Mechanical Characterization of Bituminous Materials
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Lecture-52

Fatigue of Bituminous Mixtures Part 5

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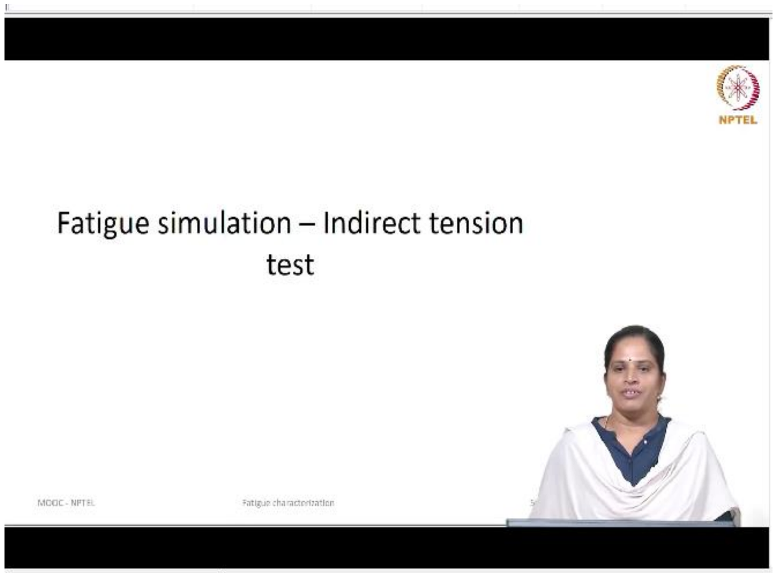

Welcome back, in last class we saw how to characterize the fatigue damage of bituminous mixture in the laboratory using four point beam bending tests. Now, we will see how to characterize the same bituminous mixture using a indirect tension test.

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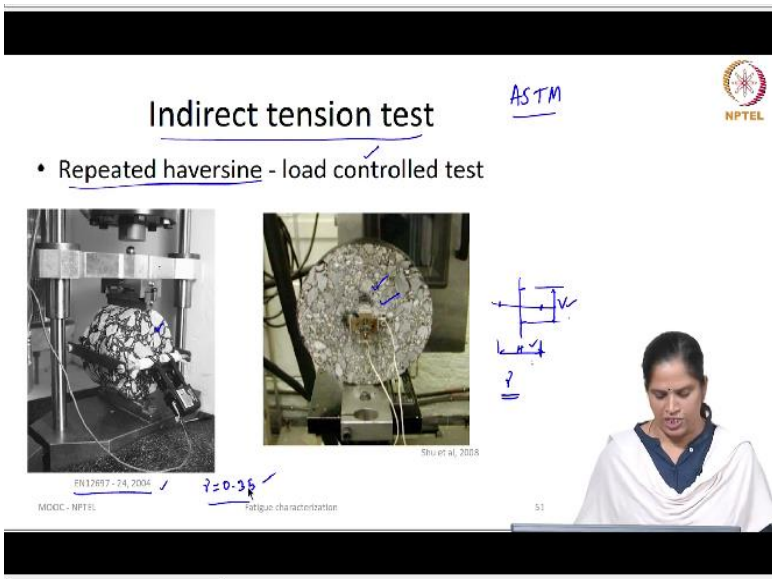

So, as the name indicates, we subject a bituminous mixture to a tension, but we apply a compressive load and subject the bituminous sample to a tension. So, like we have seen this indirect tension testing a detailed procedure recommended by ASTM in calculating the resilient modulus of mixtures. So, the same test can be used here for calculating or simulating the fatigue damage of a bituminous mixture.

But the only difference is that resilient modulus or a material characteristics properties, if you wanted to do it in a linear regime or any material characteristics behavior, if you are conducting any test for characterizing the material behavior, you do not need to apply or induce or damage in a material. So, it is sufficient enough if you apply only a few cycles of loading for characterizing the material behavior.

But if you want to simulate the damage in a material you may have to apply a continuous loading, so that the material damages and find out what is the damage behavior after damaging. So here in a indirect tension testing, we have an EN standard recommendations for conducting a indirect tension testing. The EN standard states that it prepare a bituminous sample subjected to a repeated haversine loading in a load control way, that is in a stress control way.

So, you control the load in a haversine pattern and measure the deformation. So, you apply a load in a diametrical plane as shown in this picture and measure the deformation horizontal deformations. So, apply load here, the load which you apply is a compressive in nature and you measure an horizontal deformation here, which is a along the horizontal plane, so, this is as per the EN standard, now when you use an ASTM.

So, ASTM for testing a resilient modulus you have already seen that there are 2 string are just kept at along the surface, one is along the horizontal plane, and another is along the vertical plane as shown here. So, you have a horizontal plane and an vertical plane. So, when you keep a strain goes to measure a deformation along another horizontal and vertical plane you will have 2 deformations.

Suppose if this along the horizontal plane we represented by H and this along the vertical plane we represented by V. So, the measure of this 2 deformation will help us in calculating the poisson's ratio value, this in detail you have already seen. So, this poisson's ratio value can be accurately obtained to a mixture if you measure a 2 deformations.

At this EN standard if recommends the use of poisson's ratio as some assumed value of equal to 0.35 for all mixtures, because, so, if you want to measure use a poisson's ratio measured value just use this to strain. And if you are otherwise you can assume a poisson's ratio value to be 0.35 for any further calculations. So, in this indirect tension test we are subjecting the sample to a repeater loading in a stress control loading or a load controlled way.

So that repeated loading as an haversine load. So, we have already seen that this repeated loading, if you test the mixture in either in a load stress control or a strain control way, if you do it in a repeated stress control load, there will be a strain accumulations at each and every cycle. So, on repeated loading the strain accumulation increases, then you may not be able to differentiate between rutting and a fatigue racking fatigue damage here. So, we will see how this issue is addressed in an indirect tension test.

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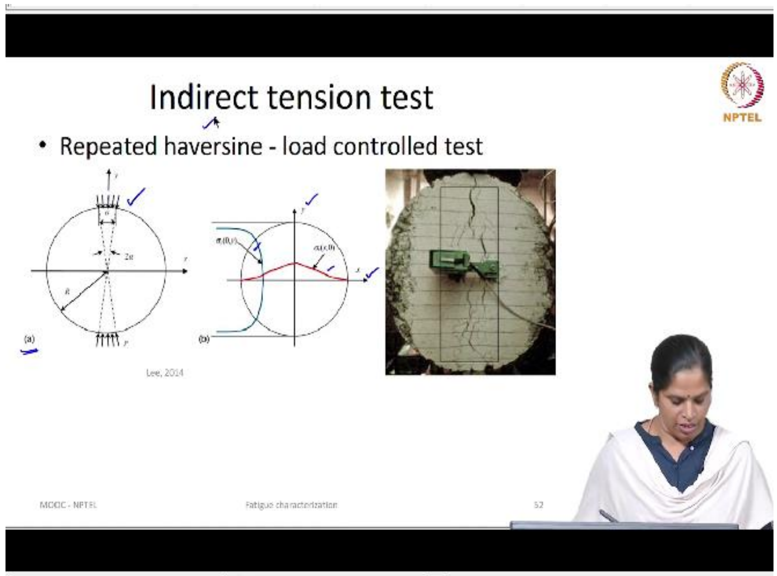

So, when you subject the material to a repeated loading along diametrical plane as shown in figure A, the stress in the material due to this loading along 2 plane, one is along a horizontal plane X and vertical plane Y will be varying along the diameter will in this pattern. So, now, for this stress, we will find out what is a deformation and find the strain value due to a repeated loading.

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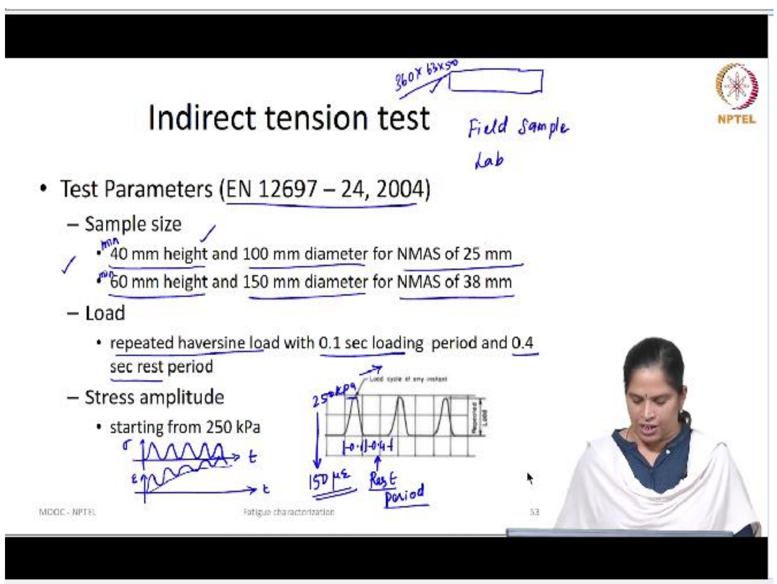

So, EN standard recommends a few testing procedure for conducting this test. So, for preparation of a bituminous mixture, if we use a nominal maximum size aggregate of 25 mm we need a minimum of 40 mm height sample and diameter of 100 mm. So, if the nominal maximum size aggregate is 38 mm we use at least a minimum of 16 mm height sample with a diameter of 150 mm. So, this is a minimum height, minimum dimension prescribed by an EN standard.

So, you prepare a bituminous mixture of this sample size. You can either use a gyratory compactor for preparing this sample or you can use a slab compactor or it can even be a field sample. This is a main advantage here, generally four point beam bending test, we generally use a flexural testing, we generally use a beam, the beam size is as we saw before it is 360 by 63 by 50 mm. So, this slender beam coring in a field is difficult.

So, if you want to test a core sample you can use this indirect tension test. So, it can be even a field sample or it can be a lab prepared sample, the dimension of a sample has to be in specific to or define the based on the nominal maximum size aggregate you use. So, now prepare the sample subjected to an indirect load indirect tension test. So, now the load you apply is a repeated haversine compressive load along the diametric plane with the 0.1 second loading and 0.4 second rest period.

So, you apply a repeated load, the load is like this, the loading time here recommended is 0.1 second followed by 0.4 second rest period. So, as we said earlier with the load control test, there will be accumulation of residual stress or residual strain at each and end of every loading to avoid this accumulation of residual strain. This EN standard recommends to conduct this test with a 0.4 second rest period.

So, this is not something like a continuous loading, which we do it for a four point beam bending test, we give a rest period at each and every load cycles, if we are not giving a rest period the response will be like this. For instance, if you are conducting a test for this continuous loading this is with time, this is stress, if you are conducting the test with a continuous loading, the deformation accumulation there will be a residual deformation or residual strain at the end of each loading.

So, this residual strain starts accumulating over a time. And so, this is what we do it for rutting characterization of a bituminous mixtures. So, it will be difficult here to differentiate between rutting and fatigue cracking. So, EN standard recommends to conduct the test with a rest period. So for conducting this test sample is subjected to a haversine loading with a rest period with the amplitude of starting from 250 kilo Pascal.

So, this amplitude you select should be sufficient enough to result a strain at least of 150 micro strains. So, you start the test with a 250 kilo Pascal and may go increase this from 250 kilo Pascal if you wanted to know the response of the material at different strain levels. So, repeated haversine loading with a rest period of 0.4 seconds.

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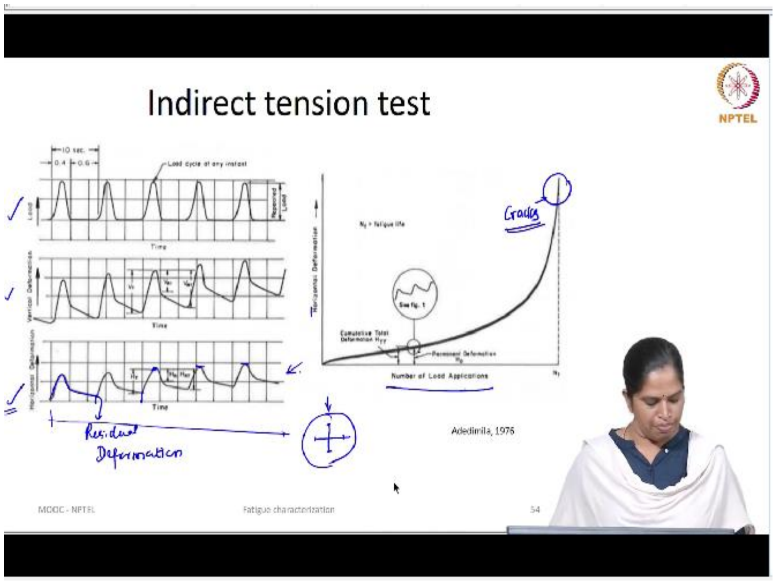

This what we apply it and this is what the response you get it. If you measure only the horizontal deformation, this is a load you apply and this is a horizontal deformation you get. In case if you fix a 2 strain gauzes like this, you apply a load here, you have horizontal strain gauze as well as a vertical strain gauze, you will get 2 deformation one is horizontal deformation and other one vertical deformations.

So, you will get a 2 deformation here. Now, we let us focus on the horizontal deformation, because this horizontal deformation along the horizontal plane will be further used in determining the fatigue damage of a bituminous mixtures. Now, if you look into the horizontal deformation variations, you can see that as a loading continuous that is a haversine deformation haversine pattern of deformation.

But during a rest period, there is a recovery here, recovery of a deformation and so, this residual deformation here, some call is as a permanent deformation also, like you know, what is permanent deformation and what is residual deformation. So, now, this residual deformation accumulates or increases as the load progresses as the time increases. So, now, if you construct the entire horizontal deformation curve pattern.

So, you can see how the horizontal deformation varies the peak value alone, the peak value alone varies as that number of load applications. So, this is a horizontal deformation, the peak value will be increasing as the load increases and at one point of time where the sample cracks completely the deformation increases in a drastic way. So, when you zoom this portion here, this will look something like this.

So, here we measure a horizontal deformation for an application of a repeated load as a function of number of cycles. So, with this horizontal deformation, how to obtain the fatigue damage, as I said before we subjected to the repeated loading, and as the load increases the deformation increases, and this is a point where the sample cracks completely, a complete crack in the sample as seen here.

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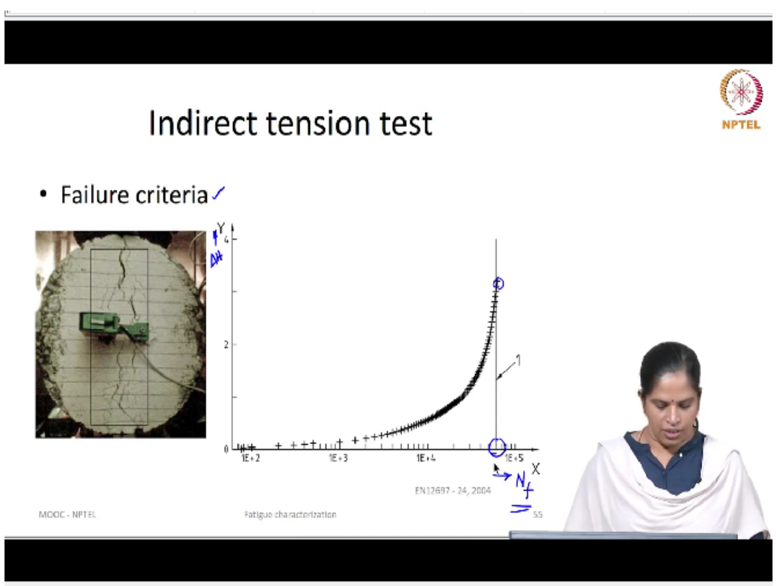

So, there will be a complete crack in a sample. So, now, we have to define a failure criteria for the estimation of a fatigue life. Now, you can see that as EN standard specification says, this is number of cycles the ***X*** here represents the number of cycles and ***Y*** here represents an horizontal deformation, ***delta H*** suppose, ***delta H*** increases with the number of cycles at the point where the sample completely cracks, find out the number of cycle.

This number of cycle is treated as a failure criteria. So, this ***Nf*** is given as a fatigue damage or a fatigue life of a bituminous mixtures.

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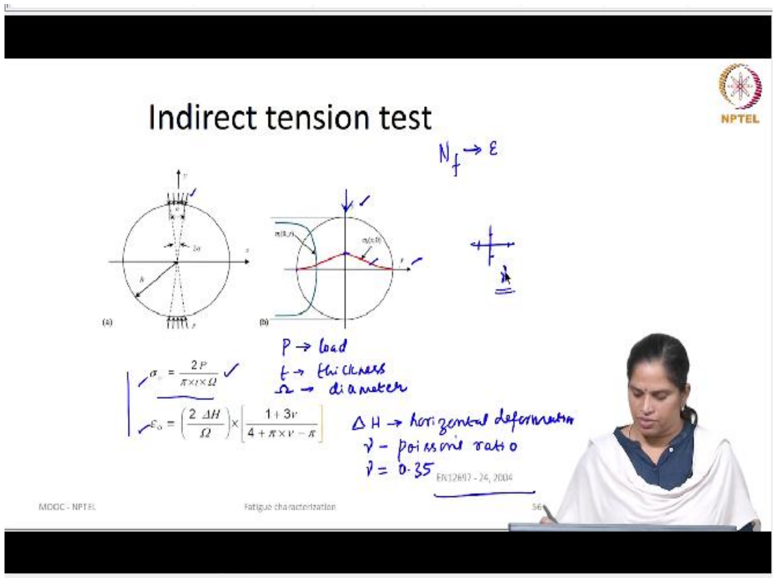

So, this ***Nf*** can be related to a strain or you can determine at a different strain levels and can finally, construct a strain ***Nf*** relation plot and use it in the mix design or use it in the design of pavement. So, now, to get this you need to find out what is strain in the mixture when you subject it to an indirect tension, so, you subject the bituminous tension to an indirect tension by applying a load here.

So, on an application of this load, there you can see that the stress in the material along horizontal plane X and a vertical plane Y varies in this pattern. So long an horizontal plane on this surface you can see a zero and it increases the maximum value occurs at the center and it is a symmetry about both sides. Likewise in a vertical plane due to a vertical compressive load along here you can see the stress here to be morely uniform.

So, the stress ***sigma not*** in the horizontal plane maximum value can be calculated using this expression. Here in this expression ***P*** indicates the peak load and ***t*** indicates the thickness of a sample and this is diameter. You may have a different notations for a thickness diameter, but this notation says as such taken from an EN standard. So, you can calculate a sigma using this expression and epsilon using this expression.

Here you have ***delta H***, this is horizontal deformation and each calculated at each cycle. So, now a new value here is the poisson's ratio. As you have measured only one deformation, then you can assume a poisson's ratio value as per EN standard recommendation to be 0.35. If you have calculated a horizontal deformation as well as a vertical deformations, you can measure using 2 strain or just something kept like this.

In case if we are conducted an experiment and measured it to strain values along horizontal and vertical plane, you can calculate a poisson's ratio as you have already seen this in resilient modulus calculations. We are not seeing in detail how to calculate this poisson's ratio here.

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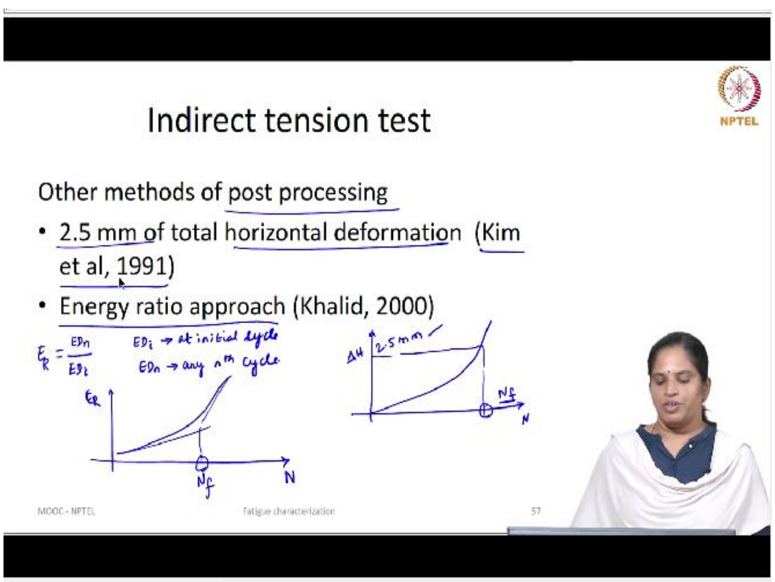

There are many other methods of post processing used in calculating the fatigue damage. For example, Kim et al recommends to identify a number of life, number of load cycles corresponding to 2.5 mm deformation, 2.5 mm of total horizontal deformations. So, subject the sample to a repeated loading. So, just identify the point where the horizontal deformation is 0.25 mm. So, we know that the horizontal deformation as delta H as a function of number of cycles increases in this pattern.

So, identify the number of cycles corresponding to the deformation of 2.5 mm and this number of cycles ***Nf*** this corresponds to the fatigue damage in a mixtures. So, we say that that damage occurred when deformation reached 2.5 mm and another approach is as similar as what we use to further four point beam bending test that is an energy ratio approach. So, energy ratio we know it is defined based on the dissipative energy.

So, you calculate the energy dissipation of different cycle and determine the energy dissipation with respect to the initial cycle. So, and take that ratio this suppose if it is energy ratios defined as ***EDn*** by ***EDi*** where ***EDi*** represents energy dissipation at the initial cycle and ***EDn*** represents energy dissipation at any ***nth*** cycle. Take the ratio and plot the energy dissipation as a function of number of cycles.

Energy ratio as a function of number of cycles and you will get the energy ratio as a 2 stage curve. Now, this is the point where this slope changes may not be drastic may gradually occur, find out the point where the slope changes in a energy ratio curve and identified this to be the number of load cycles to failure. So, now, there are at least 3 approaches we have seen are how post processing occur indirect tension test data.

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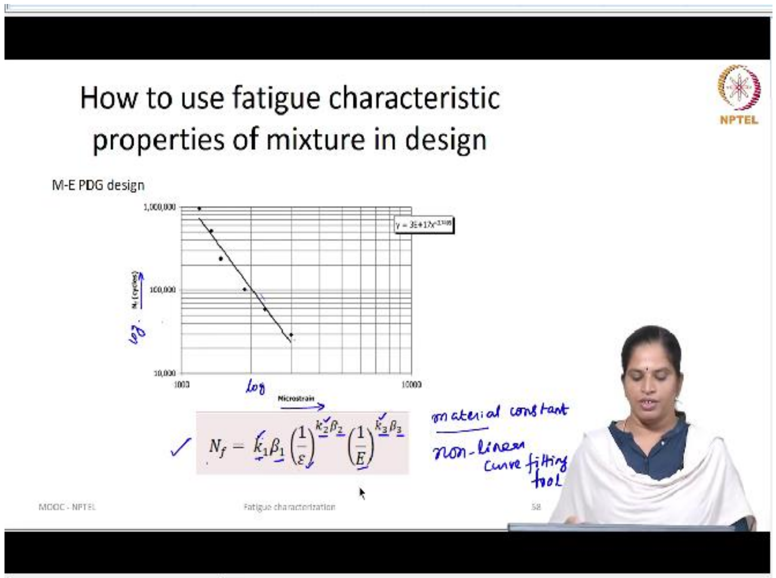

Now, we have seen how to simulate the fatigue damage in a laboratory and calculate the number of cycle corresponding to the damage of a bituminous mixture. Now, we will see how to implement or how to use these fatigue damaged values in the design. One simple example is given as an M-E PDG design here, we have a number of cycles that we have obtained in the laboratory at a different strain levels.

So, at different strain level the laboratory test was conducted and the number of cycles corresponding to the failure was measured. And you can see that in the logarithmic scale this is both in the log scale. So, in the logarithmic scale you will have a straight line. So, this straight line this data to be it has to be implemented in a design by using a material functions values. So, you might have already seen this equation ***Nf***.

So, now this ***Nf*** you can see this ***k1, k2, k3*** functions are a material constants, this ***Nf*** equation is what we used it in a mechanistic empirical pavement design and how the design of bituminous layer fatigue. So, now, this ***beta 1, beta 2, beta 3*** is our field parameter, epsilon as a strain and ***E*** is a dynamic modulus value. So, we have seen in detail about this ***Nf*** already in a before classes.

Now, this to predict this ***k1, k2, k3*** value. So, we use this laboratory simulated plot and predict this ***k1, k2, k3*** value. So it is not a constant value it depends upon the material behavior. So, we predict this ***k1, k2, k3*** value using this ***Nf*** equations, you can directly use any nonlinear curve fitting tool maybe in a math lab or any nonlinear curve fitting tool and predict this ***k1, k2, k3*** knowing the ***Nf*** and this strain value here. This ***k1, k2, k3*** we will go in an input as a design of pavement.

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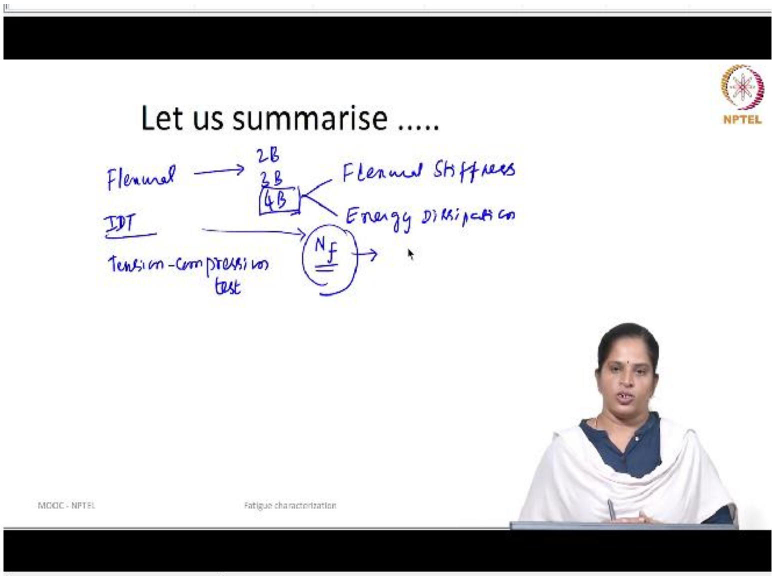

So, let us quickly summarize what we learned it in a fatigue damage. So, we have seen that there are two types of the cracking in a pavement that will structurally deteriorate the pavement. One is a bottom of cracking and other is a top down cracking that are other longitudinal cracking. So, there on subjecting the pavement to a continuous loading, there will be tensile strain, the critical locations of tensile strains are one at the top of the pavement or nearing the top or other at the bottom of the pavement.

This induces a damage in the pavement that the damage over a period of time accumulates and informs the crack in the pavement. So, the damage in the pavement if you want to predict the damage in the pavement, you should know the characteristics damage behavior of bituminous mixtures. So, to simulate the bituminous mixtures in the laboratory, we conduct different tests either in a flexural mode or in the IDT indirect tension test mode or direct tension compression test.

So, you need to subject the sample to a repeated loading in a flexural testing. So, we have seen in detail how to conduct the four point beam bending test and we have seen a different post processing method, for some of the post processing methods are based on their flexural stiffness. And some other post processing methods are based on energy dissipation. We have also seen in detail how to conduct a indirect tension testing.

And from that indirect tension testing, we have seen a post processing method of obtaining a fatigue life of a bituminous mixtures, fatigue life of a bituminous mixtures generally we denote it as ***F***. And we have also seen that this ***Nf*** value differs based on the post processing method we had and this post processing post processed data this ***k1, k2, k3*** value, we can give it as an input in a design by using determining the material constants ***k1, k2, k3*** as we have seen as an example for an M-E PDG design. Thank you. Thank you for your time.