Analysis and Design of Bituminous Pavements

Dr. J Murali Krishnan

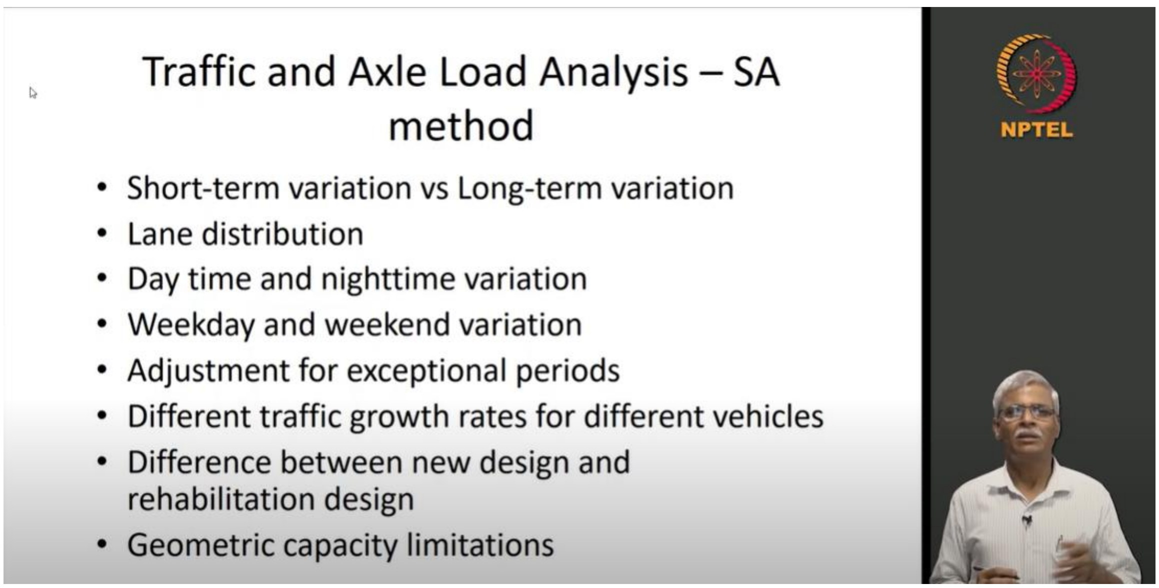
Department of Civil Engineering

Indian Institute of Technology, Madras

Lecture - 49

Overview of Mechanistic-Empirical Pavement Design Methods - South Africa - Part III

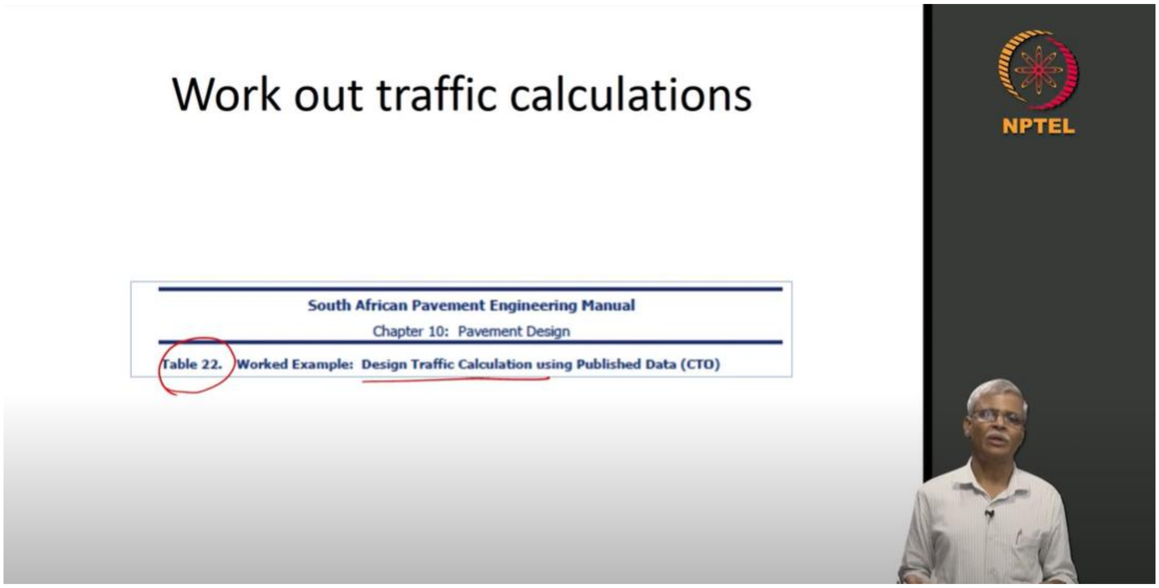
(Refer Slide Time: 00:19)



So, let us continue our discussion on the South African method of pavement design and we will conclude it in this particular lecture. So, as I was mentioning we are talking in terms of traffic and axle load analysis in terms of short-term variation as well as long term variation. The interesting issues related to lane distribution, daytime and night time variations, weekday and weekend variations, exceptional periods I explained to you in the last lecture and similarly different growth rate and this is where the students should pay close attention. If you are going to consolidate all the traffic, all the vehicles under one head, what I would call as average truck factor or what you would call as vehicle damage factor, what can really happen, the individual traffic growth rates that you might see for different vehicles get completely generalized. So, that is something that you do not want to do and of course there is a big difference between the new design and the rehabilitation design and as I mentioned yesterday again in the last lecture the geometric capacity limitation also plays a critical role.

This is a manual that is available for download if you go search for South African pavement engineering manual, you will be able to download it and I have not given the full details here. You go search for it, there is a design traffic calculation. So, a worked-out example is given. What my suggestion to you is take the axle load data which has already been some portion of the axle load data that has already been circulated to you and try to see whether you can work out what is the design traffic calculation as far as the South African method is concerned.

(Refer Slide Time: 02:03)

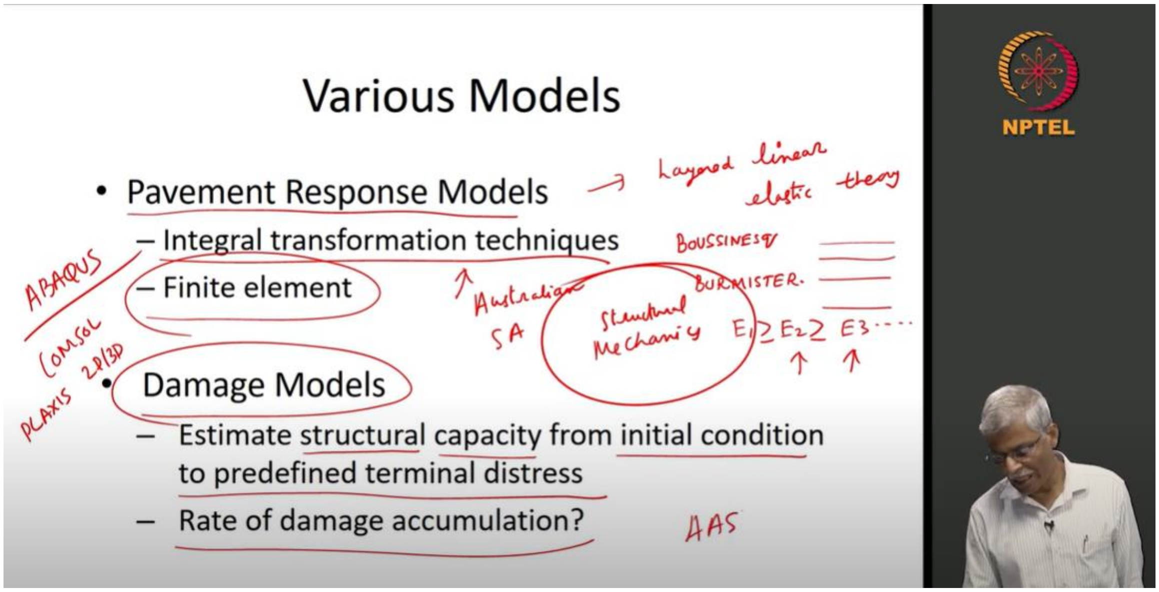


Now, come to the basic design. So, we talked about traffic, we talked about the cross section, the balanced section, issues related to inverted pavement and so on and so forth. Now, what is the general framework and when you see the general framework there is not much difference between what we have discussed at the starting of our course that there is a pavement structure, there are the resilient properties as well as the strength properties. So, the resilient properties go for design, the strength properties go for damage or distress. Now, here you use your response model what you did is with KENPAVE you could have done it with IITPAVE also. So, this is where the stresses and strains are computed. And now, what are the critical response parameters? Use this critical response parameter in the empirical damage model and then compute the pavement structural capacity estimate. If it is fine you, go ahead otherwise you start talking in terms of changing the modulus values or changing the layer thickness. So, looks like the general mechanistic empirical pavement design procedure that is followed in IRC or discussed as part of AASHTOWare in the earlier sections are more or less the same. But each and every aspect seems to be slightly different, more rigorous, more detailed and more data driven.

So, now there are various models that are given here and this is where one needs to be careful. So, now when we come to the pavement response model, what we used here was layered linear elastic theory and here we used two names Boussinesq and Burmister. Now, these are all layered equations and when you are using these layered equations, you basically assumed $E_1 \geq E_2 \geq E_3$ and so on and so forth. Are there different ways of solving this problem? Yes, there are different ways of solving this problem and these techniques are called integral transformation techniques. And these techniques are little more involved, you use some of these evolutionary integrals to solve these problems. In fact, the Australian pavement method uses this technique and here of course we are talking about South African, they use this method or what you can do is to go use some of the finite element software such as ABAQUS or COMSOL. You can do it with the PLAXIS 2D or 3D. So, there is a conscious deviation from using the layered linear elastic theory. There are many reasons. Numerically it becomes easier, most importantly if you have an inverted section, it becomes easily amenable for computation. I will not dwell deep into it, if I you need to get into the details you need to have a good background in structural mechanics. So, if any of you have the capability to do that, please get in touch with me and then I will share some literature related to this.

Then comes the next model which is the damage model and this is very interesting because the South African method makes a very clear statement. It says estimate the structural capacity from initial condition to predefined terminal distress. So, this is something that I have been emphasizing in many of the lectures. You see on the left-hand side, number of repetitions to failure that could be a predefined distress. You see on the right-hand side, what is really called as the initial condition estimated structural capacity using initial conditions. So, this ε_t or ε_c that you compute or the modulus that you compute, all comes from the as constructed property of the pavement. So, how exactly is the rate of damage accumulation reflected here is not known. And in most of the models excepting the AASHTOWare, in which you can do something but that is something that we will take it up as we go along.

(Refer Slide Time: 07:43)

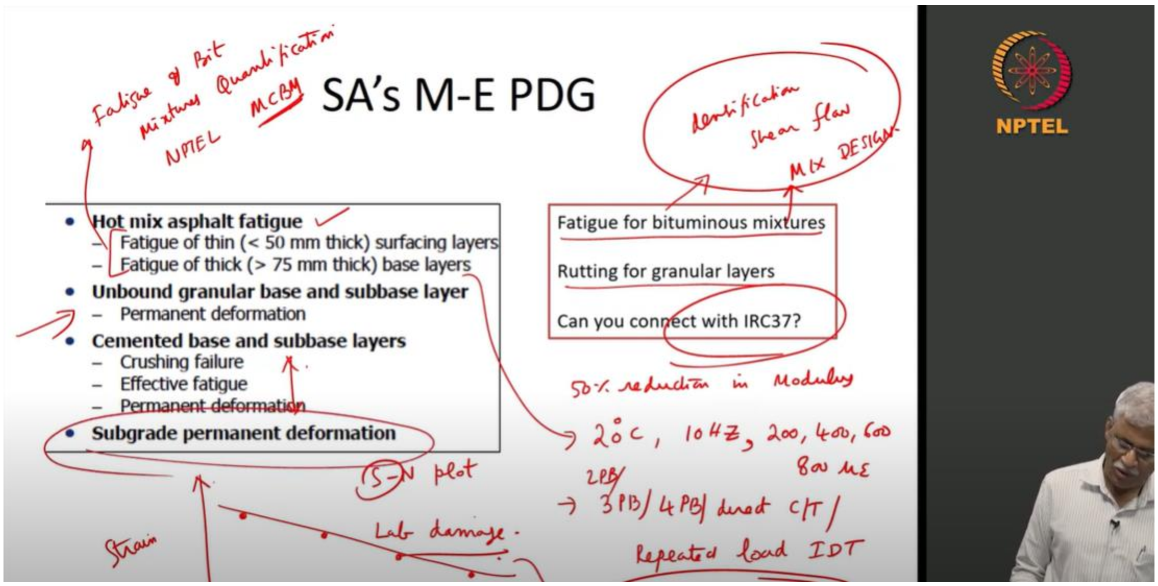


So, the South Africa's MEP-DG again makes another slight deviation. They say that for bituminous mixtures it is only the fatigue that is considered and for granular material only rutting is considered. And they also say very clearly that if there is going to be a densification or shear flow, the bituminous mixtures take care of it using mixed design. Now, this is something that is very familiar to what you have seen in IRC 37.

So, now let us look at this hot mix asphalt fatigue. There are two types of thicknesses that are given. If it is a thin pavement, what is the life and what are the coefficients, so they are different. If it is a thick pavement, what are the issues here. So, if you really need to talk about all those things, you need to understand how fatigue of bituminous mixtures are quantified. So, if you go take a look at our NPTEL course Mechanical Characterization of Bituminous Materials, you will see a lot of data. But just to give you some few parameters, I am just going to mention it here. But that is a detailed few hour of lectures that are already available there. So, normally you want to do the test at 20 ℃ for Indian conditions at 10 Hz frequency. And then we will be doing the test at let us say, 3 or 4 different strain levels. You can call it in terms of 200, 400, 600 and 800 micro strain. You can do the test in 3-point bending, 4-point bending, direct tension compression or repeated load indirect tension. You can actually also have what is called as 2-point bending. How do you estimate the fatigue life? Again, a simple example that I am going to give is 50 percent reduction in modulus value, the flexural modulus. So, what you will be doing is you will be drawing an S-N plot. So, this N is the number of cycles. So, this S is strain, normally this S corresponds to stress in the fatigue literature. But here we are talking in terms of the strain. So, you can appropriately use the log scale. So, you find out what is the number of cycles to failure for different strain levels, fit a curve and then this is the lab damage curve. Then, you need to calibrate it with respect to site specific factors. So that is how it is done. And, it was found clearly that when thin surface layers are used, what is the mode of testing, whether you have to do strain control test or stress control test compared to thick. So, that is an issue that we will not get into now. You can go take a look at the mechanical characterization of bituminous material.

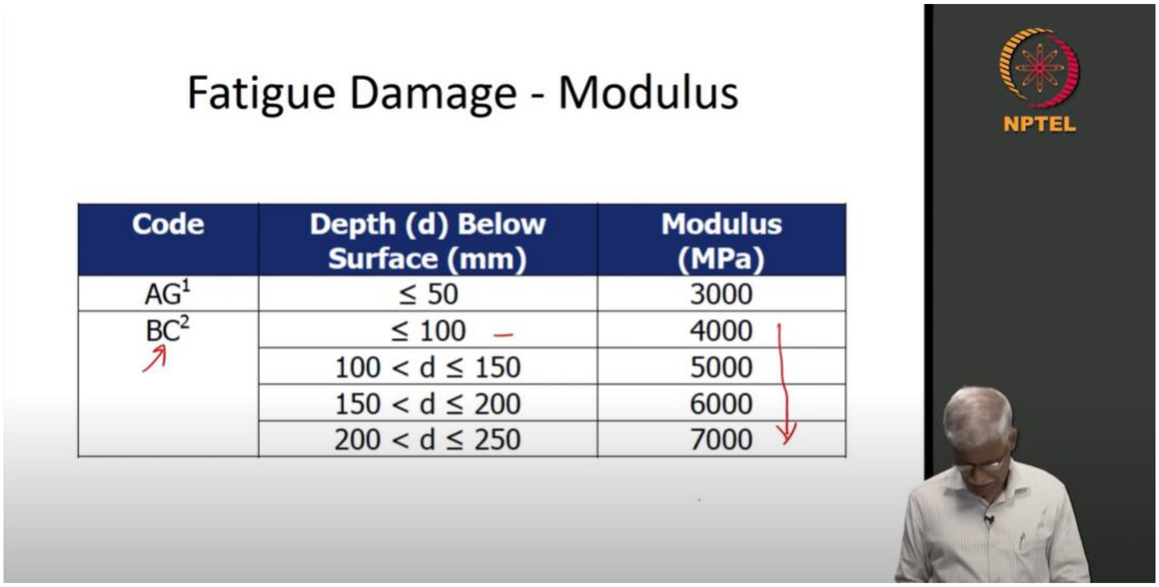
Then we are talking in terms of permanent deformation, unbound granular base and sub base layer. And then there are different failures that are given for cemented bases. And then there is a subgrade permanent deformation. So, for each of these, different models are used here.

(Refer Slide Time: 12:14)



Now, for doing the computation, there are some modulus values that are also suggested. So, you can think of this as a bituminous concrete mix, the depth below the surface, what is the modulus value? Interestingly, you will see that the modulus value keeps increasing as the thickness keeps increasing. So, you need to relate it with the stress analysis that we carried out in the initial classes.

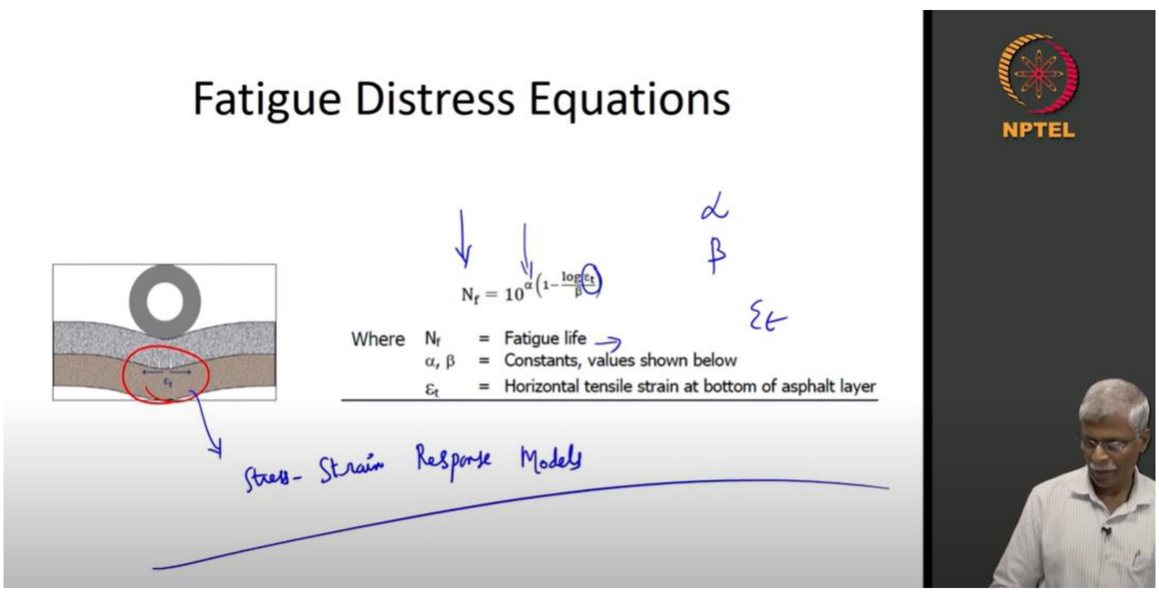
(Refer Slide Time: 12:47)



Code	Depth (d) Below Surface (mm)	Modulus (MPa)
AG[1]	≤ 50	3000
BC[2]	≤ 100	4000
	100 < d ≤ 150	5000
	150 < d ≤ 200	6000
	200 < d ≤ 250	7000

So, now, let us take this equation. So, this is your wheel load, this is the strain that you are looking at. And so, what you see here is the fatigue life. Now, this fatigue life could correspond to 10% cracked area, 20% cracked area. It depends on the category of the road that you are looking at. Remember, we discussed that they distinguish between A, B, C, D like that. Now, there are constants here what is called as α and β and this is ε_t and this ε_t comes from your stress-strain response models.

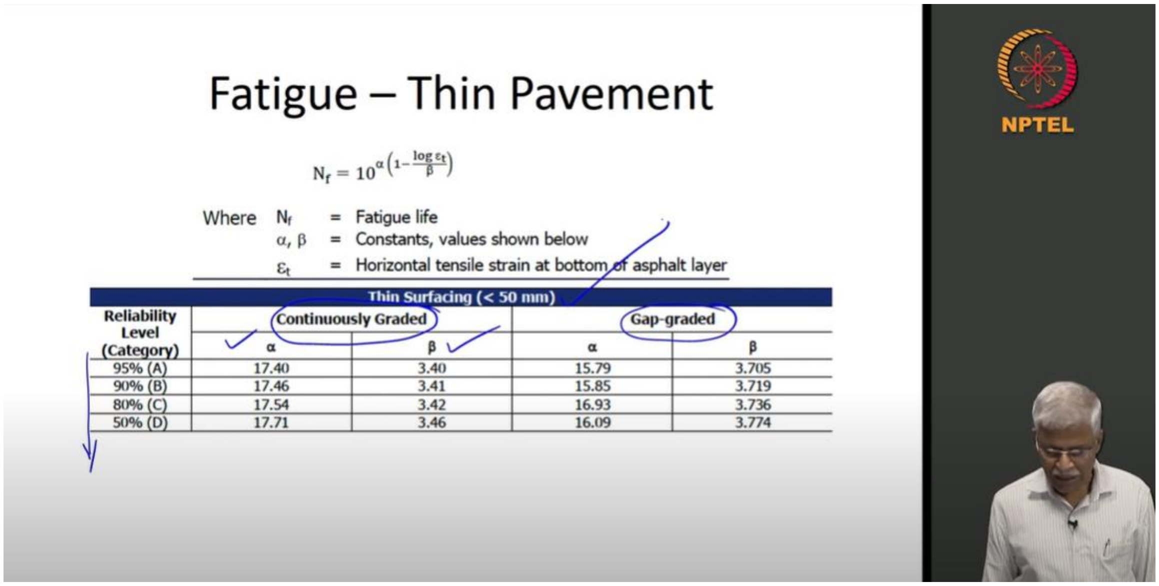
(Refer Slide Time: 13:43)



So, now, different values for α and β are given here. So, now, this is where you need to take a pass and relate it with what we have discussed earlier in IRC 37. You saw only one equation for two different reliabilities, for 90% reliability as well as 80%

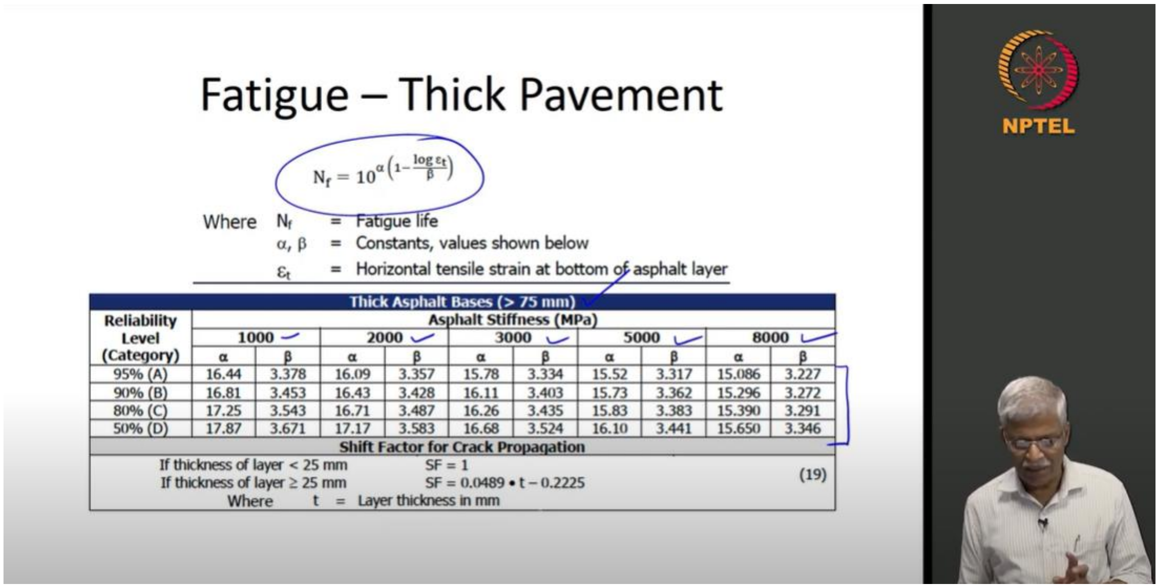
reliability. Now what you see here is for each reliability 95, 90, 80 and 50% and that too for gap graded mix as well as continuous graded mix, the values of α and β are different and this is given for thin surfacing.

(Refer Slide Time: 14:31)



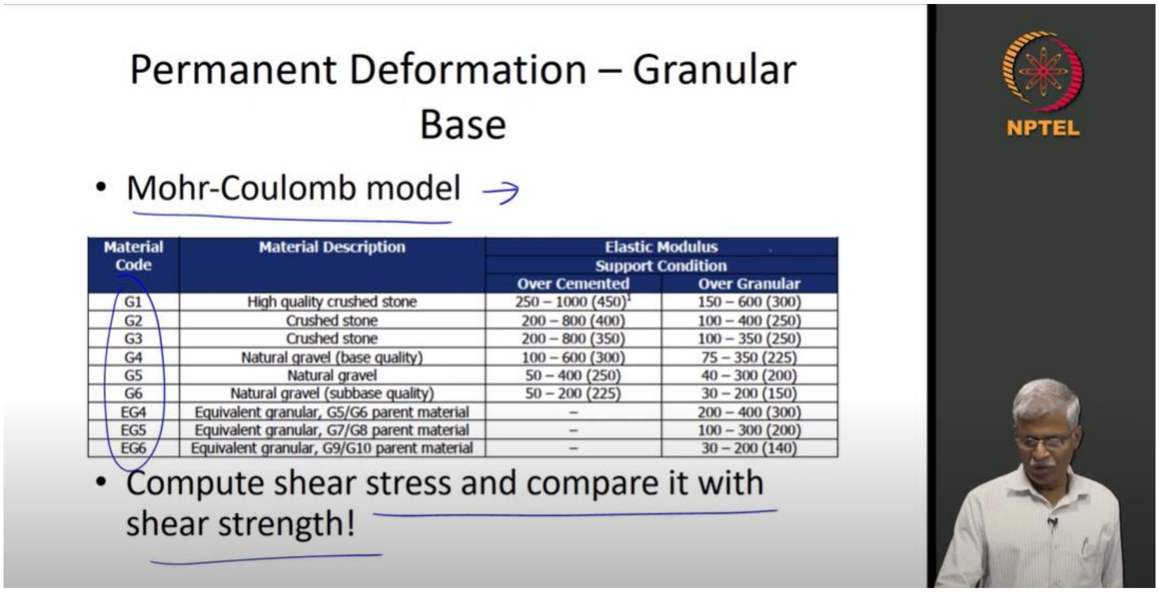
Then, if you go here, similarly, for thick asphalt bases again, for different thicknesses that you see here, for different values of modulus, you are seeing different factors that are given here. In addition to that, there is also a shift factor that is given related to the crack propagation. So, you need to use this shift factor with this particular equation to get how exactly the fatigue life will vary. So now, when you are comparing it with the way in which we have been designing, what are all the interesting things that you will notice here as far as fatigue damage is concerned. You will differentiate between thin pavement and thick pavement. You will be talking in terms of different reliability levels and for different thicknesses, you are having different sets of α and β. So that is the most important thing here.

(Refer Slide Time: 15:36)



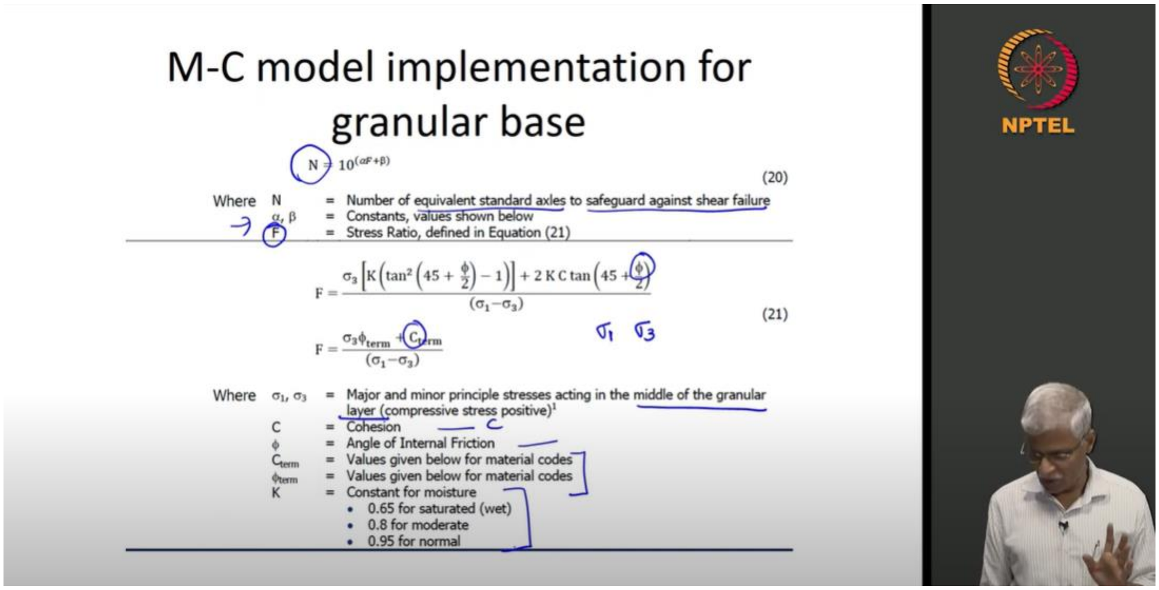
Now, let us come to the permanent deformation of the granular base. Now, the permanent deformation of the granular base, they assume that this could be defined using a Mohr-Coulomb model. You all know what is a Mohr-Coulomb model right. So, it is given as $S = C + \sigma \tan \varphi$. So, this is your Mohr-Coulomb model and it is in a sense something that you must have studied in your first course in geotechnical engineering what exactly is this model. And, what we are going to do is we are going to use the Mohr-Coulomb model, compute the shear stress and we will compare it with the shear strength. And again, for different material code, for different support conditions the modulus values are given here okay.

(Refer Slide Time: 16:29)



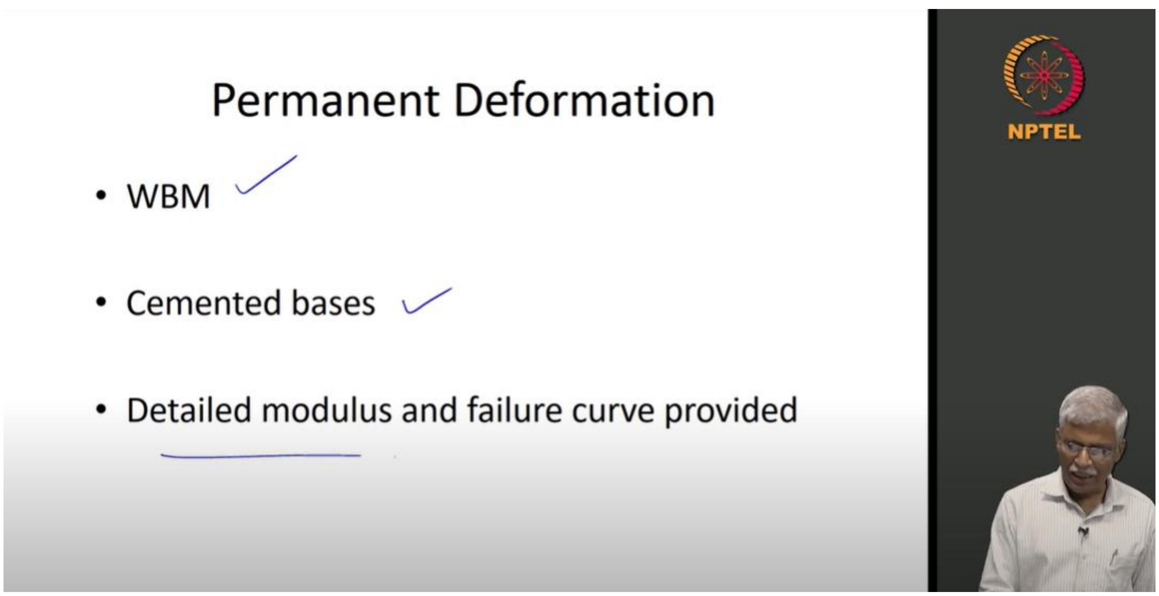
Now, how is this basically used? So, this is the N value and it says number of equivalent standard axles to safeguard against shear failure and there are again two constants that are given here α and β and F is the stress ratio. Now, what exactly is this stress ratio that is given here? So, you are familiar with σ_1 and σ_3, it is the major and minor principal stresses that are acting in the middle of the compressive layer. And then, the next thing that comes is your C which is nothing but your cohesion and φ is your angle of internal friction. And, there are few other terms that are C_{term} as well as φ_{term} , these are all the values that are given for material and K is the constant that is used for the moisture conditions. So, what you need to do is to substitute these values, get your stress ratio substitute it here for the various α and β, you are going to get what exactly is the number of equivalent standard axle loads to safeguard against shear failure.

(Refer Slide Time: 17:56)



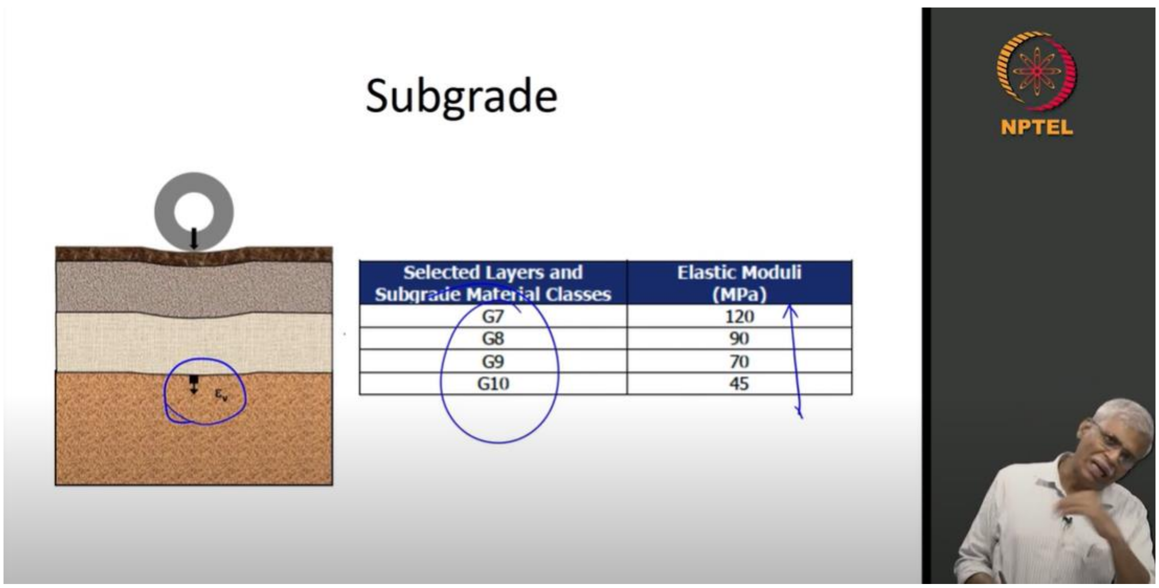
And for each of this, it could be water bound macadam, it could be cemented base and detailed modulus and failure curves have already been provided.

(Refer Slide Time: 18:06)



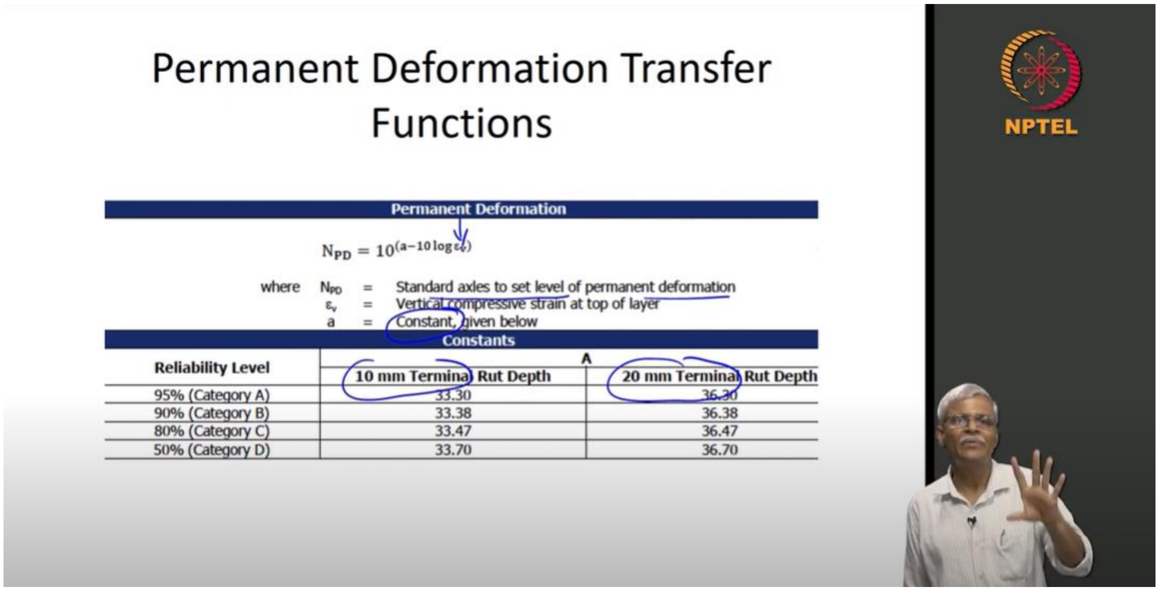
Now, let us go to the subgrade and when you are talking about subgrade, we are talking about finding out the vertical compressive strain here. Please remember one thing, what you see here is, need to notice down very carefully, we are protecting the granular layer against shear failure. So, there is no stress-strain computation, strain value that is coming here. Whereas if you are looking at the fatigue, there is a minor principal strain, horizontal principal strain that you know how to compute is given here. But when you come to the subgrade, you are talking again in terms of the vertical compressive strain. So, these are all the modulus and the associated material parameter that are here. What is very interesting to notice here is the level of standardization related to the material properties that is documented. So that means a designer can sit in his office and then pick materials. Okay, I am going to use a granular subgrade material that will fall under the category of G7 and then use these values and design the pavement. Now, in the field, the pavement engineer has to ensure that the material properties corresponding to G7 are met. So, once you make this connection, the gap between the structural design and the mix design is completely merged and that is the most important thing here. I am not talking in terms of a CBR value or a modulus corresponding to that. So, we need to categorize the material that are available for construction in India - granular base, subbase, bituminous mixtures different values into different categories, provide them with as much material properties which could be verified independently in the field here.

(Refer Slide Time: 20:22)



So, now you come here, what happens? So, this is the standard axle set to the level of permanent deformation. So, it could be 10 mm rutting, 20 mm rutting. So, this is your permanent vertical compressive strain. So, this is a constant and these constants are given separately for 10 mm terminal depth, 20 mm terminal depth. So that means, you are going to have different constants for different terminal depth for different reliability for different categories of road. So, this is the level of detail with which we need to really work.

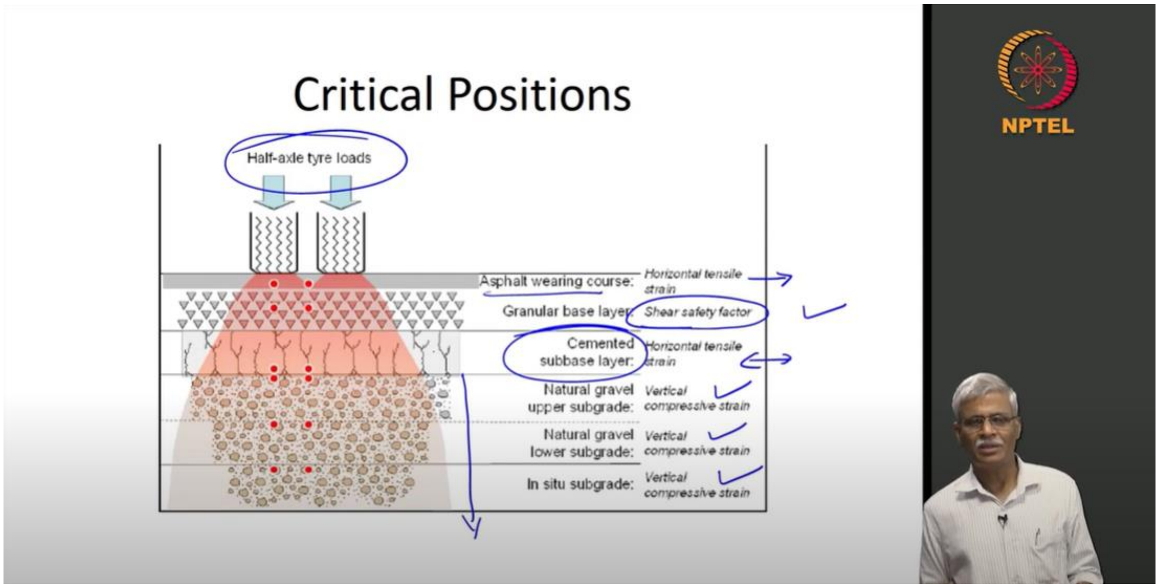
(Refer Slide Time: 21:04)



So, now finally let us look at the critical position. So, this is the notation that is used, half axle tire loads. So, this is your asphalt bearing course that you are looking at. So, the first thing is horizontal tensile strain. Then, when you are looking at the granular base layer, you are looking at what is called as the shear safety factor here. Then, after that if you have a cemented subbase, then you could have failure due to the fatigue. So, you are talking in terms of horizontal tensile strain and then comes your subgrade layers and for each of this, you are talking in terms of vertical compressive strain. So, this is the level of detail with which you need to understand.

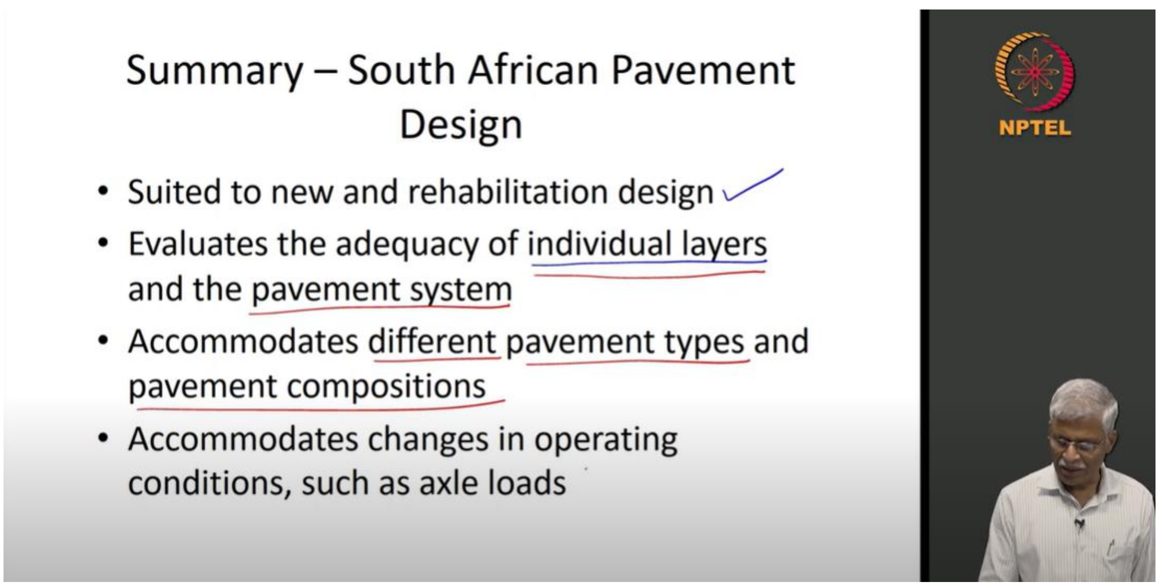
So, let me emphasize again wherever you expect that there is going to be some kind of a fatigue failure, you talk in terms of horizontal tensile strain as well as for the cemented subbase material. For the granular material, you use Mohr-Coulomb model and then you talk in terms of the shear safety factor. Okay what is the shear strength? What is the shear stress? Match them and then find out what is the safety factor. For rest of the granular layers, subgrade, different layers of subgrade, you talk in terms of vertical compressive strain.

(Refer Slide Time: 22:28)



So, what exactly is the whole basis of this South African pavement design method - suited for new and rehabilitation design, evaluates the adequacy of individual layer (I think this is something that I would really like all of us to understand), individual layers and the pavement system overall, accommodate different pavement types and pavement composition, accommodate changes in operating conditions such as axle load and so on and so forth here.

(Refer Slide Time: 23:08)



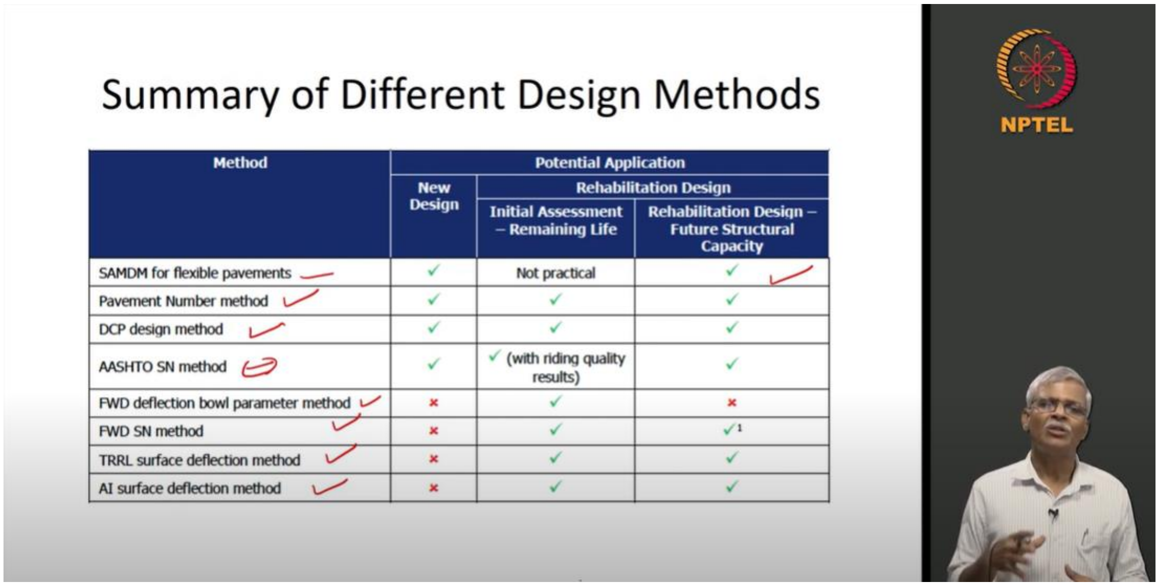
So, what exactly is the summary, if I ask you to write the keywords let us say you are sitting in my class and then I ask you, okay so we finished the South African pavement design method, what are all the keywords that are in your mind or what do you really think is the robust thing, you will say yeah traffic analysis seems to be quite robust. There is a difference between thin and thick pavement. There are different distress factors that are used between granular and subbase. There is a good material reference library that is available. There is a difference between design and distress. In addition, you will also talk in terms of balanced pavement etc.

So, you may want to go back listen to these lectures and try and write keywords that will kind of give you an overall idea of what the South African pavement design method is. And in fact, as I mentioned earlier, it will be a good practice for you to take an axle load data from Indian condition, redo the computation as per the South African method, use the material database that is already available and then try to redo the design using the South African method and then try and see how our cross sections that we are using in our country compare with the design values that you will get.

(Refer Slide Time: 24:44)

So, that will be a very interesting exercise for you to do and to finish the whole discussion, the South African method not only talks about it, it also talks in terms of the earlier old empirical methods. See for instance, this is the South African method of mechanistic empirical pavement design. So, it is used not only for new design but also for the rehabilitation design. The pavement number method is an empirical method that they have been using. The DCP is a method, the cone penetration test method that have been used in and this is the AASHTO method which Dr. Nivitha covered earlier. And then, there are also different methods that are listed here, AI surface deflection method, TRRL surface deflection method, falling weight deflectometer, SN method and all those things. So, all these methods could be used for different design. The idea is how do you relate between design and distress.

(Refer Slide Time: 25:48)



So, we will stop here and we will continue our discussion related to the Australian method of pavement design in the next class. Thank you.