Analysis and Design of Bituminous Pavements

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Lecture - 47

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

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So, let us continue our discussion on the various pavement design methods that are available in the world in fact, I have specifically selected three countries, South Africa, Australia and finally, the United States of America, especially related to the AASHTOWARE or the MEPDG, which is quite exhausting. There is a reason why I picked these two design methods, especially in South Africa, the manner in which they integrate the pavement, and construction pavement management into the pavement design process. So, that kind of integration is something that ideally in India we should be striving for. Australia comes from a completely different perspective in terms of the rigorous manner in which they handle the axle loads and the rigorous manner in which they give separate distress transfer functions for each of the pavement layers.

And finally, AASHTOWARE which is quite data driven, with thousands of long-term pavement performance sections, data collected or simulated and you can think of it like this is where we should be going in terms of the design strategies. So, what we will do is, we will do the South African design method in two different videos.

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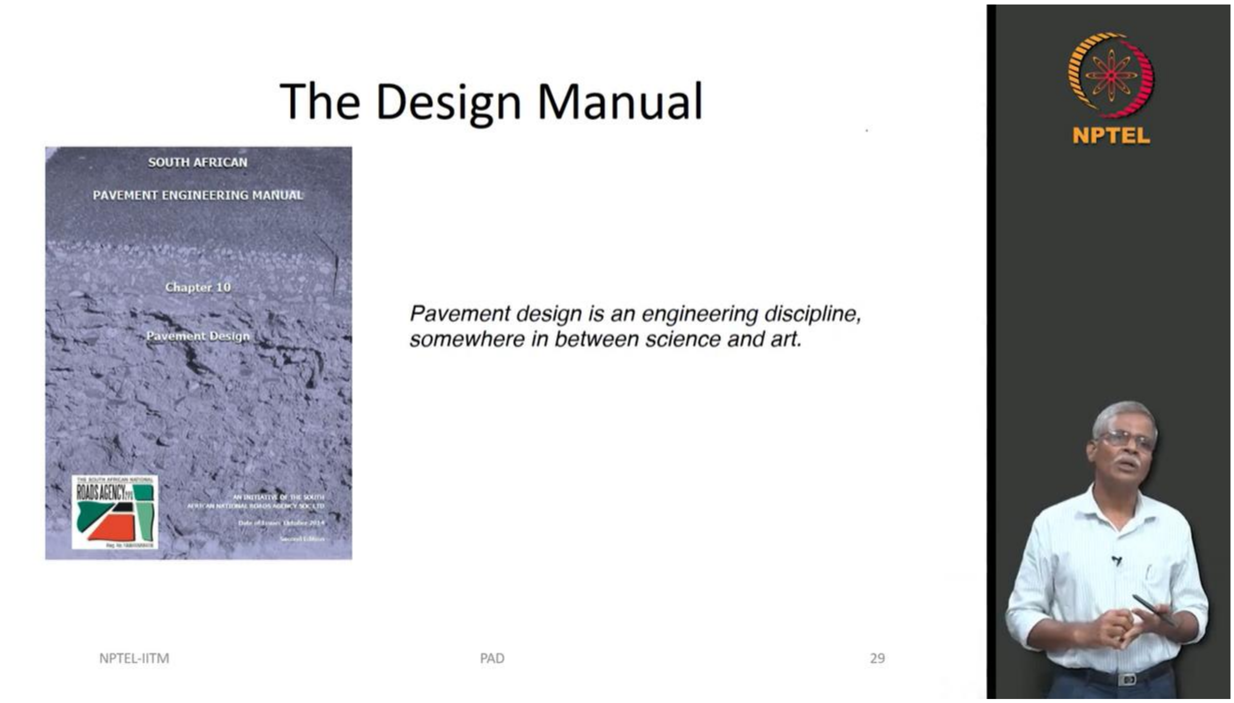

So, this is the South African pavement engineering manual, you should be able to download it, it is freely available and in fact, there is a full component of the pavement engineering manual that is available. I have shown you only chapter 10, which corresponds to the pavement design. There is a small component of concrete pavement design which is a part of it, but that is something that we will not be discussing in this course. We will have a separate course to talk about concrete pavement design.

This is the first sentence that I really liked in the pavement design manual and it says something like this. Pavement design is an engineering discipline somewhere between science and art, which is very true. In fact, in the last discussion that we had, you must have seen in the distress transfer function, how on the left-hand side, you have the number of repetitions to failure for rutting or fatigue cracking, which is the terminal condition, and this is related to the initial condition that is given on the right-hand side. There seems to be some kind of a gut feeling, engineer's intuition, or uncommon common sense that gets into the whole design part. And there are a few important concepts that you will see only in the South African pavement engineering manual and that is something that we will discuss as we go along.

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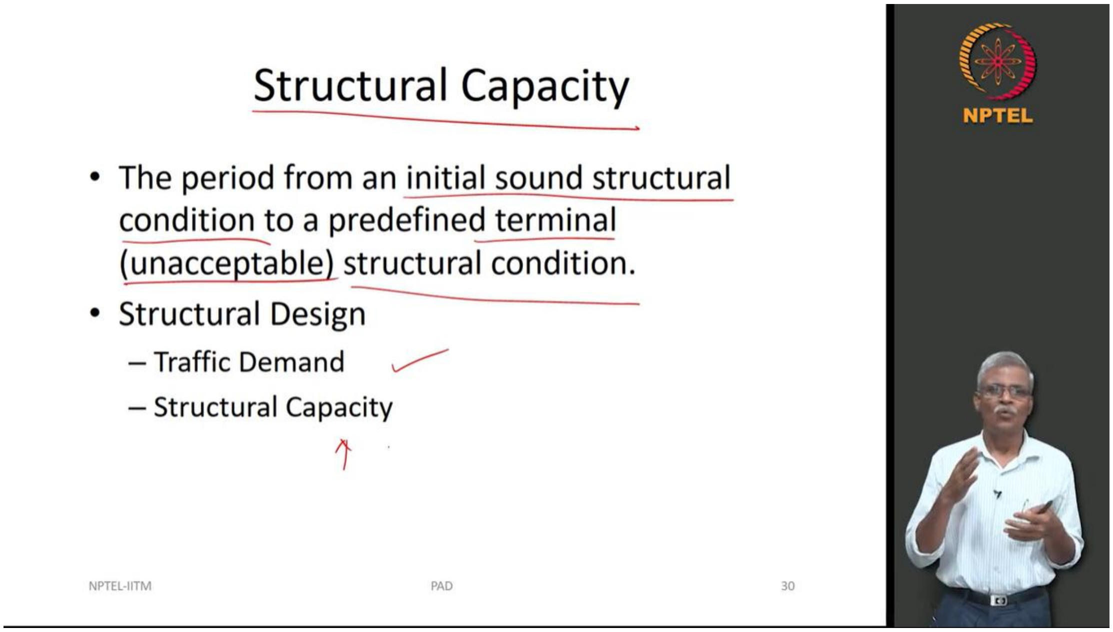

So, now, there is a very clear-cut definition of what is called structural capacity, which is the period from an initial sound structural condition to a predefined terminal structural condition. This period is where we are talking in terms of structural capacity because as we discussed in the initial lectures, as far as pavements are concerned, we always talk in terms of functional failure, and structural failure. Functional failure is when you are not able to ride your vehicle on top of your pavement with comfort at the design speed and structural failure is when it completely breaks down. Now, with that context put this into practice, what is really called the predefined terminal or what is called the unacceptable structural condition. You see a road that you think is motorable, but when you are trying to drive on top of it, the geometric design says that you can drive at 60 kilometers per hour, but you are not able to drive on top of it.

You can call that an unacceptable condition in which case its structural capacity, you can think of it in terms of reaching its terminal condition. The structural design basically here consists of two things. One is the traffic demand, and another is the structural capacity. And in fact, in the old AASHTO, you can actually see AASHTO 1993 which was discussed by Dr. Nivitha, you would have seen the difference between W_{tx} and W_{t18}.

So, given any pavement with a resilient modulus and structural number, what is the capacity for it to take this 80 kN repeats? When the condition goes from let us say 4.2 to 1.5 or 2, that tells you something about the structural capacity. Now, what is that that we need to really match it with? What is the expected traffic demand here?

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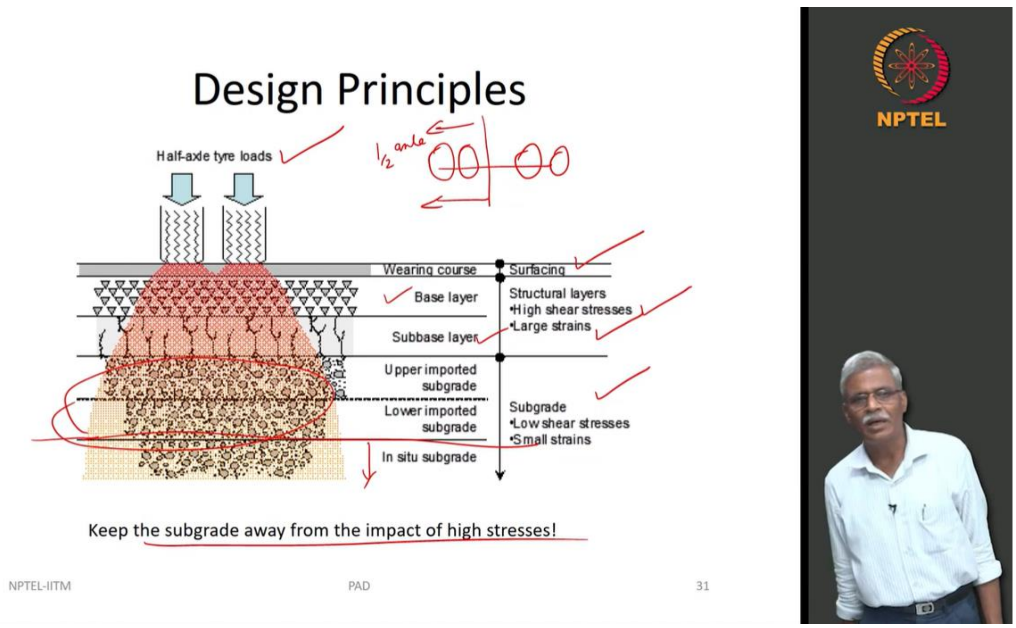

Now comes the most important thing here. This is their schematic of how the stress distribution really happens. So, you can actually see the half axle tire loads. You see that this is the wearing course, there is a base layer, there is a subbase layer and then this is your existing subgrade and you can actually have two layers on top of the subgrade, what is really called an improved or imported subgrade that you can take earth from the borrow pits and fill it up here.

So, what they really mean by the half axle is, if this is your single axle dual wheel and you call this half axle. The structural layers are subjected to substantially high shear stresses; the strains are also considerably large, whereas the subgrade is subjected to low shear stress and small strains. The simple idea with which I can express the basic design strategy of South African pavement design method is to keep the subgrade away from the impact of high stresses. So, that means to push it all the way down.

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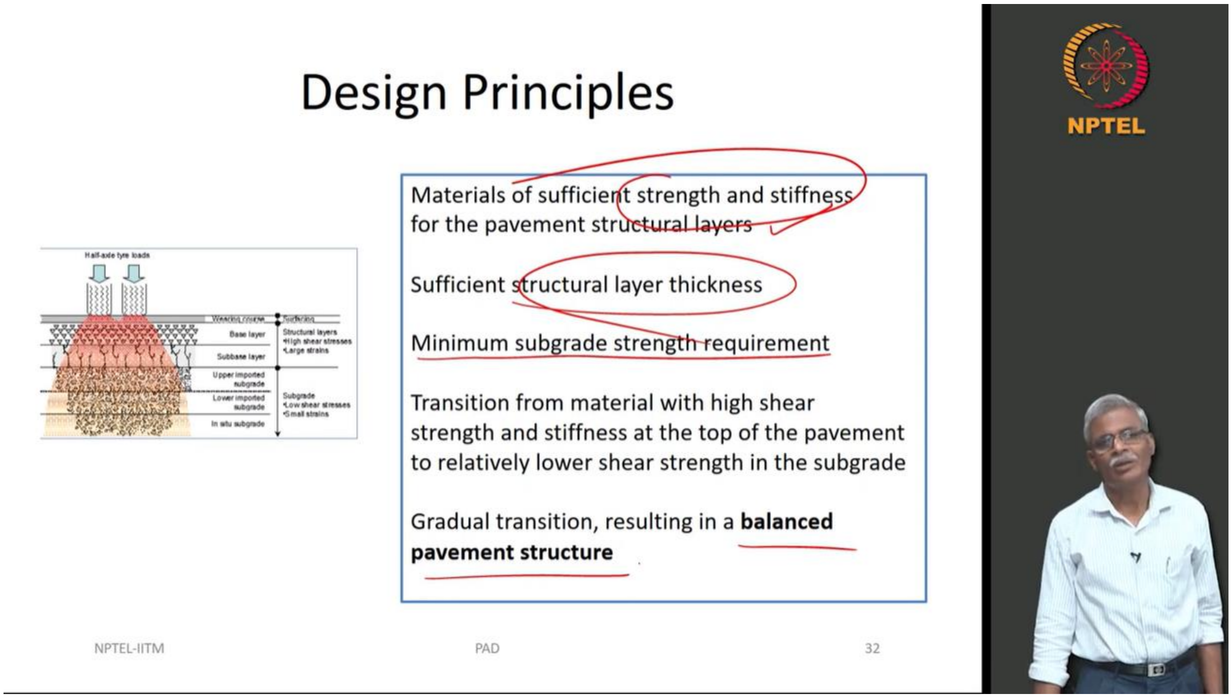

So, let us just look into each of the design principles one by one. As far as the pavement structural layers is concerned and in fact, just before I continue these are the people who also very clearly define what is a foundation for a pavement. See normally, when you are talking about a building construction, you talk about foundation, basement, superstructure and all those things. And when it comes to the pavement if somebody asks you, where is your superstructure and where is your foundation, you may not really be able to answer. So, you can think of the surfacing as something like a superstructure, you can think of the subgrade or the improved subgrade more like a foundation and somewhere in between structure to be called something like a basement. They define it in that specific way. So, materials of sufficient strength and stiffness for the pavement structural layers.

Number two is, when you say strength and stiffness, you are talking about the modulus properties, and material constitution that you are having. Second is what is the layer thickness, we need to have sufficient layer thickness and then you are talking about minimum subgrade strength requirement. The interesting part here is we will be talking about this balanced pavement structure in a short while. They would like you to transition from the material with high shear strength and stiffness at the top to the relatively lower strength in a smooth way and this is really called as balanced pavement concept. Now, there are various categories under the design considerations that are given here.

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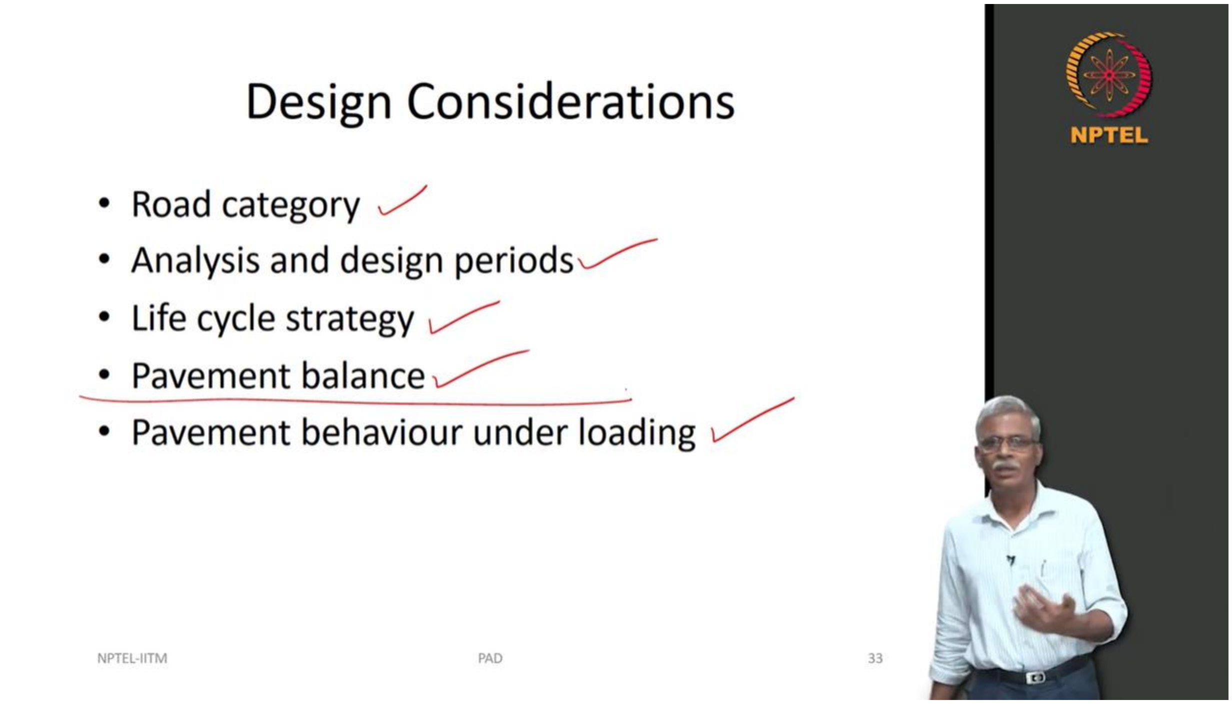

We will try to go through each one of these as we go along. So, first and foremost thing what are the road categories? What are the analysis period and design period? What is a life cycle strategy? What is pavement balance? And how does the pavement behave under load? So, in this lecture, I will try to discuss with respect to these portions, and in the subsequent lecture, we will talk about pavement behavior under loading.

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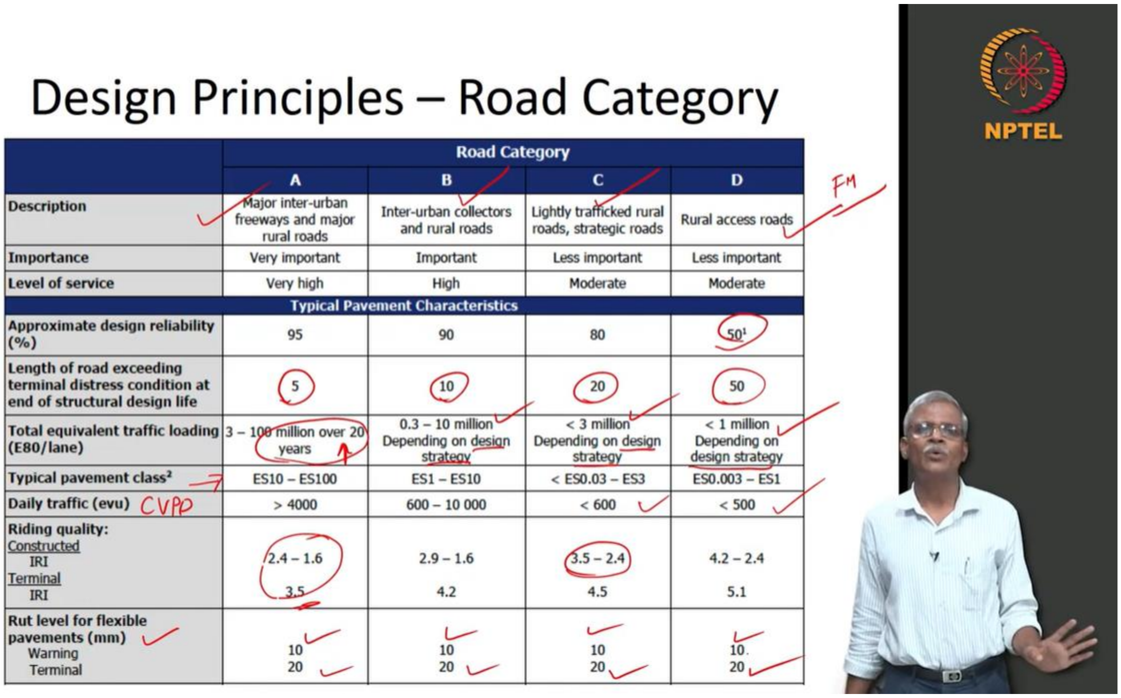

So, this is the road category they define. So, you need to think in terms of expressways, national highways, state highways, major district roads, minor district roads, and all those classifications that we have in India. So, similar to that they have the road category which they call in a very simple way as ABCD. A is a major inter-urban freeway and a major rural road. So, you can think in terms of expressways and national highways. Then B could be something like an inter-urban collector and rural roads. You can think of it in terms of a state highway and C is lightly trafficked rural roads and strategic roads. This is similar to district roads and rural access road.

There are some roads in United States which are called FM roads, farm to market roads. So, that means there is a nearby agricultural field and there is a market somewhere. These roads provided the required accessibility from the farm to the market to take the produce from a farm to the market. So, the requirements are fairly simple. Now, the strategic level of importance that you are looking at is very important, important, less important. Now what is the level of service we are looking at? Very high, high, moderate and what is the typical pavement characteristics that you are looking at? The reliability that you are looking for A is very high. It reduces from 95 to 90, 80 and finally, it just comes to 50 here. And the length of the road exceeding the terminal distress condition at the end of the structural design life is of course 5 here.

The design reliability is 95. So, this is 5 and this is 10, this is 20 and this is 50. What do we really talk about in terms of equivalent traffic loading? So, if you go by the 80 kN standard axle load per lane, you are looking at roughly 100 million standard axles in 20 year period. So, that is the typical period that they are really looking at.

So, this is 10 million, this is less than 3 million and this is less than 1 million depending on the design strategy. Now the interesting thing that you should really notice here is while this design period is mentioned here. The design strategy that they are looking at is, how much is the predefined structural condition and what is the predefined terminal condition.

The daily traffic is similar to what we have in India as CVPD, commercial vehicle per day and this is given here as EV, equivalent vehicle units. So, greater than 4000, then 6000, 600 to 10,000, less than 600, less than 500. And terminal riding quality and this is most important.

What is the IRI value initial and what is the terminal IRI value. You can see the high quality that they are looking at. So, the terminal IRI here is 3.5 whereas you can have that as a starting IRI value for category C vehicle and the rut level for bituminous pavement is 10 mm, 10 mm, 10 mm, 10 mm, and terminal is 20, 20, 20, 20.

So, the warning sign is 10 mm. That means you are expected to start doing maintenance during this period. Now, for most of you who have been following these lectures, how can you relate whatever you have learned from IRC 37 to here? And I want you to really reflect upon it, saying that did we see a separate pavement design classification for expressways, national highways? Did we see a separate classification in terms of IRI, in terms of rut depth for different classes of vehicle? But the most important point that you need to note here is the class of the road may be less important, but the acceptable rut depth remains the same irrespective of the level of service of the road, that is the most important thing.

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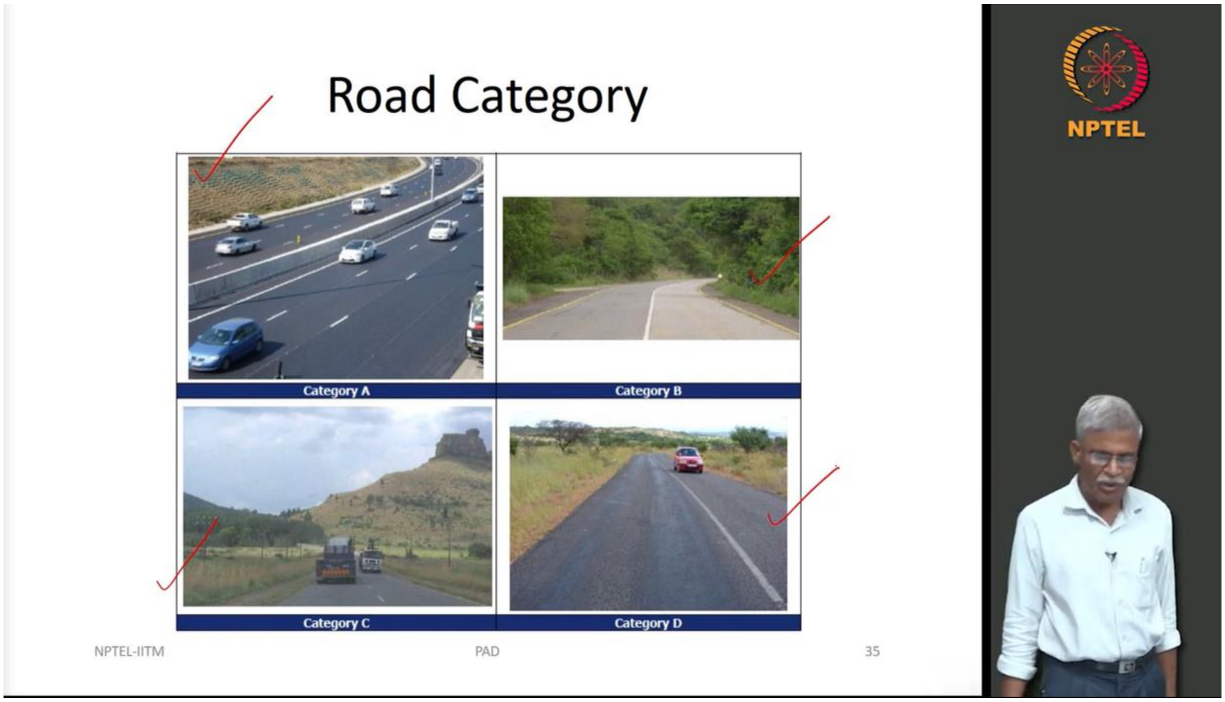

To just to give a snapshot of what these highways look like, I have just taken this from the manual. So, this is your category A, what I mentioned as national highways and A expressways, this could be category B, this could be state highways, this could be major district road and this could be village roads or farm to market roads. So, typically you can think in terms of both these roads, category C as well as category D and to some extent category B is also they are undivided two-lane two-way roads. This could also be category D, which could be a one-lane two-way road typically what you see in some of the roads in our rural area wherein the lane width is something of the order of 5 meters and so typically one vehicle that is coming here moves to the shoulder allowing the other vehicle to pass through.

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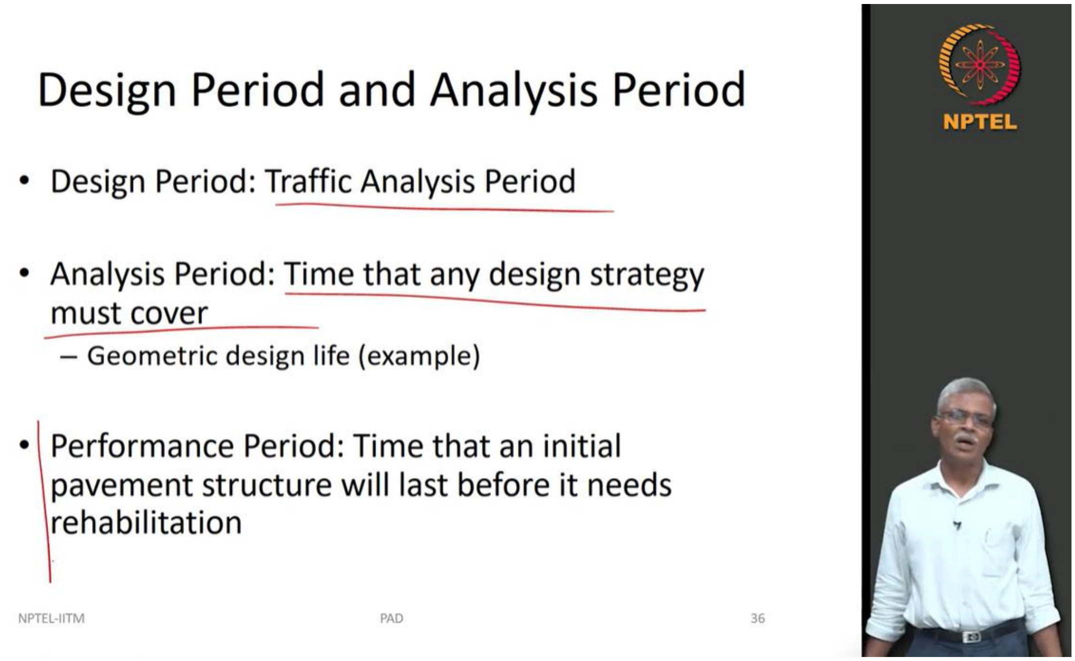

So, now we need to take a recap of the design period and the analysis period because these kinds of definitions and classifications are very important as far as the South African manual is concerned. The design period is the traffic analysis period. For instance, let us say estimate the likely traffic and then you have to do the projections for many years say, 5 years or 10 years you need. For a country like ours where we are growing these days, is it a correct way of projecting for 10 years or 15 years from now? Let us assume the following. Let us say you do your volume count, axle load count and then use your vehicle damage factor, come out with 30 million standard axles, and then let us say you design it for 10 years.

And whenever a new facility is constructed there is always a tendency for the traffic to move in that direction and what if the design period that you use is such that this whole 30 million standard axles or 40 million standard axles comes in the first 4 years, which means what you have designed for 10 years is going to have a problem at the end of the third or the fourth year. So, it is always not a great strategy to look out for projections for too long a period for a country like India in which highways are being laid, being maintained, there is a spurt in the truck traffic growth. So, we might end up with some kind of failure. What we really need to do is we need to kind of look at 5 year period, and in fact that if you are familiar with IRC 37: 2012 there used to be charts even for 250 million standard axles.

Now we have only up to 50 million standard axles which make actually a lot of sense. The design period is your traffic analysis period. The analysis period is that time that any design strategy must cover. To give an example, we will look in terms of the geometric design life where, there will be design speed, posted speed and so on. Let us say you have constructed a highway and carried out the geometric design for let us say 80 kph. So, that means your radius, super elevation everything has been taken care of as far as this 80 kph speed is concerned. Now you have high-speed trucks in fact, many of the trucks that we have in our country are very good that they can go up to a much higher speed. Now what will you need to do now is to make corrections to the highway. Is it really possible? It may not really be possible because you have designed something for 80 kph, and now if you want to elevate it to 120 kph you need to make major corrections in the geometry of the highway.

So, what I am trying to say here is the analysis period is the time that any design strategy must cover. That means if you say this road is going to be an 80 kph road. If it becomes a 100 kph road let us say at the end of 5 years or 10 years, you want to call that as an analysis period. And then performance period is where any pavement structure will last before it needs rehabilitation.

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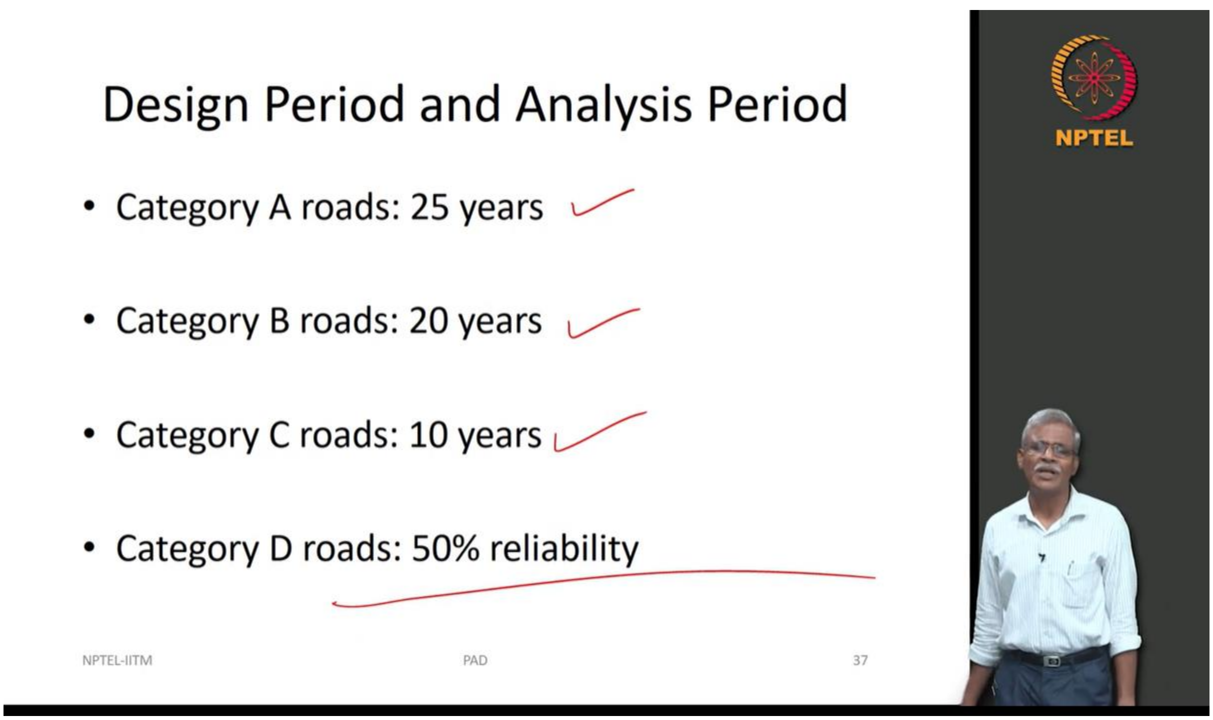

As far as the South African manual is concerned for category A roads it is 25 years for many B roads it is 20 years and for C roads it is 10 years. And for category D roads they do not really say too much about how much should be the design period and analysis period. They talk in terms of reliability.

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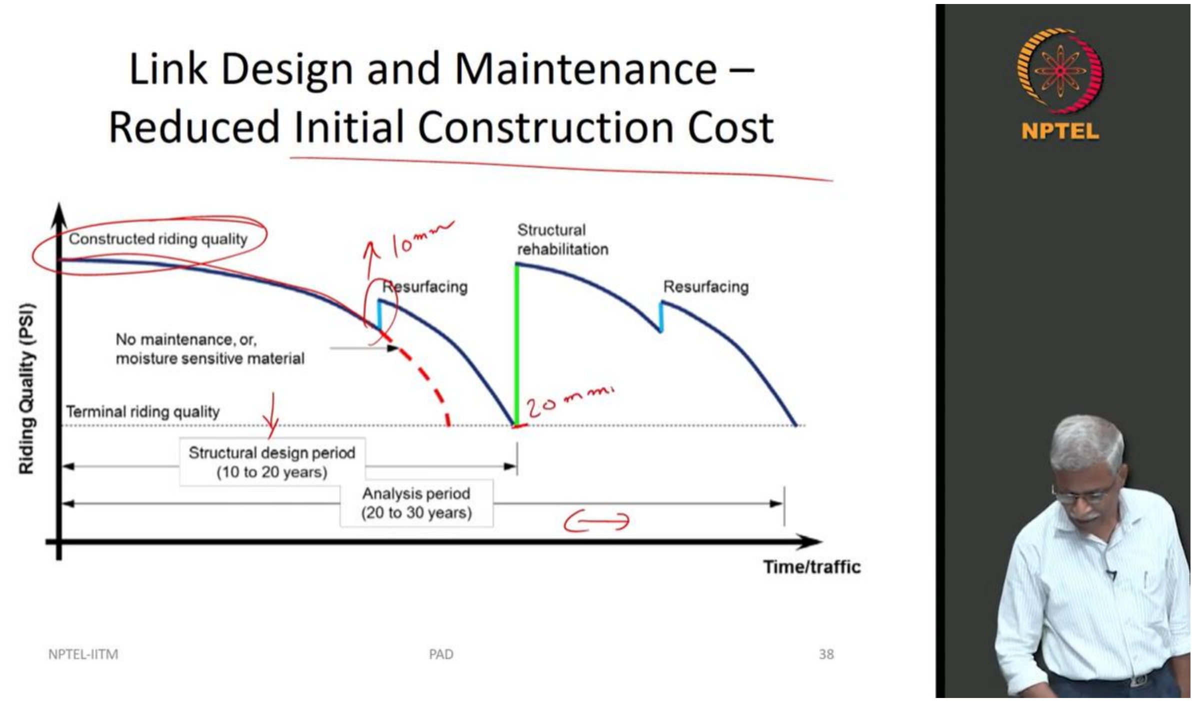

Yet another important thing as far as the South African manual is concerned is when you do the pavement design itself, you link the design and the maintenance. That is something that we do not explicitly take into account in our pavement design process. For instance, in this plot, the y-axis is riding quality in terms of pavement serviceability index. This is your constructed riding quality and I am talking in terms of two cases here, what is really called the reduced initial construction cost. In fact, it always makes sense to do the construction for an initial period of 5 years or maybe 10 years, and then depending on the traffic growth and axle load growth, you can keep increasing the structural capacity of the material.

You can keep increasing and extending the life of the pavement by keep doing rehabilitation strategies. Now, the structural design period is, let us say 10 years or 20 years, and this is your analysis period of 20 to 30 years. So, you are talking in terms of the PSI reducing and then you get a trigger, which can be small resurfacing and then the quality increases. The terminal riding quality can be indicated in terms of 20 mm or 10 mm. So, you need to do a major structural rehabilitation when it reaches 20 mm and then it goes on like this. This is your reduced initial construction cost.

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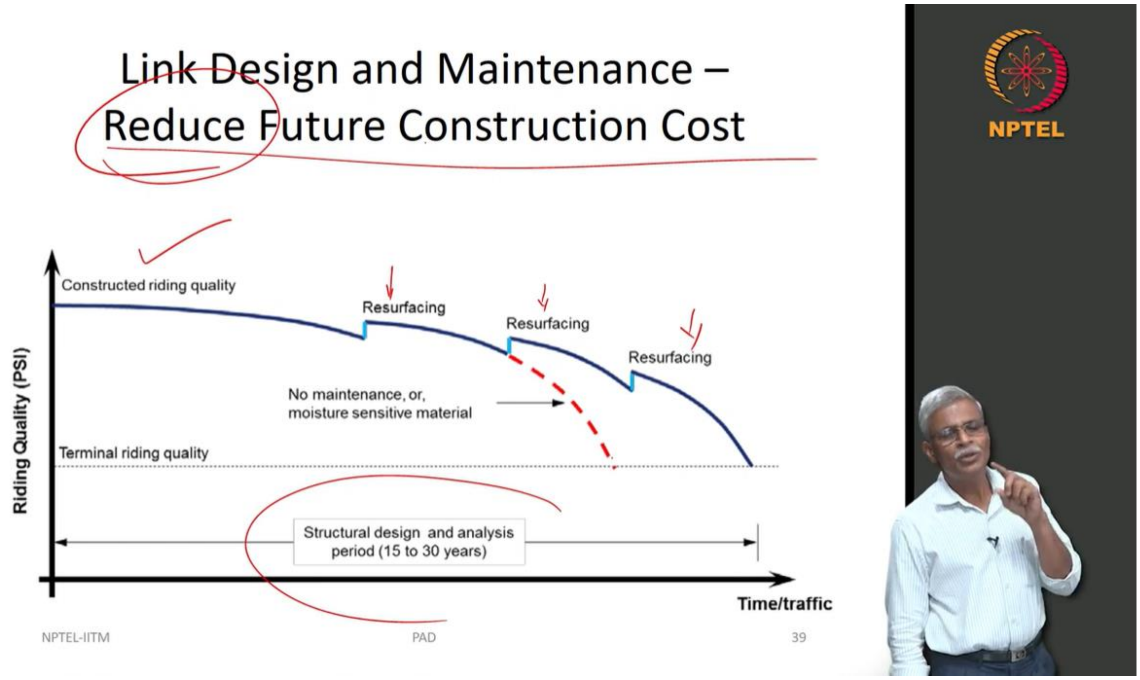

Now, what you are talking about is reduced future construction cost. This is always a problem because, whatever money you spent earlier, now the same money has a completely different value 5 years down the line. Do you want to reduce the initial cost or do you want to reduce the future construction cost?

This is something that we do as part of the pavement infrastructure management course but what is interesting in the South African manual is, these things are integrated part of the design strategy. You can take a look at the constructed riding quality with no maintenance all the way here. There is no big difference between the design period and the analysis period. You all the way keep doing only resurfacing here, which is actually cheaper and that is why you say that the future construction cost is reduced. When you now do your design, you also need to tell the pavement owner that I am going to do a design wherein, the initial construction cost is going to be high but the future construction cost is going to be less and that part has to be integrated during the design period.

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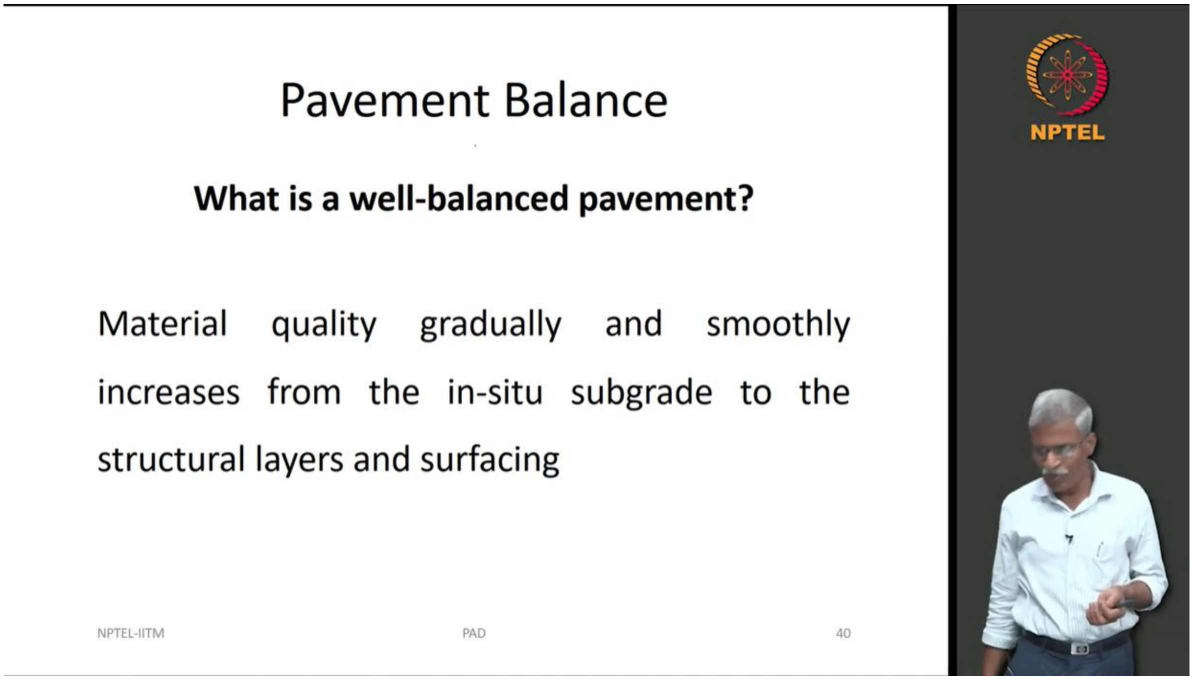

Now comes the next concept which in my opinion is a very important concept, what is called as a well-balanced pavement. Here, the material quality gradually and smoothly increases from the in-situ subgrade to the structural layer and surfacing. That means, you do not give a drastic jump in the modulus value as you go from the subgrade all the way up to the surface material. So, this is what is called a well-balanced pavement.

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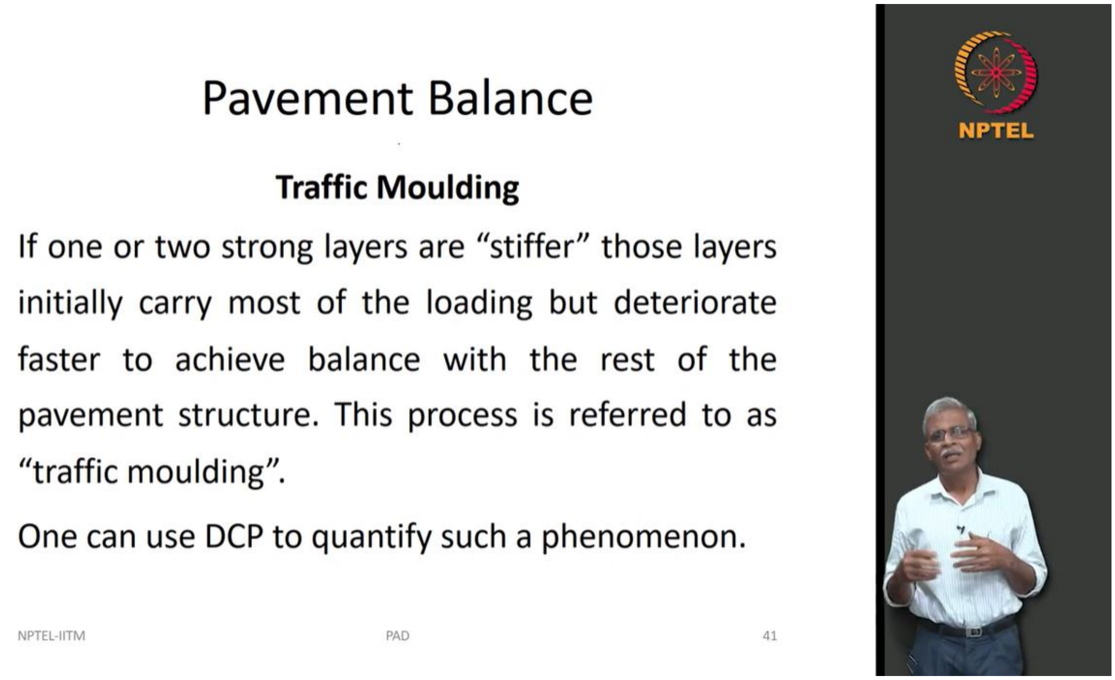

Now, if you do not do that what can really happen is that South Africans introduced a very interesting concept called traffic moulding. If let us say one or two of the layers are stiffer, these layers will initially carry most of the loading, but they will deteriorate faster to achieve balance with the rest of the pavement structure. Due to this particular process, there is something called traffic moulding that happens. A dynamic cone penetrometer can be used to test the quality of the material.

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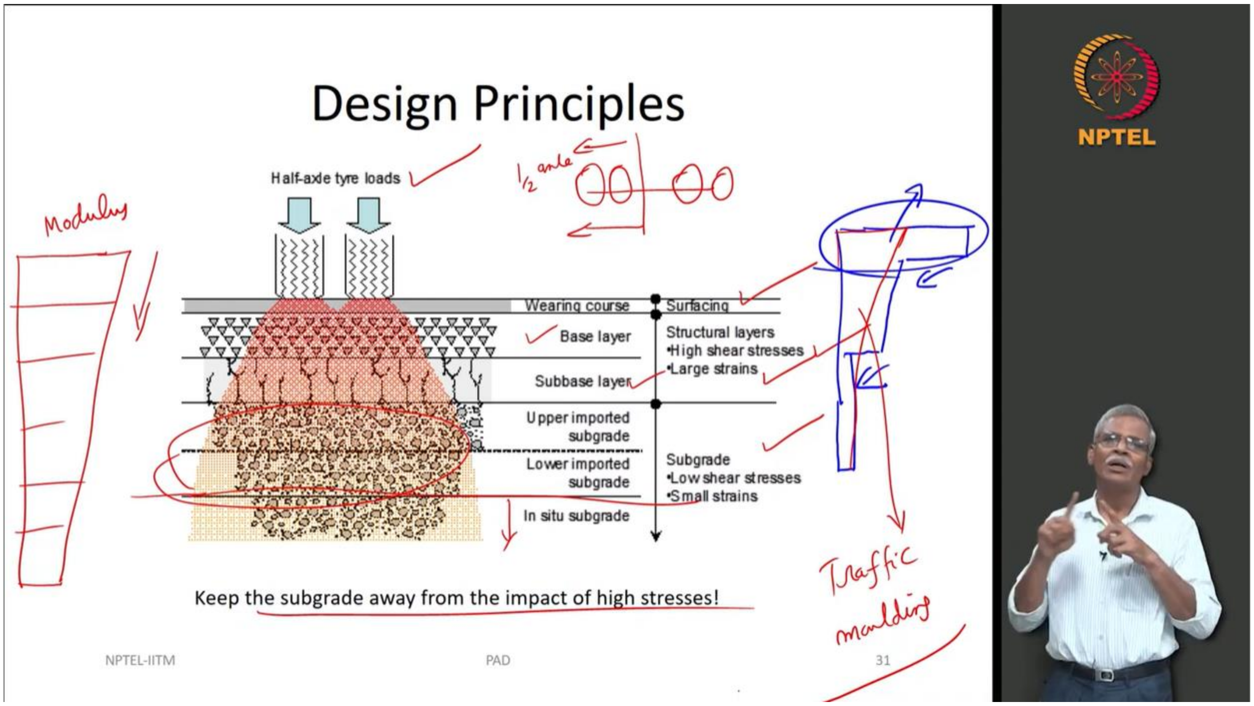

Let me explain this using this cross-section. Let us take a look at this one. Let us draw how the modulus is varying. If you assume that the modulus is gradually varying (red lines), you will call as a balanced pavement design. Now, instead, let us say, there is a stiffer layer and there is a drastic discrete jump here (blue lines), then there is another jump here. So, most of the layers on top can take more stress than what it has to and because of this, there will be a deterioration. So, after some point in time, you will see a reduction in modulus and this is called traffic moulding. I would like you to also recollect the discussions that we had in the initial lectures wherein we said that if you provide a bituminous layer or any of the binder or the surface courses with considerably large modulus values, you might reduce the vertical stress and deflection, but shear stresses and tensile strains can actually increase. How do you really make it well balanced and that will be really really interesting to do at the graduate level. If you are an M.Tech student who is taking this course, and if you would like to do your project on pavement design then you may want to think about how to verify whether any of the cross sections that are given as part of the IRC 37 catalog is well balanced or how to design a well-balanced pavement.

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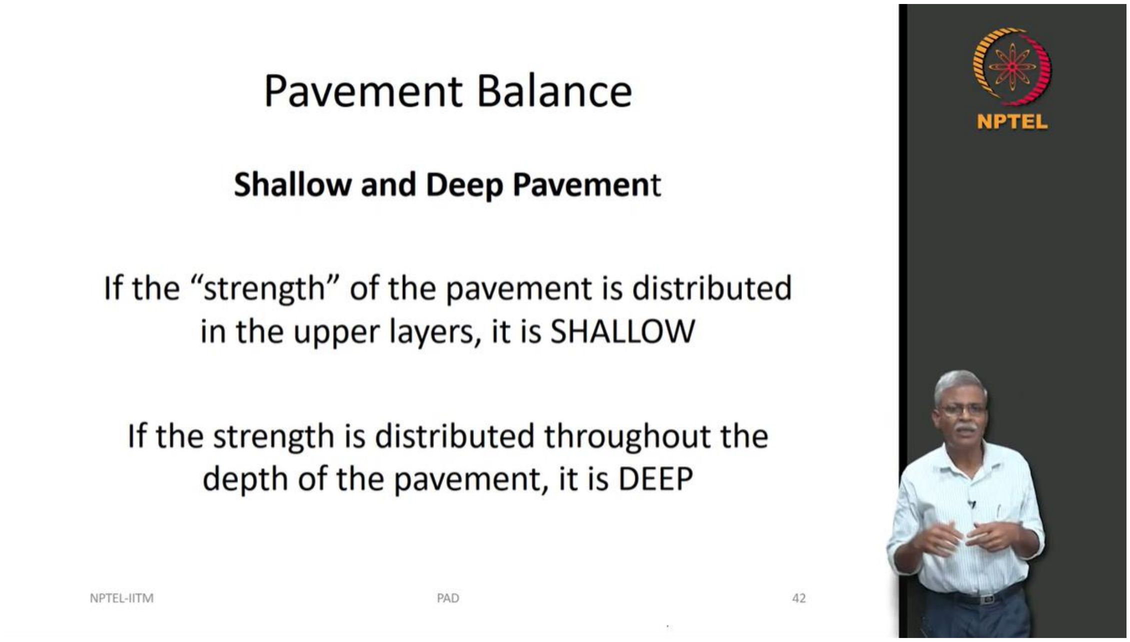

Then there is also a concept of shallow pavement and deep pavement similar to shallow and deep foundations. If the strength of the pavement is distributed in the upper layer, it is called shallow pavement, and if it is distributed throughout the depth, it is called deep pavement. Again as part of an exercise, you may want to also relate a balanced pavement with shallow pavement as well as with deep pavement.

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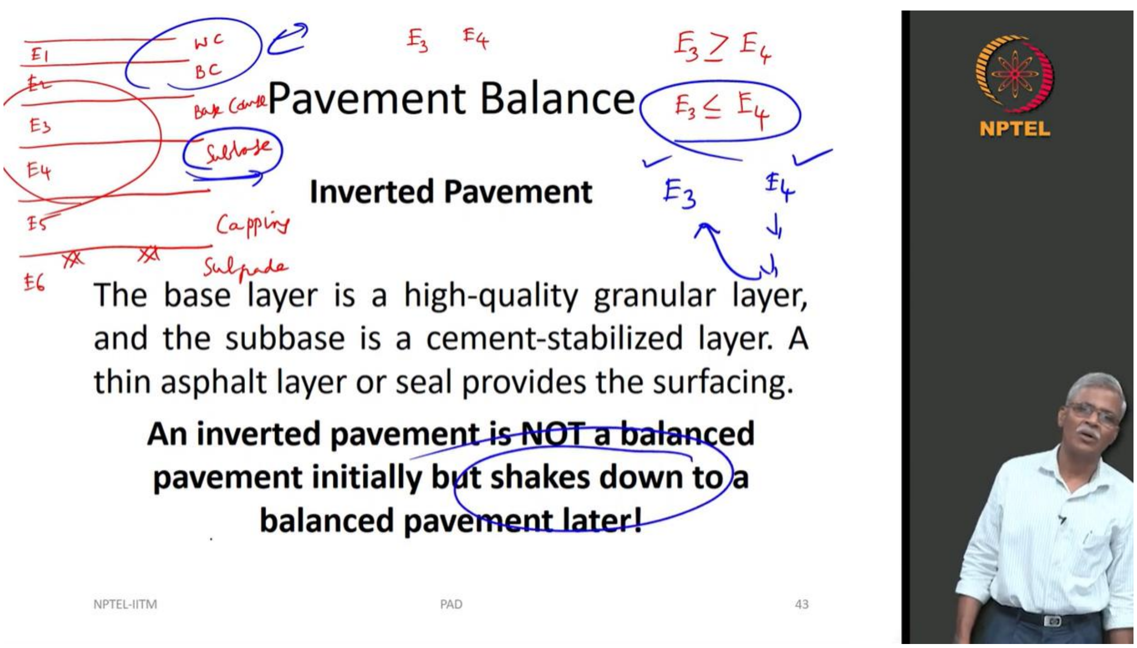

In an inverted pavement, you can have a base layer which is a high-quality granular layer but your subbase could be a cement stabilized layer. This is your wearing course, binder course, base course, subbase, capping layer and subgrade. The modulus values are E_1, E_2, E_3, E_4, E_5, E_6. Now let us take a look at these two E_3 and E_4. Now E_3 can be greater than or equal to E_4 or E_3 can be less than or equal to E_5.

So, if you are going to have some kind of a layer in which the modulus of the layer is less than the modulus of the underlying layer, it is an inverted pavement. An inverted pavement is not really a balanced pavement initially but what will really happen is, it can shake down and become a balanced pavement later. You should try to do this using a kenpave kind of analysis wherein, you try to put across modulus values that are slightly more for the higher layers and see what happens.

What can really happen is, since this has more modulus value it can take more load but it can also deteriorate faster. Initially, E_4 is higher E_3 is lower and slowly, E_3 value and E_4 value will remain the same. The value of E_4 can keep coming down and it can reach the value of E_3 in which case you will get a balanced pavement. I have used a very interesting word called a shakedown. It shakes down to one optimal status which is really called a resilient status.

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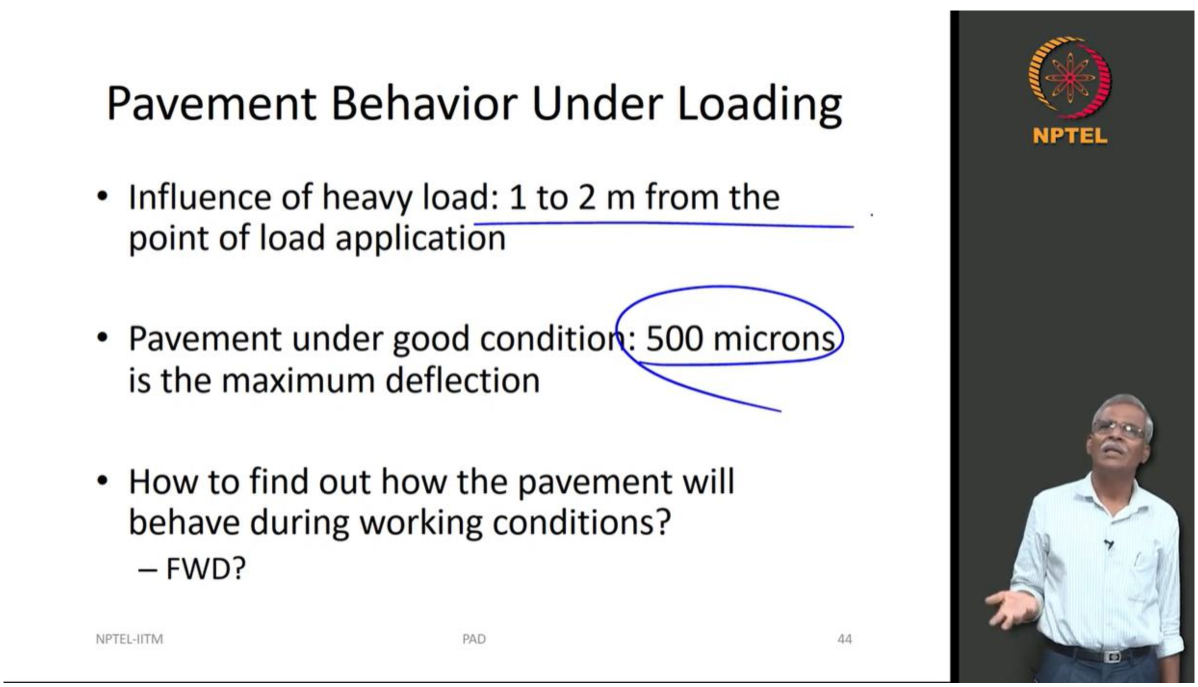

Now that you have designed a pavement, what is the maximum deflection that you are likely to get? Because most of the time what happens is, the way in which we do the design is, you have the traffic that is used to compute the vehicle damage factor, and you find out the million standard axles for 5 years or 10 years. You have the material properties and distress equations and then you relate it and say, I want 50 million standard axles and this cross section can take 60 million standard axles. Therefore the design is fine.

What I really want to do is to know what the deformation that you will get for this is. You are going to see that they basically give you a prescription that if the deformation is of the order of 500 microstrains, a pavement is under good condition this is the maximum deflection. For a given load, this analysis can be done in Kenpave. You can take a pavement as you have many cross-sections there, and apply the maximum load. You do not need to worry only about 560 kPa. If there is overloading, apply 1000 kPa or 2000 kPa. Use your Kenpave analysis, go on all the sides, try to see when the deformations will become 0 and if it is going to extend beyond 2 meters, then you are basically not looking at a great design. So, this is the design that you need to be really worried about. How do we really find out how the pavement will behave during working conditions? Either we can do a simulation or on a pavement that is immediately constructed, we could try to find out using a falling weight deflectometer.

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I am sure you all must have heard about the word falling weight deflectometer. Basically what we want to find out is, what is the extent of the deflection bowl, and from the deflection bowl how do we really read what is the extent of the deflection? So, we will discuss everything in the next lecture.