Analysis and Design of Bituminous Pavements

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Lecture - 22

Modulus for Design - Resilient modulus (Bituminous material)

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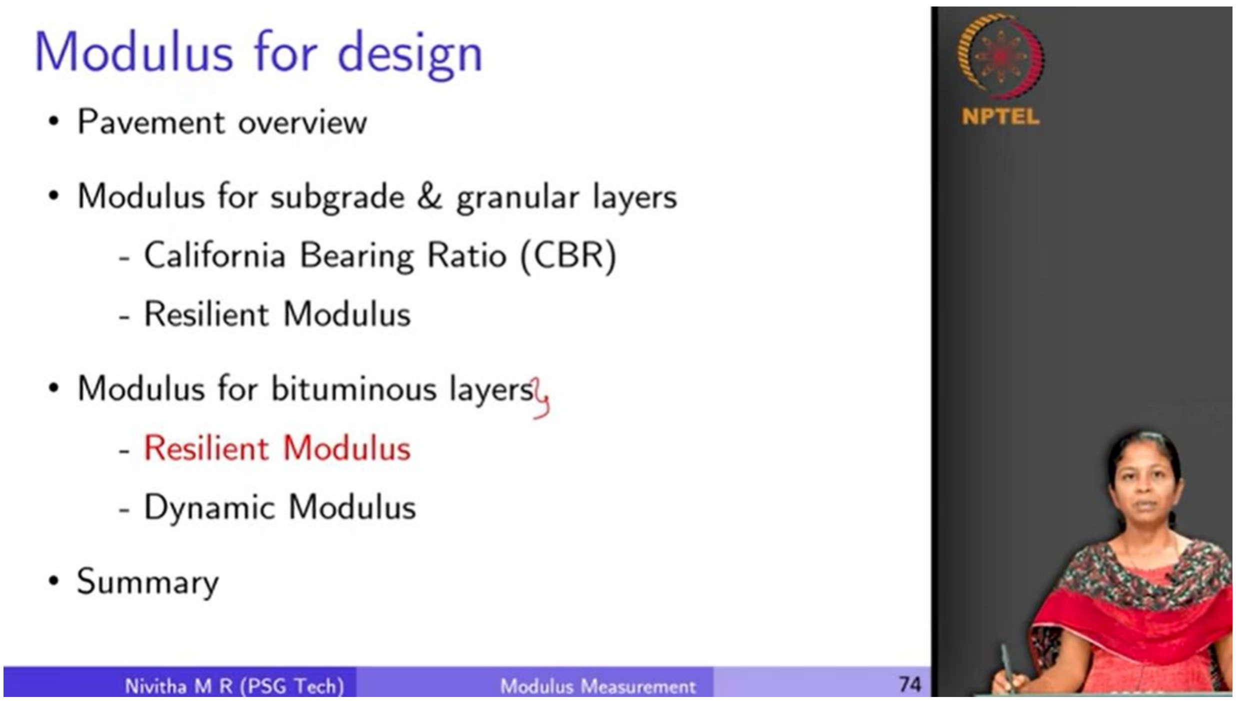

Hello everyone, welcome back. In this lecture, we will be focusing on the measurement of resilient modulus for bituminous mixtures. In the previous lecture, we already discussed the definition of resilient modulus and the procedures for measuring it in granular materials, with separate approaches for subgrade, subbase, and base materials. Today, our main objective is to understand the calculation process for determining the resilient modulus value specifically for bituminous mixtures.

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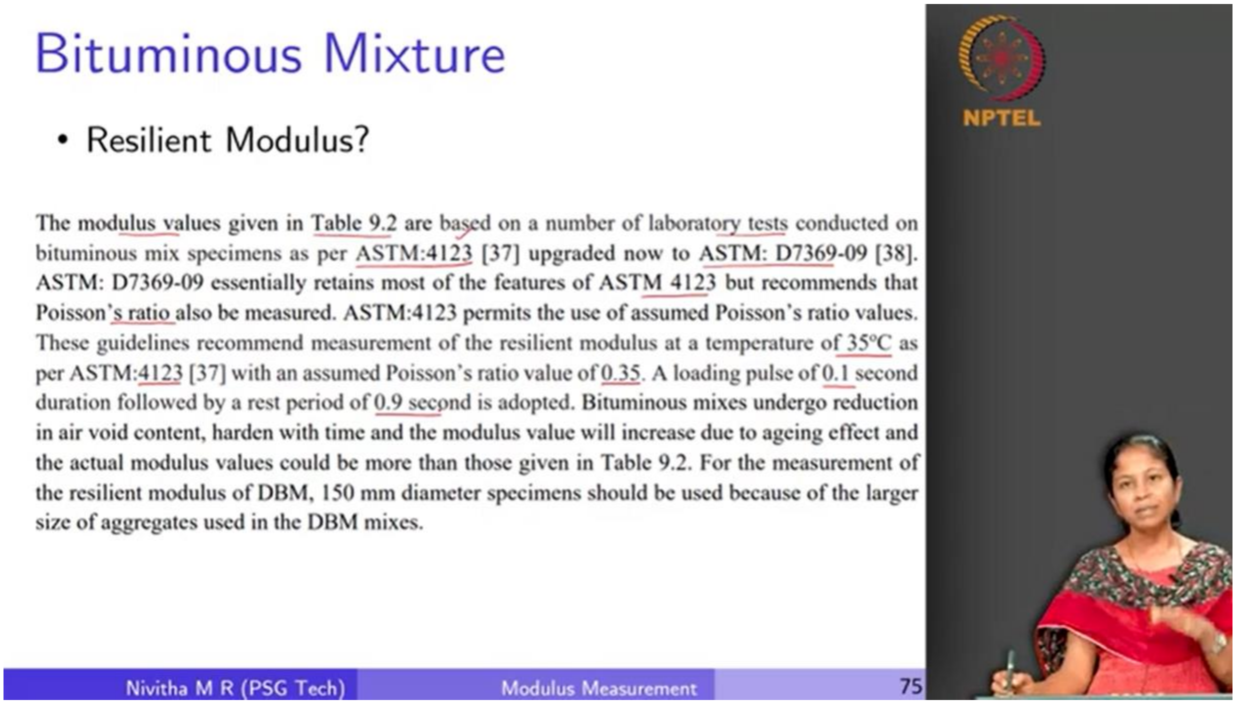

Let us start with what IRC says about resilient modulus. I have taken lines from IRC 37 and pasted here. As per IRC, you can see here, there is a table 9.2, which most of you would be familiar with, which gives the resilient modulus value for bituminous mixtures at different test temperatures for different grades of binders. This resilient modulus value is based on a number of laboratory tests conducted on bituminous mix specimen as per ASTM D4123. And this is upgraded now to ASTM D7369. You should remember that ASTM D4123 is a withdrawn standard. This standard is not currently available and that is replaced with ASTM D7369. So, IRC itself mentions the difference between these two codal provisions. ASTM D7369 retains most of the features of 4123, but it recommends that Poisson's ratio should be measured. The basic differences in ASTM D4123 are, it is sufficient if you measure the deformation in one direction and basically in the horizontal plane, you can assume Poisson's ratio and compute the resilient modulus. Whereas in ASTM D7369, it is required to measure the deformation in both horizontal and vertical direction and we have to calculate the Poisson's ratio. Using the Poisson's ratio, we will be calculating the resilient modulus.

So, you can see here, the guidelines measure resilient modulus at a temperature of 35°C as per 4123 with an assumed Poisson's ratio of 0.35. They also use a loading pulse of 0.1 second and a rest period of 0.9 seconds. In the previous lecture, when we measured the resilient modulus for granular materials, we applied a similar kind of a loading pulse, a haversine loading with 0.1 second loading and a rest period of 0.9 seconds. So, a similar procedure is specified for bituminous mixtures also.

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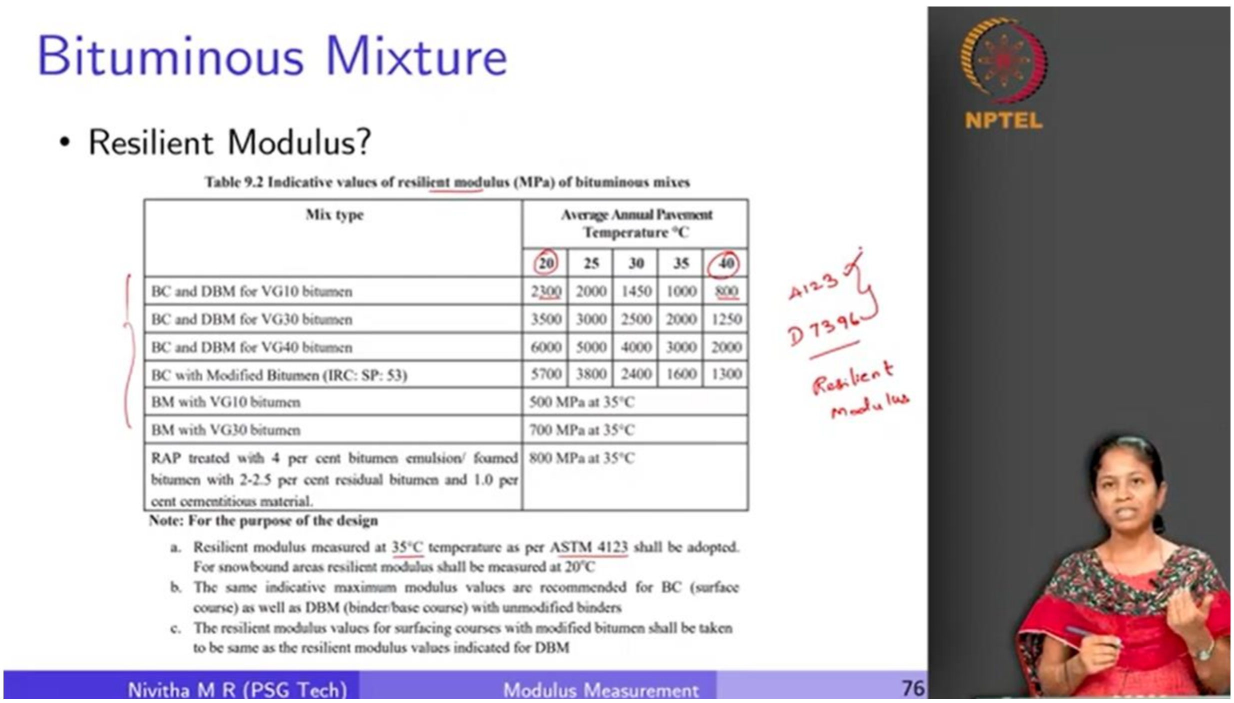

Now, if you look at this particular table 9.2, which has indicative resilient modulus, you can see it is given for different annual average pavement temperatures from 20 to 40°C, again for different grades of bitumen. So, we have VG10, VG30, VG40 and modified bitumen and separate modulus values are specified. You can see here, our interest here in this particular module is to quantify the effect of environmental parameters.

If we look into the effect of temperature on bituminous mixtures, you can see the modulus is 2300 MPa at 20°C and it has reduced to 800 MPa at 40°C. So, there is a significant effect of temperature on the resilient modulus value. One thing that you should note here is IRC specifies that the resilient modulus is measured at a temperature of 35°C as per ASTM 4123. As I told you, ASTM 4123 is a withdrawn standard and the standard is currently not available for circulation.

Hence, it might be difficult to use this kind of a standard and however, for the sake of completeness and to comply with the IRC codal provisions, we will see how to measure this with ASTM 4123 procedure. In addition, we will also see how to measure this as per the current standard which is ASTM D7396. So, we will be going through both the procedures 4123 procedure and 7396 procedure for measurement of resilient modulus for bituminous mixtures. In one of our previous course which is on mechanical characterization of bituminous materials, Dr. Neethu Roy has explained in detail about the measurement of resilient modulus and dynamic modulus for bituminous mixtures.

Basically, she has used the ASTM D4123 test procedure there, highlighted what are the issues in this particular measurement, mostly involved with post processing of the data and the computation involved. So, the detailed version of this measurement procedure is available in that particular lecture. However, for the sake of completeness for this particular course, I will be briefly going through the content given in 4123. Again, I will be borrowing some of the content that she has already explained just to maintain uniformity of terminologies across both the lectures.

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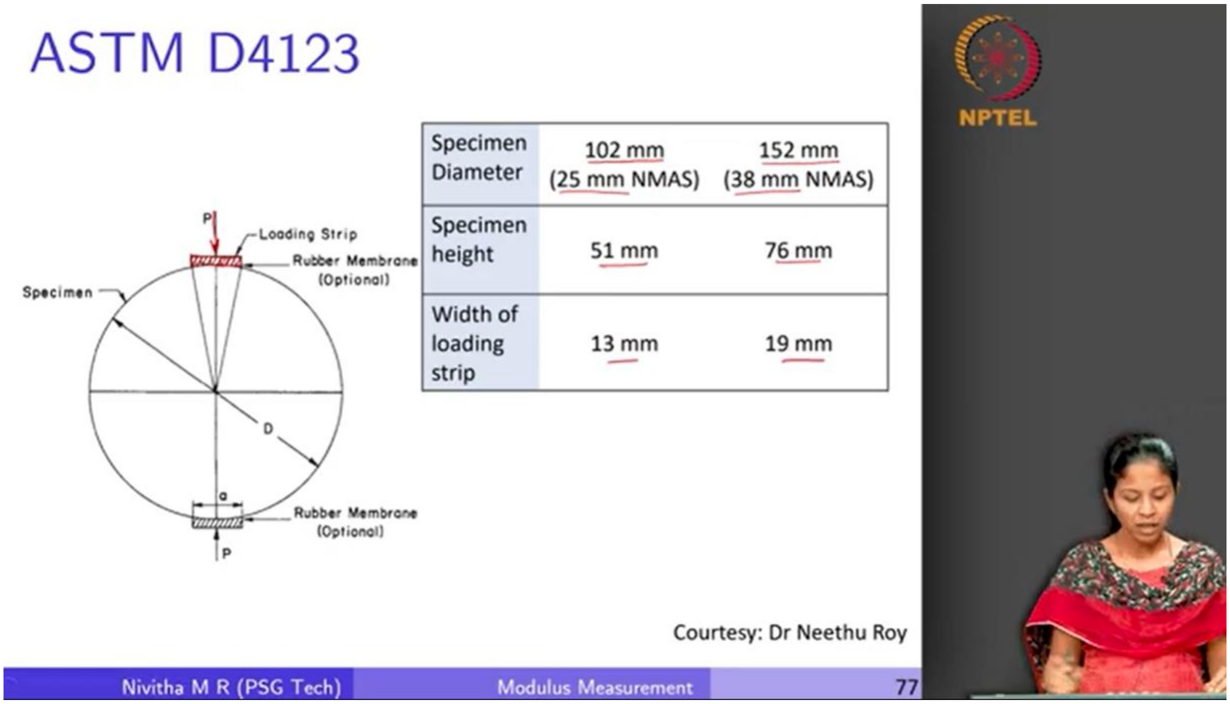

Now, let us look into the procedure given in ASTM D4123. We have a cylindrical sample which is used for testing here. You can see the details with regard to the sample preparation. So, we have a specimen of 102 mm diameter or 150 mm diameter. The sample size is specified depending upon the nominal maximum aggregate size. If we have 25 mm nominal maximum aggregate size, use of a 100 mm diameter specimen is suggested. If we have 38 mm nominal maximum aggregate size, a larger specimen which is 150 mm diameter is suggested for testing. The specimen height also varies with the diameter of the sample. So, if we have 100 mm diameter sample, we have approximately 50 mm as the sample height. And if we have 150 mm diameter sample, we have 76 mm as the sample height, which is kind of half of the diameter.

And there is also a loading strip which has to be placed on the sample for the testing purpose. If you look at the sample, it is basically a cylindrical sample. We place the cylindrical sample like this and we apply the load over the diametric plane. So, this will be the cylindrical face of the sample. So, we will be applying the load here on the diametric face of the sample. So, if you look at this illustration here, this is the load P that we will be applying on the sample. And just to disperse this load over a small area, we have a loading strip that is present here over which this particular load is applied. The width of this loading strip again depends upon the size of the sample. In one case, we have 13 mm and in another case, we have 19 mm. So, this is the specimen and this is how the loading is applied on the specimen.

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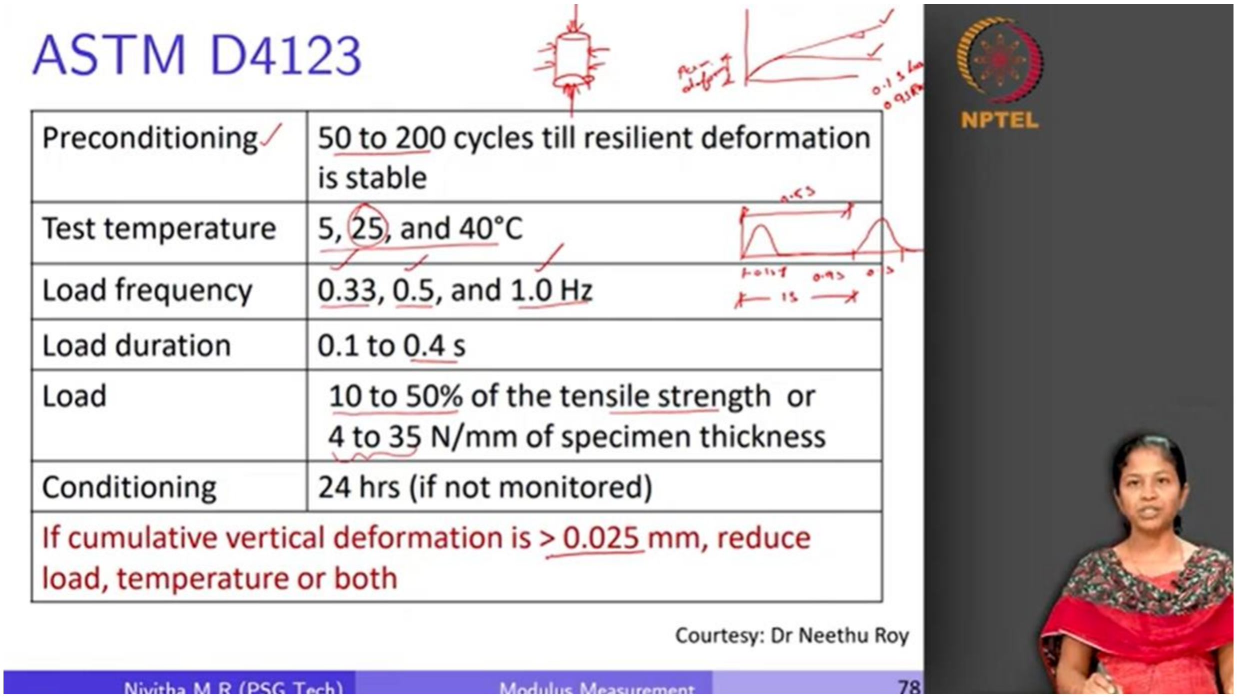

Now, what are the other test conditions that have to be used? So, there is again preconditioning that we have to apply. We have seen the preconditioning part for the granular material also when we were measuring the resilient modulus. We have a similar preconditioning procedure that we have for bituminous mixtures also. So, we have 50 to 200 cycles until this resilient deformation is stable. In the previous case for the granular materials, we said that if we look at the deformation, the permanent deformation is increased and then after some time it remained stable. This is the permanent deformation. After this, we saw that there was insignificant permanent deformation and most of the deformation was recoverable. This is for granular materials. For bituminous mixtures also, it is expected that we reach this kind of a state. That is what we had defined as a resilient state.

So, we are trying to apply 50 to 200 cycles, still this resilient deformation is stable. But we should note that for bituminous mixtures, especially in the testing temperatures of 5 to 40°C, it is hardly possible to get this kind of a resilient state. We will get a state wherein initially there would be an increase in deformation, and then maybe the rate would remain constant. So, we are not very sure here whether we have to exactly reach this resilient state or we have to reach a state like this where the rate is constant. That is one concern about the use of this particular codal provision in measurement.

Next is the test temperature. The test temperature is 5, 25 and 40°C. When these 3 temperatures are indicated, it is typically done at 25°C. If the requirements mandate, we can also test it at 5 and 40°C. Similarly, the loading frequency, we have different loading frequencies that we can use 0.33, 0.5 and 1 Hz. The loading frequency is nothing but the number of load cycles that we apply per second. Let us take the standard case wherein we have 0.1 second loading and 0.9 second recovery. So, this is loading part, this is recovery part. We apply a load like this for 0.1 second and we allow it to recover for 0.9 seconds. Again we start with the next loading cycle and so on. One load cycle is going to take us 1 second. So, the number of cycles I apply per second is 1. So, it is of 1 Hz frequency. Similarly, we can have different loading times; we can reduce this loading time and appropriately proportion the loading and the recovery period to get different frequencies.

This is with regard to the frequency of testing. In this load duration, we typically use 0.1 second loading, but we can have up to 0.4 second loading also. So, we can have a larger cycle time in this case when we have 0.2 second loading and we can have an appropriate recovery period also. What is the load that is to be used for this testing? So, the load is 10 to 50 percent of the tensile strength. We are expected to do an indirect tension test on this material. Then there is another thing that we have to note. When we measure the resilient modulus for granular materials, there is confining pressure applied on this. Over and above this, there is an axial load that is applied. So, the sample is tested for compression loading in the case of granular materials for measurement of resilient modulus. But in the case of bituminous mixtures, we are doing an indirect tension test. So, we are rotating the sample and then applying a load here and then measuring the deformation.

So, it is an indirect tension state in which we are measuring the resilient modulus. So, there is a difference between the state in which the measurement is carried out for granular materials and for bituminous materials. So, now we are expected to do an indirect tension test, find out the load on the material and then use 10 to 50 percent of the tensile strength for testing. In case if it is not possible, we can also use a load of 4 to 35 N/mm thickness of the sample. So, we determine the sample thickness, use any of the value between 4 and 35, calculate the appropriate load and then use it for testing. Then we have to condition the sample also for 24 hours if the temperature is not monitored. If there is a way in which we can measure the temperature of the specimen, then once it reaches the entire sample reaches the test temperature, we can start the test. Also in this particular test procedure, we should note that if the total vertical deformation at any point as the test progresses is greater than 0.025 mm. Previously, if you remember, we have seen that in the granular materials at any point if it reaches 5 percent, we stop the test even if it is in between any kind of a loading sequence. So, the same thing here except that it is specified for a vertical deformation of 0.025 mm. So, in that case, we stop the test, we reduce the load or the temperature or both of these parameters and then do the test again. So, this is the requirements as per ASTM D4123.

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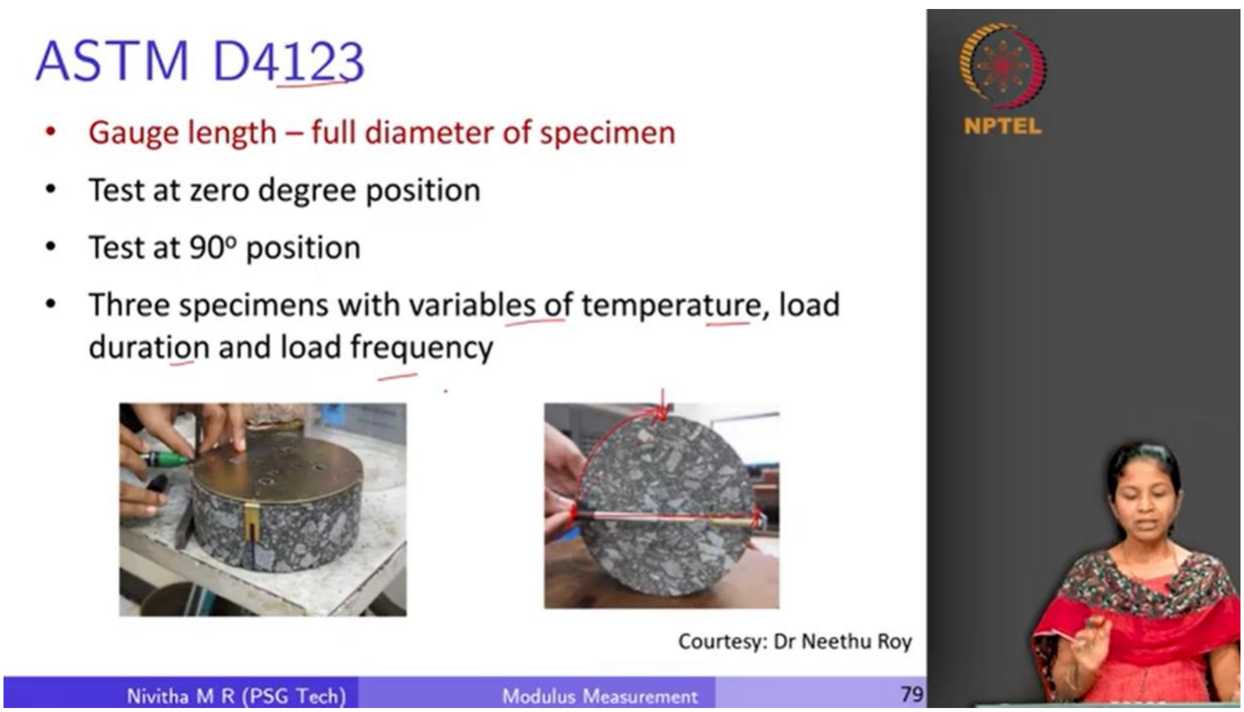

Now where do we measure the deformation? We said we are placing the specimen like this, you can see here, we place the specimen like this and apply the load here on the diameter plane. Now where do I measure the deformation? So, as per this ASTM D4123, we are supposed to measure the deformation for the full gauge length that is for the full diameter of the sample. So, this is the length over which we are supposed to measure the deformation. First, we measure the deformation like this in this position and then this is called as the 0° position, then we rotate the sample. Let us take this is the 0° position and let us take one point here. I rotate the sample such that this point now is here. I rotate the sample by 90°, and then I measure the deformation again. Do the same test again on the rotated position and then we measure the deformation. We are supposed to test 3 specimens just to ensure the repeatability. So, these 3 specimens could be with also with variables of temperature or different load duration or even different loading frequency. So, these are the measurements that we are supposed to take. We know the load that we are supposed to apply for 50 to 200 cycles, load pulse of 0.1 second and recovery period of 0.9 seconds. We keep applying the maximum load of 10 to 50% of the tensile strength. Now we are measuring that in 2 positions, one is a 0° position, then I rotate it by 90° and then I test it in the second position also. These are the experimental parts that we have to carry out on the sample.

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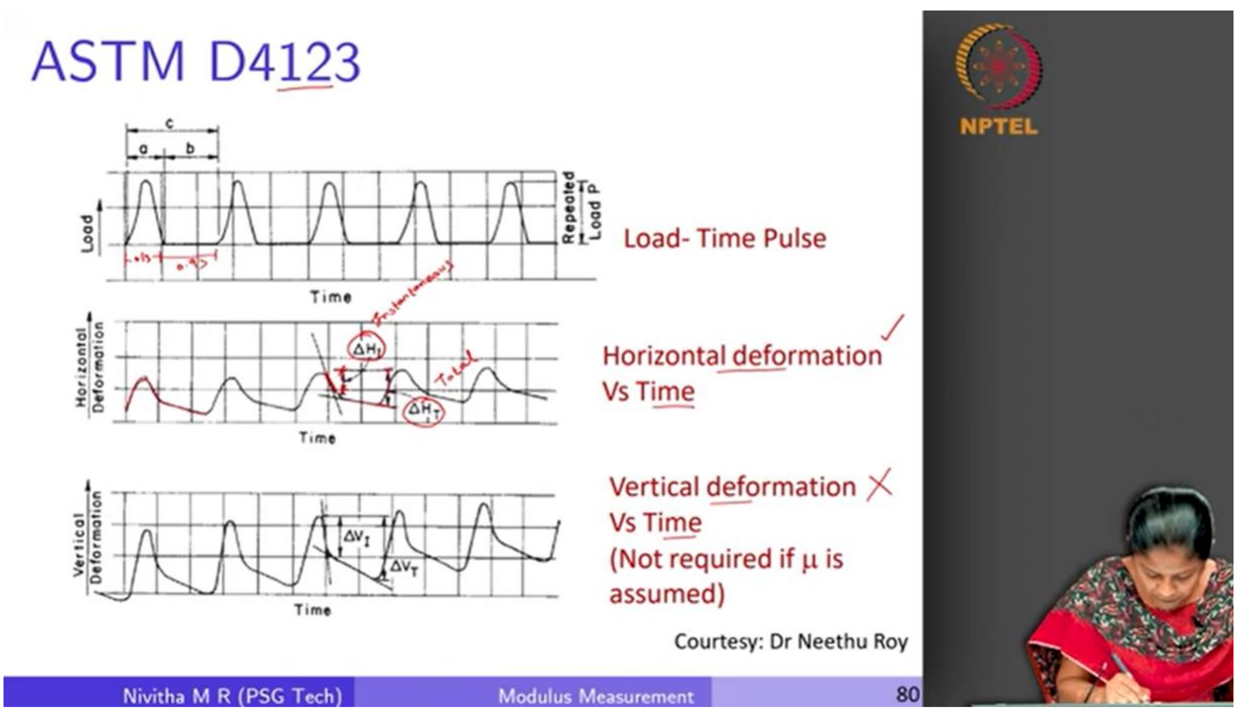

We have already seen that the load pulse is a haversine load, the loading period is 0.1 seconds and the recovery 0.9 seconds in our case. And then we also measure the horizontal deformation. If this is the load pulse like this, the corresponding deformation pulse is like this. You can see that it reaches a maximum slightly after the maximum load is reached and then it starts to recover. This is during the unloading portion and this much is the recovery during the rest period. So, the second plot is horizontal deformation versus time and the third plot is vertical deformation versus time.

Again you should note that if you do not want to compute Poisson's ratio, you do not have to measure this. But this particular standard has provisions to measure both horizontal and vertical deformation and compute Poisson's ratio if it is required. But as per the suggestion given in IRC 37, you do not have to measure the vertical deformation and you do not have to compute Poisson's ratio. So, for a moment let us forget about this vertical deformation.

Consider only the horizontal deformation. Now there are two parameters specified here, which are the instantaneous deformation and the total deformation. We need both these parameters to compute the resilient modulus. What is this instantaneous deformation? Once I remove the load, there is an instantaneous deformation that happens in a moment, how much it is able to recover the strain. So, that is my instantaneous deformation. We compute that and indicate that as ΔH_i. How do we compute that? Once the load is removed, we take this initial portion of recovery and draw a tangent to it. This is our instantaneous deformation ΔH_i, you can see from this picture, there is a tangent drawn to this portion and from the maximum load, how much it is able to recover here, this is the instantaneous deformation. Similarly, there is also the resilient deformation here, which is nothing but after the rest period is over, how much of a strain it is able to recover. So, this is indicated as the resilient deformation or the deformation that the material is able to recover completely. Using these two parameters, we will be computing the resilient modulus.

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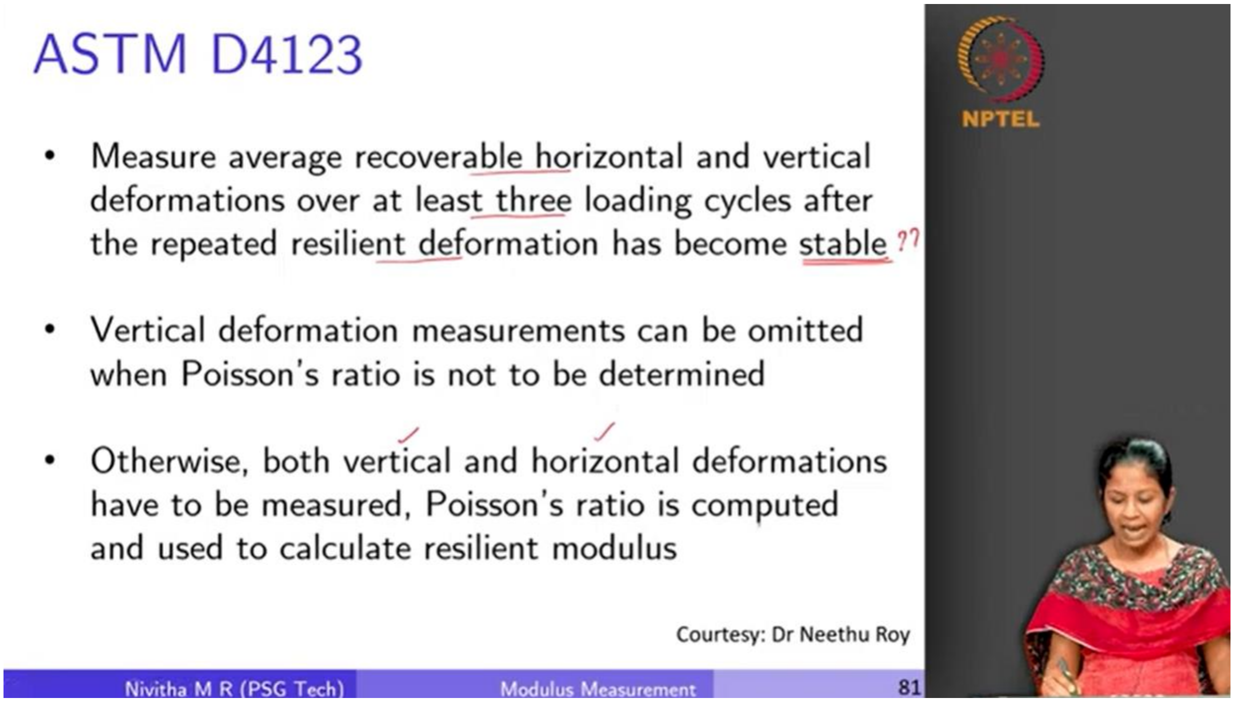

Now we are supposed to measure the average recoverable horizontal and vertical deformation over at least 3 loading cycles after the repeated resilient deformation has become stable. Now, when does it reach this stable state, it is a cause of concern as I had mentioned to you earlier. Vertical deformation measurements can be omitted if Poisson's ratio is not to be determined. But this codal provision like I said earlier has provisions to measure both vertical and horizontal deformations and if required, Poisson's ratio can be computed.

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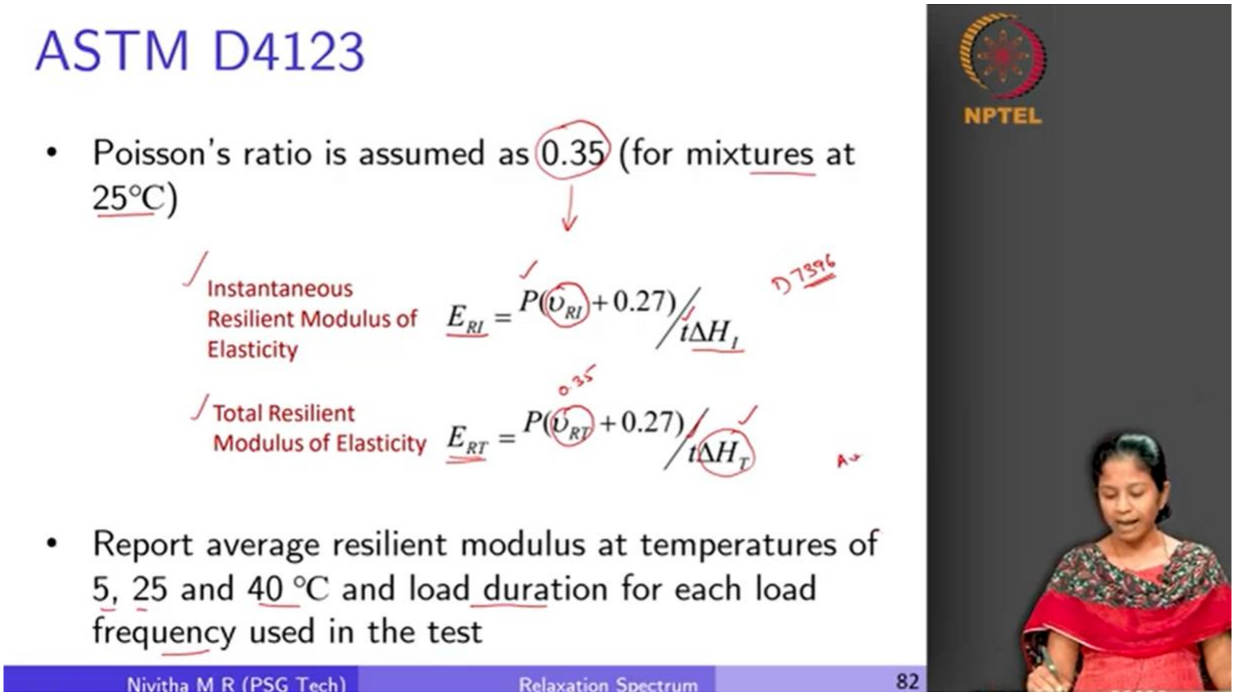

If you do not want to measure Poisson's ratio and assume as suggested in IRC 37, you can assume a Poisson's ratio of 0.35 for bituminous mixtures at 25°C. Using this Poisson's ratio, let us see how to compute the resilient modulus. There are two resilient modulus values that we would be computing. One is an instantaneous resilient modulus and the other one is total resilient modulus. So, we said instantaneous is once we remove the load, how much it is able to recover quickly. So, for that portion, we will compute a resilient modulus and we will compute another modulus parameter for the total resilient deformation after the completion of the rest period. So, the instantaneous resilient modulus (E_{RI}) is calculated as a function of P which is the maximum load applied. ν_{RI} is the instantaneous Poisson's ratio that we have to use. If we have computed we can use that value, otherwise we can use this assumed value of 0.35. Depending upon the diameter, we have different thickness; we have either 50 mm or 75 mm. t is the thickness of the sample and this ΔH_I is the instantaneous deformation that we have computed as shown here. So, these are the parameters that we have to use in this equation. If you look at the updated version, which is D7396, clear procedures are given how to compute this instantaneous and total deformation.

$$E_{RI} = \frac{P(\nu_{RI} + 0.27)}{t\Delta H_I}$$

$$E_{RT} = \frac{P(\nu_{RT} + 0.27)}{t\Delta H_T}$$

The next one is the total resilient modulus of elasticity, a similar formula except that we replace this instantaneous Poisson's ratio with the total Poisson's ratio (ν_{RT}) and then this instantaneous deformation with the total resilient deformation (ΔH_T). The other form of the equation remains the same. For both of these cases, we will be substituting a value of 0.35. So, once we know the thickness of the sample and the instantaneous or the total deformation, we will be able to calculate the resilient modulus. And we have to report the resilient modulus at temperatures of 5, 25 and 40°C and the load duration for each load frequency that is used. If we do 3 trials for a given condition, we have to take an average of all the 3 trials and report that as the resilient modulus value. So, this is regarding the procedure that is given in ASTM D4123.

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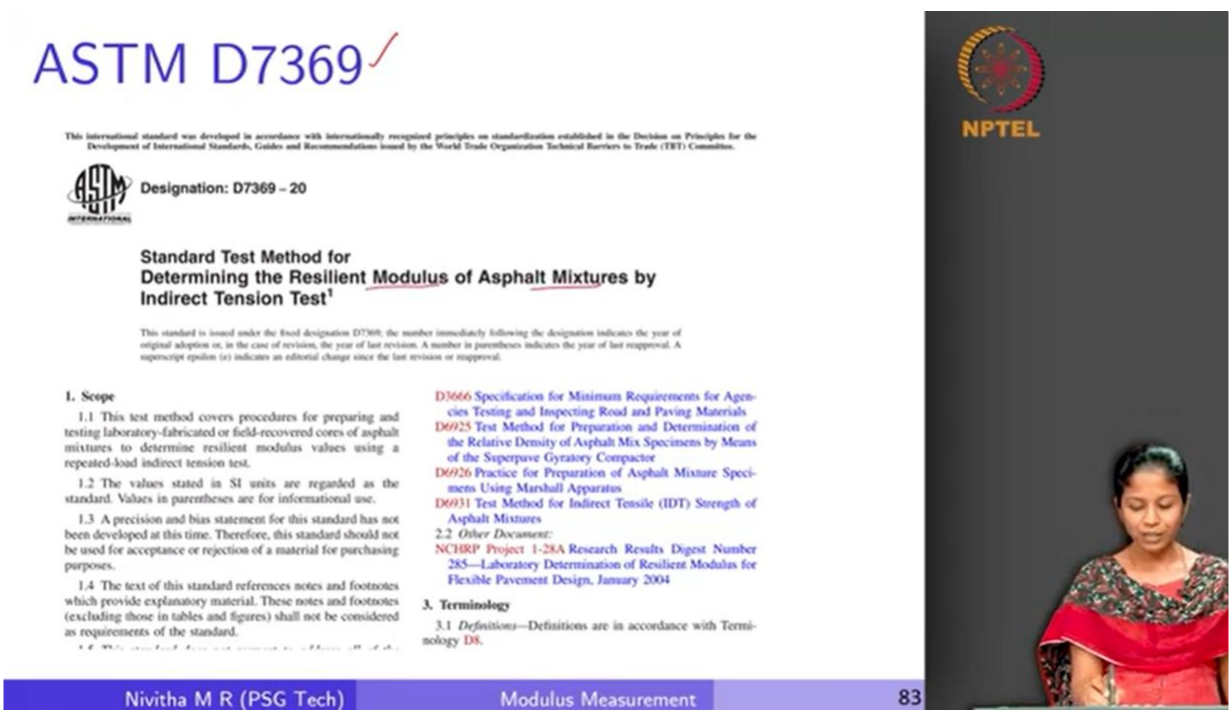

Now we will look into the procedure that is given in ASTM D7369 because this is the standard which is currently available. So, this standard test method is used for determining the resilient modulus of asphalt mixtures by an indirect tension test. It is the same procedure but an updated version with a lot of details and clarity in computation of parameters.

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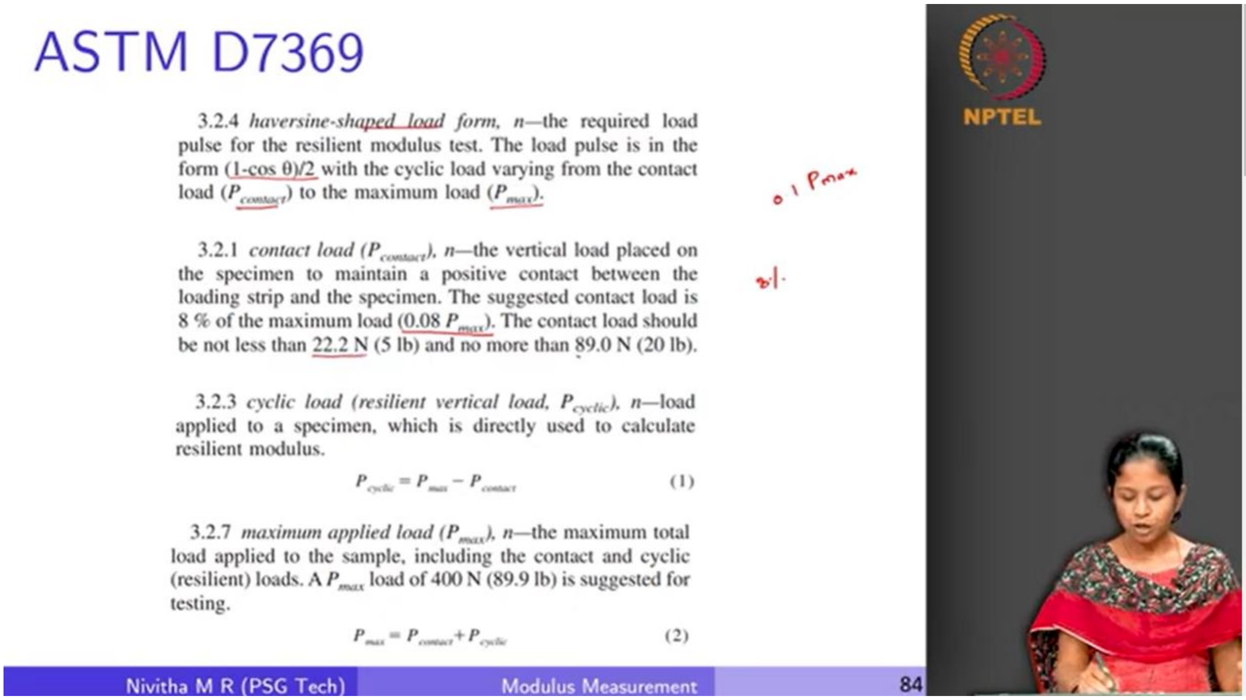

Here, they define the load again. Since we have seen all the definitions earlier, I will quickly go through all these denotions which are used in this particular standard. So, we have a haversine shaped load form of the form (1 - cosθ)/2, we had already seen this earlier and we have 2 loads, one is a contact load and the other one is a maximum load. In the previous case, we had used a contact load which is 0.1 of the maximum load. In this case, we will be using a contact load which is 0.08 of the maximum load. So, it is about 8 percent of the maximum load that will be used and they have also given boundaries for this contact load, it should not be less than 22 Newton and it should not be greater than 89 Newton. And we have a cyclic load (P_{cyclic}) as defined earlier, which is the maximum load (P_{max}) minus the contact load ($P_{contact}$) and the maximum load is defined as the sum of contact and cyclic load.

$$P_{cyclic} = P_{max} - P_{contact}$$

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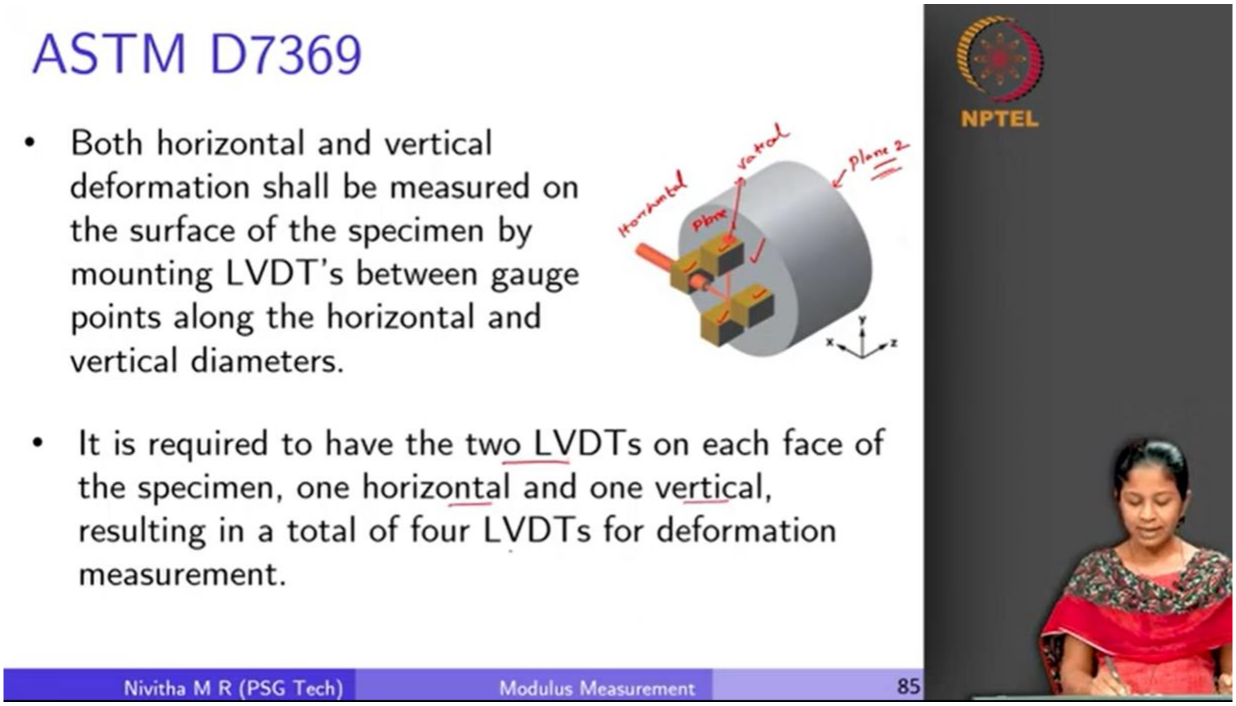

Now we will come into the measurement part. Here we are supposed to measure both horizontal and vertical deformation. It was again the case in ASTM D4123 also, but only the IRC suggestion was we could ignore the vertical deformation and measure the horizontal deformation alone, and assume a Poisson's ratio. Let us assume that we are going to now measure Poisson's ratio and then compute resilient modulus. In that case, how do we go about this test procedure? So, we have LVDTs which are mounted in the horizontal direction and in the vertical direction for a given plane. So, if we take a cylindrical sample, it has two planes.

This is plane 1 and the exact similar one on this side is plane 2. And then we have these gauge points which are fixed onto this particular face of the sample. So, we have 4 gauge points which are fixed on this face of the sample and another 4 gauge points which will be fixed on the opposite side of the sample on plane 2. Now, in these gauge points, we will be fixing the LVDTs. So, in a given plane, we will be having two LVDTs, one in the horizontal direction and the other one in the vertical direction. For a given sample, we will be measuring the horizontal and vertical deformation in the first plane and we will be measuring the horizontal and vertical deformation on the second plane also. So, it is required to have two LVDTs as mentioned on each face of the specimen, one horizontal and one vertical resulting in a total of 4 LVDTs for deformation measurement.

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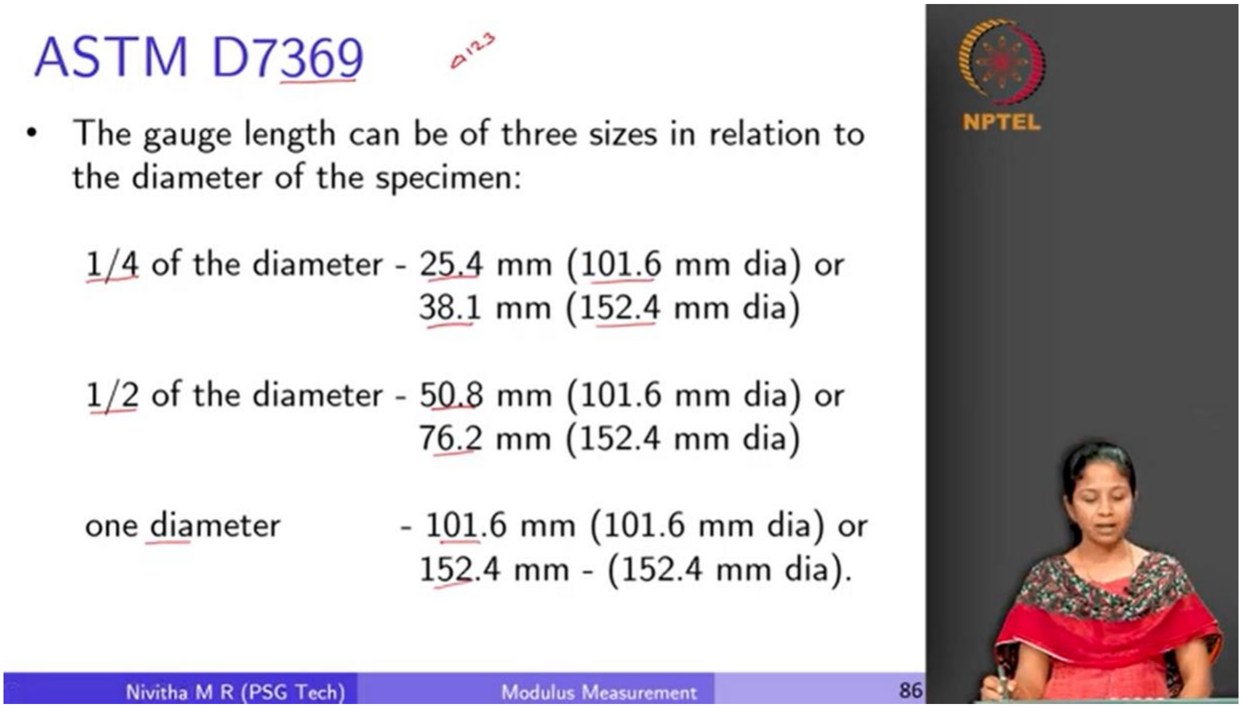

Now, what is the gauge length? In ASTM D4123, we use the full gauge length. We took into account of the full diameter, we measured the deformation over the entire diameter of the specimen. This is the full gauge length. Here we have provisions for 3 different gauge lengths. So, one could be one fourth of the diameter or half of the diameter or the full diameter also. So, if you use a full diameter case for ASTM D7369, the results would be comparable to what we get from ASTM D4123. But we have options. So, it could be 25.4 mm for 101.6 diameter sample or 38.1 for 150 mm diameter sample and half we can see 50.8 and 76.2 are the full diameter. So, we can choose the gauge length that we have to use for measurement of this resilient modulus.

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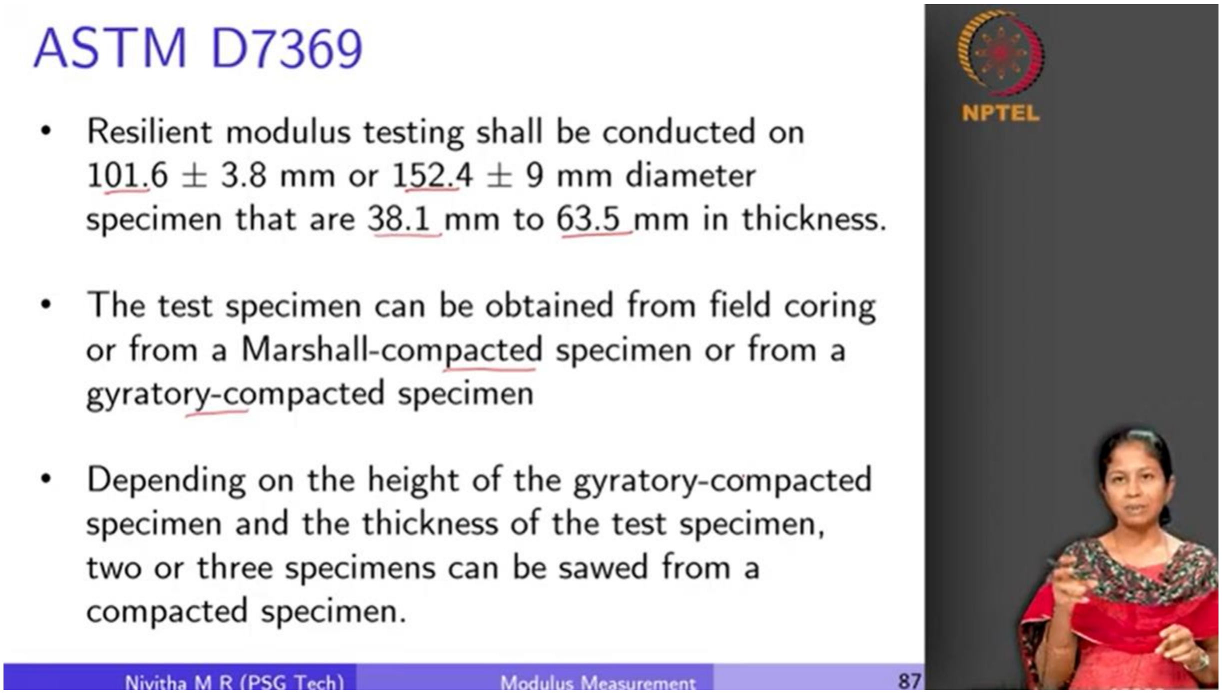

Now, we have similar sample sizes of 101 mm and 152 mm and the thickness of the sample is 38 mm and 63.5 mm depending upon the diameter of the sample, we have different thicknesses in both the cases. And the test specimen can be obtained from field coring, or it could be a Marshall compacted specimen or it could be a gyratory compacted specimen. Depending upon the height of the gyratory compacted, if you have one particular sample which is prepared, we can take two specimens from it for testing.

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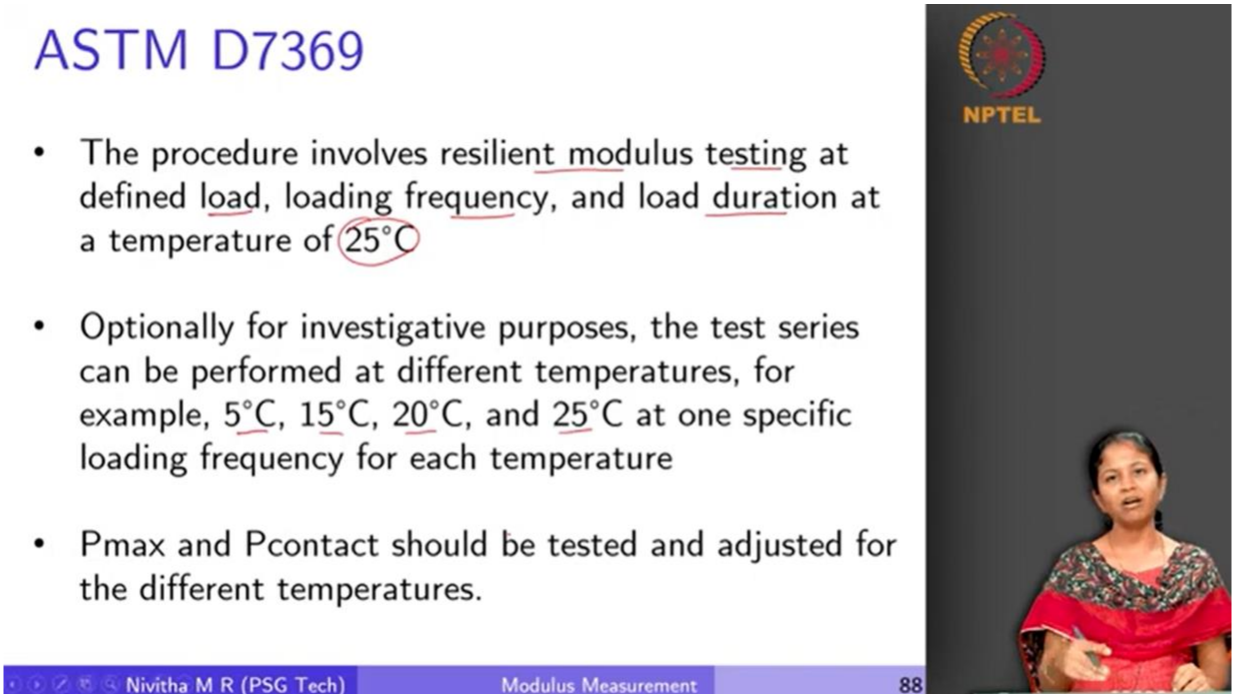

So, that is regarding the sample preparation. This procedure involves resilient modulus testing for a defined load, for defined loading frequency and load duration at a temperature of 25°C. As a standard, it is specified to measure the resilient modulus at 25°C, but if needed we can do the same procedure for other test temperatures also. So, optionally for investigative purpose it can be performed at other temperatures and some indicative temperatures are 5, 15, 20, 25°C and so on. And again it could be done at one specific loading frequency or different loading frequencies for a given temperature. For each case, the P_{max} and $P_{contact}$ value should be tested and adjusted. So, that is the only thing that we have to do when we vary the test conditions from this particular standard condition.

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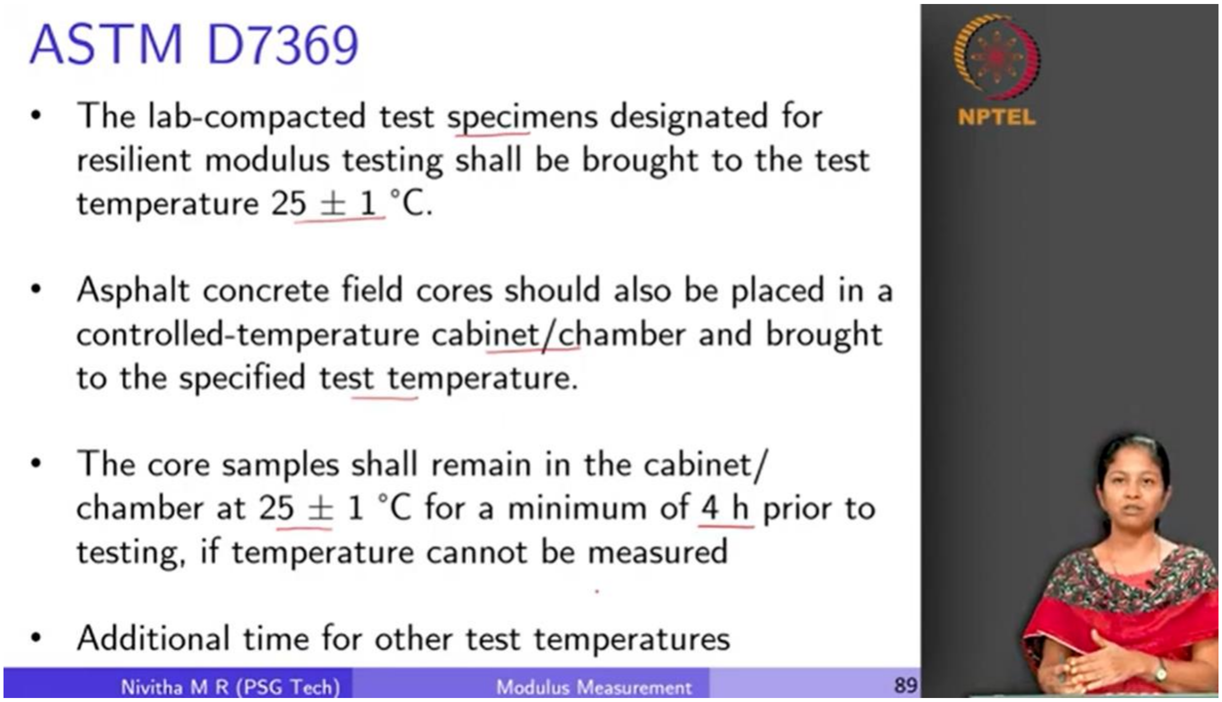

So, the lab compacted test specimen shall be brought to this test temperature. Again test temperature control is very important. We did not have the necessity of temperature control when we were testing granular materials, but this is a very sensitive parameter when we are testing the bituminous mixtures. So, the cores have to be placed in a temperature controlled cabinet or chamber and brought to the test temperature. If we can measure the test temperature we can measure it once the entire sample reaches the test temperature we can use it for testing. If there is no provision to measure the test temperature, it is suggested to keep the sample at 25°C for a minimum period of 4 hours before the testing is carried out. This is for a test temperature of 25°C which is more close to the ambient conditions. If we have test temperatures which deviate from it let us say 40°C or 5°C, which are quite different from this temperature we have to keep it for additional time.

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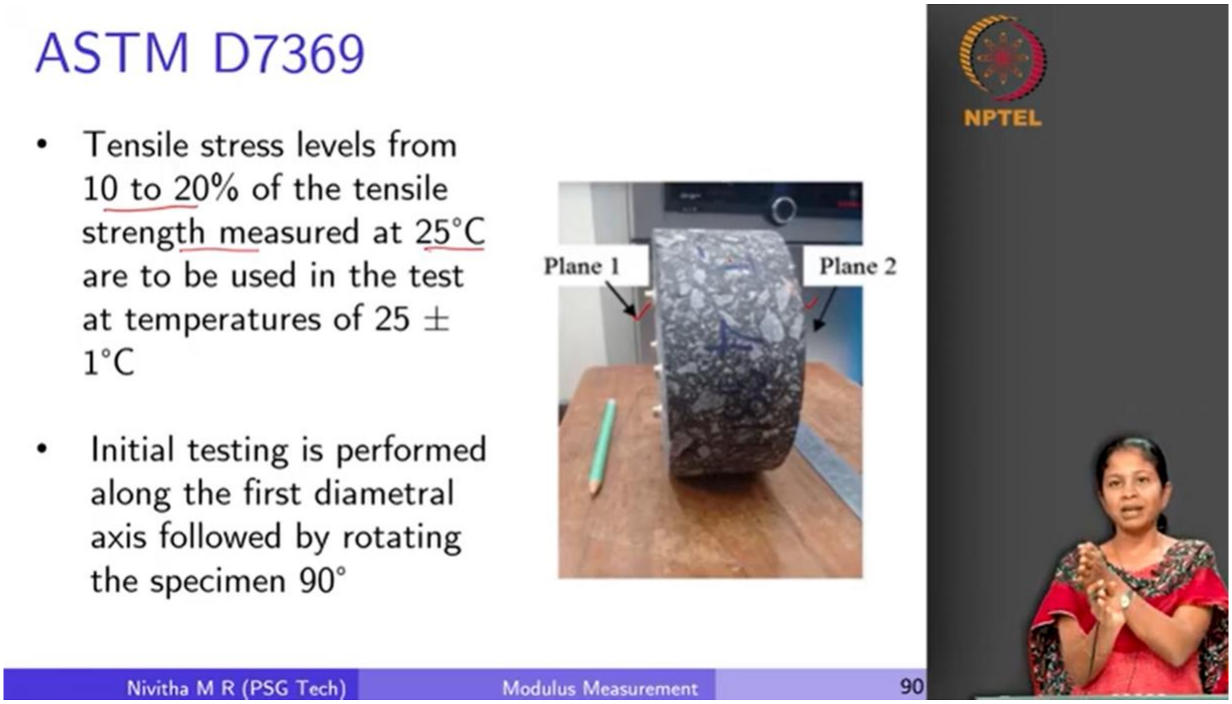

Now the tensile stress levels that are suggested to be used here are 10 to 20% of the tensile strength which is measured at 25°C. So, we do an indirect tension test to measure the tensile strength of the specimen at 25°C and then use 10 to 20% of this value for testing. You can see that as I told here, we have this plane 1, the opposite side plane 2 and we have fixed these gauge points and then we will be mounting the LVDTs on this. The initial testing is performed along the first diameter axis followed by a 90° rotation and then we repeat the same test. Now if you think how many measurements we are going to make on this sample in total, we said we have 2 planes for a given position let us take the 0° position, we have 2 planes. So, we will be measuring the horizontal deformation and vertical deformation on the plane 1. And the horizontal deformation and vertical deformation on plane 2. So, we already have 2 horizontal and 2 vertical deformations. Now we rotate the sample by 90°.

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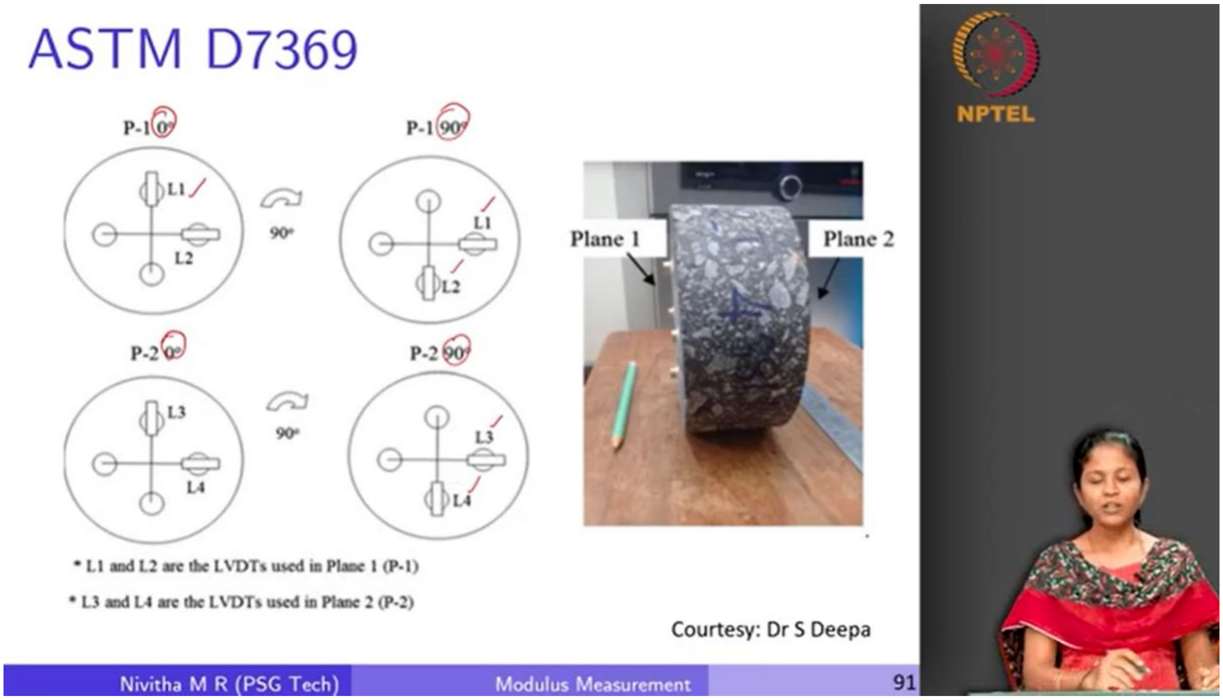

We have L1 and L2, 2 LVDTs in plane 1. Plane 1 is nothing but one face of the sample and plane 2 is the second face of the sample. So, in plane 1 and plane 2 this is in 0° position in plane 1 and plane 2. We have 2 LVDTs, L1 and L2 on plane 1 this is vertical and horizontal again in plane 2 we have 2 LVDTs, L3 and L4 right. Now we rotate the sample so we have the 90° rotated position where we again have 2 planes. So, we have L1 and L2, L3 and L4. We measure the horizontal deformation using L1 and vertical deformation using L2 in this position now. Similarly, horizontal and vertical deformations are measured using L3 and L4. So, these are the measurements that we will be making on this sample.

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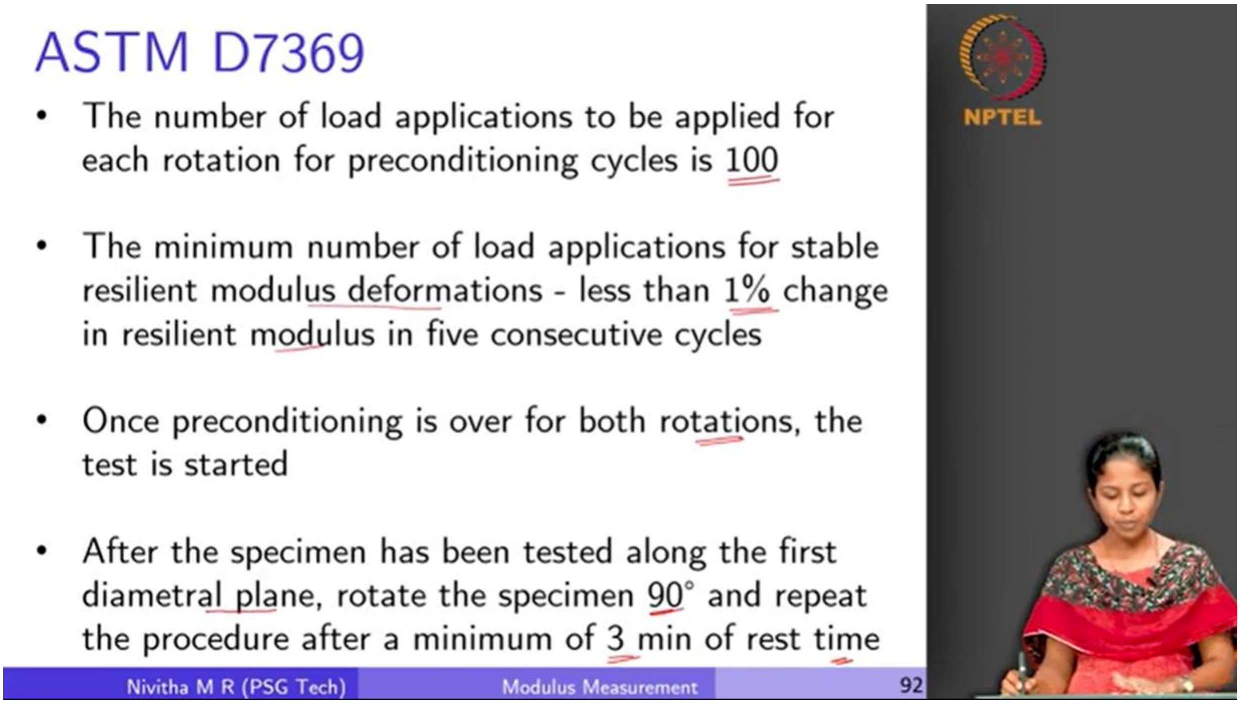

What is the number of load application that has to be provided on the sample? The number of load application that has to be provided is 100. Now let us come to the loading part. What is the load application that has to be provided on this sample? Again we have a preconditioning phase here. In each position of 0° position and 90°, we are supposed to apply 100 cycles. So, the number of load application is going to be 100 cycles for each position. This minimum number of load application is necessary for stable resilient modulus deformation. What do we mean by a stable resilient modulus state? There should be less than 1 percent change in resilient modulus for 5 consecutive cycles. Then we call that state to be a stable resilient state. We get that we are able to quantify that easily for granular materials. We say that between 100 and 200 cycles or close to that we will be able to get that kind of a resilient state.

So now identifying that state is going to be a challenge for bitumen. So, we identify this condition when it reaches the resilient state and then we use the values for calculations. So, once this preconditioning is over for both the rotations, we reach a resilient state wherein the variation in resilient modulus is less than 1% for 5 consecutive cycles. So, once we reach that resilient state we start the actual testing. After the specimen has been tested along the first diametral plane we rotate the sample by 90°.

We repeat the procedure with a minimum of 3 minutes rest period between the 2 positions. Once we finish the test in 0° position, rotate it by 90° wait for 3 minutes, and then start the test in the new 90° position. This is the test procedure again we are going to take the values of only 5 cycles after the preconditioning is over for calculation purposes. So, let me stop this lecture here. We will look into the analysis part that is the calculation part of resilient modulus and the dynamic modulus measurement in the next lecture. Thank you.