Mechanical Characterization of Bituminous Materials
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Lecture - 48
Fatigue of Bituminous Mixtures - Part 1

Welcome all. By now we know that the main distress in the flexible pavements are rutting and a fatigue cracking. This rutting and fatigue cracking occurs in a pavement over a different period of life. Rutting occurs at the initial stage of a pavement and a fatigue cracking occurs at the later life of the pavement.

These distresses are affected by various factors that includes the traffic factors, climatic conditions and the material characteristics. In this lecture, we are going to focus on the bituminous characteristics' behavior through fatigue cracking.

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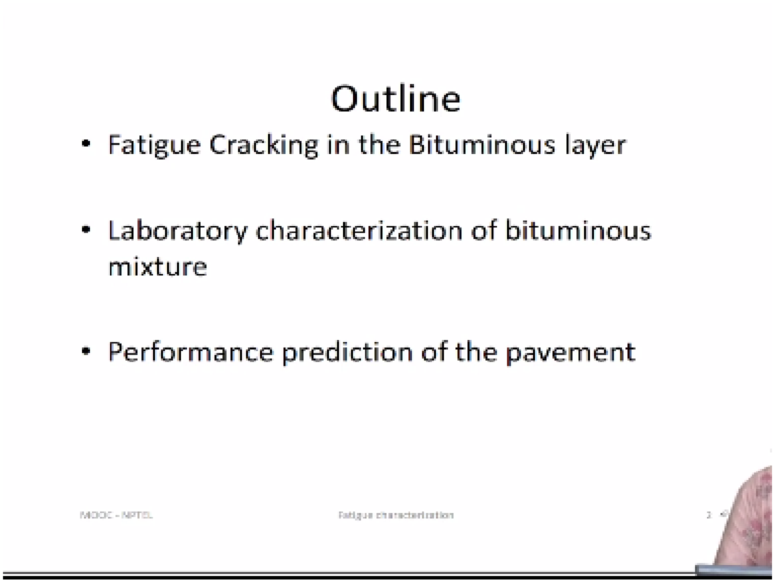

The outline of our presentation is as follows. So, we will study what is fatigue cracking in a bituminous layer and what are the factors that controls the fatigue cracking followed by, we will focus more on the bituminous mixture related properties. So, we will see how to characterize or simulate the fatigue damage of a bituminous mixture in the laboratory and how to find out the fatigue life of the bituminous mixtures.

And we will use this laboratory characterized property of bituminous mixtures and give us an input and see how to predict the fatigue performance of a bituminous layer. Especially this step is used when you do a pavement design.

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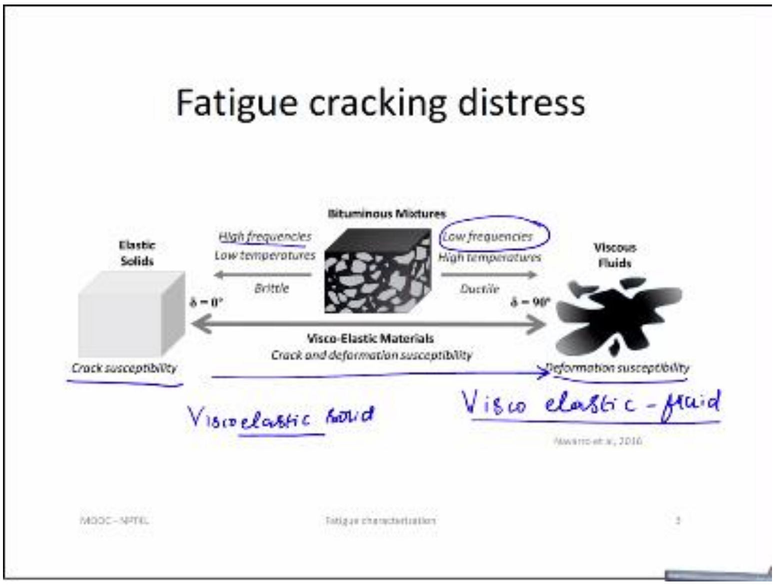

We know that the bituminous mixture in a pavement is subjected to a wide varying temperature. For example, if the pavement temperature is varying from 0 to say 70 degrees Celsius, at very high temperature, the bitumen behaves as a viscoelastic fluid like behavior and at very low temperature bitumen behaves as either an elastic or a viscoelastic solid like behavior.

Now let us see when does the pavement rut or when does the pavement cracks. Now if you look into this picture, so as the temperature varies from a low to high, low to high, at high temperature, the bitumen will be more viscous or viscoelastic, viscoelastic fluid as the fluid behavior dominate the pavement being subjected to a traffic loading with a viscoelastic fluid like behavior, there will be a permanent deformation on a material.

So, at high temperature, the bituminous mixture is more susceptible to permanent deformations. Thus, in addition, if the traffic is moving at very slow speed or otherwise in a laboratory if you test it at very low frequency this will increase the rate of deformation. So, at low when the traffic is moving at very low speed, the load on the pavement will act for a longer duration of a time.

So, this critical viscoelastic behavior is time dependent. So, for long duration of a time the deformation will increase. So viscoelastic fluid like behavior in combinations with a slow speed vehicle if you get this kind of a situation the pavement will be more prone to rutting. Likewise, the pavement will be more prone to fatigue cracking when the temperature of the pavement is very low.

The pavement will exhibit viscoelastic solid or elastic behavior will dominate. So, this viscoelastic solid behavior in combination with a high frequency or a fast-moving vehicle, if this situation happens in a field, the pavement will be susceptible to cracking.

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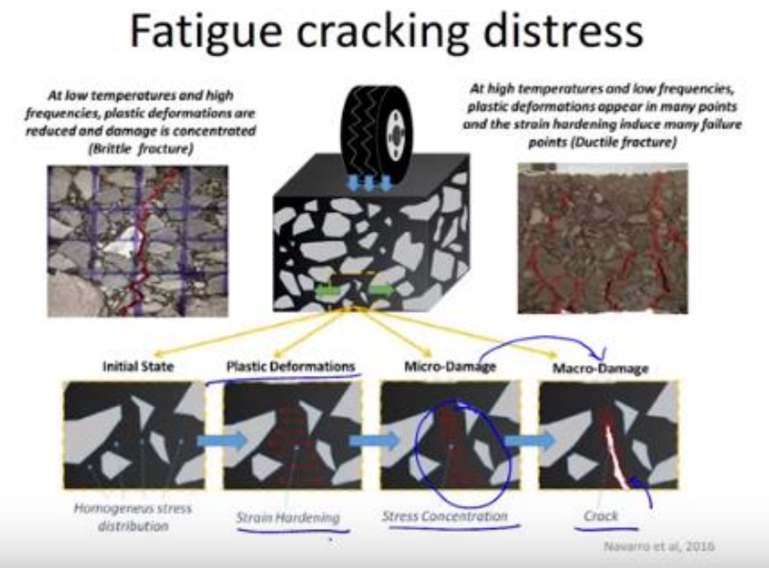

The cracking in the pavement does not occur all of a sudden. At the initial life of a pavement, when the pavement is subjected to a traffic loading, there will be a permanent deformation in a material and at the critical locations there will be a strain hardening. On continuous loading at this critical location where the stress concentration occurs and the stress concentration will develop a micro cracking in the pavement as shown here.

Over a period of time again on a continuous loading, this micro cracking or a micro damage coalesce to form a macro damage. So, this crack formation here you can see a micro crack here from the critical locations combine together to form a macro cracks or crack formations. So, this fatigue cracking or a cracking in a pavement does not occur all of a sudden.

It occurs due to a repeated loading, when and the process is like initially there will be a formation of a micro cracks and the micro cracks combine together to form a macro crack.

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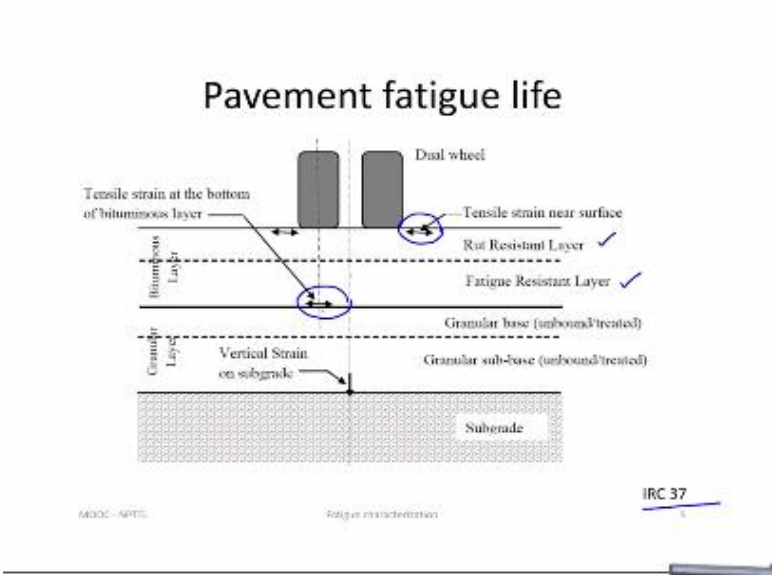

Now if you look into the critical locations, so IRC 37 gives a critical location where the crack starts. If you see this picture clearly you will have two location. One is at the bottom of a bituminous layer. You have two bituminous layers here. One is rut resistant layer another is fatigue resistance layer. If you see the tensile strain at the bottom of a bituminous layer will be critical for a fatigue damage to occur in the pavement.

And the other condition is tensile strain near the surface of the pavement. So, these two strains lead to the fatigue cracking in the pavement.

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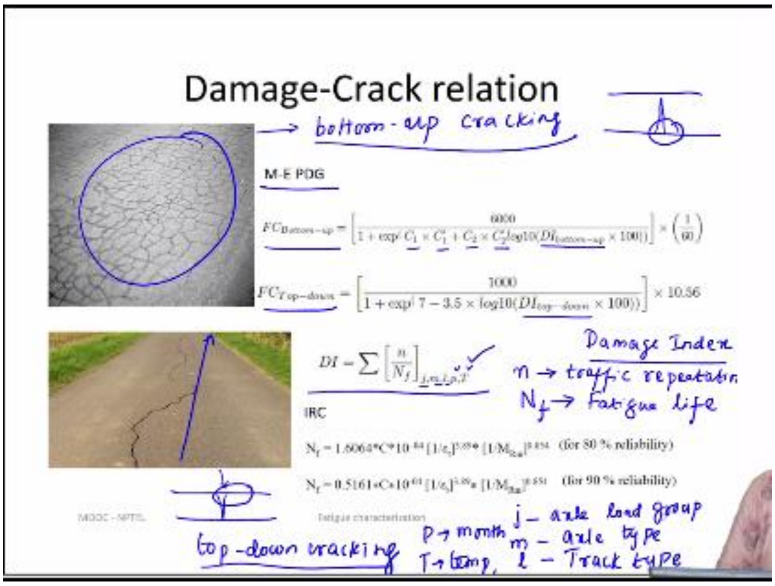

When you see a cracked or a damaged pavement, you can see a two types of crack. One is something like a group of cracks here, which we call it as an alligator crack, another is something like a longitudinal crack on the pavement. This alligator crack is said to initiate from the bottom of an asphalt layer, and we call it as bottom up cracking. So, the crack initiates from the bottom of an asphalt layer and propagates to the top something like this.

Initiates at the bottom of an asphalt layer and propagates to the top. These longitudinal cracks initiate from the top of an asphalt layer and propagates towards down. So, this bottom up cracking will be due to a tensile strain at the bottom of an asphalt layer and the top down cracking will be due to a result of a tensile strain nearing the top surface of an asphalt layers.

So, we have two structurally structural related cracks that occurs due to a repeated load application. One is bottom up cracking; another we call it as top down cracking. The occurrence of bottom up and the top down cracking depends on the material behavior. In a mechanistic empirical pavement design guide, the bottom up cracking and the top down cracking are predicted using these two expressions which are shown here.

Now if you see a bottom up cracking so the bottom up cracking as an empirical expression in which these C_1, C_1^*, C_2, C_2^* are constant parameters. And $DI_{bottom\ up}$ is a damage index for a bottom up cracking. For a top down cracking again, you can see

$DI_{top\ down}$ in an equation. This is again a damage index predicted for a top down cracking.

So, a cracking in a pavement is related to the damage in a pavement using a DI. This DI is called as a damage index. So this damage index can be calculated using this expression, damage index which is nothing but n/N_f where here n is a traffic repetitions, existing traffic repetitions and N_f is a fatigue life of a pavement for a conditions, j, m, l, P and T.

This j can be an axial load group, m - axial type, l maybe truck type, P as per MEPDG design P is defined as month and T as pavement temperature. So here, damage index is the ratio of an actual traffic to the number of traffic that pavement can withstand at any given conditions. So, you calculate separately for a given conditions and sum it up to get the total damage index.

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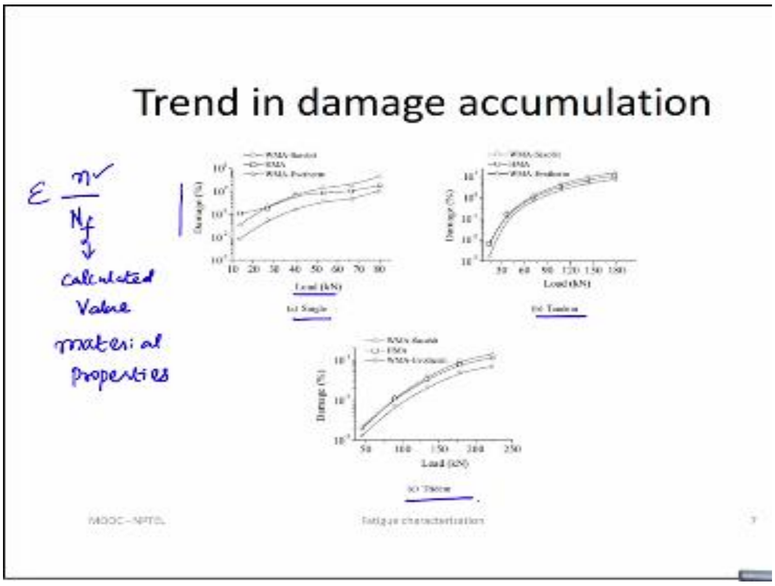

Now if you into the sample damage index of a sample, sample damage index, you can see a three picture here. One corresponds to a single axle, other corresponds to a tandem axle and the third one corresponds to a tridem axle. So now the x axis in this figure is load and y axis a damage index, which is n/N_f. So, n is actual traffic on the pavement is subjected to. This N_f is a calculated value.

This N_f is calculated value and this depends on a material property. Now if you see ratio of n to N_f. So, as the axial load increases, you can see a damage increase. So, for a small axle, small axial load the damage is minimum and as the axial load increases the damage increases. So, you sum it up over a different axial load to get the cumulative damage. So, you can split it into different zones, different axial zones and sum it up to get a cumulative damage.

So likewise, you can calculate separately for a single axle, tandem axle, tridem axle.

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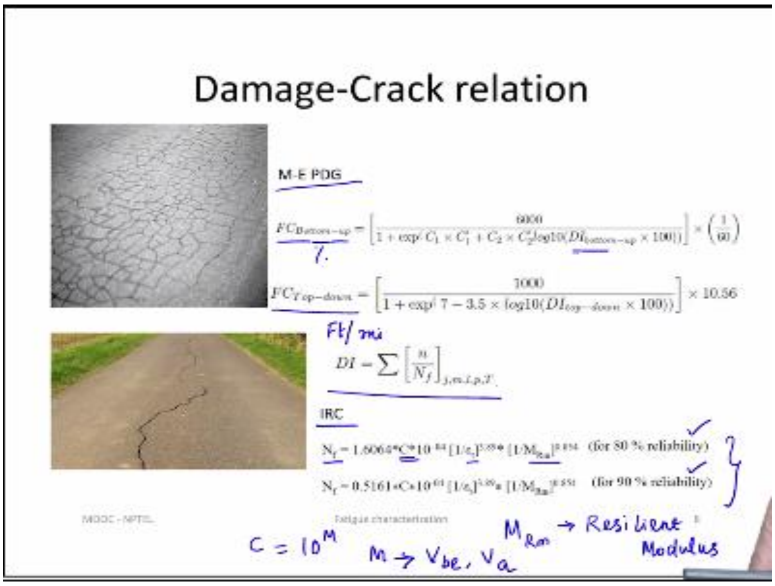

And for different truck and for different month durations and for different pavement temperature, find out what is the damage index and use this damage index in this fatigue cracking expressions to determine the extent of fatigue cracking either a top down cracking or a bottom up cracking. So, in this fatigue cracking, top down cracking is expressed in length or otherwise feet per miles.

And this bottom up cracking is expressed in the percentage of area cracked. So, this is what MEPDG suggest in relating a crack and the damage of the pavement. So, this damage, full 100% damage does not occur at the initial stage of a life. It is a cumulative damage that occurs over a period of time. And this cumulative damage at any given instant of time is used to predict the extent of cracking in the pavement.

IRC suggests using these two equations for determining the fatigue damage in the pavement. Now if you look closely into these expressions, you have N_f which is nothing but the number of repetitions of a standard axial load is related to tensile strain in the pavement. This is a critical tensile strain in the pavement. It can be either on the top of the pavement, on top of a bituminous layer or at the bottom of a bituminous layer and M_{Rm} which is nothing but the resilient modulus of the mixture.

So now if you look into this equation there is another constant another parameter called C. This C is related to a mixture property and C is given by 10^M, where this M is again related to the volume of effective binder content and the volume of air voids in the mixture. So, this N_f which is nothing but the number of repetitions of a standard axial load the pavement can withstand before it fails in cracking.

So, you have two different N_f value. One corresponding to 80% reliability and other corresponding to 90% reliability. So, in IRC directly uses the material property here resilient modulus and the C value and directly calculates the N_f without using any damage index here. So, this is how you relate a damage to the fatigue cracking that occurs in the pavement.

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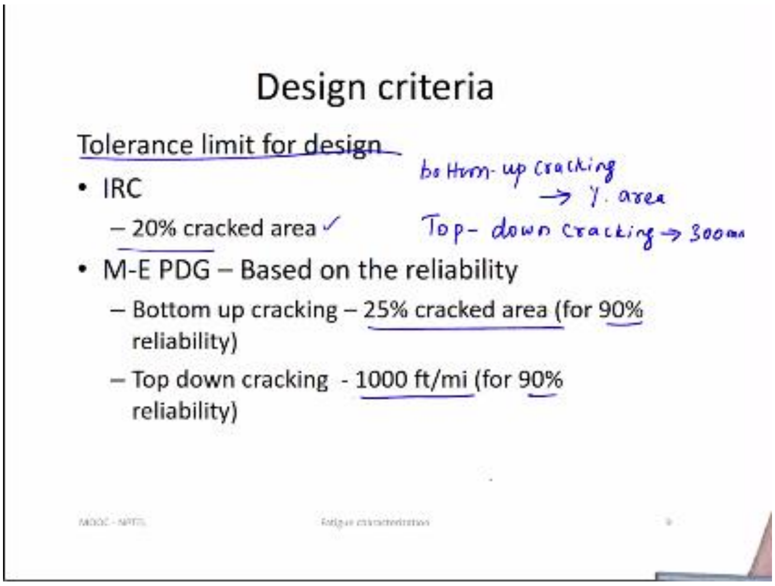

So, when do we say that the pavement has fully damaged or it cannot be used further for a traffic movement is, so there is a tolerance limit defined for the design. IRC defined the tolerance limit to be a 20% cracked area. Here, bottom up cracking and the top down cracking in terms of a units because bottom up cracking as per IRC will be something a map like crack and we do not have any issue here in defining the units for a bottom up cracking in terms of a percentage area.

In terms of top down, cracking for top down cracking, top down cracking is generally a longitudinal crack. IRC assumes 30 mm wide crack and calculate the area and represent in terms of area. So, the tolerance limit as defined as per IRC is 20% of a cracked area. M-E PDG design defines a tolerance limit based on the reliability. For a bottom up cracking it is 25% of a cracked area and for a top down cracking it is 1000 feet per miles.

So, this all corresponds to 90% reliability. So, for a higher reliability the value will go down and for a lower reliability this value can be increased.

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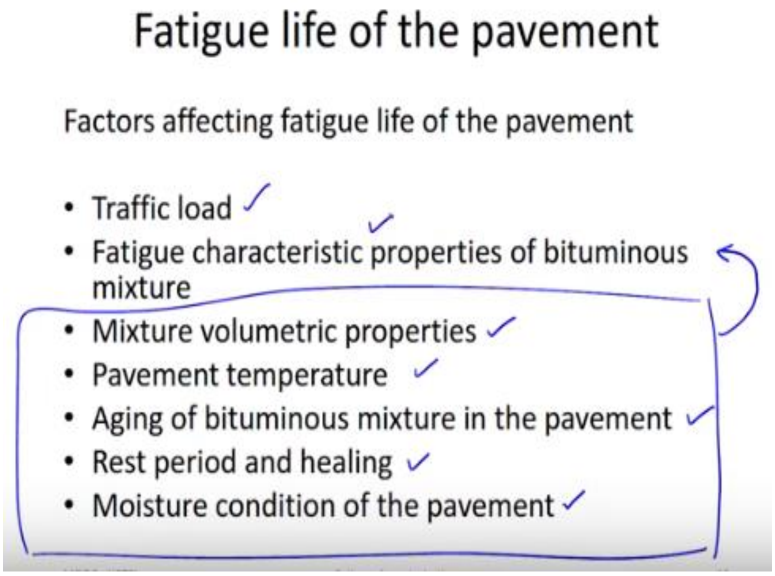

By now we know that the fatigue life is expressed in terms of a number of repetitions of a traffic load. So, there are various factors that affects the fatigue life of a pavement. One main factor is the traffic load. So, the traffic load governs the magnitude of a tensile strain in the pavement. So higher the tensile strength, the crack will propagate faster in the pavement and another factor is a fatigue characteristics property of bituminous mixtures.

And allied properties like volumetric, mixture volumetric properties, pavement temperature, ageing of bituminous mixtures in the pavement, whether we provide a rest period to simulate the traffic conditions in the field or is there any healing of a material that happens during a rest period or a moisture condition of the pavement whether the pavement is dry or a wet.

All these properties are taken care when you simulate and find the fatigue characteristics properties of a bituminous mixtures. So, the main common two factors which is considered in a fatigue life prediction is one is a traffic characteristics or a traffic load and other is a fatigue characteristics of the bituminous mixtures.

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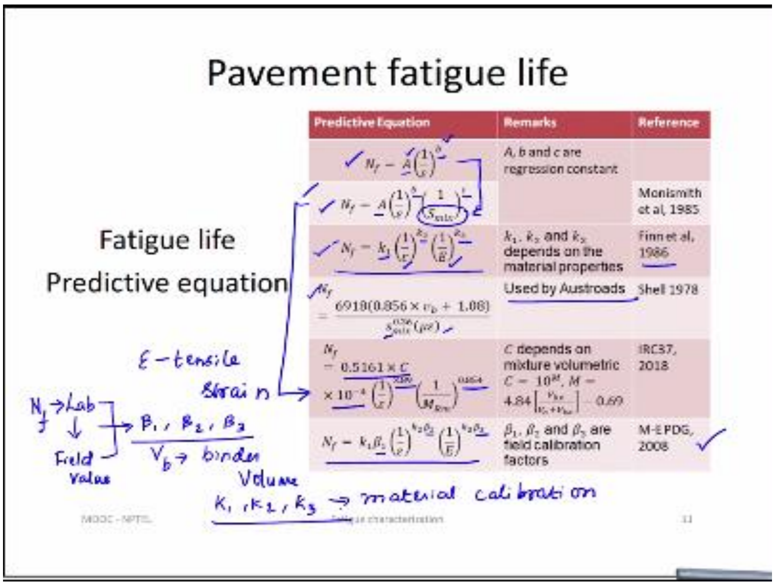

Now there are few performance prediction equations, performance prediction equation given here. When you look closer into this equation, the basic equation is of this type. Here N_f is number of repetitions to failure. So N_f value is given by a constant. It is a function of strain, 1 upon strain to the power another constant and you have an exponential equation here. So here this A and b are a regression constant and ε is a critical tensile strain in the pavement.

So, this A, b are regression constants and the ε is a critical tensile strain. So, over a period of time this equation has been modified to a second equation here N_f with a function material function that is stiffness of a mixture included in the equations. So, you have another function with stiffness S_{mix}. So here again A, b and c are regression constants.

So now if you look into the current IRC codal practice, the current IRC codal practice equation is of a same form where a function constant A is given, 1 by strain, b is 3.89. And the stiffness of a mix is given in terms of a resilient modulus of a mix. So, M_{Rm}

here is a resilient modulus of a mix and to the power c. So, this IRC equation is of the form the one which is given in the second row.

So, this equation was further studied and modified. Finn et al. in 1986 gave a equations for predicting the fatigue life of a bituminous pavement or a bituminous layer with a more material dependent functions and if you look into this equations, it is again a function of strain, critical strain and E which is nothing but a dynamic modulus of a mixture here and the factor or the functions, material functions here k1, k2, k3 are material dependent property.

So, this is, this functions k1, k2, k3 are no more a regression constant. It depends on the material behavior. Shell uses N_f equation to be this. N_f as a function of stiffness of the mix and the strain. We can also see this N_f depends upon the volume of a binder used. So, the same equation is used by AASHTO for the design of flexible pavement. Now another equation which the current M-E PDG design uses is, in M-E PDG relations, this N_f was obtained in the laboratory lab predicted value.

This lab predicted value is compared with a field value. So, on comparing this lab predicted and the field value they have suggested three factors, $\beta_1, \beta_2, \beta_3$ as a three calibration factors, which we call it as a field calibration factors. So, this constants k1, k2, k3 are the material calibration factors.

Now if you want to predict the fatigue life of a pavement, say for example, using this M-E PDG design equation, these k1, k2, k3 values, material calibration factors have to be determined based on the material functions. Not only this we also need to know a performance prediction of bituminous mixtures, how it performed, bituminous mixtures, how it performs at a low temperature or how it performs at a high temperature.

So, this further will help us in selecting a bitumen or a binder for a particular location. So now we need to predict the characteristics behavior of a bituminous mixtures beforehand we use. So how to simulate this fatigue cracking that occurs in a pavement in a laboratory and predict these constants k1, k2, k3.