Analysis and Design of Bituminous Pavements

Dr. J Murali Krishnan

Department of Civil Engineering

Indian Institute of Technology, Madras

Lecture - 52

Overview of Mechanistic-Empirical Pavement Design Methods - AASHTO - Part I

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Hello, so let us continue our discussion related to the various pavement design methods. I just gave you an overview of IRC, I am sure that you know you would have done extensive calculations related to the same. Then, we went to South Africa and then we went to Australia and then finally, we are going to go to United States of America. Now, most of the developments related to the analysis, design of pavements, material characterization, everything started more or less with the United States of America. Earlier, what was called as AASHO road test and later what becomes as AASHTO design guide and the concept of mechanistic empirical pavement design method, in addition to the earlier versions of software such as Darwin and right now what is really called as the AASHTOWare have all provided us a very rigorous framework for analyzing and designing bituminous pavement. Now, if I have to teach AASHTO, it has to be a separate easily 10 to 15 hours of an NPTEL course or if you come and sit in my class you are going to look at least 4 weeks of classroom sessions. Typically, at IIT Madras, we teach 50 minutes per class, so if I have 3 classes per week or 4 classes per week you are looking at 4 weeks. So, that much of extensive information has to be provided to you. So, this is in terms of how to understand traffic, how to understand the materials, how to do distress characterization, how are these distress transfer functions generated, what about reliability and so on it goes. It is a detailed calculation that one needs to do. Right now, what I am going to do is, to kind of give you an overview of it, a snapshot of it, because then you can immediately understand, okay, so this is how a pavement design should be done. Many practitioners will say that this recent version of AASHTOWare is an overkill because you are looking at getting so much of data that is, more than 150 plus kind of parameters that needs to be input into the system and analysis has to be done. So, that is one school of thought, but from the students' perspective you need to have a comprehensive background about the most sophisticated pavement design method as of now available and that is what we are going to do now.

So, this is the interim report that was submitted, the Mechanistic Empirical Pavement Design Guide, what is really called as the MEPDG and the manual of practice, this is the interim edition July 2008. So, this is the version that I have with me and all my discussions are going to be based on this.

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Where is the starting point of all these things? So, we need to kind of have a general idea about how all these things happen. So, this is the starting point. This is the AASHO road test, there is a detailed highway research board bullet in 1961 in which all these details are provided. So, now this construction was between 1956 to 1958, traffic application was from 1958 to 1960 and the test facilities are 6 two-lane loops as given here. And, in fact, you can actually see that this is the test tangent, there is a pre-stressed concrete section, flexible pavement, rigid pavement, of course we said we will not use flexible and rigid but bituminous and concrete but again, this is 1961, so you know what I am talking about. So this is the whole thing that are seen here okay. And then, what I am showing you is loop 5 and loop 6. So, if you take a look at loop 5 and loop 6, these were the loads that were applied, the front axle is 6,000 pounds, the rear axle is 22.4 kilo pounds, see like that, these loads were basically applied and you can actually see the overall gross weight that was used here. That is the whole idea behind this and in fact, this 18 should be something that should give you some idea about what we are talking about.

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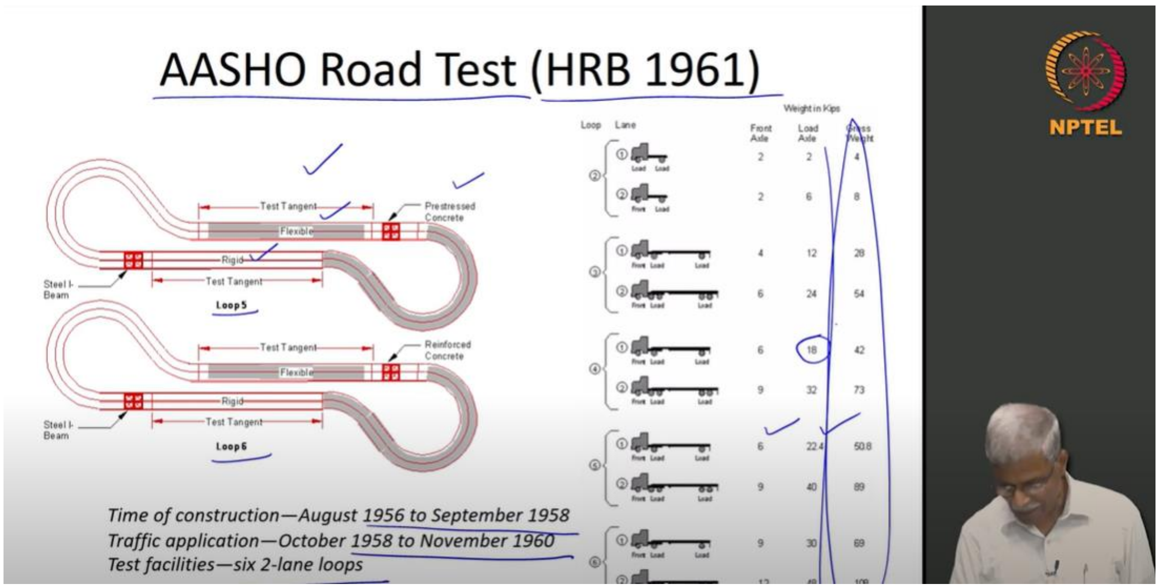

So, what was basically the outcome of the AASHO road test? The AASHO road test came out with the concept of the equivalent single axle load. So, W_x/W_{18} and similarly you can actually see that these are the various equations that were used and this is completely different for bituminous pavement as well as concrete pavement. And, these are things that have already been discussed in relatively simple terms in some earlier lectures.

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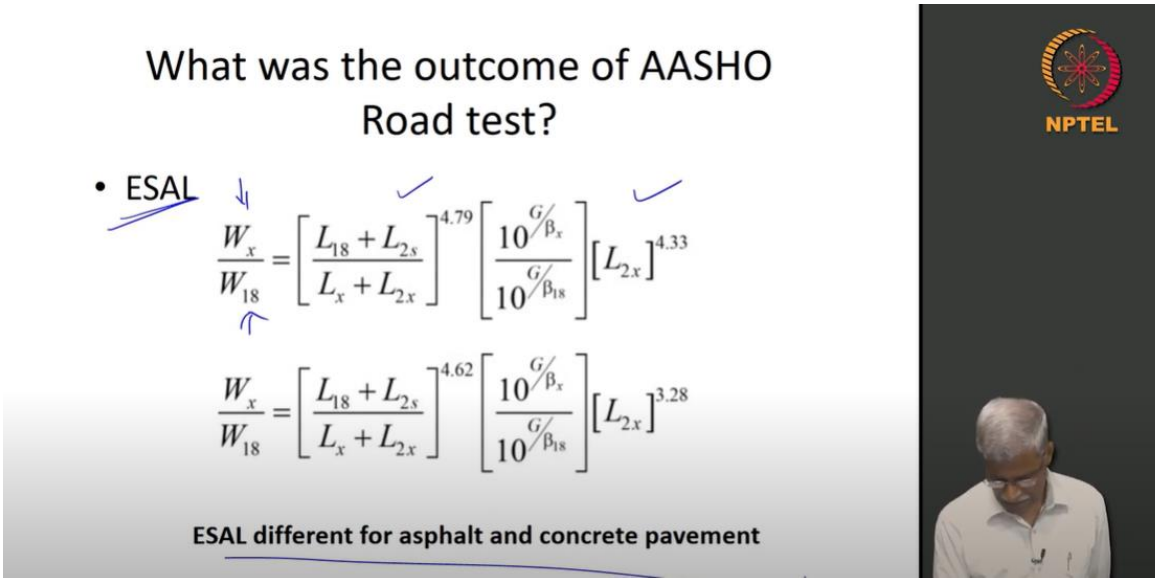

So, what is the genesis of this whole thing? So, the first bituminous pavement guideline was released in 1961. The next year they released the concrete pavement guidelines. Then they integrated everything and released one AASHO interim guide for the design of pavements in 1972. And then, there were some revisions that were made in 1981, basically stiffness modulus, various calibration factors and the stress ratios that are used. In fact, if you go back and take a look at some of the concrete pavement design methods, the PCA method of pavement design in which you are relating the flexural stress ratios with the modulus of rupture, all those things actually came in here. But we are not really talking about concrete pavement in this course.

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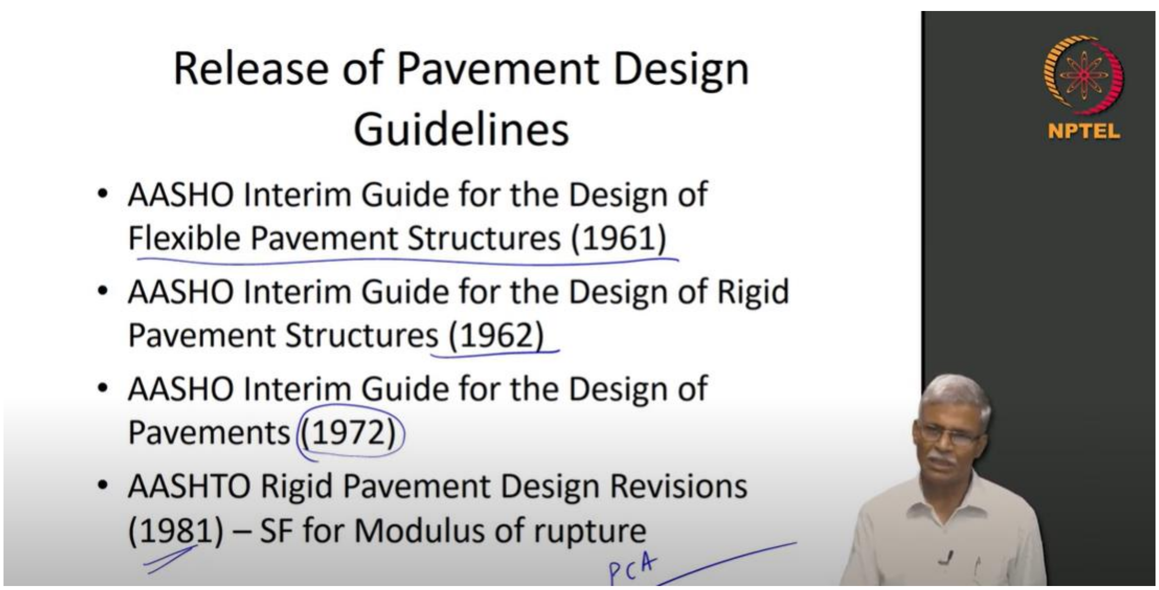

So, these are all the things that happened in the 1986 version. First and foremost thing, very clearly reliability was integrated, number one. Number two, is resilient modulus for soil support. So they did away with CBR, R value and all those things and then they came out with a pressure dependent resilient modulus. Drainage was explicitly taken into account. Improved environmental considerations were taken into account and various environmental related models that influence the mechanical response of the materials were calibrated and validated and integrated with the pavement design. Then, extension of the load equivalency values is also taken into account and improved traffic data and this is the most important thing, they not only stopped at collecting the data before the design, they also monitored the response of the pavement for the continuous traffic loading conditions for which a new pavement is constructed and then used that information to keep validating the distress models. Layer coefficients came because you started talking about the structural number and all those things. How to do the rehabilitation, that also was taken into account. Then, this was integrated as part of the pavement design method. So, this is how ideally one should have a comprehensive framework. So, we need to take a pause here. It is not that these things do not really exist within the IRC guidelines that we have but they are all at different places. So, somebody who designs the pavement has to have this information so that one can integrate this as part of the life cycle process. Pavement management information was considered and in addition, design of pavements for the low volume roads. So, you have an IRC guideline which is majorly influenced by the AASHTO method of pavement design and the state of the knowledge on mechanistic empirical design concepts were evolved. In fact, they also understood that you need to go to the next level, that is what really happened.

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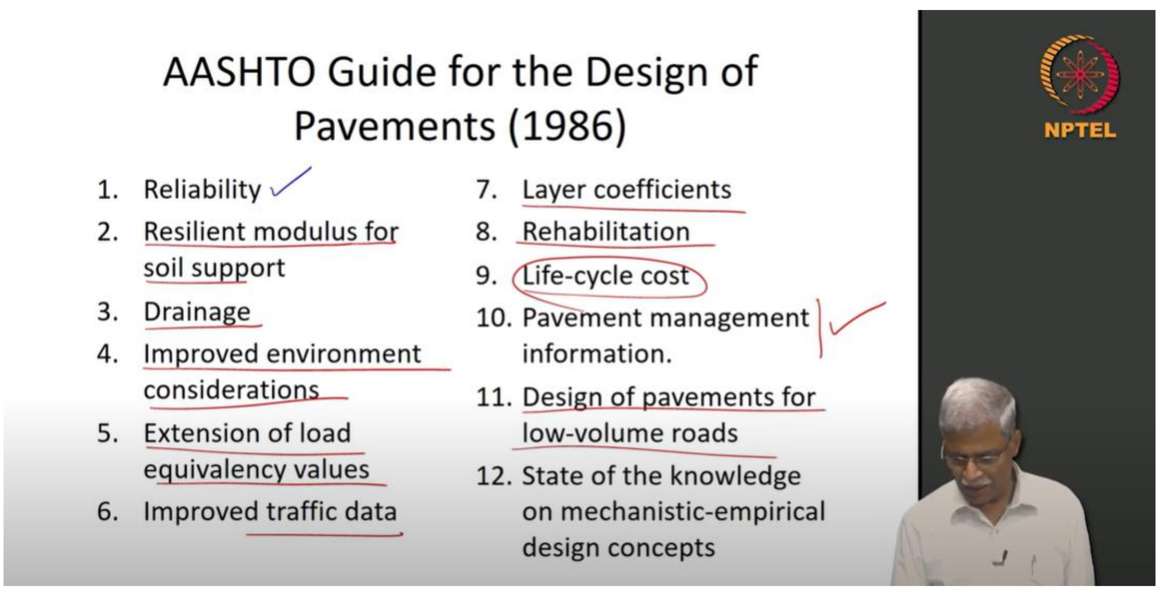

Then, this was something called as the long-term pavement performance LTPP. So what was happening was detailed data was collected on major sections. So, you can actually see here, test tracks from which such kind of a data were collected and these test tracks were throughout the entire United States map.

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So, these are the general purpose and special purpose pavement sites. So, whichever is given in blue color are the general purpose. So, which means there are highways that go from south all the way to the north and in fact, I strongly suggest that you go take a look at the interstate map of United States. So, you will understand what I really mean. It will also be interesting for you to understand how these states are divided like this. So, in our country, the division of the state is based on language as we all have read in our history book but here the divisions are completely different. But what you really need to do is, they basically have a crisscrossed highway system that was going like this and similarly you had highway systems like this and at each and every location, you saw that there are some long-term pavement performance test sections.

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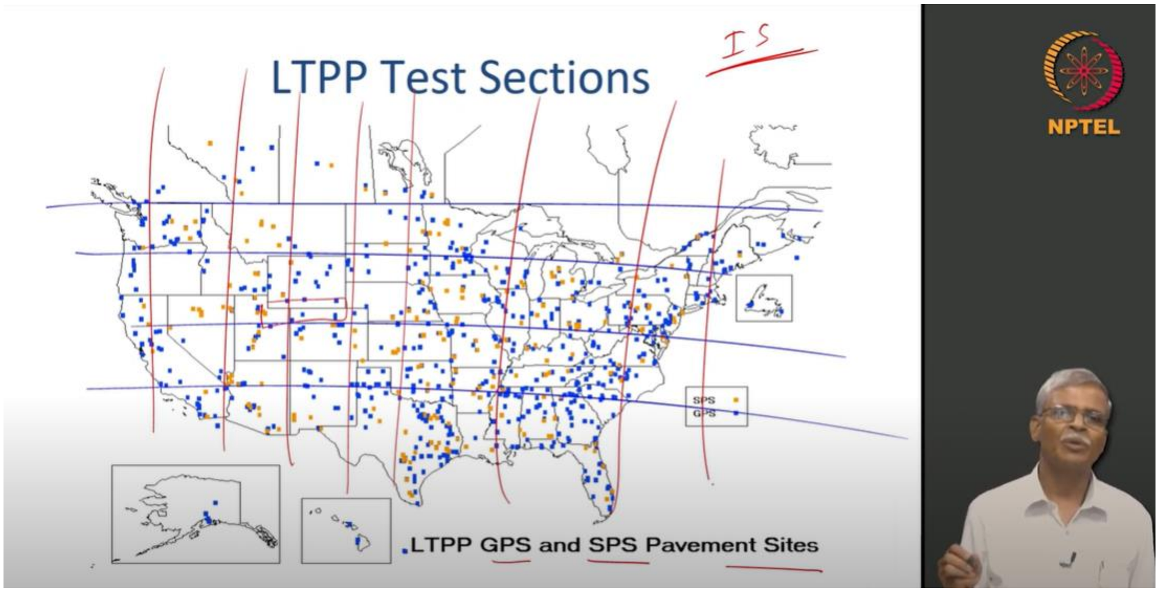

Now, this massive data was collected, assimilated and what are all the data that were collected from all these things. They collected the climate data, they collected the material properties, they collected what is the load that was coming in, the response was also calibrated and validated and finally they were in the process of developing the distress models. See that is the whole idea. So, your material response is going to depend on which location it is being constructed.

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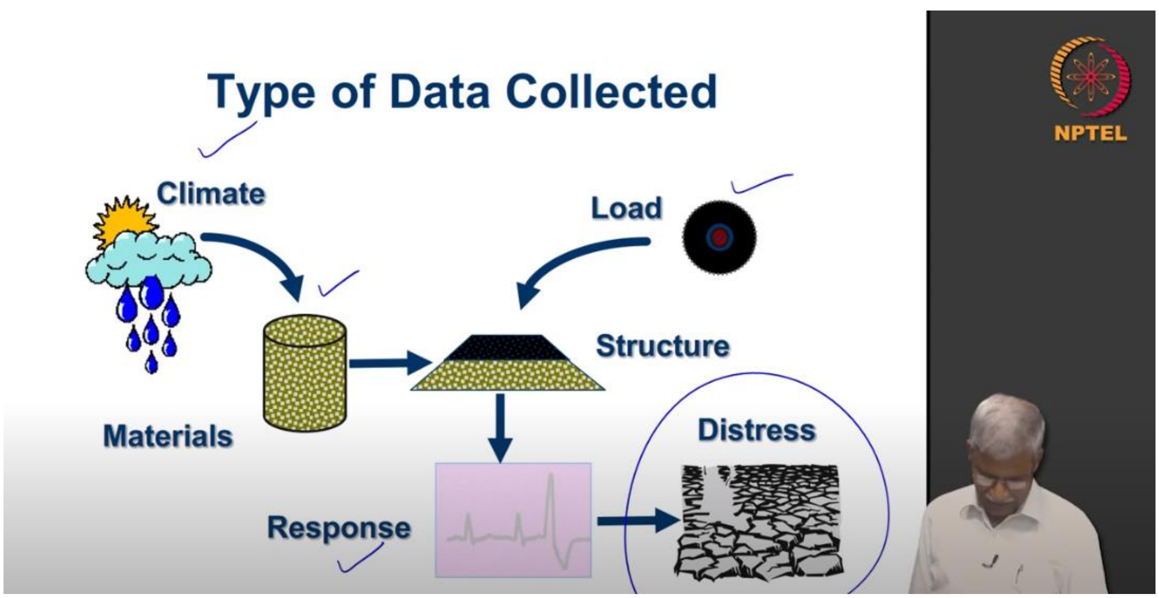

So, the variability in the traffic, variability in the material and in the performance, so this is the analysis that was carried out. You might design your pavement for a specific axle load combinations but after the pavement is constructed the traffic that is going to come can be considerably different that is number one. Number two is, if you are a highway engineer and you will understand this very clearly, you might design a bituminous concrete grade two with 5.3 or 5.4 percent bitumen content and then, when you go to the site and take the mix and see it, it does no have the same binder percent. This is something to do with the variability that one has to face. Considering you know that thousands and thousands of tons of bituminous material is being laid, in fact, just to give an example typically in a day a HMA construction, if you have an excellent contractor, he might do more than thousand tons per day. I am talking about a new four lane road or a rehabilitation exercise that is happening. So, in that thousand tons, it is going to be extremely difficult to maintain that 5.2 or 5.3 percent of binder content so there is going to be variability. Because of the variability, the modulus values will change and because the modulus values change, the response of your pavement structure also will change. So, these need to be clearly categorized and data collected.

Development of an improved design process, this resulted in this mechanistic empirical pavement design grade and then we also want to compare various pavement cross sections related to their performance and then you do the field validation of the pavement design procedure. And, in addition to this, there is a new dynamic modulus program and in fact, if you go take a look at the mechanical characterization of bituminous material which is an earlier NPTEL course that we offered, you will see that we discuss in detail the new the dynamic modulus test and in fact at IIT Madras, where I teach and research for the last 18-19 years, we have the testing facilities for measuring the dynamic modulus as a function of frequency and temperature.

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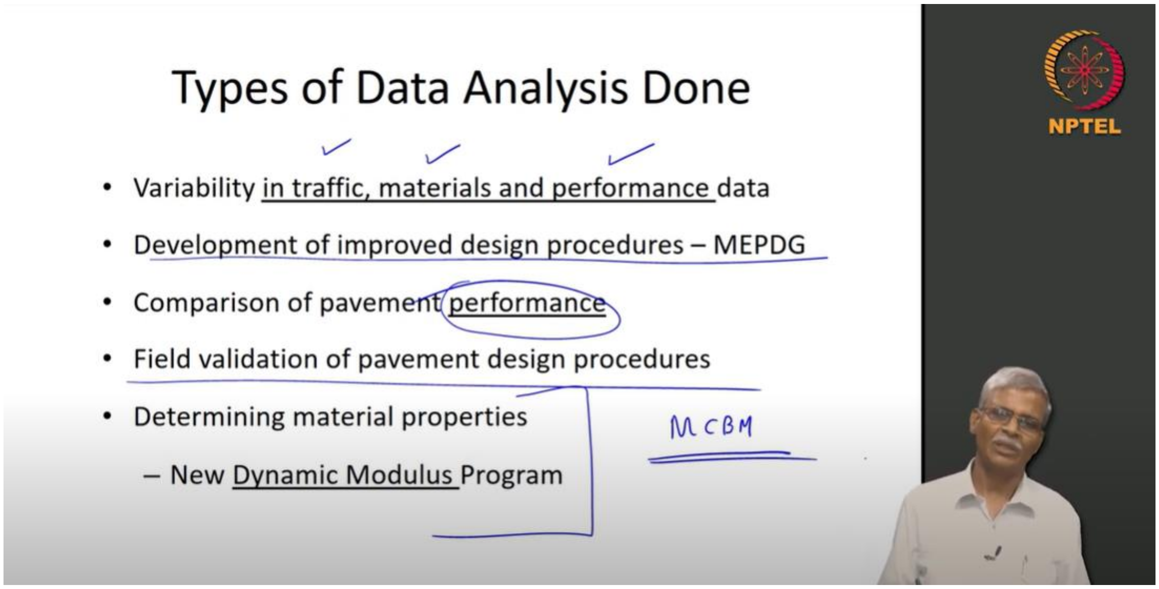

So, then this whole thing now has to be translated into a new design code. So, they came out with the National Cooperative Highway Research Program 37A. So, this resulted in the MEP-DG design guide. So, the climate impact, the material aging properties and axle load spectra for predicting the pavement distress and in fact they basically ditched the load equivalency factor and then they said we will take the actual axle load, apply it on the pavement and compute the damage. So, these are all some of the failure modes that was considered here.

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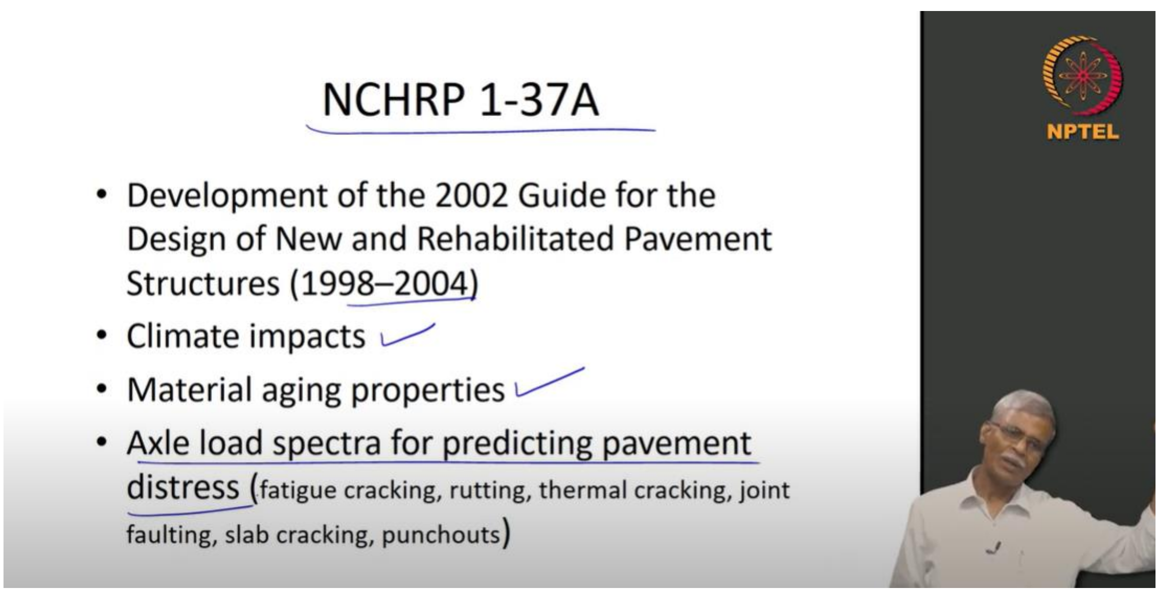

And finally, what I showed you in the starting of this lecture, this book came and there was also an AASHTOWARE pavement ME design software that also came.

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So, now, with all this background, let us redefine what is really called as mechanistic, what is really called as empirical. We also made some statements similar to this earlier but let us do it again. Analytical calculations for transforming pavement loading, that is, truck and climate and inherent material properties to critical pavement responses - stress, strain or deflection, no damage, this is the mechanistic.

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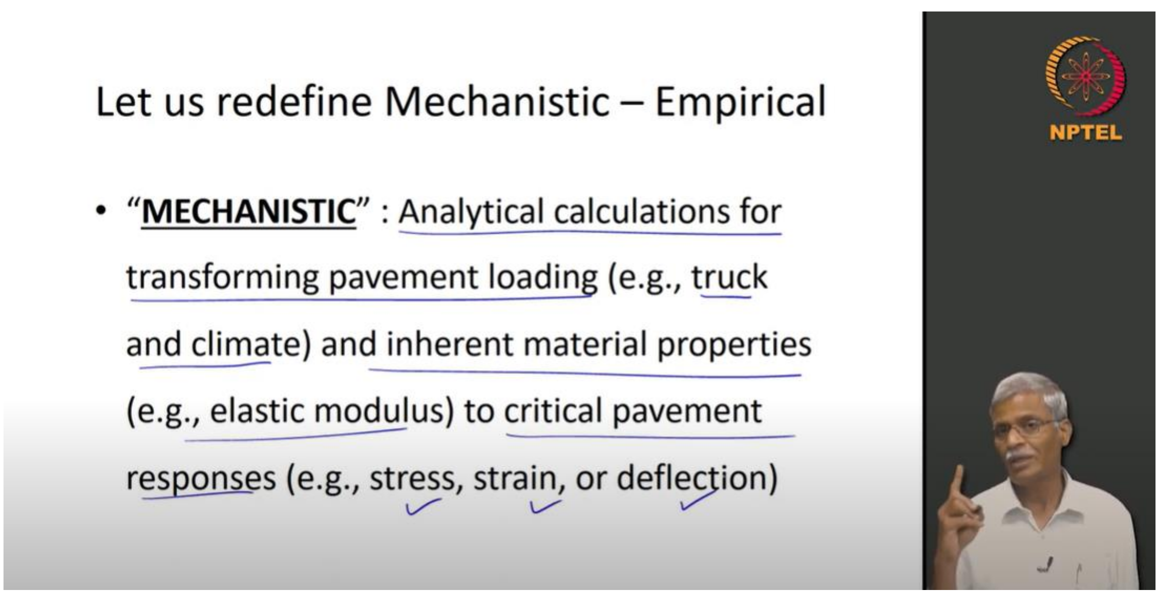

What is empirical? This is where things become slightly fuzzy. Empirical is to relate the pavement responses - the stress, strain, deflection with the observed distress, such as rutting or fatigue, faulting, IRI this comes more from the functional perspective.

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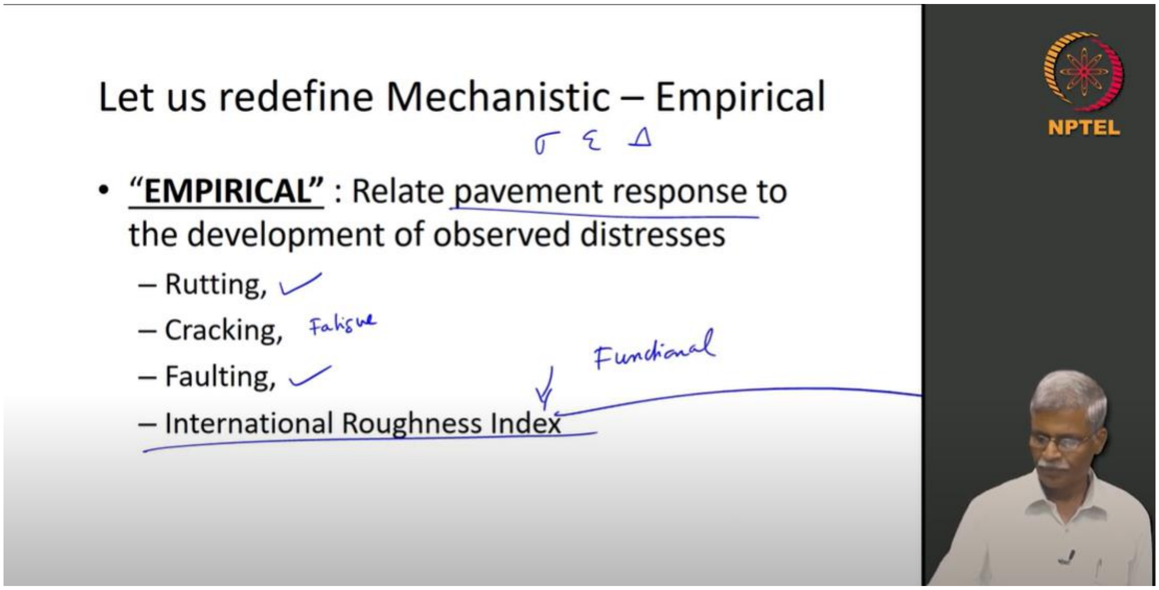

So, that also happened but why do we really need now ME-PDG because you know you must be listening to this, 30 hours are going on and you have looked into various issues related to pavement design, do we really need a new method? You really need a new method, a better method, because what is really happening is the vehicle types, axle loading and tire pressures are varying. In fact, many years back you must have noticed there were only hardly two trucks in this country, there was a Fargo there was an Ashok Leyland and maybe a Tata. Now, you look at the kind of trucks that are available in this country, look at the kind of loading that they really carry in this country. So, what we really need is, if we have to address the challenges associated with such kind of a diverse range of axle loads trucks and traffic, we need a much better and superior pavement design method. And then, we also need to incorporate material parameters that better relate it to pavement performance. Right now, if someone asks you, you have some modulus values that you have measured in the laboratory and can I tell you whether this modulus property will give me some indication of the expected rutting, not really and that is why you have different sets of material properties that you do, one that is related to modulus determination, another is related to the laboratory distress measurements. And then finally, you are talking in terms of local material in addition I also want to add something here about RAP - reclaimed asphalt pavement material.

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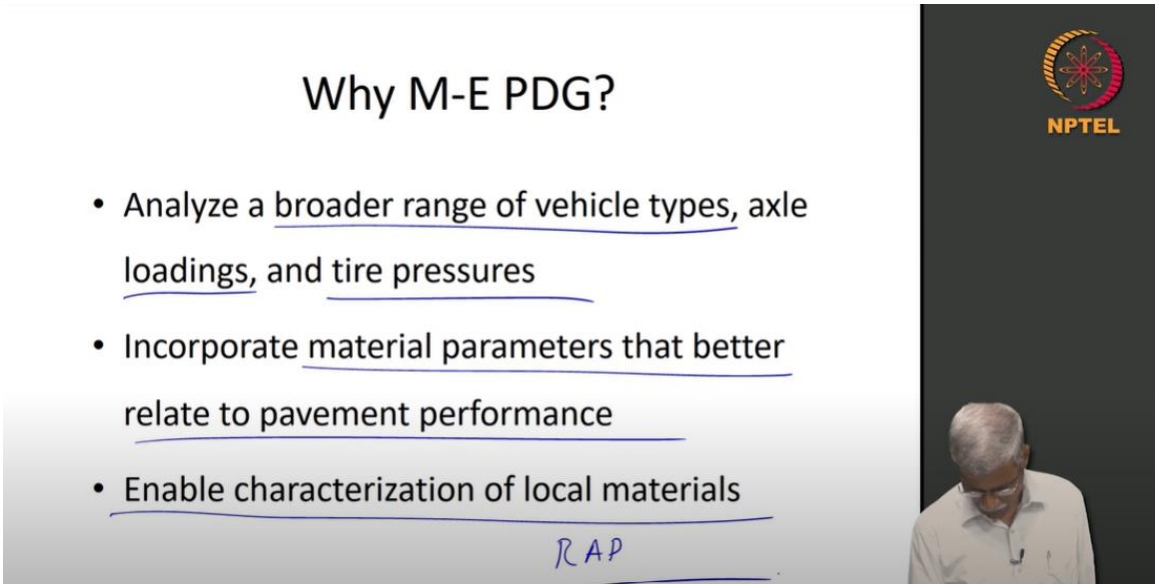

So then, there are also few other things, the binder ages, when the binder is aging what happens, the modulus value increases. So, what should we really do? So, when the modulus value increases the manner in which the pavement will carry the load keeps changing, there may be sudden initiation of fatigue cracks that can happen. And, this also gives you some kind of guideline about what binder, what mixture should ideally be used. Improve the characterization of the existing pavement layer parameters. So, we have already constructed a pavement, let us say with IRC 37 and now you want to check how long this existing pavement will perform by using MEPDG. Can we do that? Yes, we can do. Then improve the reliability of the pavement performance prediction.

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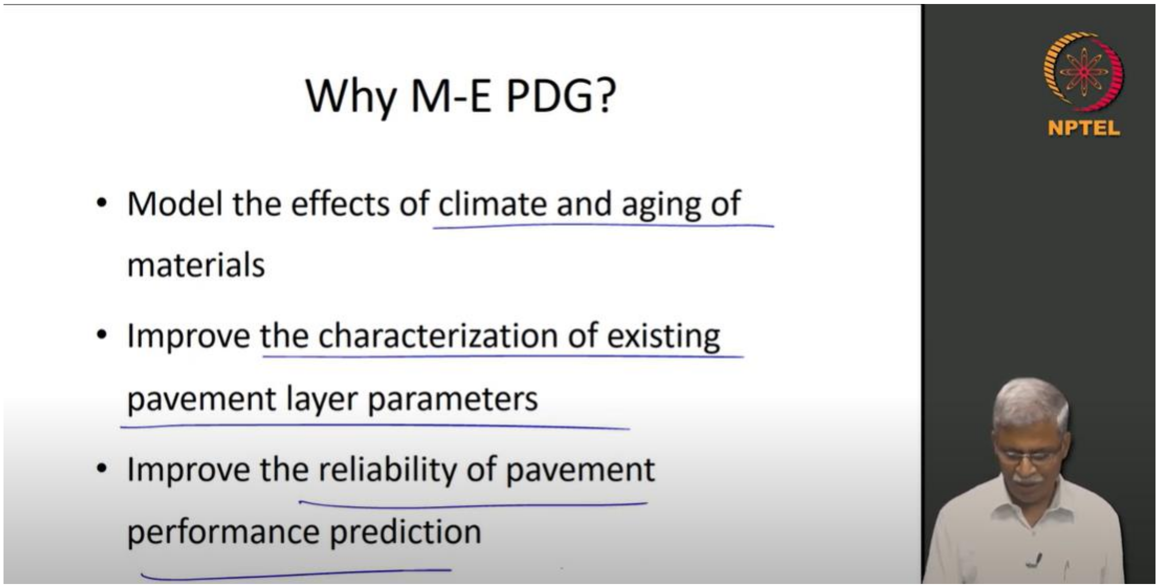

So, what are all the steps. So, we will spend some time talking about the traffic load, characterization of the material, climate, performance prediction and also characterization of the existing pavement structure. So, we may not really talk about this, I will give you a short overview of the various performance prediction, climate, material characterization and traffic load.

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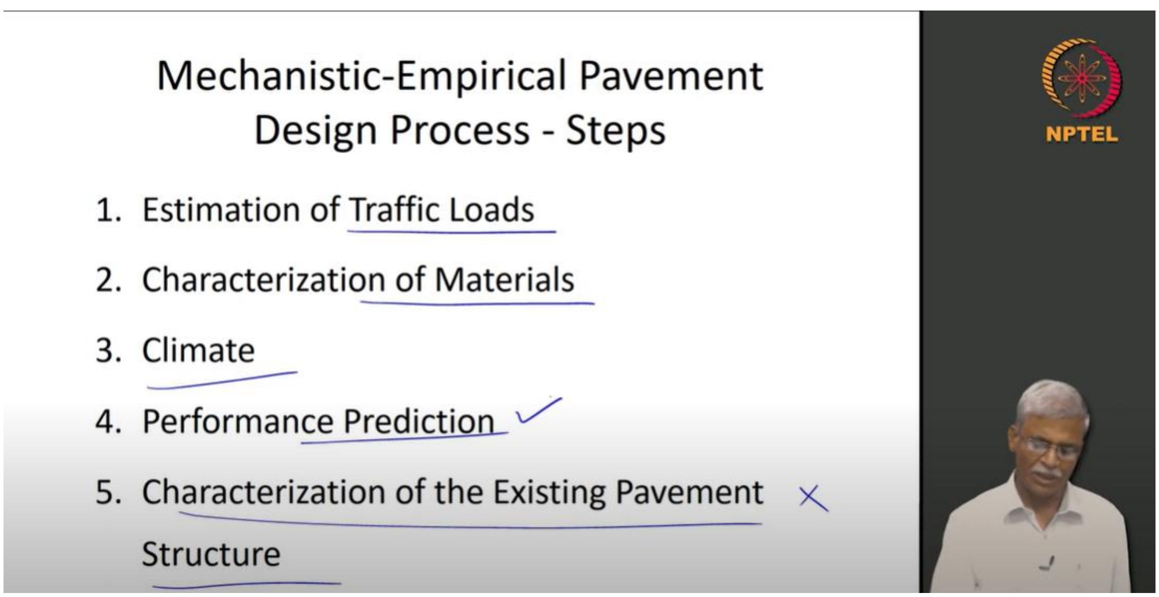

So, what is that again, the typical methodology - select the trial pavement section, remember we are only doing a proof checking, calculate stresses, strains and deflection. Now, for all the axle load, there is no load equivalency factor, compute the incremental damage, this incremental damage is going to be separate for each load application for rutting, load related cracking, non-load related cracking, check the reliability and now you see that IRI comes in. So, this is the functional requirement check for the IRI. Now, you have a separate model here for IRI and then if the design criteria is met, yes otherwise you basically modify the design.

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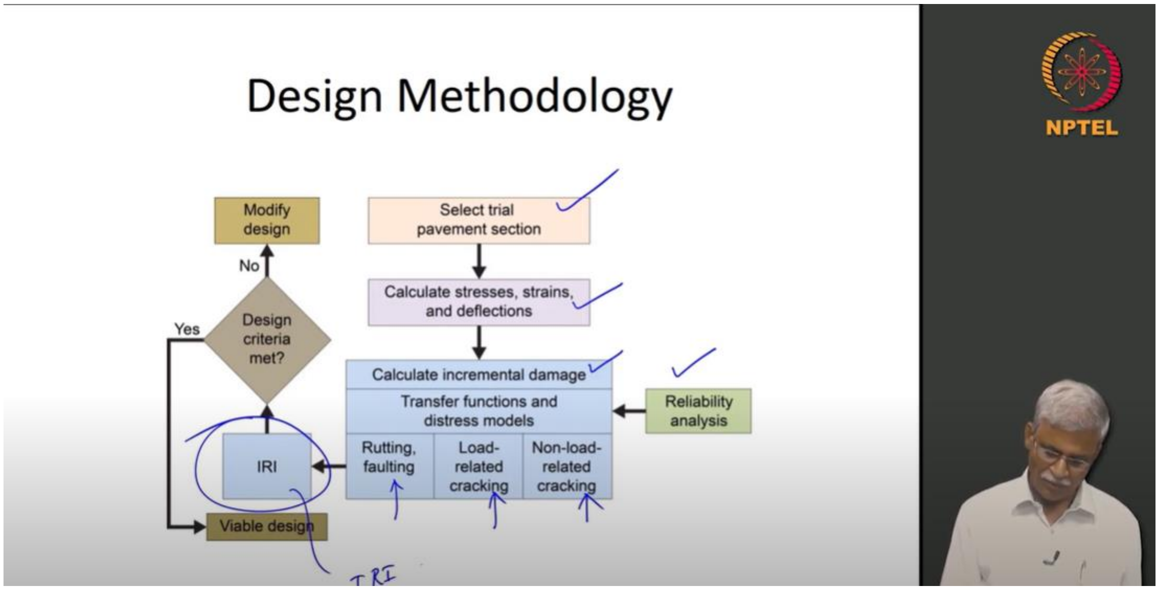

There are few other things that need to be mentioned, what is really called as the local calibration. So, whenever a pavement is designed, it is going to be designed for a general broad-based framework, see, for instance, if you go take a look at these transfer functions, these transfer functions will vary depending on the location. The bituminous mixture may be the same but if it is subjected to identical load one at Nagpur, one at Chennai, they are not going to behave in the same way. That is basically because of the temperature conditions that exist. The truck applied that is going on the roads of Chennai may be going at a much slower speed compared to what you see at Nagpur. So, the loading rate sensitivity also plays a critical role here. So, that means you are talking in terms of local materials. I mentioned the same bituminous mixtures but ideally what will happen, let us say, if you are constructing a road in Tamil Nadu, you will be taking the bitumen from Chennai petroleum, if you are constructing something in Andhra, you probably will get it from Vishwagapatnam refinery. So, the binder changes, if we think that if we specify VG 30 grade of bitumen, it will all be the same, it will not be the same. That is a story for different course but as of now, local materials, you can talk in terms of aggregate specific gravities. I know for a fact that some of the road projects for which we gave some technical assistance, let us say, Jaipur and all the specific gravities go all the way up to 2.95 whereas, the aggregates that are available in Tamil Nadu, they may not exceed 2.80, so there is a big difference in the material that is used. So, local material, local climate, local traffic and other local inputs should enter the ME analysis, predict the distress profile and then compare this with the measured distress profile and then you need to keep adjusting the calibration factor. We may not be able to show you how to do the calibration and adjust the calibration factor but this is the overall idea.

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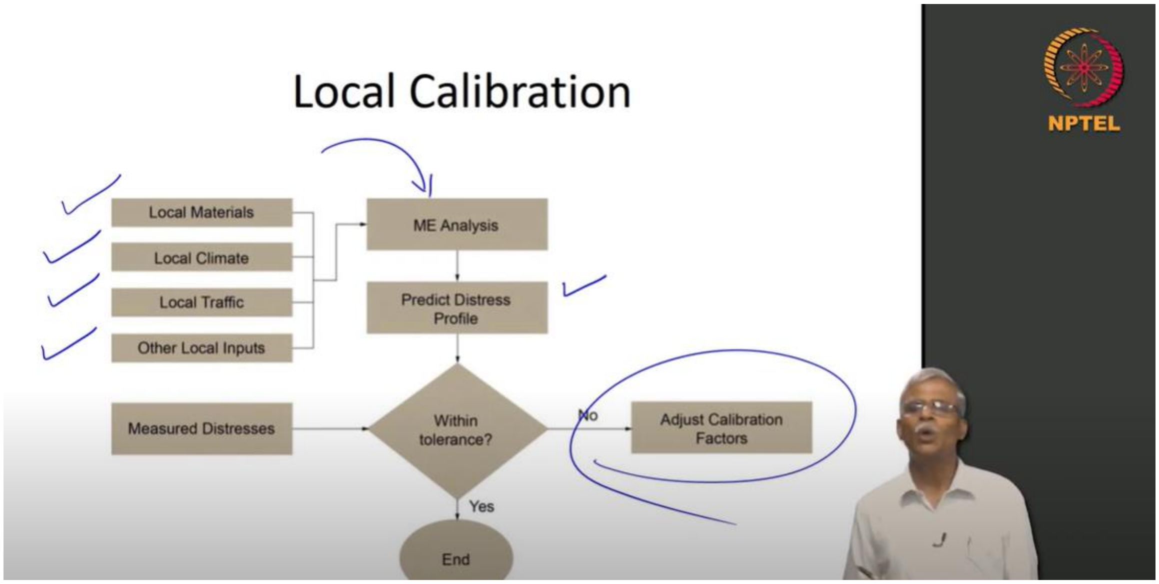

Now, let us take a look at the cross section that is provided here. So, now let us look at each of these things separately okay. So, let us take a look at the conventional bituminous pavement, you can have HMA - 1 to 3 layers, then you can have an asphalt treated permeable base, you can have unbound aggregates again 1 to 3 layers, you can have stabilized subgrade, improved subgrade or whatever it is, then this is your foundation soil and this is what is really called as the bedrock. So, if it is a full depth pavement, you can actually see that asphalt institute method of pavement design it is going to be a full depth HMA and then you are going to have an asphalt treated base and then you are going to have an asphalt treated permeable base that is what is going to be there. Deep strength pavement, you are going to have bituminous material, asphalt treated base, you are going to have asphalt treated permeable base and then you are going to have granular material. The semi rigid payment, you are going to have bituminous material, cementitious stabilized base, unbound aggregate base. And here, I just need to give you one caution.

Some of you have asked these questions, in some of the earlier discussions that we have been having informally with some of you. So, what is this inverted pavement, what do we do really and all. So, one needs to understand very carefully. The layered linear elastic theories that are used for computing the stresses and strain have some strict assumptions related to the variation of modulus values. So, that means you know $E_1 \geq E_2 \geq E_3$ and so on and so forth. If you really want to compute the stresses and strains in an inverted pavement, I would always suggest that you use something like a finite element package, ABACUS or something like that. At least, below the bituminous layer, if you have a granular layer and if you then have a CTB below the granular layer, which is normally seen in some of the inverted pavement cross sections, then you might end up with some erroneous results. One needs to be very careful, I would not get into those details here, because that basically means I need to ask you to do the analysis using a numerical method and many of you may not necessarily have the background to do those things. So, my suggestion to you is to stick to IRC 37, look at some of the example problems that have been worked out in IRC 37 as well as the problems that have been worked out by Professor Padma. So, I think that should be suffice for that.

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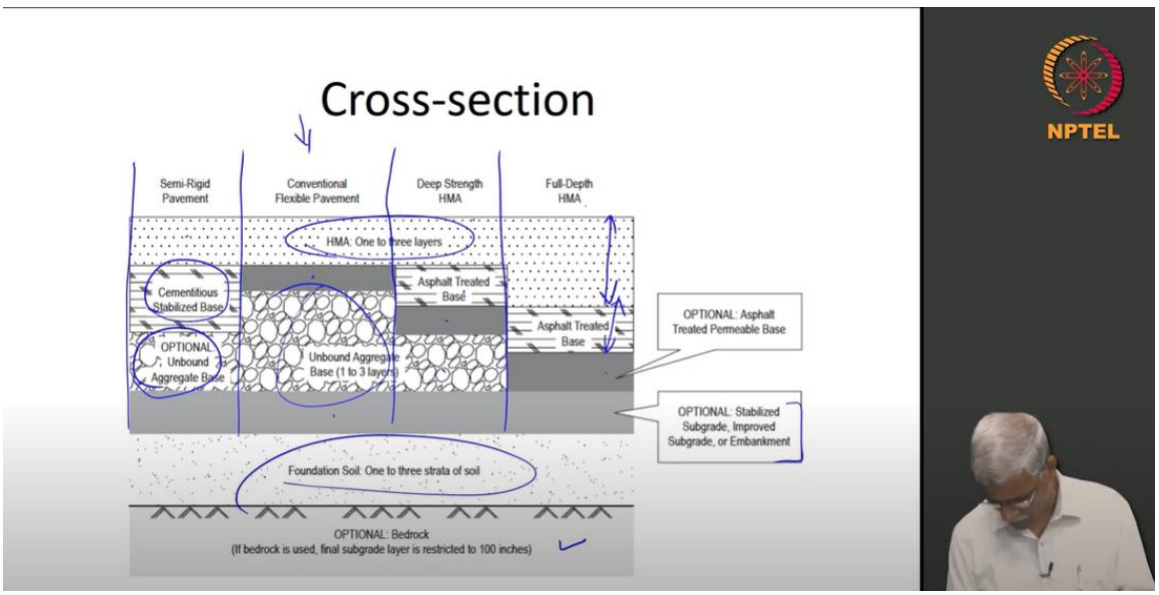

So, let me introduce few definitions for this session of this lecture and then in the next lecture, what I would do is to talk about traffic, material properties and the distress functions. So, first and foremost things and these definitions are very important and if you are listening to this lecture at least, you may want to write some of these underlined words that you have. Okay, so what is a calibration factor? Adjustments applied to the coefficients under exponents of the transfer function to eliminate bias between the predicted and the measured pavement distress. So, these are your calibration factors. So, these calibration factors can be global or these calibration factors can be local.

Second set of definition, one needs to be very clear here because of the fact that MEPDG will exclude any damage that is caused by the construction traffic. Okay, so now what is construction month? The month and year that the unbound layers have been compacted and finished and the month and year that the HMA has been placed to cover the unbound layer. So, so this is your construction month. What is the traffic open month? This is the month and year that the road way is open to the public. Now, this is actually in a sense very important if you really understand that the granular layers, when they are being constructed, they are being subjected to substantial amount of loading by the construction machinery. And in fact, during that time these materials fail and that is why you use the concept of resilient modulus because what you typically do is you take this granular material, start subjecting it to variable passes, compaction and so the material deforms plastically and then reaches an optimal interlocked state in which you now know you can call it as the reference state. Subsequently, when the load is being applied in terms of the HMA layers that are being constructed on top, it reaches the so-called shakedown state or the resilient state from where you can actually start measuring the modulus value. So, this is the idea behind this specific definition of construction month as well as the traffic open month.

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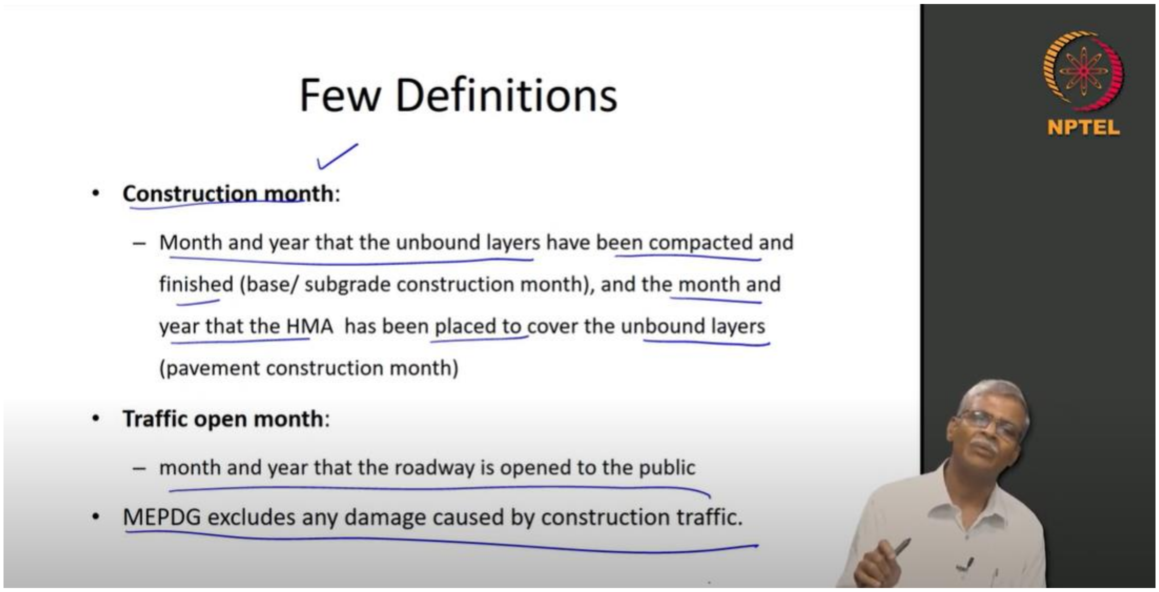

Now, comes what is really called as the threshold value. It represents the amount of distress or roughness that would trigger some type of major rehabilitation activity. So, this is where you are waiting, let us say the IRI value or the rutting that you measure, you basically say if it crosses 5 mm, I need to go for a rehabilitation, that is the threshold value. And now, comes the most important definition what is called as the design life, the time from initial construction until the pavement has structurally deteriorated to the point when significant rehabilitation or reconstruction is needed. Please understand this is called as design life here. So, let us not get confused here.

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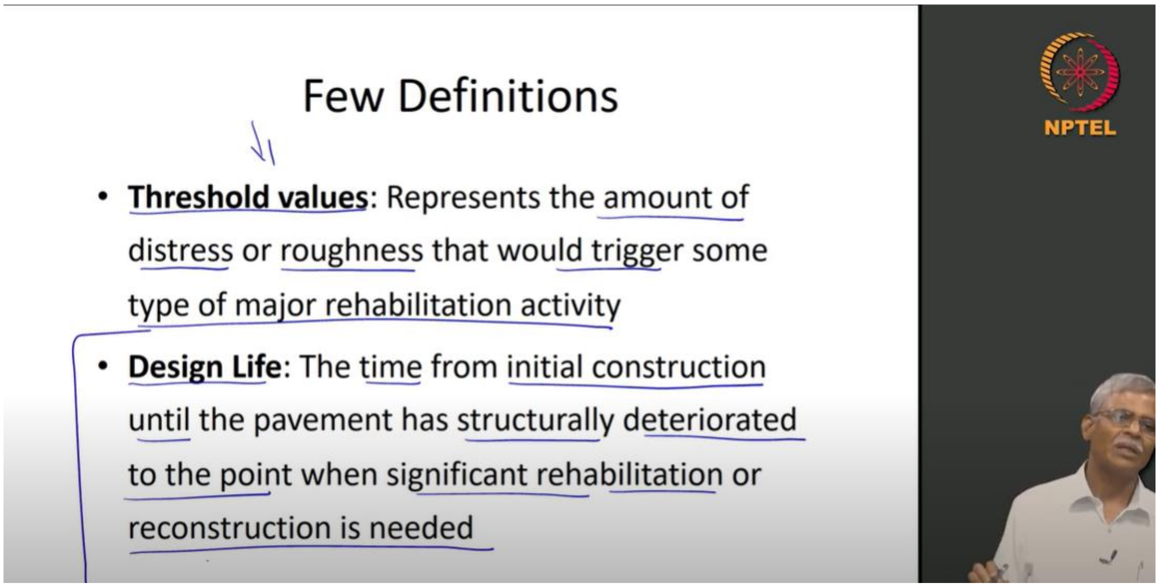

Now, another two other definitions are introduced what is called as an endurance limit. The tensile strain or stress below which no load related fatigue damage occurs. To me, this is a very important concept because you know, you can actually ask this question. So, I have this commercial vehicle which has a laden weight of 4 tonnes, will it cause damage? You know intuitively that it may not cause damage but you need to put a number. So, I am going to say the following, if the strains are of the order of 1×10^{-5}, no matter what happens there is not going to be any fatigue damage that is going to happen. If instead, if it becomes 10^{-4} or 10^{-3}, then you are going to have to say that there is a load related damage that can actually get accumulated, that is endurance limit.

What is this incremental damage? Incremental damage is, so let us take the case of an axle load that causes a strain of 1×10^{-3}. Now, this has to be related to some kind of a damage. A ratio which is defined by the actual number of wheel applications for a specific axle load and type within an interval of time divided by the allowable number of wheel load applications defined for the same axle load and type for the conditions that exist within. So, you are talking in terms of n/N. If this axle load is applied for n, there is an N that is going to be a damage. If it is applied for n, there is an incremental damage. So, this is defined as the incremental damage.

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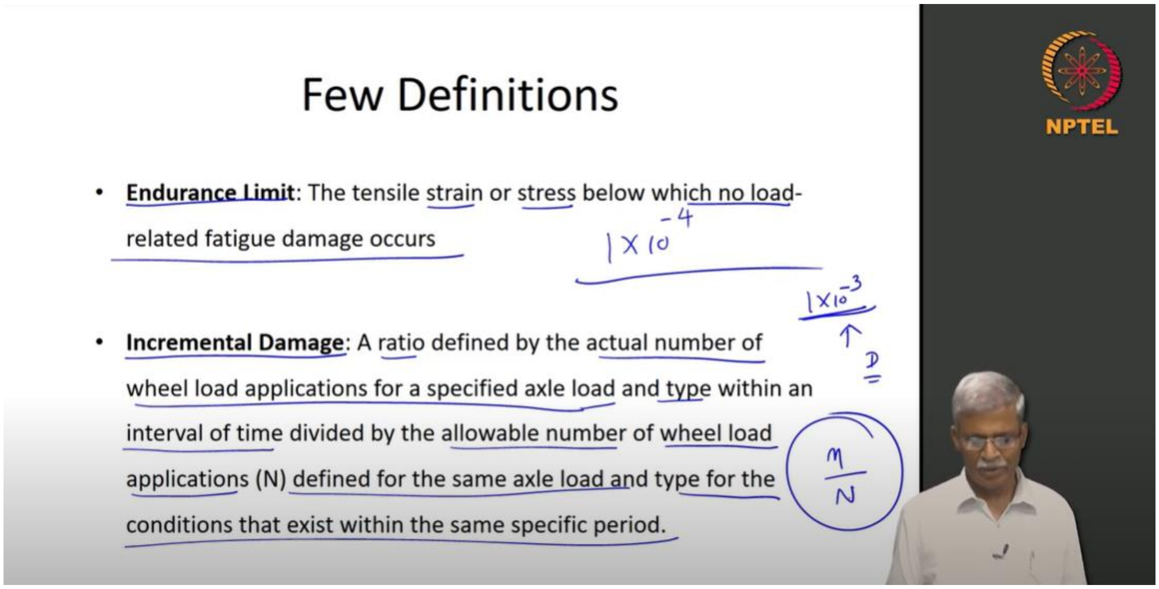

And few other definitions - long life pavements. So, this is something that I really think we should not really be worrying about in a country like India because it is possible for a country like United States to think in terms of long-life pavement and design something for a 50-year service life. Our country is still growing, still evolving. We are yet to have idea about the load distributions that we are going to expect in our highway. So, designing something for more than 5 years or maybe maximum 30 MSA or 40 MSA is something that I would not really think about.

And then, what about that reliability of the trial design? The probability that the predicted performance indicator of the trial design will not exceed the design criteria within the design analysis period. I am just restating this definition so that you will have clarity about it.

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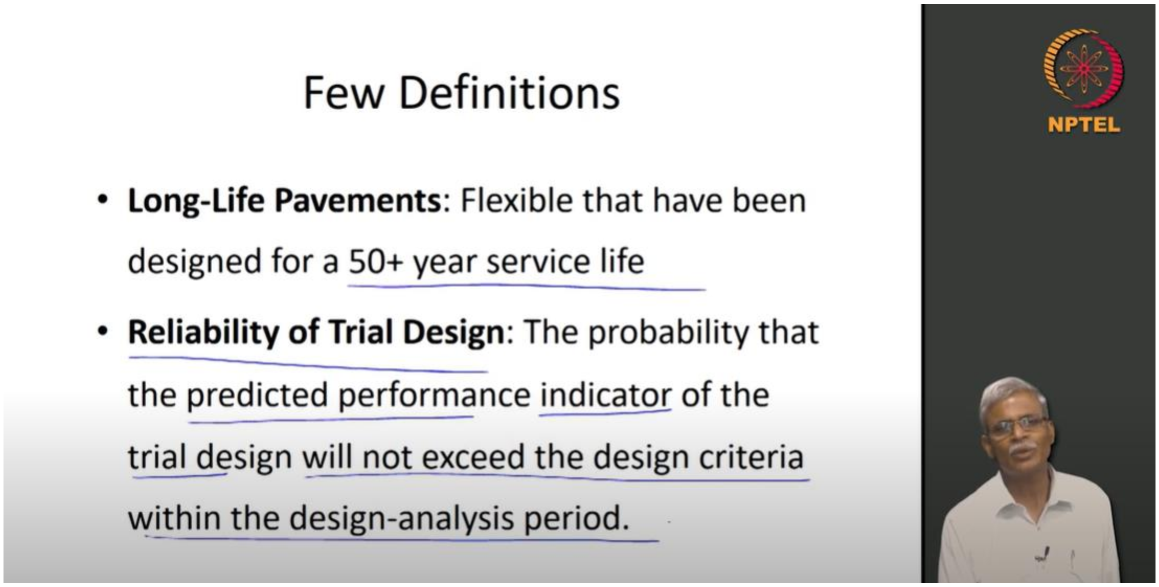

Then comes the transfer function. Now this is the empirical part. Empirical part of the distress prediction model that relates the critical pavement response parameter either directly or through the damage concept to pavement distress. So, this is your distress transfer function.

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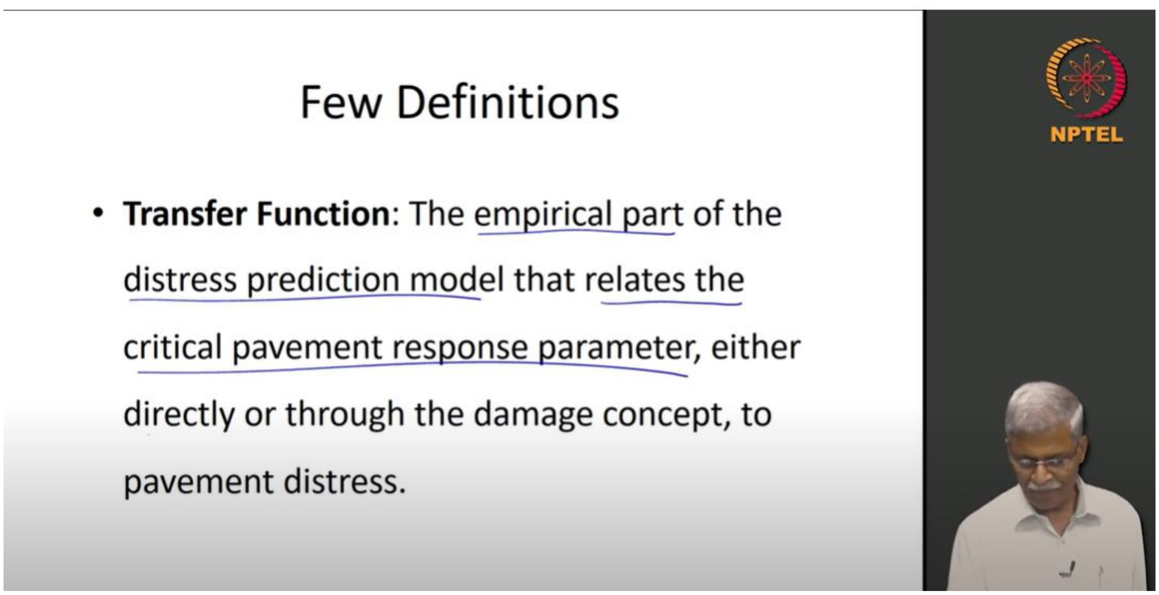

So, we will be seeing some of this distress transfer function in the next lecture. So, thank you so much.