Analysis and Design of Bituminous Pavements

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Lecture - 48

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

(Refer Slide Time: 00:19)

So, let us continue our discussion about the South African method of pavement design and in fact the reason why I just want to have a detailed discussion about three other pavement design methods in addition to what we discussed in detail about Indian Roads Congress guideline is for you to understand how other countries actually carry out their pavement design. And in fact, in a nutshell, you need to have some idea about the pavement cross section, you need to have some idea about the materials that you are going to use, you need to have some idea about the model, the structural model that is going to be used and you need to have some idea about what are the distresses. Then, you can add things such as reliability here, so that is the overall framework. What is very interesting in the South African method of pavement design when we compare it with the Indian method of pavement design is the specific details to which they get into. For instance, we would like to know clearly how the pavement will behave after it is constructed. So that is why we talked about balanced pavement cross sections and we also talked about how the inverted pavement may not necessarily work out the way we visualize.

So here is a fairly straightforward tool that is used by pavement engineers to estimate the existing structural capacity of a pavement and this is typically a non-destructive testing method. Some of you may have heard about it. Normally these things will be discussed more in a pavement management strategy. So given a pavement and if you are going for a rehabilitation, you would like to find out what is the existing structural capacity of the layer.

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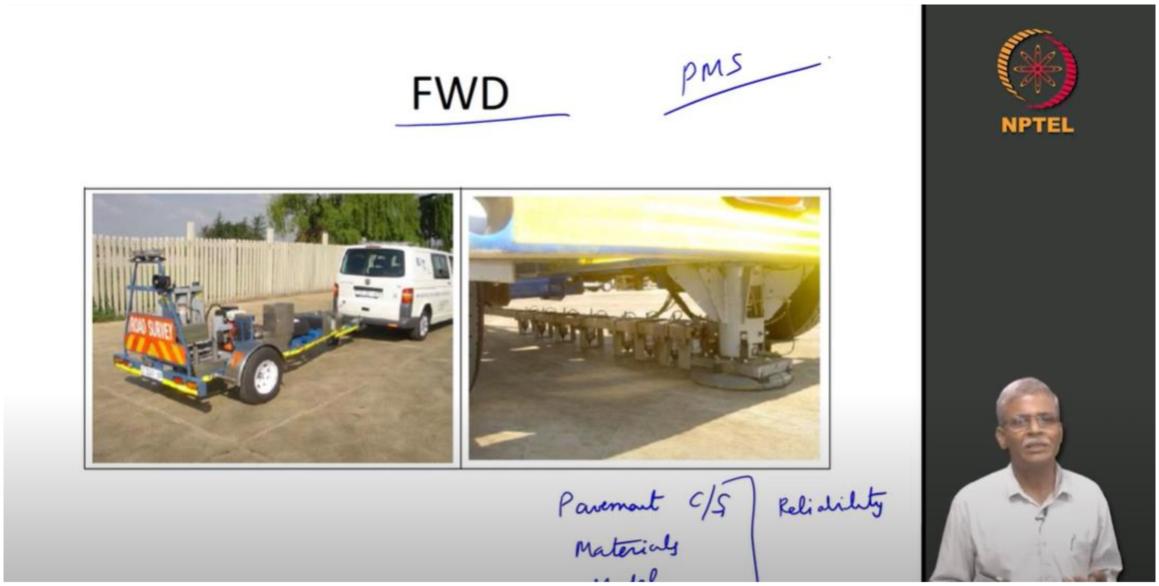

What is interesting is, in the South African method, they would like us to understand little more about the stress distribution versus deflection. Now what you see here as the black line is this stress contour. So that means you are looking at what is the load that is distributed. So, from the center line, you can actually see how the load transfer area keeps increasing. So that means the intensity of the load keeps decreasing. So, typically if you use the FWD procedure, you talk in terms of a deflection bowl, you use words such as geophone, there is a back calculation procedure, we will not get into all those things. But I just want to give you an overview of how one can visualize how a pavement that I am going to construct might behave depending on the relative strength of each of these layers. So, you have an asphalt surfacing, you have base and of course you have the subgrade. Now what can really happen and this this white line is the deflection. So if you are really looking at this particular point here, you see that the deflection here, because of your stress, consist of asphalt base and the subgrade. But by the time you come here, the stress that you are seeing, the load that is transferred, this is going to be dependent on the base as well as the subgrade. You still go further down and you realize that this is going to be dependent on the subgrade only. So using these, in fact you can actually find out what exactly is the expected stress distribution as well as the expected load carrying capacity of the pavement when you actually construct it.

So, what you could do is to construct a test section, run an FWD, find out what exactly is the load carrying capacity. And this is not a straightforward thing that is understood by many of the pavement engineers who are used to designing the pavement in terms of okay, so all we need to do is to do a volume count and take the axial load distribution, compute the wheel load, vehicle damage factor and there are some modulus parameters that are given. We just need to plug it in the distress equation and find out okay, so 40 mm BC, 100 mm DBM, but that is not actually the point. The point is when you do the stress analysis, you make specific assumptions about the load carrying capacity of the material. That is not how actually things might work out.

So, as I keep mentioning, there is a concept called the shakedown that will happen. So, all these layers with different modulus kind of rearrange themselves during this loading and unloading and they start showing a response which is not the response that you get when you try to analyze by just assuming only the modulus values. Because if you recollect carefully, we make some assumptions about the interface conditions here. This may not necessarily be the interface conditions that will actually happen. So, it will be nice if you could construct a pavement, find out the structural capacity and then convince yourself that this is the structural capacity for which the pavement has been designed and keep that in mind before you do the pavement analysis and design part.

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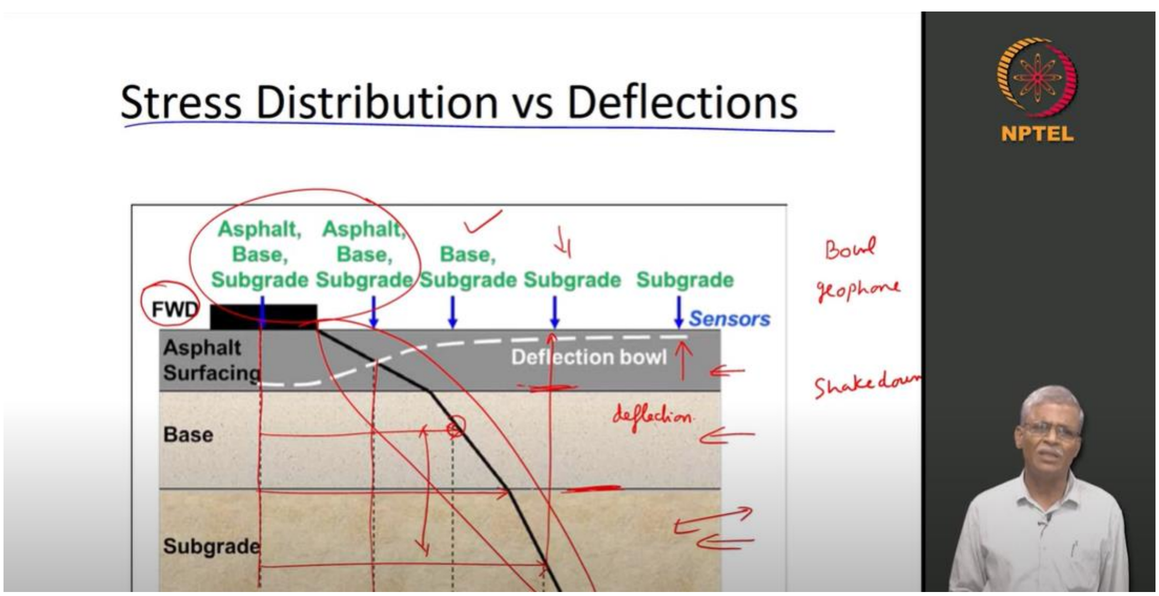

So how do you really prove-check a design? This is the point. In fact, there are 3 scenarios that are given here. So, this is scenario 1 which corresponds here. This is scenario 2 that corresponds here and this is scenario 3. The difference between a new pavement and the old pavement and a pavement somewhere in between can really be assessed by looking at this. So, if you look at the thicknesses that you are seeing, so the subbase thickness is 250 mm in all the three scenarios. The base is 125 mm in scenario 1, but the base thickness is slightly different in other scenarios. The thickness of the asphalt layer is 40 mm, 60 mm and 30 mm in the 3 scenarios. So, now you can actually see by looking at the thickness, so each of these layers have different load carrying capacities and the such load carrying capacities are explicitly seen when you try to do such kind of analysis. So that is the whole point. I think it will take some time for you to get to the crux about the whole pavement design as far as the South African manual is concerned.

And in fact, at the end of this course, I will be listing out some of the design projects that you can check. And in fact, what I am going to tell now is, how is traffic handled in South African or Australian or American pavement design method? How is the material characterization handled in these three countries? How are the distress equations handled in these three countries? So, that means if I give you the axial load spectrum and the material properties and also tell you the location where the pavement has to be designed and if you learn these three methods and design a pavement, will you get a thickness identical to the thickness that we get when you do it with IRC 37. And this is something that you can do it as a mini project or a graduate level project or if you try to do a sophisticated analysis, it can even become a PhD thesis. So, this is the whole idea here, right?

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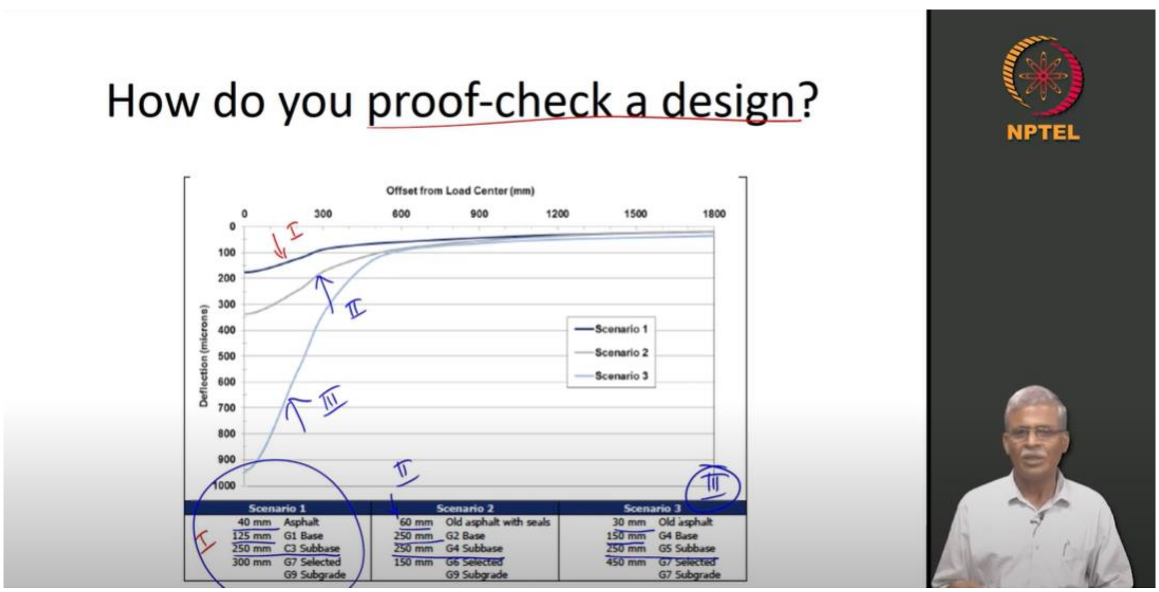

So, the load sensitivity and traffic response, this is where I believe the South African score. For instance, what they really talk about the pavement balance and same traffic load spectrum might convert to different equal and standard axle values. Now this is also something that we need to be careful, I am going to talk about this. And so, what it means is, if we are talking in terms of the exponent 4 that must have been discussed earlier, this exponent 4 related to rutting or related to fatigue can be different for different constituent of the layer. So, it is not necessary that one needs to use a constant load equivalency factor across all the distress and across all the layers.

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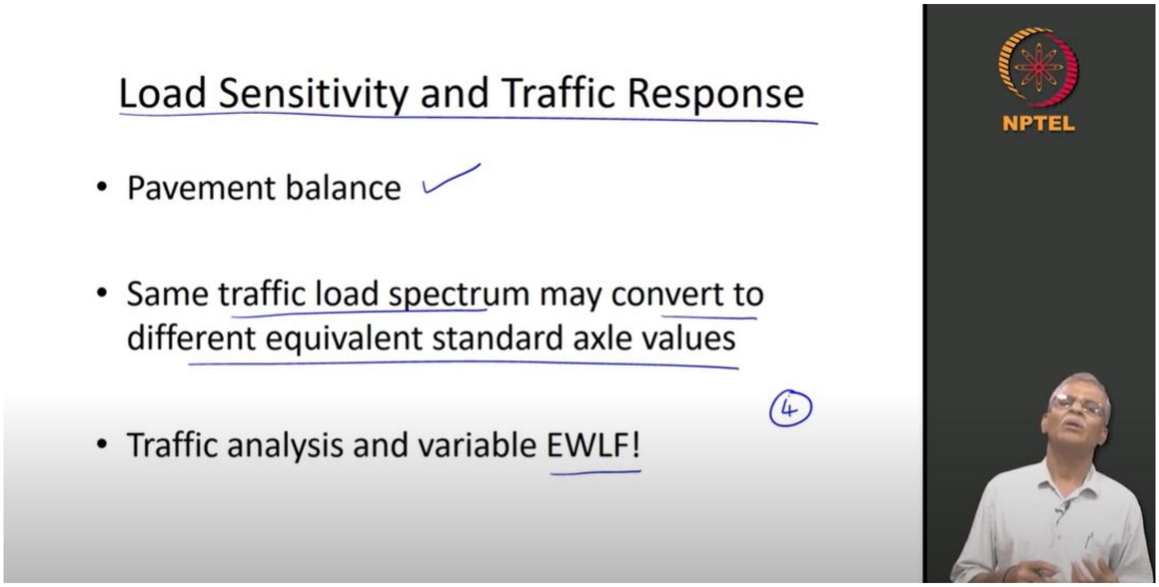

So how do we really see it? So, the first thing that we need to understand here is that the variability is going to be a critical issue here. So, we will be listing the various modulus values that we are expected to measure as far as the South African pavement design method is concerned, that is what is given here. So, depending on the category of the loading the variability in the material parameters can vary this much. So, that means you are looking at category A is 95%, so that means at best you can have 5% variability. So that means if you assume something like 3000 MPa, okay, you can have variability of only 150 MPa. So now you understand the point that I was trying to make. The mix design and the structural design has to be interconnected. You cannot do a mix design and then take it to the site and lay the pavement and the structural design cannot be done for a modulus value for which we may not necessarily have the mix in our hand. So, depending on the category of the road, you can go from 95%, 90% to 80% and in my opinion, this is the unique design method that links the variability in the material parameters to the road category. So, let us say this is your national highway and so let us say this is your ODR, right. So both of them have same bituminous concrete grade 2 and for both of them you measure the resilient modulus at 35 °C and let us assume your design says for the mix that you use it has to be 2000 MPa. How much is the variability that you are really looking at here? So, what is this kind of strict quality control that we need to have.

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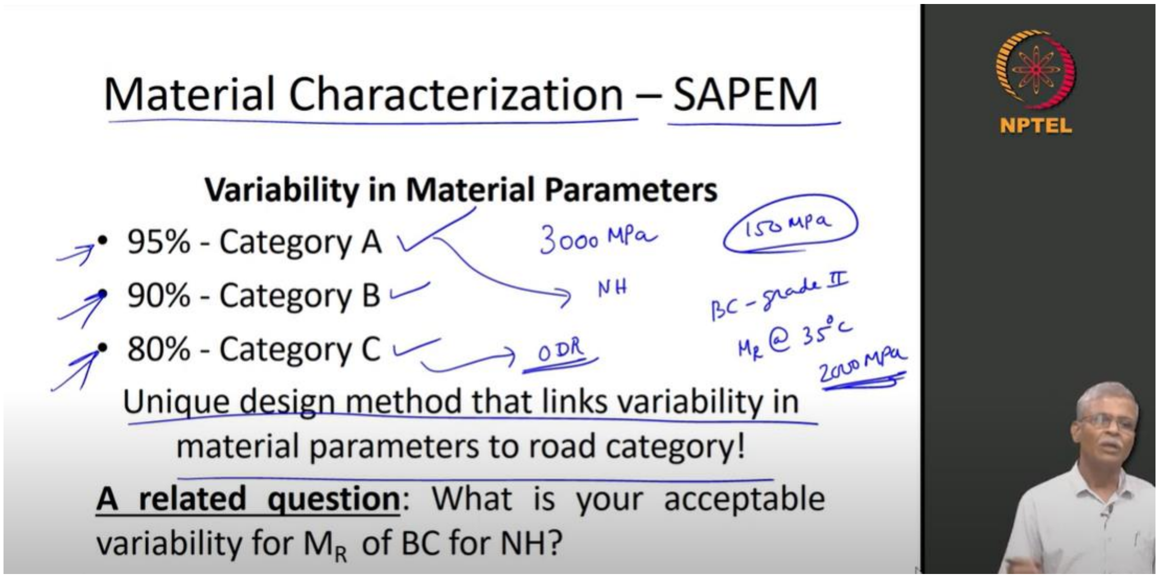

And another important thing again, this is a subtle issue that is raised in IRC 37 but not read and understood with the intent with which it is meant. See, for instance if you look at it, the South Africans will always very clearly say for any pavement design, you need a minimum 15% CBR in situ subgrade. So, if your in-situ subgrade is greater than 15%, you go ahead and construct the pavement on top of it. But if your in-situ subgrade is not 15%, let us say it is 7 to 15%, you add a layer to it and again if it is let us say between 3 to 7% then you go in steps okay. Construct a first layer with around 10% and then another layer above with above 15%. So, this is what is really needed and what is really called as the foundation. So, what I mean as foundation is, when I do the calculations, I am looking at around 1 to 1.2 meter as the material depth. So, that is what I am really looking it as foundation. So, this is what is needed. So, I am looking at 15% CBR material of the order 1 to 1.2 meter.

So, what you can actually see is if you go and search for something here in IRC you might see something called compacted subgrade and it will also be shown with these words you can search and find a 100% proctor. So that is going to be something of the order of 50 cm okay. Now, is this constant for all the highways that is not very clearly given. But here I am able to see that this is given in terms of the road category.

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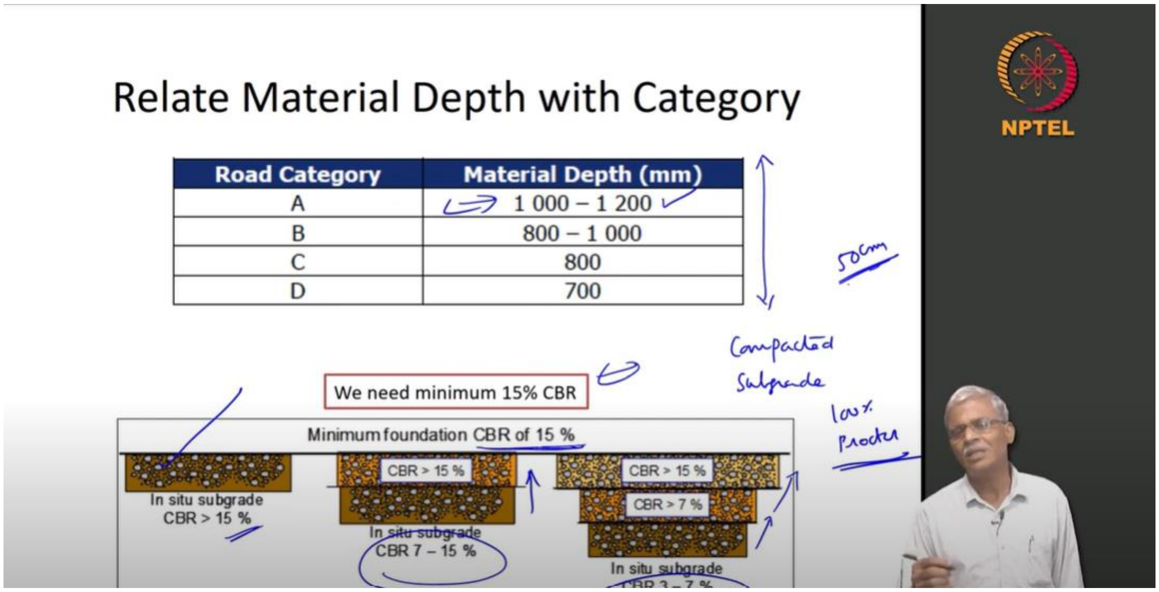

Now, comes the critical things here, what are all the road categories and what are all the design cross sections. These are the different road category and design traffic class. For instance, if you are looking at ES100, you are talking in terms of 100 million standard axles or 30 million standard axles or 10 million standard axles. So, you will get to know it and it is there. Now focus your attention here on this one. So you are talking about ES100, so you want to have a cemented granular material, granular material cemented, cemented. So, there are many bases that you can have. So, if you have a base of granular base, they want you to use a cemented one. Similarly, if you want to use the base category as hot mix asphalt, the sub base is going to be a granular. So this is bitumen stabilized material, this is more like a recycled material and the most important statement that they make which I have copied and pasted here is there is no design method that accurately predicts the condition of a length of the road 10 to 20 years in the future. This is a very important aspect that we all should understand okay.

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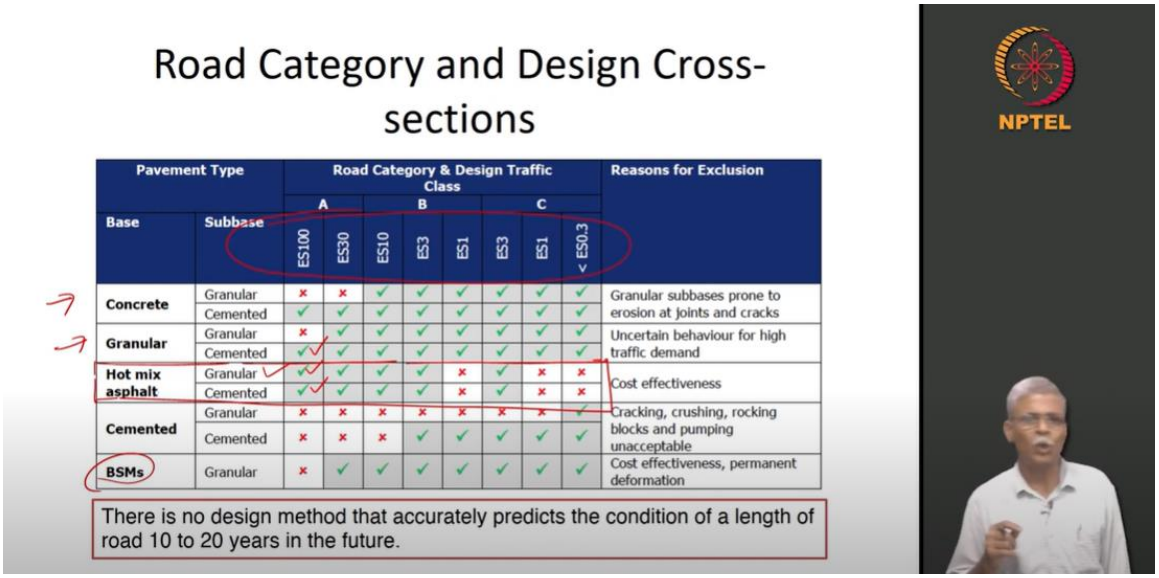

So, when we now continue talking about the traffic, you can have the truck here, the static mass weight is given here for each of this. So, you can have typical truck with steering axle and single axle and that it could be single, dual wheel, single and similarly you are talking about a tandem as well as a tridem that you see here and what are all the wheel configuration and the associated weights are given here. Now, similarly for bus it is given here. In fact, what I would really like to emphasize is ideally when you are doing this pavement design with IRC 37, the IRC 3 that talks about the various axle categories should be actually part of it probably as an annexure or probably as part of the main design guideline itself because you are designing a pavement and for the pavement what is that you are designing for, you are designing for the axle load and those different axle load categories should be part of this guideline. So, that will give you lot of insight about how the pavement has to be designed.

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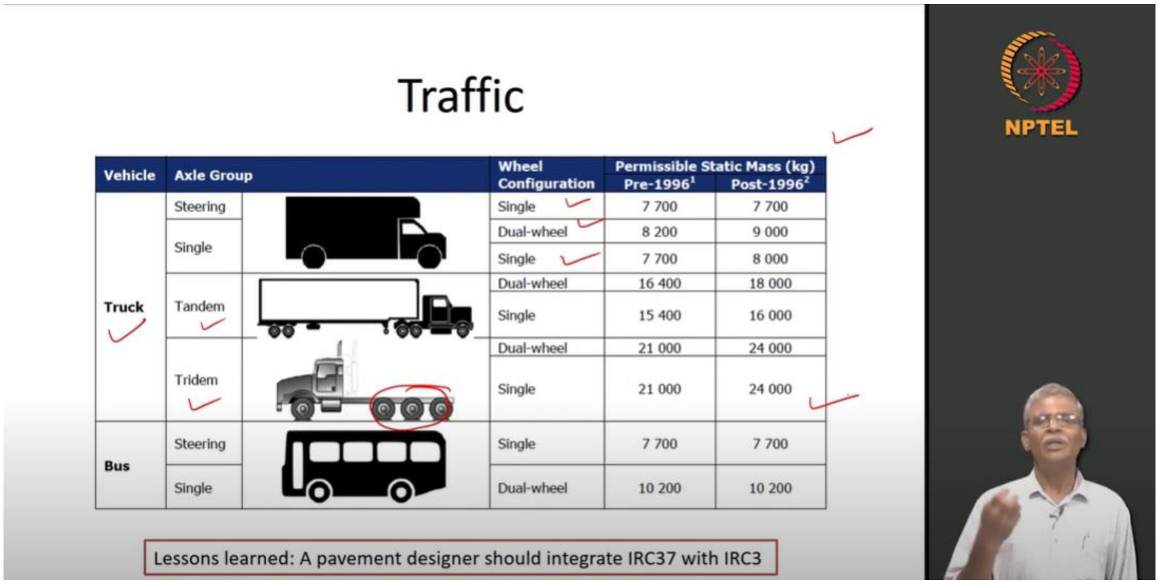

The next important thing that we need to talk about is what is called as an axle load spectrum. Now, just want to tell you something slightly outside the crux of the course. If you go to the United States, you are going to see this, what are called as interstate. So, you can actually take a look at the map of United States and you are going to see highways going from north to south and east to west. So, one will be even number and another will be odd number. So if you go from south all the way up to the north, you can have I10, I20, I30 and if you go from eastern side to the western side, you are going to see I5, I15, I25, I35 and all those things. Now what is the idea here? The idea is each and every highway has a unique characteristic. And again, there are many websites that are devoted to that specific highway. So, you can separately have a website for I10 that will clearly tell you where the highway is starting, where it is ending, what is its characteristic. See the highway has a life, means it is picking up different materials from different places and it is unloading different materials at different places. So, if there is a highway, let us say starts at Chennai and goes to a specific location where some ores are picked up, raw material is picked up and then from there it goes to a factory where this raw material is being converted into finished product and then from the finished product let us say it goes to a nearby port or harbor where these materials are downloaded. So, this highway has a history and the axle loads that you are going to see for this highway, the axle load spectrum is not going to change. So that means if it is going to be a binomial distribution means it is going to be a binomial distribution. The intensities of the load might change but the spectrum will remain more or less the same.

So that means what is very very important for India is to go and map all the national highways in this country, collect the data completely from each and every point and then come out with the axle load distribution, axle load spectrum. Most of the time what we do, we do not seem to be collecting such kind of a data and doing the detailed statistical analysis and in fact we have been doing for the past 18 years or so at IIT Madras collecting as much data as possible, fitting distribution to it, finding out the extent of overloading that you see here. This is the permissible limit, so you can actually see how much is the overloading that you see there. So, there are also empty loaded vehicles and all those issues, what kind of distribution that you can fit and there are also interesting distributions that one can fit what are called as extreme value distribution such as Burr distribution and so on and so forth. So, these kind of distribution and analysis will give us lot of insight about how to analyze the axle load. So, it is just not the question of before designing a highway going to the site and collecting some 24×7 data and doing a volume count and then doing it. We need to really understand what is the nature of the particular highway here.

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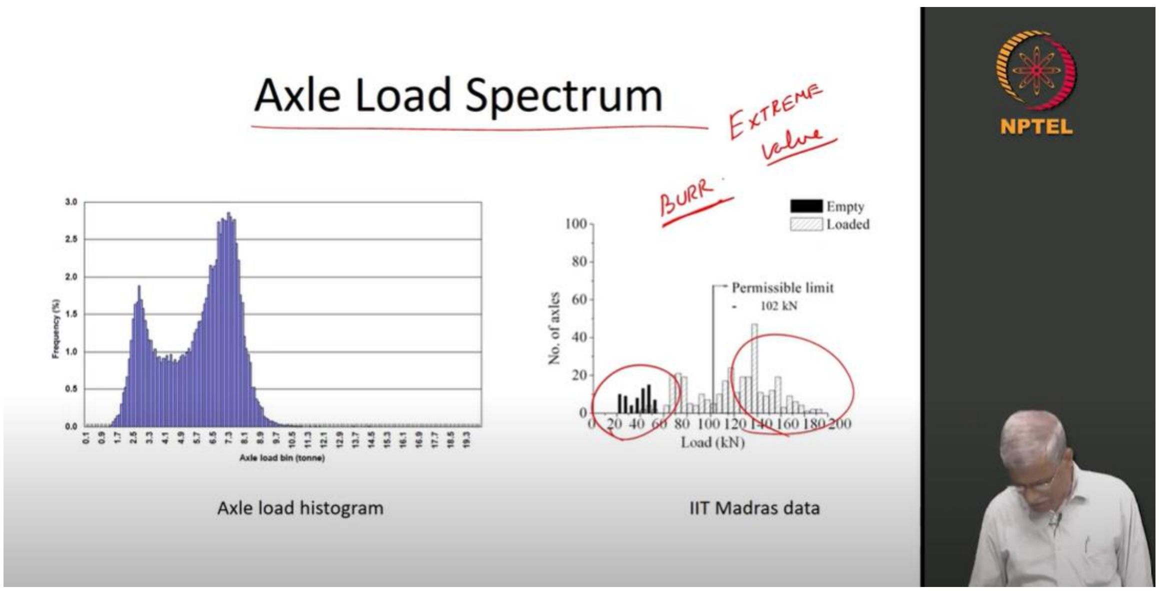

And once we do this, the earlier method of South African way was using like everyone else which is what we even use, the so-called load equivalency factor and of course this is based on the 80 kN standard axle load, so 20 kN on each wheel. So, this is something that you are familiar with. But what is interesting is this n is given differently for different base and sub base combinations. So that means, the structural capacity for the reference load and structural capacity for the load. Now this is defined in an interesting way. This is not mentioned in terms of the damage because if it is mentioned in terms of the damage then you are going to ask me okay what damage you are looking at, rutting or fatigue and all those things. We want to talk in terms of the structural capacity and that is what I mentioned few slides back about having a falling weight deflectometer help you with assessing the structural capacity and what is called as a balanced pavement and how inverted pavement may work or may not work. So, what we really want to do is to find out the structural capacity for a reference load and find out the same structural capacity if you are going to use it for any given load P. Now, this exponent is now going to vary depending on the different granular sub base combination. So, it could be bitumen stabilized material and granular, it could be hot mix asphalt and cemented. So, these are the numbers that are normally given here and these numbers are expected to be used.

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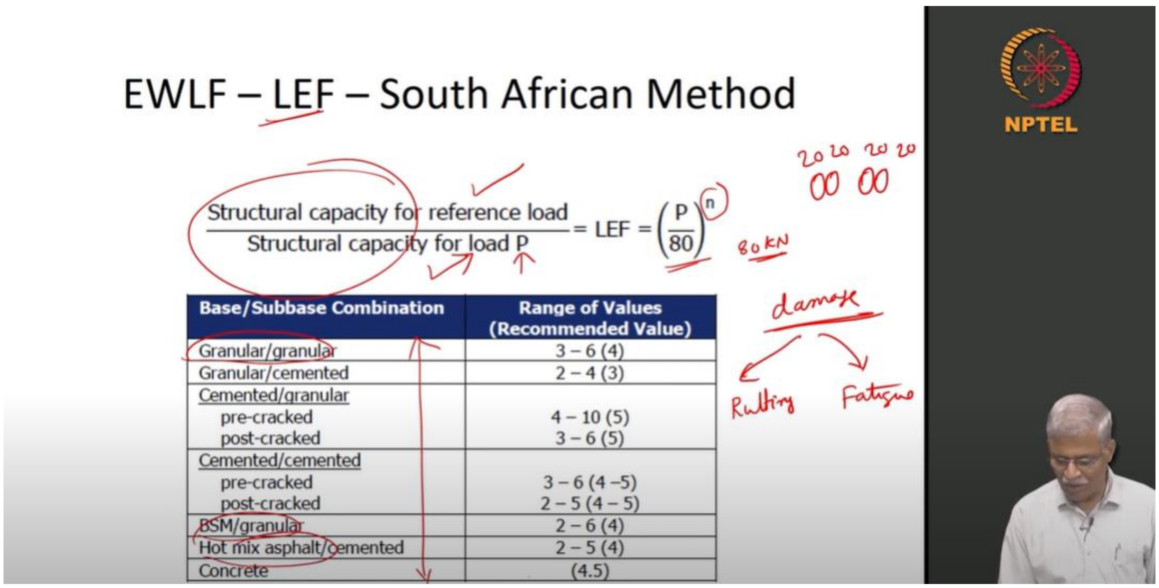

But what these days South African pavement method does is to find out the damage, if you start talking in terms of the damage instead of starting talking in terms of the structural load capacity is to do it for each and every axle load and not bringing it down at the level of the load equivalency factor. So, now if you are talking in terms of the load equivalency factor, the way in which you could do is not worry too much about different configurations, different actual traffic load spectrum, but take the whole thing and try to see what exactly happens as far as the standard axle load is concerned and earlier based on this, these damage factors are also given.

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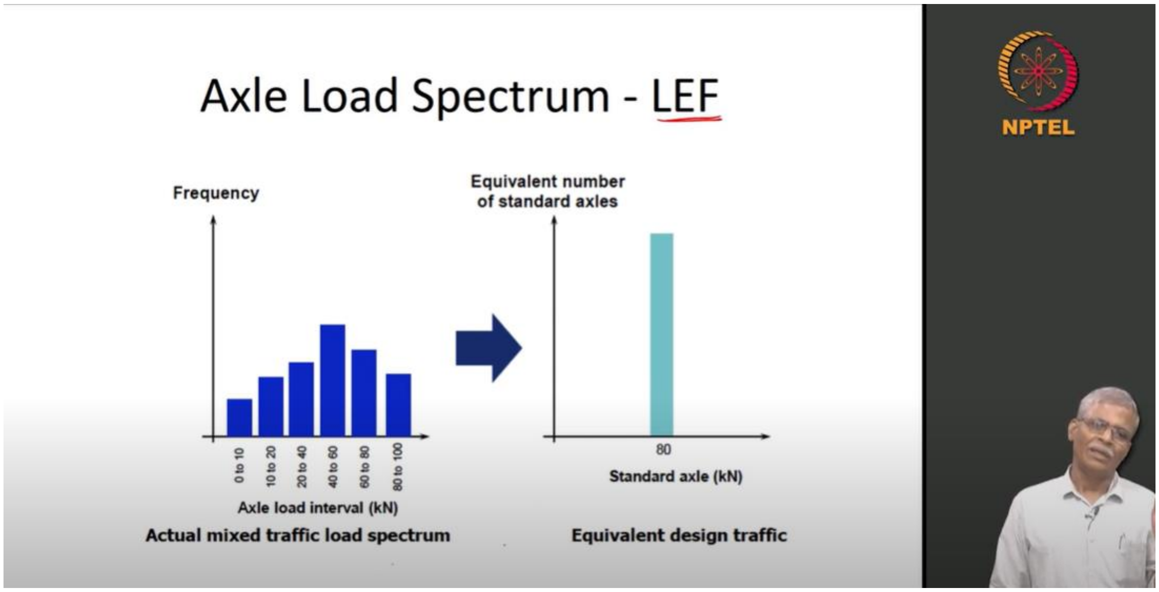

So if you are looking at this one, which is your 20 kN load and if you are really looking at your 18 kips or 80 kN, okay, so this is the factor here. You are basically going to see somewhere here 4 times. So this is the 4 tires 20 20, 20 20 and if I am going to have 8 tires tandem axle what exactly is the damage that I am going to have. So, if the load is going to be of the order of 60, this is the damage that you are going to have. If the load is of the order of 120, this is the damage factor that you are going to have, okay. You may want to take a look at what are the damage factors that are used in the IRC 37 equation and find out whether those damage factor that we have used there are related to the damage factors that are mentioned here.

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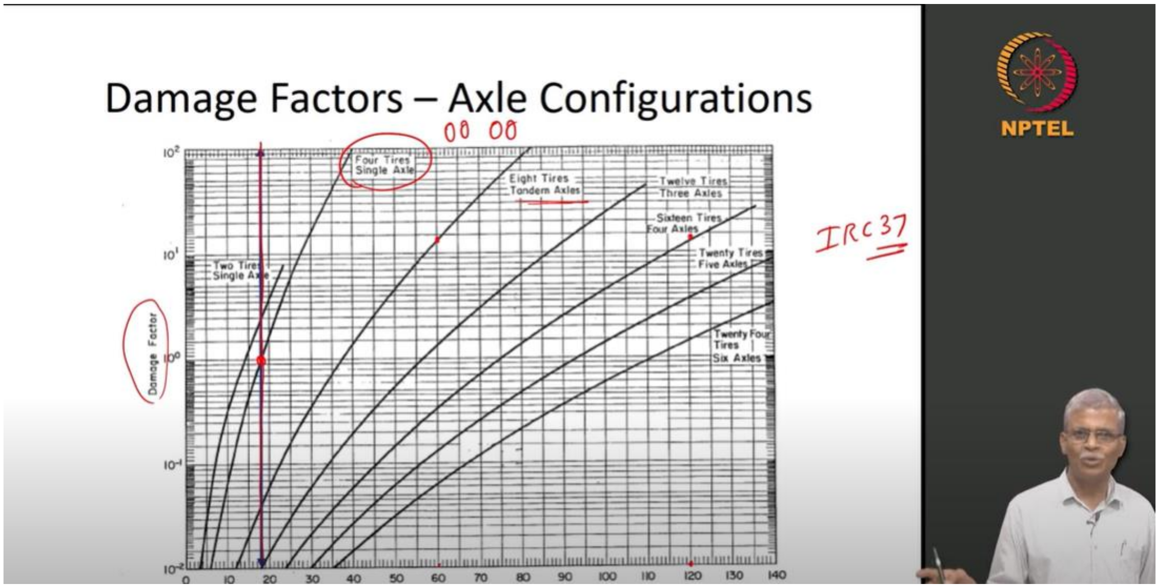

Now comes the important thing. So, we are not now going to talk in terms of load equivalency factor for each of this. Rather, what we really want to do is we want to do it for the full traffic spectrum. So, that means if I take single axle, single wheel, so this is your steering axle, then tandem dual wheel, so this is your rear axle. So, for each of this or maybe you know you can just take a look at this picture. So, let us say there are going to be 20 repetitions and let us say there are going to be 50 repeats and then let us say there are going to be 40 and let us say there are going to be 10 repetitions. I am just giving an example. So, what you will do, you will compute for each of this what is the damage and so let us say there are 4 classes here. So, we use these 4 classes here, right and for each axle what it is and then we will sum it up. Now how does all these things come into picture? It comes into picture in terms of what is really called as the Miner's Equation.

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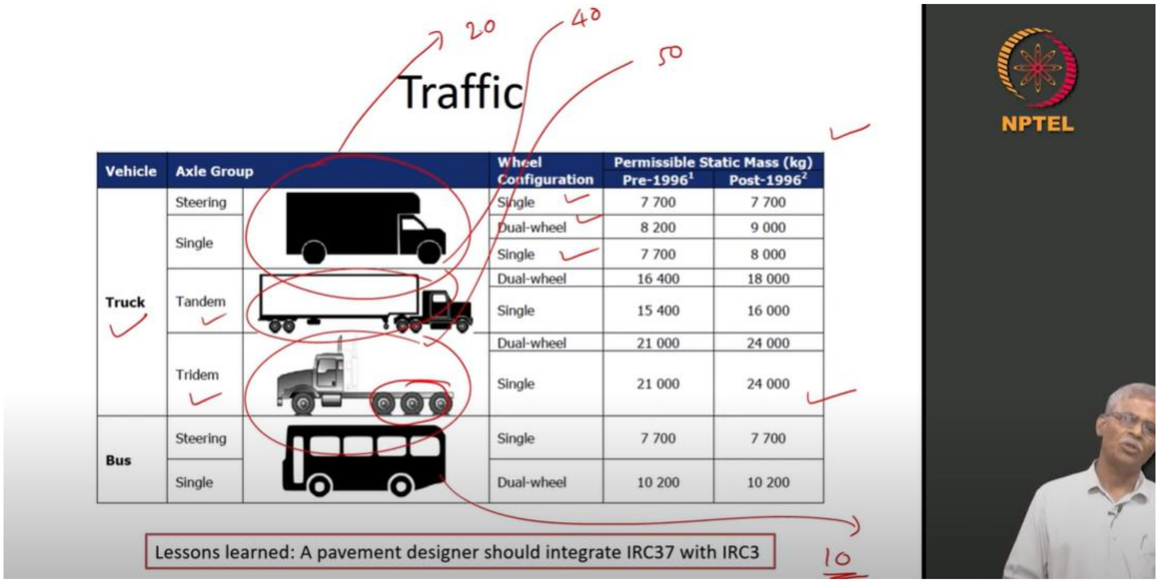

Now what exactly is this Miner's Equation? Let us say we are trying to do a repeated fatigue test. Think of it this way. So let us assume, you have a structural member. So let us fix it somewhere here like this and then we are going to apply a load like this. So up and down. So, hold it like this and then keep moving it up and down. Now, what you can do here is you can vary the load here. It could be σ_1, it could be σ_2, it could be σ_3 and so on and so forth. And then, you will say that when you apply only σ_1, you find out the point of failure (N_1) and again when you are talking about fatigue test the way in which you define failure depends on what you have in mind. I will as of now to simplify things, I will say number of repetitions to failure. So that means it breaks somewhere here. So let us say this is N_2 for σ_2 and let us say this is N_3 for σ_3 and so we will assume something like this $\sigma_1 > \sigma_2 > \sigma_3$. σ_3 is the maximum. So, what is really going to happen is N_1 is going to be greater than N_2 and so on and so forth. Now, what I want to ask you is the following. So, if I give 100 kPa load and if the corresponding life is, let us say 10,000 cycles and if I give 200 kPa load and let us say the corresponding life is 4000 cycles. Now, I want to ask this question to you. If I give 100 kPa load only for 3000 cycles and 200 kPa load only for let us say 2000 cycles what is the remaining life? So, what will you do? Oh, it is very simple. 10,000 cycle is the life, 3000 cycle only you have applied. So, I still have around two-thirds life here. Now, 4000 cycle is the life and you have applied 2000 cycles so that means one half. So, what you will do? So, you will basically say around 67% life is there in the first out of which 50% you have taken it away. So somewhere around 17 or 18% is the remaining life that is there. That is the calculation that you will do. So, intuitively you will do it and this was done by Miner in 1940s. It is called as the Miner's fatigue relation. What is the idea behind this Miner's fatigue? You are basically saying that the loading intensity, the successive loading intensity does not necessarily damage the remaining load carrying capacity of the material. So, that means assume that the material has the same structural constitution, it is not changing. We have discussed this before when I talked about the distress equation and that is the whole point of this exercise.

That means you know you have a $1/\varepsilon_t$term or $1/\varepsilon_c$ term and this ε_t and ε_c does not change. But the material is getting damaged, the modulus value is reducing. So obviously the ε_t and ε_c should increase, but we assume that they do not change.

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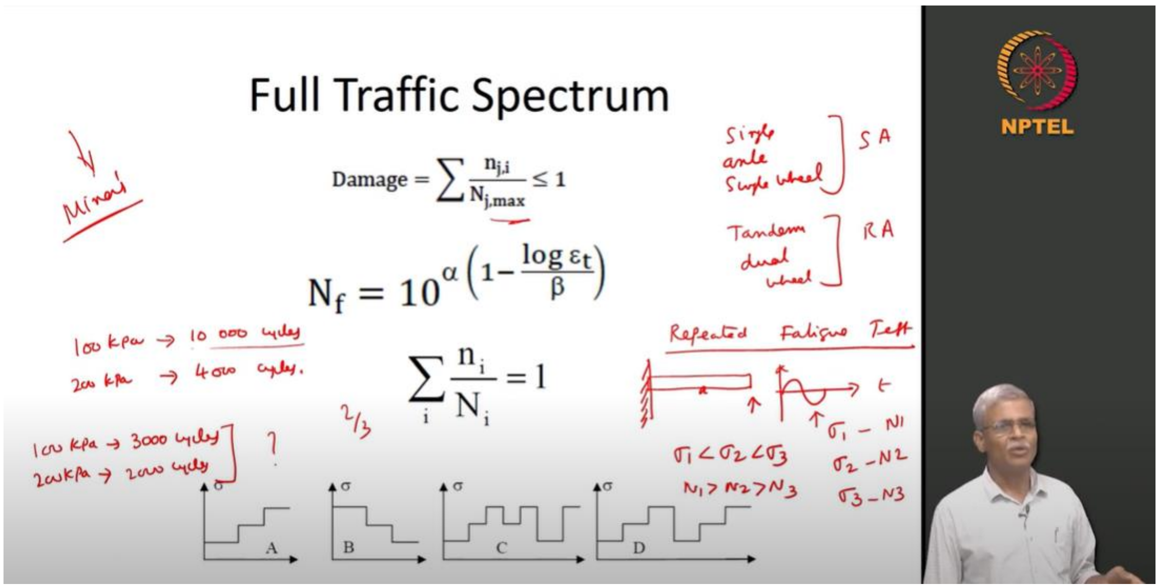

The South Africans also do it in a slightly different way. Instead of trying to do it in terms of a load equivalency factor what they actually do, take your full truck whatever is the truck that you see, okay. So, this is what you are doing. So let us take that simple truck that you see, the first one. If this simple truck is applied on one existing pavement and let us say to the point of damage whatever that damage be, let us say if it takes 50 million repetitions and let us say we are going to have only some portion of it, then we estimate that okay it is going to have remaining life of 80% or 70%. Then we take the next one tandem, apply the required repetitions and whatever is the remaining life is there that we are going to do.

Now, what you are doing is application of the first truck followed by the application of the second truck is not going to diminish in any way the structural capacity of the pavement. Is this a very restrictive assumption? It is indeed a restrictive assumption, but that is how we normally do it. There are even more superior and refined ways of doing it. What are they? We will talk about it as we go along.

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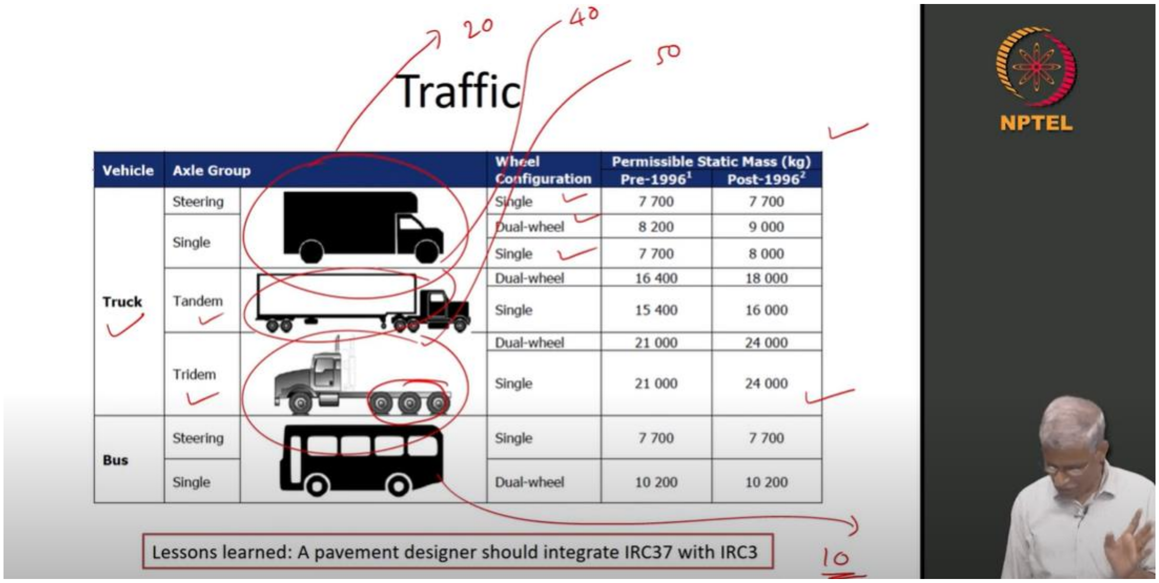

So, now what I want to discuss before we just close for the traffic part here is, there is the traffic analysis in my opinion is quite detailed as far as the South African is concerned. There is a short-term variation versus long term variation which is discussed. There is a lane distribution that is discussed. There is a daytime and the nighttime variation that is discussed. There is a weekday and weekend variation that is discussed and then you can also have what are called exceptional period. Suddenly, there is a harvest or a festival and there is suddenly an increased traffic growth and axle load that are coming on your road. So how do we really handle that? Then different traffic growths are given for different vehicles. What is the traffic growth rate that you use in IRC 37? You do not differentiate between different vehicles, right? Because, you are talking in terms of the load equivalency factor. Now, what is the interesting thing, when you start looking at it in terms of the vehicle? In terms of the vehicle, when you are doing, you can give different growth rates and then similarly, there is a difference between a new design and the rehabilitation design. The rehabilitation design is actually an experiment for all of us to really understand and do it. Why we have constructed a new pavement and we have monitored how the traffic is increasing and how the load carrying capacity of the structure is diminishing. So, we have now in our mind of how actually this new test stretch is behaving and that should give us enough idea to refine our equation. And finally, what is interesting is the geometric capacity limitations and this is where you now link between a two-lane, two-way, three-lane, four-lane, six-lane roads, what exactly is the capacity that we have and whether we are able to match that capacity.

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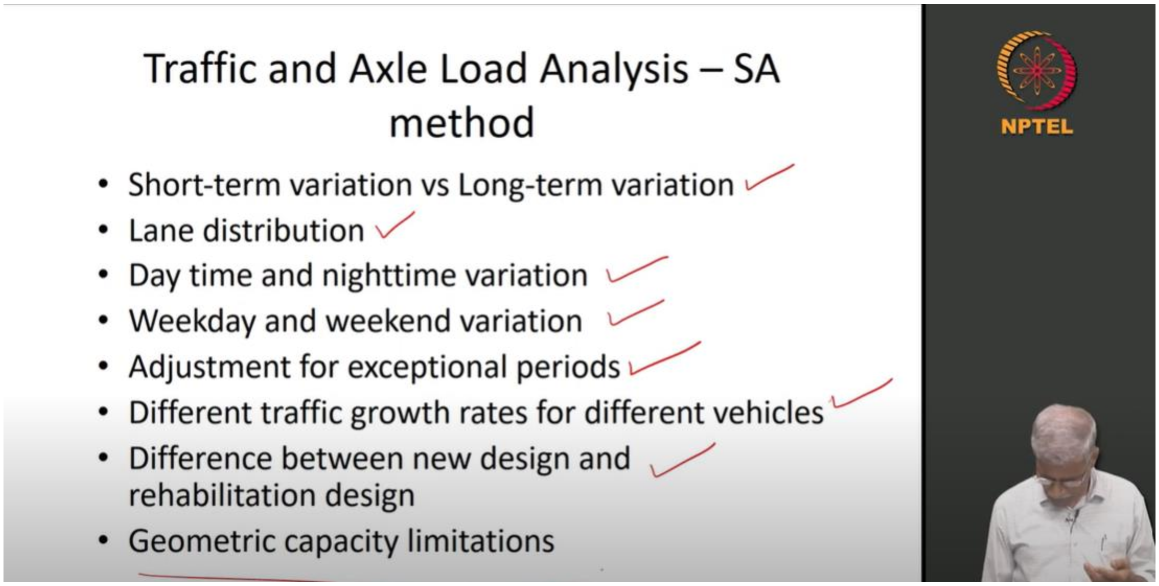

So, in the next lecture, what we will do, we will talk about the various materials as well as the design methods. Thank you so much.