Mechanical Characterization of Bituminous Materials

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Lecture - 42
Resilient Modulus of Bituminous Mixtures - Part 1

Hello everyone, today in this lecture we will discuss about resilient modulus of bituminous mixtures.

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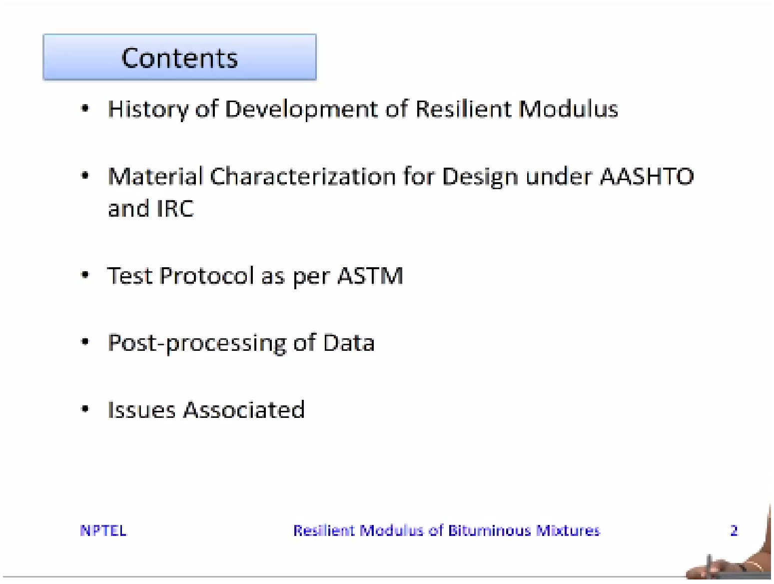

So I will discuss about what is the modulus value that is being used in the pavement design context with respect to the AASHTO standards and as well as with respect to the IRC standards. What is the history of development of this pavement design strategies over a period of time? But this will be in the context of use of material or the material characterization alone and I will not be going in detail about the pavement design strategies okay.

So we have ASTM protocols to determine the resilient modulus of bituminous mixtures. Those will be discussed in detail.

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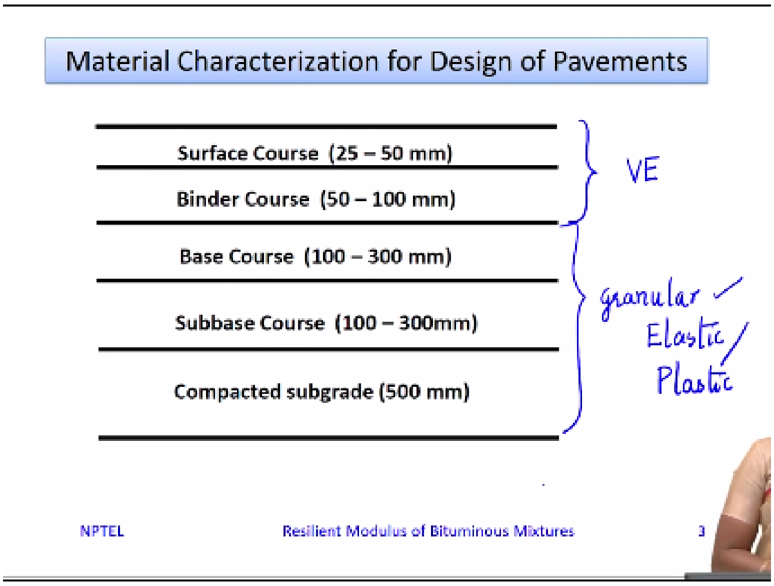

So as we all know this is a typical cross-section of a bituminous pavement. We know that the bottom layers, the base, subbase course and all, are granular materials whereas the top layers are the bituminous layers okay. So this granular material essentially shows an elastic behavior or an elastoplastic behavior or you can say that is a plastic behavior okay.

Whereas, the top layers are or bituminous layers exhibits viscoelastic behavior. Now when you want to design pavement layers like this, we should have sufficient information about the material behavior. You should have some modulus value which will go into the analysis of this pavement structure. Let us first discuss about granular materials.

The modulus value for granular materials is more or less straightforward, because the understanding about granular materials is to some extent well established.

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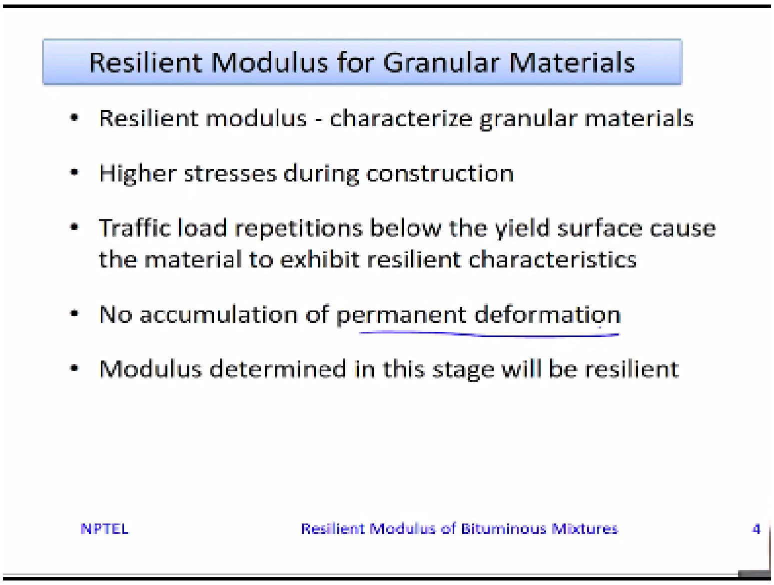

Wherein we know that especially in the case of a pavement structure, the granular layers come at the bottom. So during their construction or compaction, they will be subjected to substantial amount of loading and hence a lot of permanent deformations or the plastic strains might have already happened in the material and the material might have reached a steady state.

So if I continuously load a material you can say that there will be recoverable as well as irrecoverable deformations. But after a certain point of time, the irrecoverable deformations will cease and there will be only recoverable deformations. So when this pavement is laid compacted and when the traffic load comes on top, the amount of traffic load intensities that is distributed to the bottom granular layers will be substantially less.

And also since the material is pre-loaded sufficiently, you can say that there will be only resilient deformations that will happen in the material. So this is what it is mentioned here. No more permanent deformations will happen in the material. Whatever deformations that happened is resilient in nature and one will be able to identify a modulus value based on this resilient deformation.

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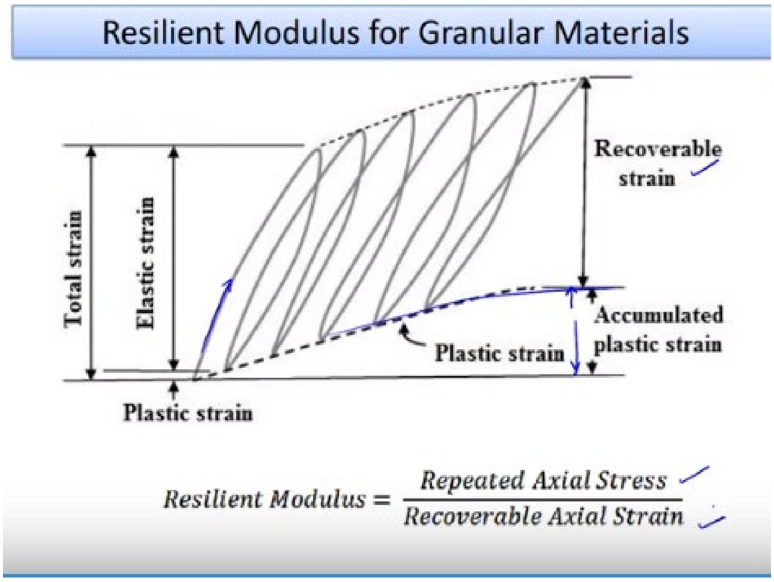

As you can see here this is a strain versus time plotted for a repeated loading test on a granular material. Over a period of time you can see that the accumulated plastic strain as shown here has come to more or less a constant. Whereas, it is the recoverable deformation or recoverable strain you can straightaway measure from this. And the modulus can be explained as the ratio of the repeated stress to the recoverable axial strain okay. So this is called the resilient modulus which is used to characterize the granular materials. So when one wanted to construct a pavement structure with a bituminous layer on top they wanted to characterize the top layers also using a similar resilient modulus procedure, so that a similar kind of test procedure can be adopted for this material as well okay. So let us discuss about how the AASHTO design method has evolved over a period of time and what are the kind of moduli they have considered during the design process.

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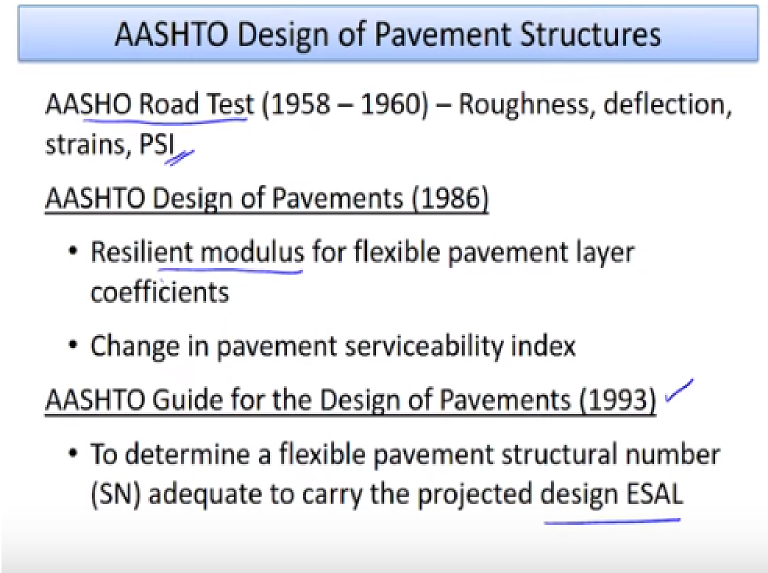

So as you know this AASHTO design pavement design strategy was developed as part of the AASHTO road test, which was from 1958 to 60, which collected considerable amount of information from the road data such as the pavement surface evaluations based on roughness, deflection and the strains happening in the different layers, the pavement surface index or serviceability index are also computed.

So based on all these information, they have come up with the design strategies in which resilient modulus was chosen for flexible pavement layers and essentially the design was based on a layer coefficient concept. So in that the resilient modulus of bituminous material is also taken as a parameter. And essentially what you look at is how the serviceability conditions of the pavement deteriorate over a period of time. Or what is the kind of deterioration that is permissible and accordingly you will design the pavement structure. So that was the whole idea.

Now in 1993 the idea of design of pavement as per AASHTO was to determine a pavement structural number that will be able to take care of the design equivalent standard axle loads. So whatever traffic is coming you decide what should be the structural number for that layers and from the structural number you decide how much should be the thickness of each layers.

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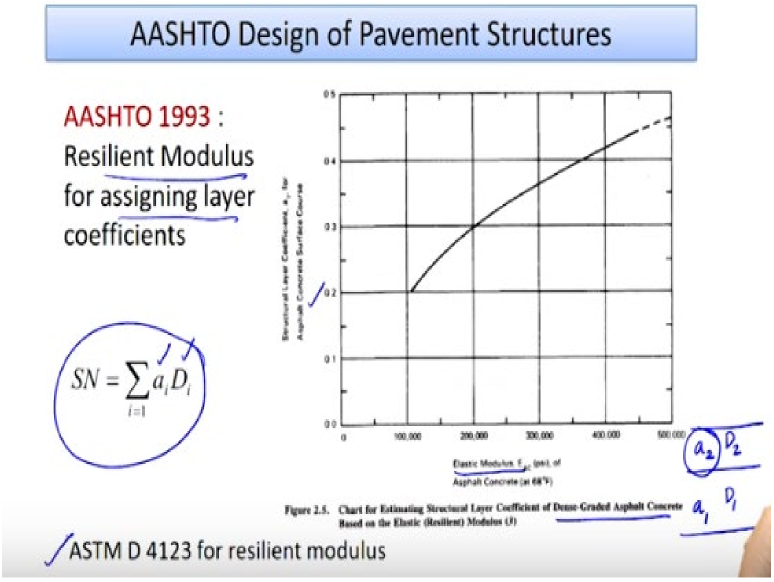

Now the structural number is computed like this, which is a cumulative of the layer coefficients multiplied by the layer thickness. Say for example, you have multiple layers, granular layer and bituminous layer. For each layer you will have a layer coefficient a_1, a_2 and so on and D_1, D_2 are the thicknesses for these layers. So sum of this will give you an indication of the structural number.

So first what is decided is that for the design traffic you identify how much should be the structural number and knowing the layer coefficients you can identify how much should be the layer thickness. So that is the whole procedure in which the layer coefficient for the bituminous materials is defined in terms of the resilient modulus.

As you can see from this chart for estimating the layer coefficient for bituminous layers, so this is for dense graded asphalt concrete is given here. Based on the elastic modulus of this material, it is noted as elastic modulus or resilient modulus, based on the elastic modulus this layer coefficients are identified. So these layer coefficients go into the design of flexible pavement layers, as per AASHTO 1993. And the resilient modulus was determined as per the D 4123 protocol.

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AASHTO Design of Pavement Structures

AASHTO 2002, 2008 : Mechanistic-Empirical Pavement Design

Dynamic modulus, Tensile strength and Poisson's ratio

Variable	Level	How to acquire and/or measure
Dynamic Modulus, E^*	1 ✓	AASHTO T342, *Standard Method of Test for Determining Dynamic Modulus of Hot Mix Asphalt (HMA)*
	2 ✓	E^* predictive equation
	3 ✓	E^* predictive equation
Poisson's ratio, µ	1	Estimated from laboratory testing ✓
	2	Regression equations
	3	Agency historical data or default values
Tensile strength, TS	1	AASHTO T 322, *Standard Method of Test for Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device*
	2	AASHTO T 322
	3	Regression equation (input values obtained from testing or historical data)

Now coming to the latest mechanistic empirical approach by AASHTO, which was developed in 2002 and later revised in 2008. You call it as the MEPDG approach or the mechanistic empirical pavement design. Here the material modulus is developed as a dynamic modulus. So dynamic modulus is something which is time dependent as well as temperature dependent.

So understanding the fact that this is a viscoelastic material and then you should capture the characteristic of the material with respect to time as well as with respect to temperature, different the modulus values will be captured at different frequencies and temperature and then later shifted to a master curve and that will go as an input in the design methodology.

The computation of dynamic modulus and development of master curves everything will be discussed in some other lectures during this course itself. So MEPDG allows you to have three stages or three levels of design; level 1, level 2, and level 3. In the level 1 it is expected that you conduct laboratory investigations to determine what is the dynamic modulus value as well as the Poisson's ratio.

Whereas in the level 2 and level 3, you can have predictive equations. So based on the bituminous material character or bituminous material aggregates skeleton, based on the binder content binder type that you have used, what is the viscosity of the binder and the temperature of test and everything, there are predictive equations provided to determine the dynamic modulus also.

So either one can use the predictive equations or you can do the dynamic modulus test in the laboratory to investigate these parameters. And the Poisson's ratio is also either regression equations are given or you can do it from the laboratory testing.

And regarding the tensile strength, again you can do a tensile strength test or regression equations are provided if you are working with a level 3 of the pavement design.

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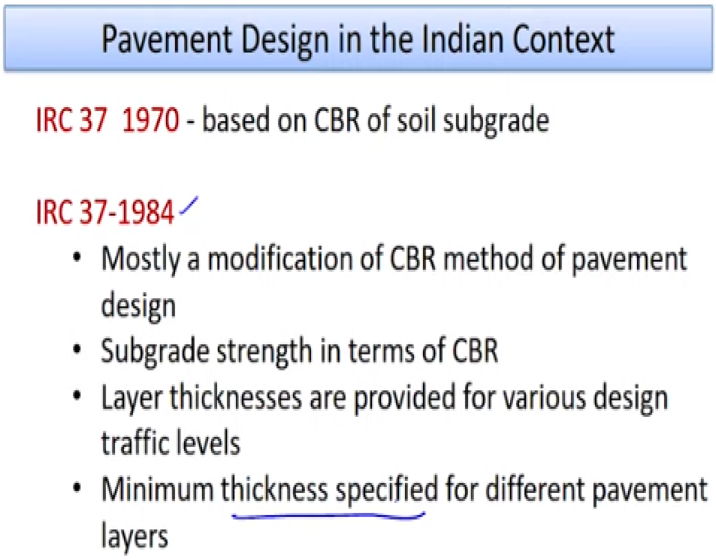

Now coming to the Indian scenario, we have been designing pavements based on IRC 37 standards developed way back in 1970s. IRC 37 started with the design of flexible pavement layers on the basis of CBR of the subgrade or the subgrade strength is taken as a parameter to identifying or to evaluating what should be the layer thicknesses okay.

And it was later modified in 1984. Again, it is an extension of the CBR method itself where the subgrade strength or CBR forms the basis for finding the layer thicknesses and also the minimum thicknesses are specified for different types of layers. Suppose you are using a bituminous layer or the granular layer what should be the minimum thicknesses required is also defined in IRC 37 1984.

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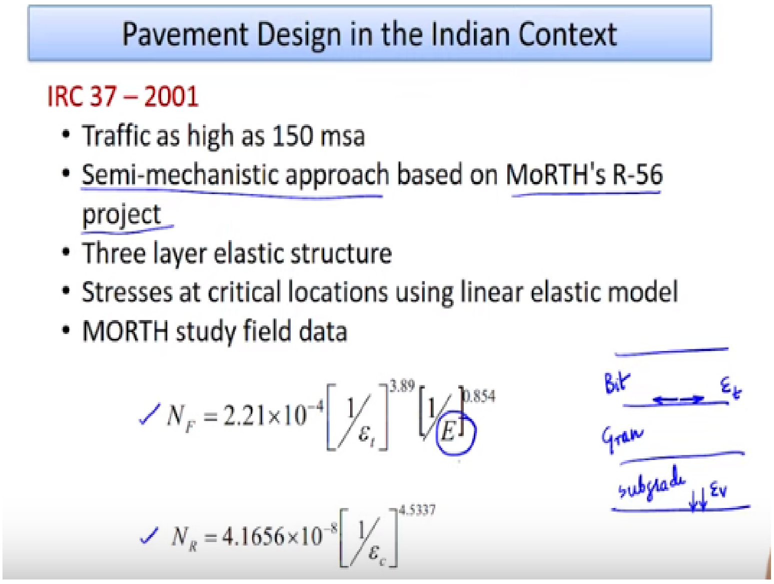

Now the later revision of IRC in 2001 was to cater for higher traffic say of the order of 150 million standard axles. They started using the semi mechanistic approach or again that can be considered as a semi empirical approach or a semi mechanistic approach based on sufficient data that was collected as part of the Ministry of Road Transport and Highway Project R-56 project. So that field data was correlated to various laboratory investigations and then this methodology was devised.

So in this the pavement structure is considered as a three layer elastic system. And a layer elastic analysis is done to find what are the critical stresses in this layers. Say the different layers are subgrade, granular layers and the bituminous layer.

The tensile stress at the bottom of the bituminous layer is identified as ε_t is critical as far as the fatigue behavior of the material is concerned and the compressive stress on top of the subgrade ε_v is considered as a critical parameter when you consider rutting. And based on this field study two distress transfer functions are provided, one is for the number of repetitions to failure due to fatigue and the second one is number of repetitions to failure due to rutting.

And as you can see that the material parameter is estimated as a modulus of elasticity which is given as E here.

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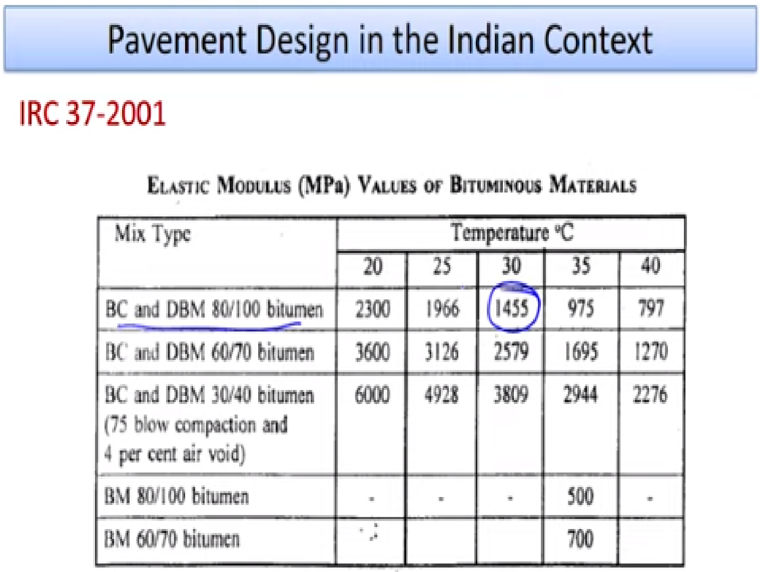

ELASTIC MODULUS (MPa) VALUES OF BITUMINOUS MATERIALS

Mix Type	Temperature °C				
	20	25	30	35	40
BC and DBM 80/100 bitumen	2300	1966	1455	975	797
BC and DBM 60/70 bitumen	3600	3126	2579	1695	1270
BC and DBM 30/40 bitumen (75 blow compaction and 4 per cent air void)	6000	4928	3809	2944	2276
BM 80/100 bitumen	-	-	-	500	-
BM 60/70 bitumen				700	

And the code also provides you indicative values so the values that you can choose for the design of the structure. Say for example, these are the elastic modulus values given for bituminous material say BC and DBM with an 80/100 penetration bitumen at say 30 degrees Celsius is 1455 MPa. So this was the elastic modulus values which are given in the design code of IRC 37 2001.

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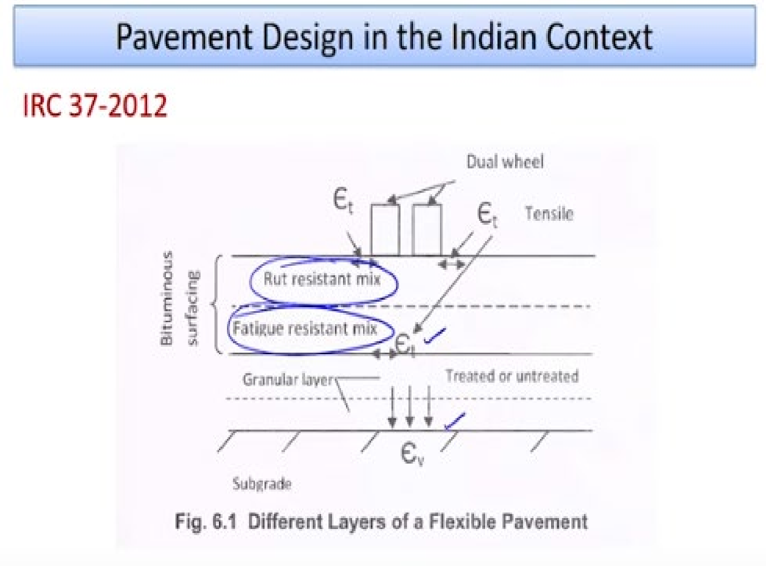

Fig. 6.1 Different Layers of a Flexible Pavement

Later revision in 2012 also gave a similar structure and the approach is also same wherein the bituminous surfacing it is mentioned that it has to be a rut resistant mix and it has to be a fatigue resistant mixture. Layer towards the top, bituminous layer towards the top of this, ie towards the surface, should be rut resistant and the bottom bituminous layer should be fatigue resistant. And also the critical stresses that are identified are ε_t and ε_v itself for the fatigue and rutting distress.

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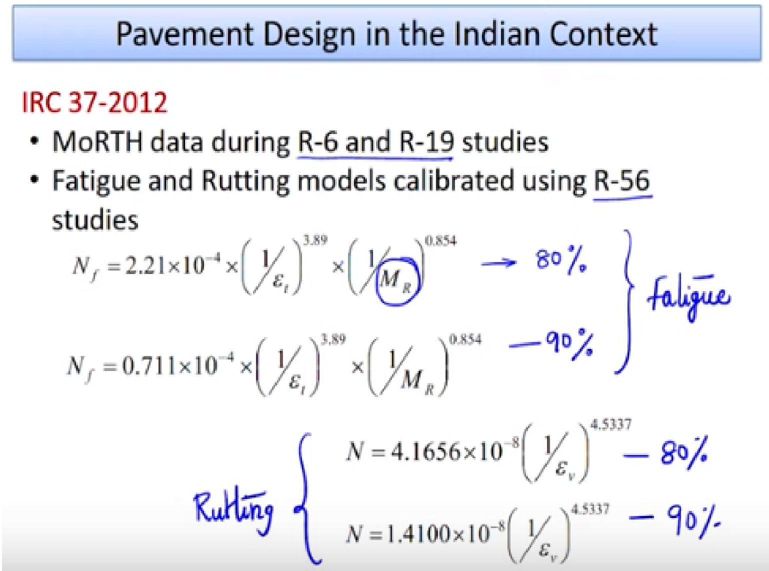

So as you can see, they have used data from MoRTH R-6 and R-19 studies and these equations were further calibrated using data from R-56. So you have two expressions given for rutting and fatigue. One is at 80% reliability level and the second one is 90% reliability level. So these are the two expressions related to fatigue behavior and these are the two expressions related to rutting.

Again this is at 80% reliability level and this one is at 90% reliability level okay. So as you can see there is an M_R is the coefficient that goes in here which is the resilient modulus okay.

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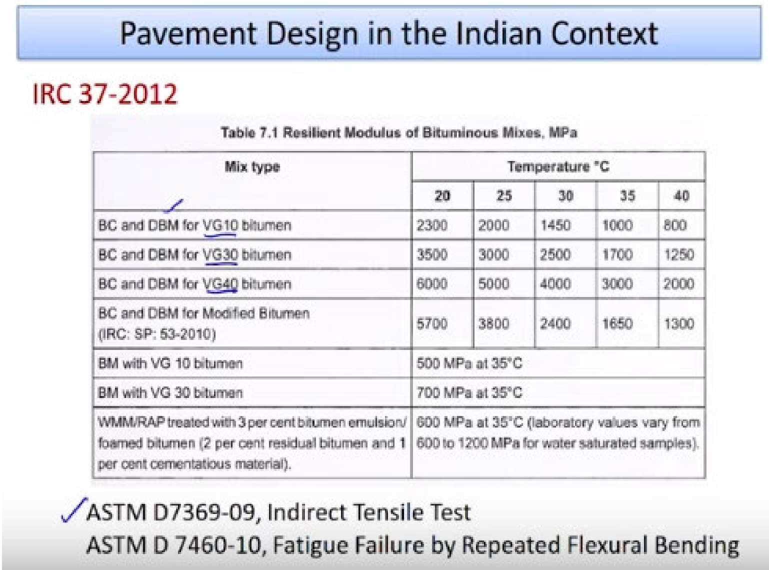

Table 7.1 Resilient Modulus of Bituminous Mixes, MPa

Mix type	Temperature °C				
	20	25	30	35	40
BC and DBM for VG10 bitumen	2300	2000	1450	1000	800
BC and DBM for VG30 bitumen	3500	3000	2500	1700	1250
BC and DBM for VG40 bitumen	6000	5000	4000	3000	2000
BC and DBM for Modified Bitumen (IRC: SP: 53-2010)	5700	3800	2400	1650	1300
BM with VG 10 bitumen	500 MPa at 35°C				
BM with VG 30 bitumen	700 MPa at 35°C				
WMM/RAP treated with 3 per cent bitumen emulsion/ foamed bitumen (2 per cent residual bitumen and 1 per cent cementatious material).	600 MPa at 35°C (laboratory values vary from 600 to 1200 MPa for water saturated samples).				

So as suggested by IRC 37-2012 these are the resilient modulus given, values given for different bituminous mixtures and the test protocol they have used is ASTM D7369-09 by indirect tensile strength test or ASTM D7460 wherein a fatigue failure test by repeated flexural bending test is conducted. So these are the values that are given in IRC 37-2012 for different types of mixes and for different types of binders.

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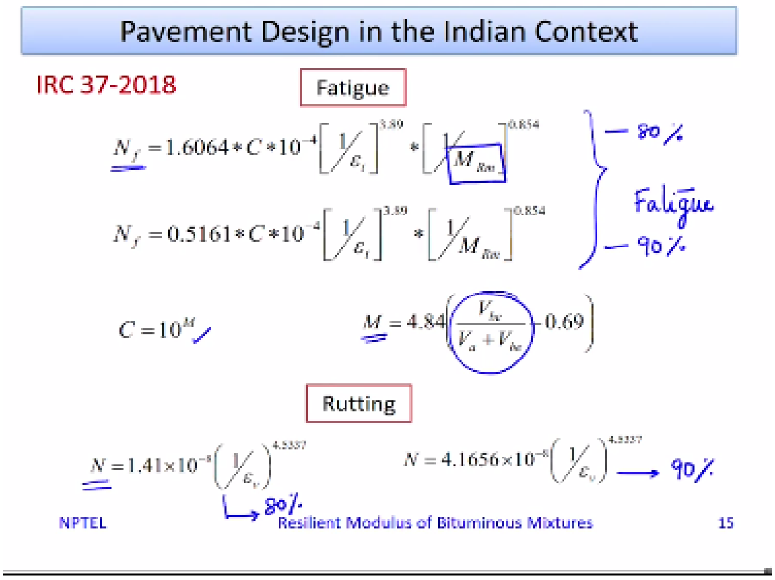

Now coming to the latest edition of IRC 37, which is IRC 37-2018 a similar approach is adopted here also. The layers are analyzed as linearized elastic layers and then the rutting and fatigue transfer functions or the distress transfer functions are derived based on the MoRTH data itself, but there are certain modifications done on the equations.

So as you can see the first two expressions are for fatigue failure. This is at 80% reliability level and this is at 90% reliability level. And this is for rutting at 80% reliability level and this is at 90%. There are certain modifications done here for example, a parameter C is introduced with an M constant so as to introduce the variations that may come in the aggregate structure.

Say for example, what is the voids filled with bitumen, what is the voids in mineral aggregate and so on. So those parameters are also incorporated in the distress transfer function. When I say failure, N_f represents what is the number of equivalent standard axle repetitions for failure due to fatigue and when I say failure it is 20 percentage of area is cracked, is termed as failure.

Whereas, in rutting N corresponds to number of repetitions of equivalent standard axles for failure due to rutting. And a 20 mm deformation on the surface is noted as rutting failure. So here M_{Rm} is the material modulus that is given here, which again is a resilient modulus.

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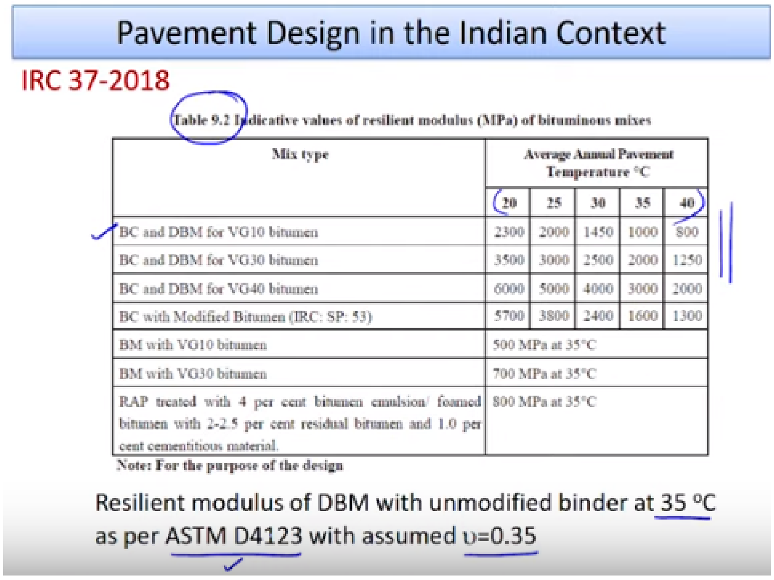

Mix type	Average Annual Pavement Temperature °C				
	20	25	30	35	40
BC and DBM for VG10 bitumen	2300	2000	1450	1000	800
BC and DBM for VG30 bitumen	3500	3000	2500	2000	1250
BC and DBM for VG40 bitumen	6000	5000	4000	3000	2000
BC with Modified Bitumen (IRC: SP: 53)	5700	3800	2400	1600	1300
BM with VG10 bitumen	500 MPa at 35°C				
BM with VG30 bitumen	700 MPa at 35°C				
RAP treated with 4 per cent bitumen emulsion/ foamed bitumen with 2-2.5 per cent residual bitumen and 1.0 per cent cementitious material.	800 MPa at 35°C				

So IRC 37-2018 gives indicative values of resilient modulus for the various mixes and binders. Say for example, for the first mix BC and DBM with VG10 binder for different temperatures start from 20 to 40 degrees, these are values given in MPa. These are the modulus values and these values are estimated using as per ASTM D4123.

Now there is an, it is also specified that one can always use these values for the design of the flexible pavement. Whereas, if you want to investigate the resilient modulus for other materials using say modified binders, you can estimate the values at 35 degrees Celsius using the same ASTM standards. But this ASTM standard is now withdrawn and it has been replaced with a newer version, the latest version, but the code specifies that you still use this ASTM 4123 standard at 35 degrees Celsius and in the standard you actually assume a Poisson's ratio of 0.35. We will not compute what is the vertical deformations. So you have to do it as per the old standard itself. And for a DBM mixture. And if it is found that this value is higher than what is specified in this table, one has to go and use what is provided in this Table 9.2, that is indicated as the maximum values. So this is what is mentioned in IRC 2018.

So we have an earlier version of the code which is a ASTM D4123 which is to be used as per this IRC method and also a later version of ASTM code for the determination of resilient modulus. So in the coming session we will be discussing about both these code practices.

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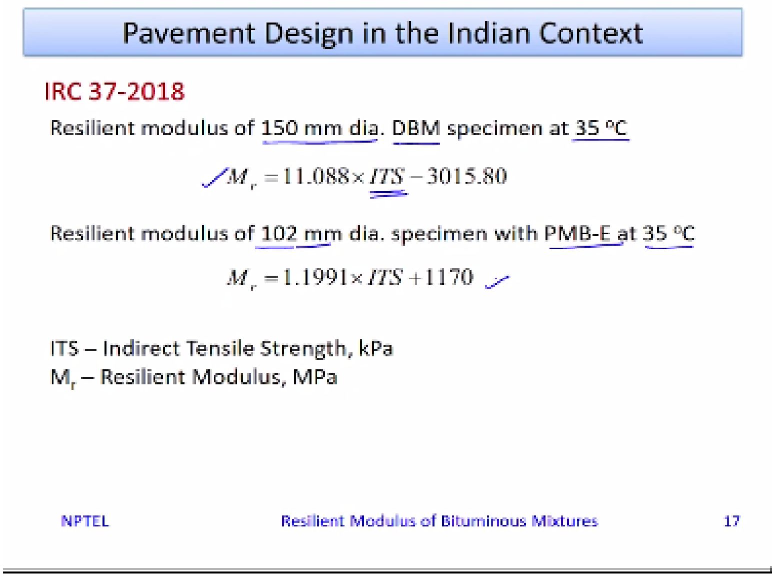

IRC also give you some empirical relations to determine the resilient modulus in terms of the indirect tensile strength of the material. Say for example, on a 150 mm diameter sample for DBM specimen at 35 degrees Celsius the relation of resilient modulus with the indirect tensile strength value is denoted here.

And also for 102 mm diameter specimen with polymer modified binder with elastomer as the modifier at 35 degrees Celsius is also given here. So you can do an ITS test on the specimen and appropriately substitute in this equation and to get the resilient modulus value. So these are some empirical relations also provided in the code.

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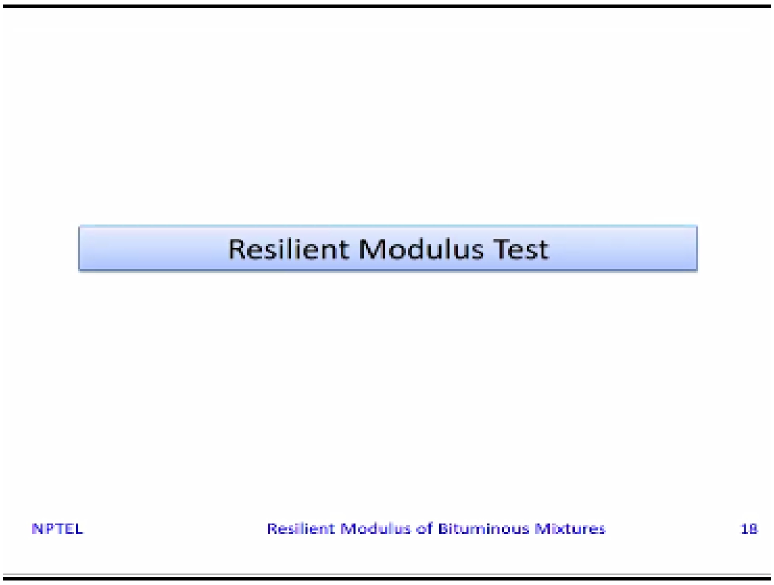

Let us discuss about these two standards. One is the earlier version of ASTM standard for determining the resilient modulus and one is the latest version and how this test is conducted. And what are the post processing methods adopted we will be discussed in the coming slides.

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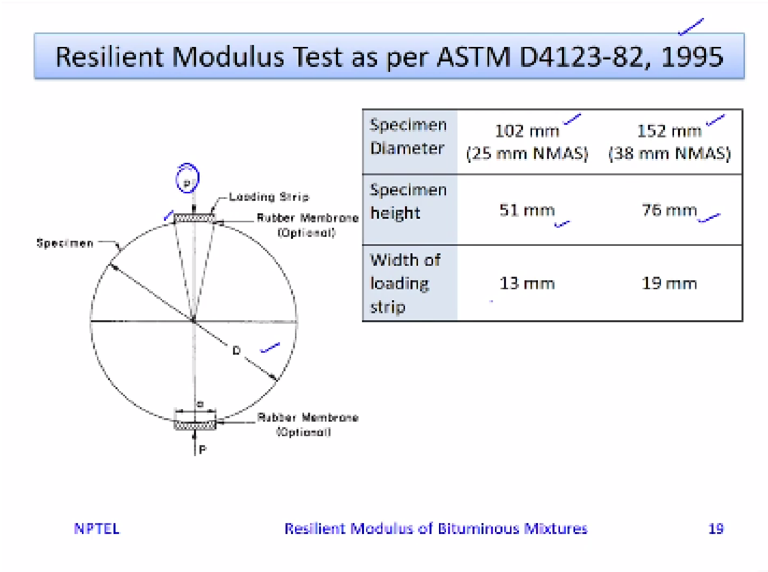

Specimen Diameter	102 mm (25 mm NMAS)	152 mm (38 mm NMAS)
Specimen height	51 mm	76 mm
Width of loading strip	13 mm	19 mm

So let us look at a ASTM D4123, which is the 1995 version of ASTM. Here a specimen, a cylindrical specimen will be subjected to a loading in the diametral direction and then a repeated compressive haversine load will be applied and you will denote what is the deformations that is happening. So this is a typical sample that is shown here of diameter D and it is loaded in the diametral axis.

There is a loading membrane. Through the loading membrane you apply a load of P. Now the specimen diameter's dimensions are you can do it on a smaller size specimen or a larger size specimen of 102 or 152 mm. If your nominal maximum aggregate size is still 25 you go for a 102 mm size specimen. And if it is more than 25 and less than 38 mm, you go for a 152 mm size specimen.

And the thickness of the specimen or the height of the specimen is 50 mm and 76 mm respectively. And you provide the loading strip on top on the specimen you provide the loading strip which should have a width of say 13 mm or 19 mm.

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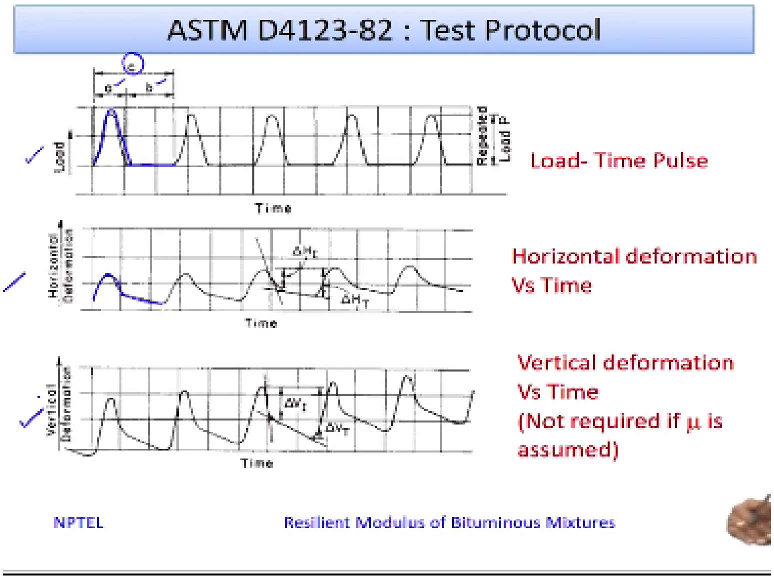

So this is how the loading is done. The first figure shows the load time pulse. You can see that there is a loading in a haversine fashion and then you give a rest period. So a is the loading time and b is the rest period and c is the total cycle time. So such repeated load cycles will be given and you will capture the corresponding deformation. Now the deformations will be measured in the cylindrical specimen.

You will measure the deformation in the horizontal direction as well as in the vertical direction. You can use linear variable differential transducers to measure these deformations. But this code says that you need not collect the vertical deformations. You can collect only the horizontal deformation also. But if you are not collecting the vertical deformation then in that case you have to assume the Poisson's ratio for the computations okay.

So the first figure shows the load versus time and in the second figure you can see that as the loading increases, the deformation increases. And when it is unloaded the deformation decreases and during the rest period also there will be recovery of deformation. This continues and what we are looking is the instantaneous recovery that happens.

So when one starts unloading there will be instantaneously there will be a recovery and during the rest period there will be a continued recovery. So we will look at the instantaneous recovery as well as the total recovery that is happening in every load cycle. So using those two recovery parts or the deformations, we will be computing the Poisson's ratio for the material as well as the resilient modulus okay.

So the first figure shows the horizontal deformation. Similarly, you can get the vertical deformations if you connect a LVDT in the vertical direction. There also as the load increases, the deformation increases and as the load is unloaded, there will be recovery and during the rest period of load also there will be recovery that is happening.

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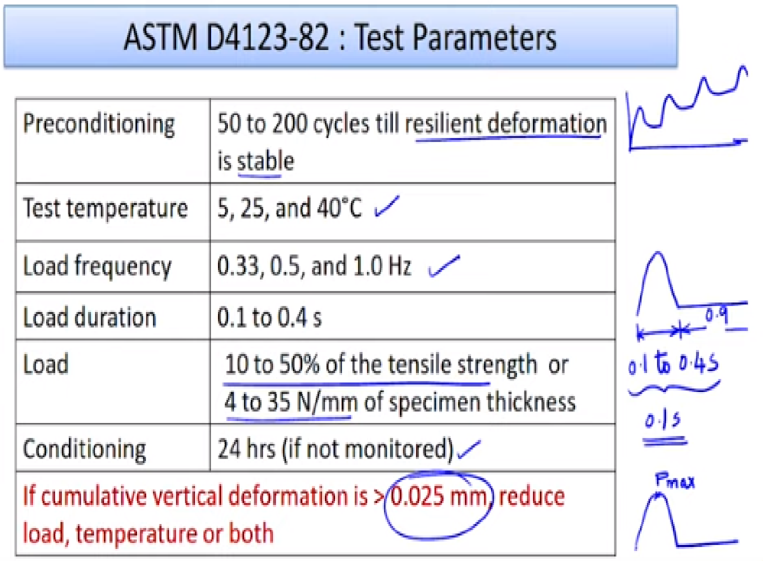

ASTM D4123-82 : Test Parameters

Preconditioning	50 to 200 cycles till resilient deformation is stable
Test temperature	5, 25, and 40°C
Load frequency	0.33, 0.5, and 1.0 Hz
Load duration	0.1 to 0.4 s
Load	10 to 50% of the tensile strength or 4 to 35 N/mm of specimen thickness
Conditioning	24 hrs (if not monitored)
If cumulative vertical deformation is > 0.025 mm reduce load, temperature or both	

Now the test parameters are like this. You have to apply precondition cycle. Essentially our idea is that you do a repeated load on the specimen so that your strain reaches a stable state or it is, it is, mentioned here that the resilient deformation is stable. So if we plot the deformation, eventually a state will be reached when this reaches a stable state.

It is not very clear whether you are looking at a stable strain or you are looking at a stable strain rate. So what is mentioned is that you are looking for a resilient deformation. Whenever the resilient deformation becomes stable you can do the test for the computation. So it is mentioned that 50 to 200 test cycles are to be, cycles are to be, given for preconditioning.

Now the test temperature as specified is that you can do it three possible temperatures. They are 5, 25 and 40 degrees Celsius. And at every test temperature, you can either do it at one frequency or different frequencies can be tried out. For example, you can have load frequency of 0.33, 0.5 or 1 Hz. Now as I said it is a load haversine wave with a rest period. Now this load duration can be 0.1 to 0.4 seconds.

This is what it is mentioned in the code and it is ideal to choose 0.1 second in order to consider the traffic loading. So essentially you go for a 0.1 second loading and the rest period, suppose you want the cycle to be of 1 Hz frequency, you can have 0.9 seconds of rest period. So your cycle will look like 0.1 second loading and 0.9 seconds of rest period. So it is a 1 Hz cycle.

Similarly, you can go 0.3 hertz or 0.5 hertz as suggested by the code. And what should be the maximum load? So we said there is a peak load. So what should be this P max? This P max has to be 10 to 50 percentage of the tensile strength.

So what you have to do is that for the test condition say for the particular temperature and frequency of testing, for the particular mix that you are looking at, you have to cast specimen and test it for the indirect tensile strength and find out how much is the indirect tensile strength of the or the maximum load in the test and then 10 to 50 percentage of that can be applied as a maximum load in this test.

Or you should go for say 4 to 35 Newton per millimeter of the specimen thickness is the maximum load that you can apply, that is what is specified. Now the conditioning is that at every temperature you are testing, you should condition the sample for sufficient long time and you can monitor the temperature of the specimen and if you are not monitoring, you should at least condition for 24 hours.

And also one more thing is that you look for the cumulative deformations in the material. If you see that this cumulative deformation that is happening is more than 0.025 mm then you can assume that the material is going to be a failure stage or going somewhere towards the failure stage. So the code says that if it goes beyond 0.025 mm you have to bring down the parameters, say you have to reduce the load or you have to test it at a lower temperature.

So you are not allowed to exceed this 0.025 mm limit of total deformation.

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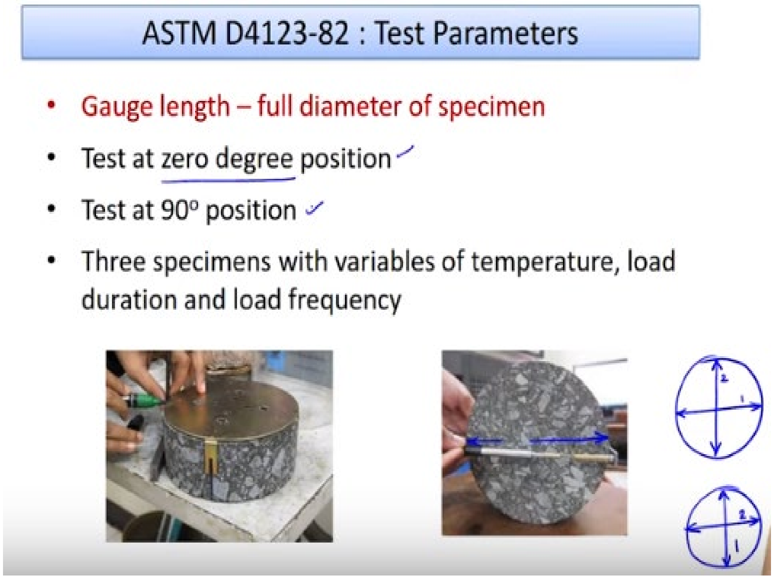

Now regarding the fixing of LVDTs. The gauge length for an LVDT suggested here is the full diameter of the specimen. As you see here, this is your specimen and this is the diameter of the specimen. You connect an LVDT to capture the deformation of the full diameter of the specimen. Now as you see here, this is a horizontal direction in which you will collect the deformation.

And also as mentioned, you can have the vertical deformation also. Or you do not have to do it if you are assuming a Poisson’s ratio. So we can connect one in the horizontal position and second one is in the vertical position. Now you do the test at this position, this is the first position or I call it as a zero-degree position.

And after the test is completed, immediately you will turn the specimen by 90 degrees so that the positions 1 and 2 will get shifted. So you will just turn it and then repeat the test. So this is essentially to eliminate if there is any variability in the measurements in the vertical and horizontal direction. So that is why you do it in both directions. So you call it as a zero-degree position and the other one is called the 90-degree position.

And always you test at least three specimens to check the repeatability of results. Again the test can be conducted at a particular temperature for the three specimens you can go for three different load durations or as well as the frequencies.

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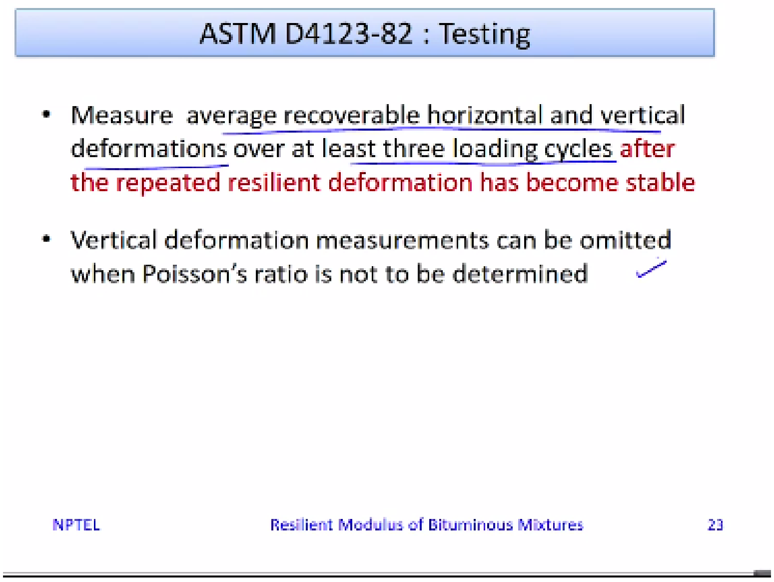

Now for every test you measure the recoverable horizontal and vertical deformation. Suppose you have both LVDTs connected over the last three loading cycles after the preconditioning cycles. As I said 50 to 200 cycles of preconditioning has to be given till your resilient deformation become stable. And after that, you take three cycles. Those three cycles will be used for the computation of the resilient modulus.

Now as I said vertical deformation can be omitted if Poisson's ratio is assumed.

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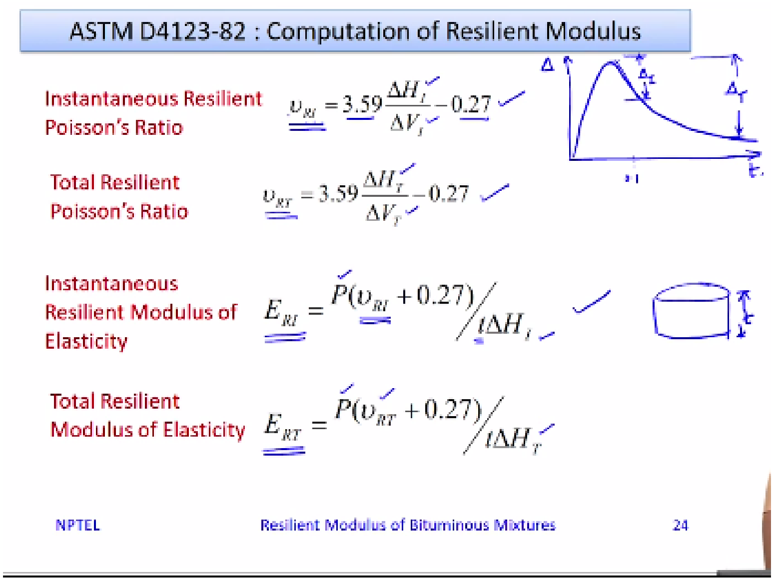

Now these are the computations. So from the last three test cycles, you take the average value. So suppose this is the deformation, marked as Δ in y axis. And this is time in the x axis. First of all, you have to note how much is the instantaneous deformation okay.

As I said during the recovery, so suppose this was your 0.01 loading cycle. So when your load is unloaded instantaneously there could be certain amount of deformation. So that deformation will be marked as delta instantaneous, Δ_i. Suppose, I am looking at the horizontal LVDT I will mark it as ΔH_i and when you are looking at the vertical LVDT you mark it as ΔV_i.

So i is denoted for the instantaneous recovery. And the second one is a total recovery. So from the maximum point till the end of the test you see that this much of deformation is recovered. So if I mark it as Δ_T for total deformation. So if I look at the horizontal LVDT I will mark it as ΔH_t and if it is a vertical LVDT it will be marked as ΔV_t.

Now based on the horizontal deformation and the vertical deformation, you can compute the Poisson's ratio using this expression. You have certain constants here related to the gauge length and the its arrangement. So this is the expression for finding the instantaneous recoverable Poisson's ratio. So it is noted as υ_{RI}, I stands for the instantaneous part and R is called the resilient part.

So υ_{RI} corresponds to the instantaneous resolution Poisson ratio which is computed using this expression. Now as I said you can note the total recovery also. So based on the total recovery you can get a Poisson's ratio which is termed as the total resilient Poisson's ratio υ_{RT}. So once you get your υ_{RI} and υ_{RT}, you can get two resilient modulus values. One is the instantaneous resilient modulus and the other one is the total resilient modulus.

So this is the instantaneous resilient modulus of elasticity given by the equation as shown here, where P is the load that you have applied in Newtons, υ_{RI} is the instantaneous resilient Poisson's ratio, T is the sample thickness. So this is T and ΔH_i is the instantaneous recovery in the horizontal direction. Similarly, you can compute the resilient modulus as per the total recovery.

So E_{RT} represents the total resilient modulus of elasticity, which is connected as your load $\upsilon$with respect to the total recovery and ΔH_T is the total recovery in the horizontal direction. So what you have arrived at is two resilient modulus values. One is with respect to the instantaneous recovery. And the second is with respect to the total recovery.

And you have two Poisson's ratio values. So this is how the resilient modulus is computed.

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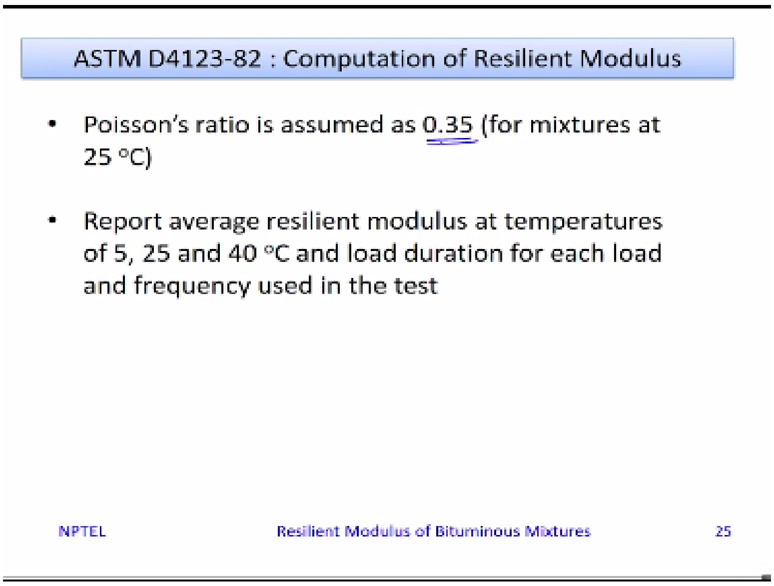

And you are asked to average out the values at every temperature. Suppose you are doing it for three different specimens, you have to average out the values and you get two resilient modulus values. And suppose you are not taking a measurement in the vertical direction, you can assume a Poisson's ratio of 0.35 for the mixtures at 25 degrees Celsius test.

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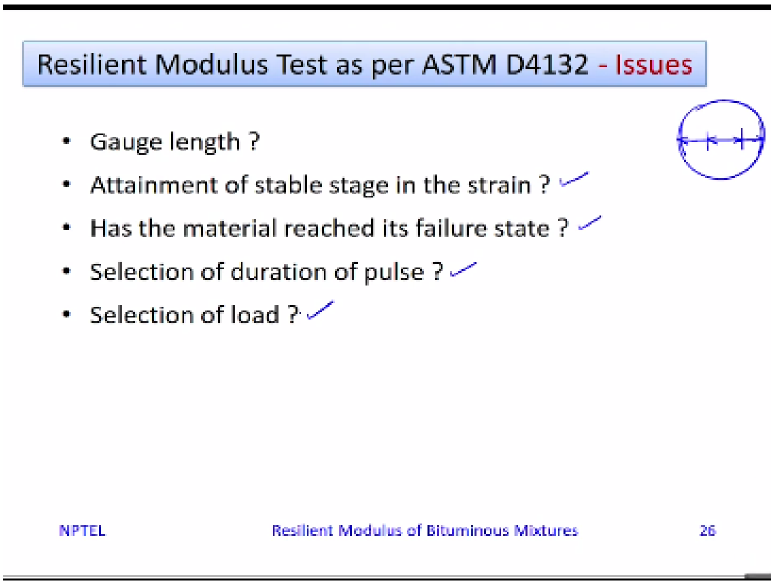

Now what are the issues associated with it? The first thing is regarding the gauge length of the LVDT. As I said, you will use the entire diameter as the gauge length. So what you are measuring is the deformation with respect to the diameter of the specimen. There could always be certain repeatability issues because there could be end effect also.

Another important thing is that even if you go for say the load as 10 to 50 percentage of indirect tensile strength ratio, indirect tensile strength, the deformations could be very large okay. So it can so happen that your total deformation limit of 0.025 may get exceeded. The aspect is, suppose you go for a shorter gauge length, then the advantage is that your repeatability will be more because this end effects will not be much there.

And also you will have much more control in the test and another aspect is that you can have a larger loads may not cause excessive deformations okay. So it is not sure whether using a total gauge length or a gauge length for the diameter is a better choice or not.

And the another one is that it is mentioned that you have to attain a stable stage in the strain. So as I said it is not clear whether this 200 cycles or 50 to 200 cycles of preconditioning will help you to attain that strain, of constant strain or it could be a constant strain rate also. That also is not clear. And again you have to check whether the material has reached its failure state or not.

Because you do this preconditioning cycles say for example, if you are taking 50% of ITS as the load and you choose certain frequency and do the testing and at the end of the test, your specimen might have failed. So it is necessary that you conduct an ITS on the specimen after the testing and check whether there is much variation from the results and your material is failed or not.

So it is essential to note whether this test sequence that is given will be creating a deformation in the resilient elastic states because that is what we are looking at. And next is the selection of load and the load pulse. As is mentioned this 10 to 50% will it be sufficient to create sufficient deformation or will it be, will it create more deformation than it is required is one thing.

And another thing is the duration of the load pulse. As is mentioned you can go from 0.1 to 0.4 seconds. So what exactly one should take is not clear. So regarding the load pulse, its duration, then the preconditioning cycles and also the gauge length that you have to choose there is a little bit of uncertainty or confusions in the selection of all these parameters as far as this AS 4123 is concerned.

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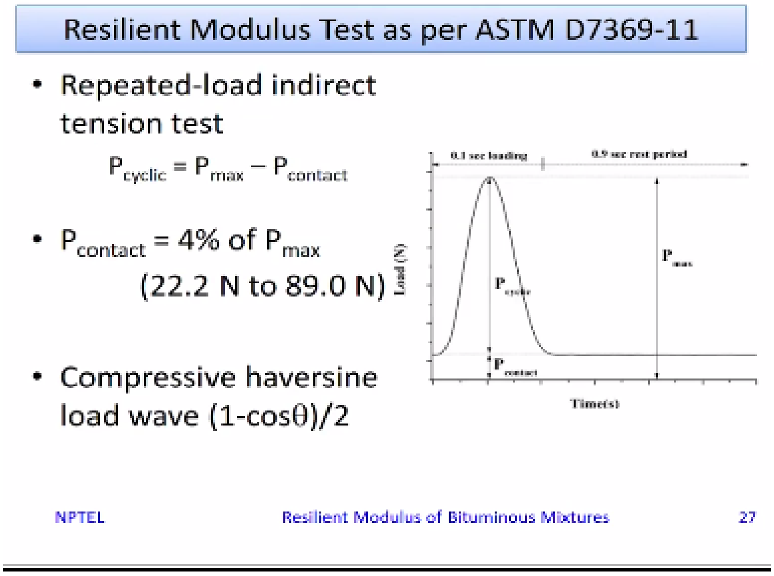

Now many of these issues are addressed in the latest revision which is ASTM D7369-11.