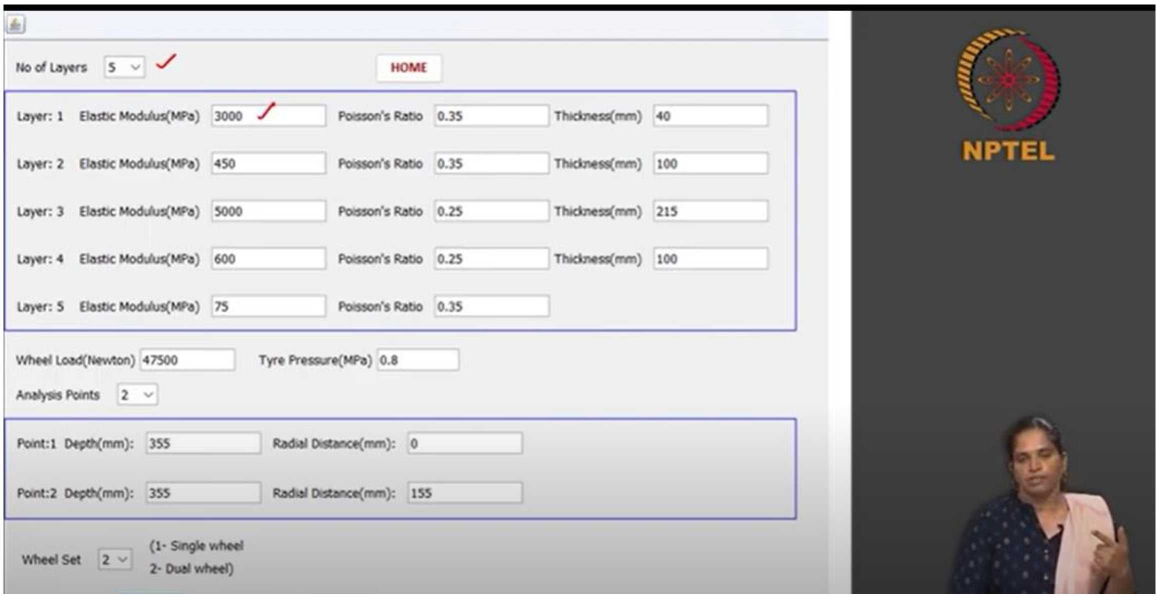

So, this is again a 5 layered structure, because this is after completion of construction. So, it is considered as a 5 layered structure, the top is a BC layer, the second layer is a crack relief layer, third layer is cement rated base, fourth layer is cement treated subbase and fifth layer is a subgrade layer and the effect thickness of each layer is here. Now, you see that we have considered the cement rated base of thickness to 215 mm, this is after verification of a damage of a cement treated base that occurs during construction.

Now, we consider a wheel load first of 47.5 kN for the tire pressure of 0.8 and we will absorb stresses and strains at 2 different points that is at the base of a cement rated layer that is where we need σ_t base of a cement rated layer. So, it is going to be 215 + 100 + 40, so it is going to be 355. So, we will compute at a radial distance of 0 and at a radial distance of 155. Now, when you see the stress value, this will be the critical stress at this location.

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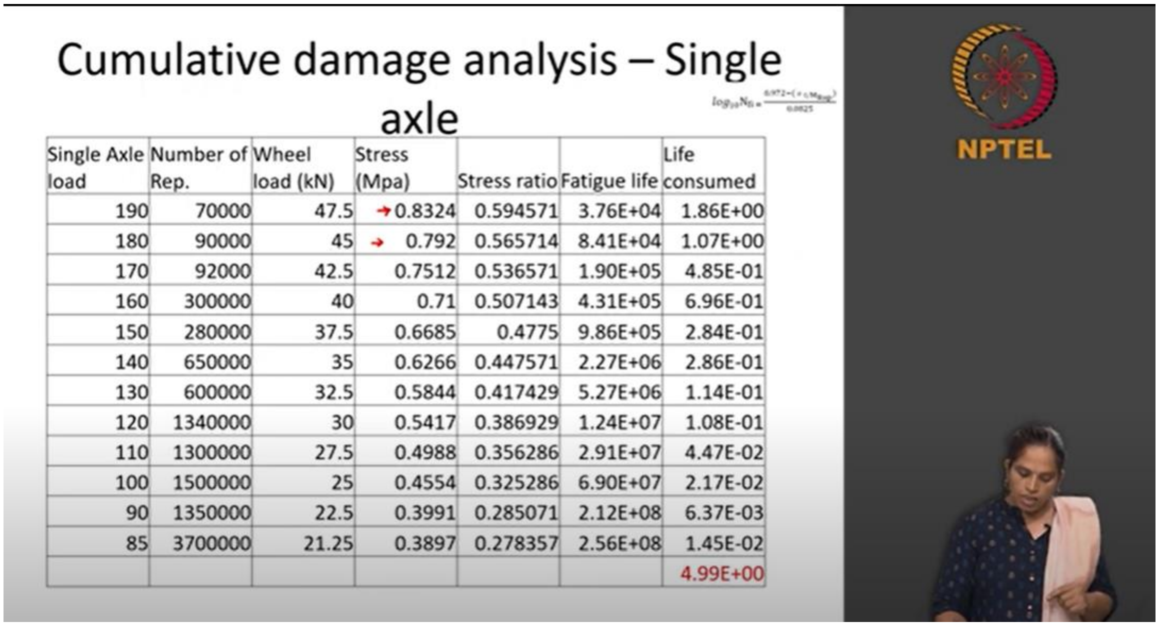

Single Axle load	Number of Rep.	Wheel load (kN)	Stress (Mpa)	Stress ratio	Fatigue life	Life consumed
190	70000	47.5	0.8324	0.594571	3.76E+04	1.86E+00
180	90000	45	0.792	0.565714	8.41E+04	1.07E+00
170	92000	42.5	0.7512	0.536571	1.90E+05	4.85E-01
160	300000	40	0.71	0.507143	4.31E+05	6.96E-01
150	280000	37.5	0.6685	0.4775	9.86E+05	2.84E-01
140	650000	35	0.6266	0.447571	2.27E+06	2.86E-01
130	600000	32.5	0.5844	0.417429	5.27E+06	1.14E-01
120	1340000	30	0.5417	0.386929	1.24E+07	1.08E-01
110	1300000	27.5	0.4988	0.356286	2.91E+07	4.47E-02
100	1500000	25	0.4554	0.325286	6.90E+07	2.17E-02
90	1350000	22.5	0.3991	0.285071	2.12E+08	6.37E-03
85	3700000	21.25	0.3897	0.278357	2.56E+08	1.45E-02
						4.99E+00

Now, when you compute the stress value at the bottom of a cement rated base for the wheel load of 45, you can see that the stress value will be 0.792. So, each one is one analysis here, you compute the value of σ_t. Now, for a modulus of rupture value M_{RUP} of 1.4, you can compute a stress ratio σ_t /modulus of rupture if you know the σ_t value and this is the stress ratio value. Now, substitute the stress ratio value here in this expression, you will get the N_{fi} value.

$$\log_{10} N_{fi} = \frac{0.972 - \left({}^{\sigma_t}/_{Mrup}\right)}{0.0825}$$

So, number of repetitions for fatigue life computed for different load groups to be this. Now, we compute this life consumed for each group by taking a ratio of number of repetitions of that particular axle group and particular load group that is 70000 divided by N_f value, which is 3.76E4, we get the total life consumed by this specific load group and this specific axle. So, when you compute a fine life consumed for all load groups and you sum it up, so this will be the final total life consumed by single axle group. So, we expect this summation to be less than 1.

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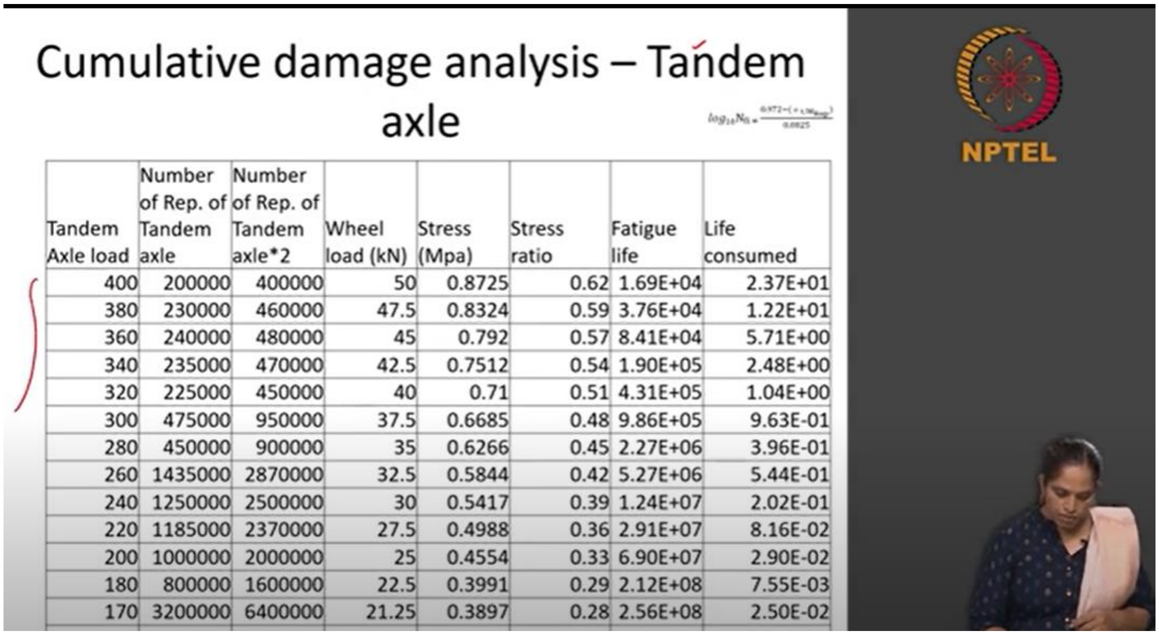

Tandem Axle load	Number of Rep. of Tandem axle	Number of Rep. of Tandem axle*2	Wheel load (kN)	Stress (Mpa)	Stress ratio	Fatigue life	Life consumed
400	200000	400000	50	0.8725	0.62	1.69E+04	2.37E+01
380	230000	460000	47.5	0.8324	0.59	3.76E+04	1.22E+01
360	240000	480000	45	0.792	0.57	8.41E+04	5.71E+00
340	235000	470000	42.5	0.7512	0.54	1.90E+05	2.48E+00
320	225000	450000	40	0.71	0.51	4.31E+05	1.04E+00
300	475000	950000	37.5	0.6685	0.48	9.86E+05	9.63E-01
280	450000	900000	35	0.6266	0.45	2.27E+06	3.96E-01
260	1435000	2870000	32.5	0.5844	0.42	5.27E+06	5.44E-01
240	1250000	2500000	30	0.5417	0.39	1.24E+07	2.02E-01
220	1185000	2370000	27.5	0.4988	0.36	2.91E+07	8.16E-02
200	1000000	2000000	25	0.4554	0.33	6.90E+07	2.90E-02
180	800000	1600000	22.5	0.3991	0.29	2.12E+08	7.55E-03
170	3200000	6400000	21.25	0.3897	0.28	2.56E+08	2.50E-02

Now, you can see a cumulative damage analysis for a tandem axle. So, tandem axle again, it is the mid value of all the load given here and this is a number of repetitions of a tandem axle. So, we consider one tandem axle to be 2 times the single axle. So, we multiply this by 2 to get the number of repetitions of a single axle. So, this is a total tandem axle load of 400 kN. Now, if you need a wheel load, single wheel load divided by 8 because you have 8 wheels there, so you will get a single wheel load. Now, for this specific single wheel load, if we use IITPAVE software or KENPAVE software, you can find out what is the stress at the base of a cement treated layer. So, now you will get this to be the stress. Now, knowing the modulus of rupture, you can compute the stress ratio and using this equation, you can calculate the N_{fi} value which is the fatigue life. Now, taking the ratio of this fatigue life with N value number of repetitions, you will get the total life consumed.

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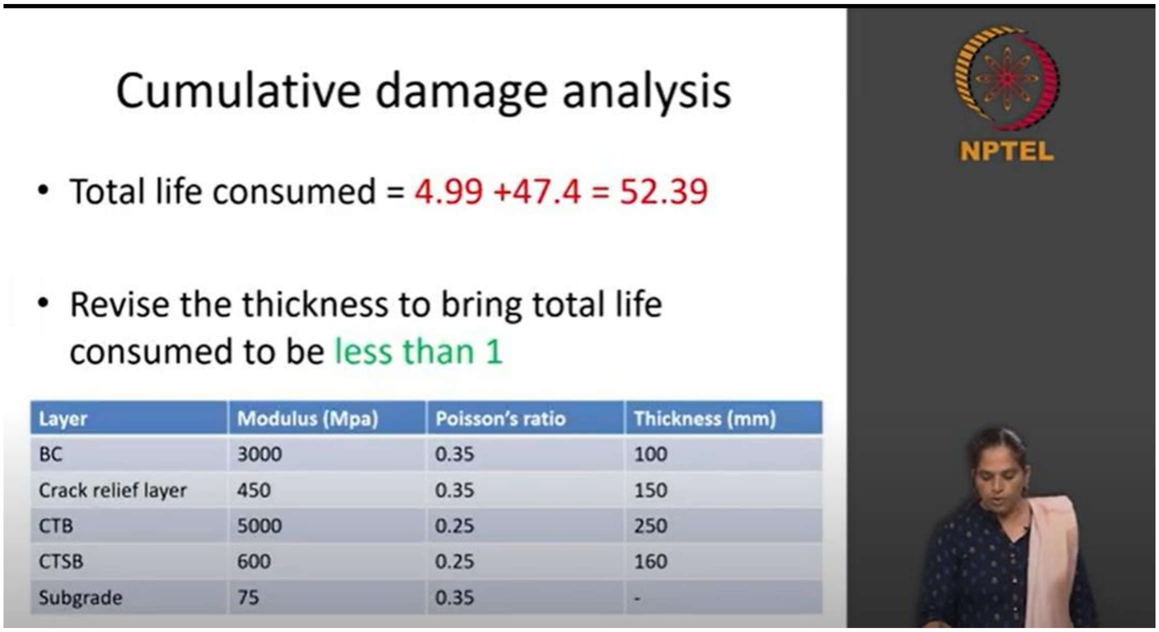

Now, sum this total life consumed for all the load groups, you will get the summation here. So, the final life consumed considering all the load group that is single axle and tandem axle comes out to be 52.39 in this case, but this is the total life consumed by the given cross section, but we want to restrict this number to be less than 1. So, for restricting this number to be less than 1, now we need to increase the thickness of different layer and try and to reduce this to be less than 1. You can try with this thickness and check it out whether this total life consumed comes to be less than 1. If it comes to be less than 1, so whatever thickness we assumed here is good enough to prevent a cumulative damage of a cement treated base layer.