Mechanical Characterization of Bituminous Materials
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Lecture - 43
Resilient Modulus of Bituminous Mixtures - Part 2

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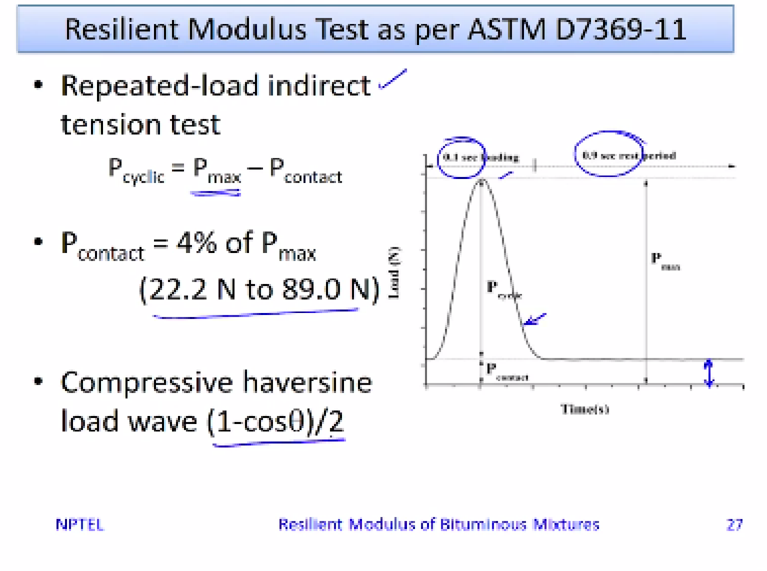

Here also the test procedure is the same wherein the test cycle is the same, wherein you apply a repeated load indirect tension test, but the load duration and the frequency is fixed. It is mentioned that you should apply the load for 0.1 second and the rest period is given as 0.9 seconds. So your total cycle length becomes 1 second or it is a 1 Hz frequency cycles.

And then you have a total load which is P max and there should be always certain contact load given. Say for example, 4% of the total. So this is your total load. 4% of the total load is given as contact load so that your specimen and the loading strip will not lose contact. So but also this is mentioned that this should not exceed 89 Newton.

So there should be at least 22.2 Newton of contact load and also it should not exceed 89 Newton as what is suggested. And the compressive haversine load that is that you apply is of the form of (1–cos θ)/2.

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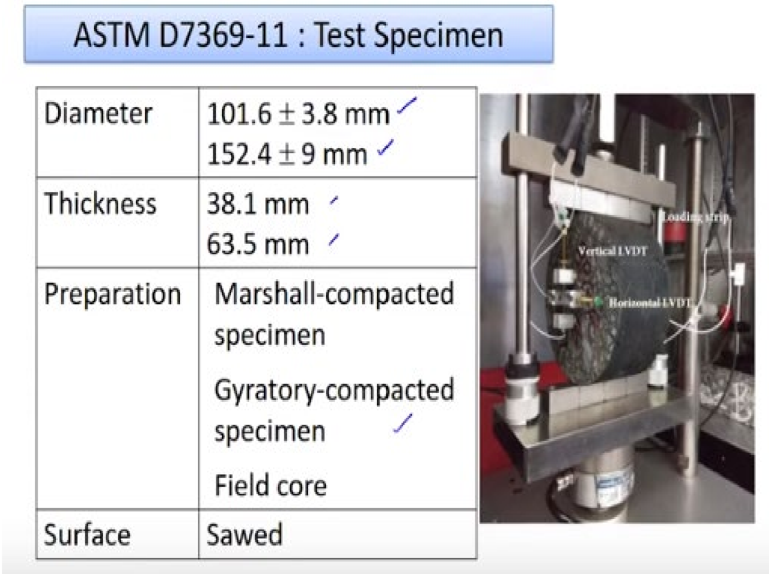

ASTM D7369-11 : Test Specimen

Diameter	101.6 ± 3.8 mm 152.4 ± 9 mm
Thickness	38.1 mm 63.5 mm
Preparation	Marshall-compacted specimen Gyratory-compacted specimen Field core
Surface	Sawed

The specimen dimensions are like this. You have a diameter of 101.6 or you can go for a larger diameter of 152.4 with thickness of 38.1 or 63.5. The specimen can be cast either using a Marshall compaction or you can go for a Gyratory compactor or field core samples can also be tested. Only thing is that you should have a sufficiently neat sawed surface.

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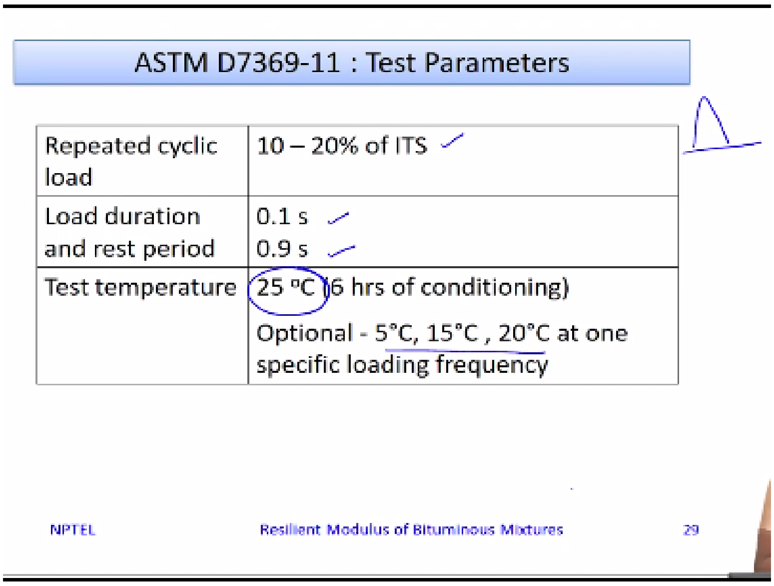

ASTM D7369-11 : Test Parameters

Repeated cyclic load	10 – 20% of ITS
Load duration and rest period	0.1 s 0.9 s
Test temperature	25 °C (6 hrs of conditioning) Optional - 5°C, 15°C , 20°C at one specific loading frequency

The load that is to be applied is 10 to 20 percentage of ITS. So this is different from the previous version. There was, it was 10 to 50 percentage of ITS. Now here the load that you have to apply that is the P max okay. The P max has to be 10 to 20 percentage of the indirect tensile strength value. And the load duration as I said is 0.1 second loading and 0.9 seconds of rest period. And the test temperature is specified as 25 degrees Celsius.

It is suggested that you can do it for other temperatures as well say 5 degree, 15 and 20. And at every temperature you can do it at one particular frequency, say 1 Hz frequency. And your specimen has to be conditioned. At least 6 hours of conditioning is required so that your entire specimen is at the test temperature.

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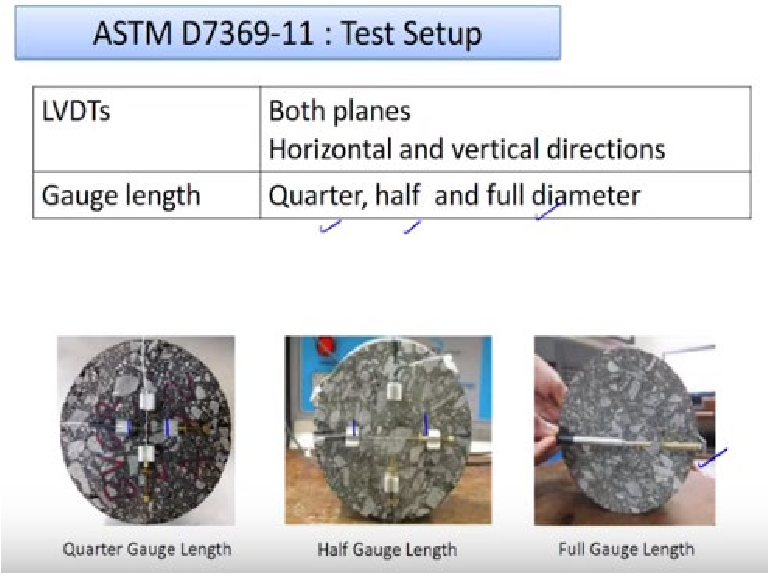

Now another improvement that is made in the new ASTM standard is, where to fix this LVDTs. In the earlier version, the LVDTs were fixed only on one face or you can say that one plane okay. If you have right plane and left plane, it was only fixed either on the right or the left.

So it could include some amount of repeatability issues because as you cast a specimen and you keep it like this, some may keep, place the LVDTs on the top surface of the specimen and some may keep it on the bottom surface of the specimen. As I said it can be on the right side or it can be on the left side. So in order to avoid that issue here it is suggested that you have to place LVDTs on both the planes, on the right as well as on the left.

And regarding the gauge length. As I earlier mentioned, this total diameter as the gauge length could be a problem. So here it is suggested to have three different gauge lengths. One is a quarter gauge length, half gauge length and full diameter okay. As you can see here, in this case here LVDT is connected for the full length of the specimen or the full diameter. Whereas here it is connected for the middle half portion, whereas here it is connected at the middle quarter portion, okay. So these three gauge lengths can be suitably chosen. And accordingly you can find; either any one of these you can adopt.

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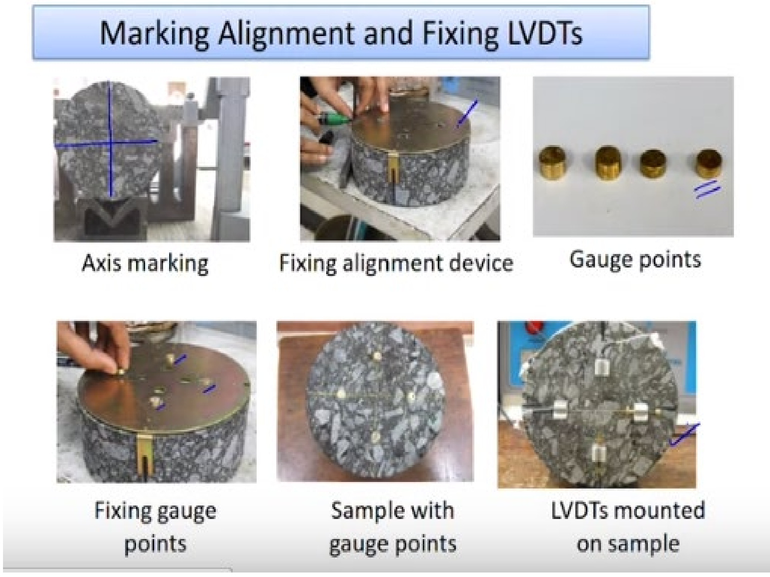

So this is how the specimen is aligned and how the LVDTs are connected. You have to first of all mark the axis as shown here. You have a groove where you can keep it horizontally and then the markings can be done. And then there is a fixing, an alignment device, so that alignment device can be properly fixed on top wherein these gauge points can be fixed.

So you see here, these are the gauge points being fixed through the alignment device and they are glued into the surface and hence, in these gauge points, you can connect the LVDT. So this last figure shows the LVDTs connected in both the horizontal and vertical direction. And in this code, it is very clearly specified that you have to collect information both in the horizontal as well as in the vertical direction.

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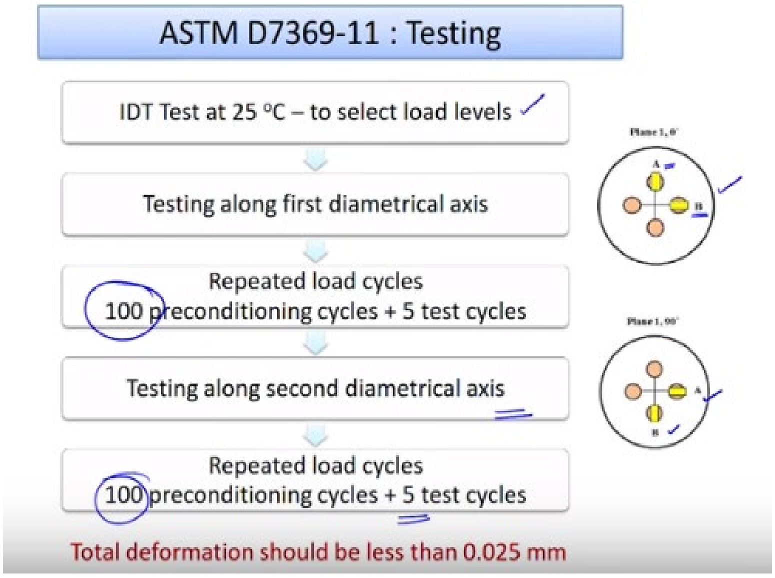

So this is the test procedure. First of all, you have to conduct the IDT, indirect tensile strength test on a similar specimen at 25 degrees Celsius and find out what is the indirect tensile strength and 10 to 20 percentage of that will be taken for the testing as mentioned. So you select the load here, then you place the LVDTs and this testing will be first done in the, along the first diametral axis.

Say for example, this is on plane 1, this is the zero-degree arrangement. Say for example, your B is in this direction and your LVDT A is here in the vertical direction. Now do the preconditioning cycles as mentioned here as 100 preconditioning cycles. And after 100 preconditioning the next 5 cycles will be taken as test cycles. So you capture the information during those 5 test cycles.

Then you rotate it at 90 degrees. So what happens is that A and B get shifted by 90 degrees. So you turn it 90 degrees, keep the specimen and then again repeat the procedure of 100 preconditioning cycles and 5 test cycles. So you have 5 test cycles in one plane in one arrangement of zero degree and you have 5 test cycles in the second arrangement of 90 degrees.

This is the data that is collected from plane one that is a right side plane. Similarly, you have LVDTs on the left plane so that is plane two. You will have 5 cycles of data when it is placed in the zero-degree arrangement and you will have another 5 sets of data and it is placed in the 90-degree arrangement.

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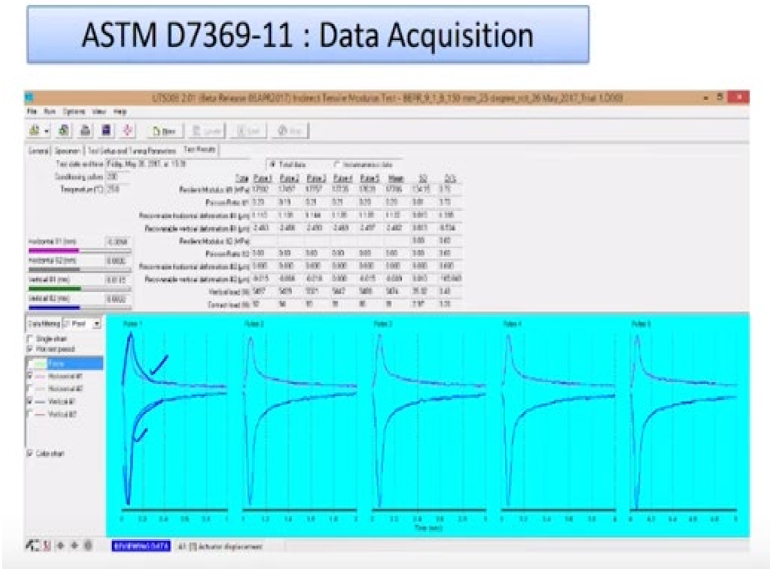

So this is a typical screenshot of how this, well, the data is being collected. You can see here that this pink line shows the horizontal deformations collected through the horizontal LVDT. And this blue line indicates the vertical deformation which is collected using the vertical LVDT.

And similarly in here this is shown in the downward direction. You can see the peak value and the recovery that is happening.

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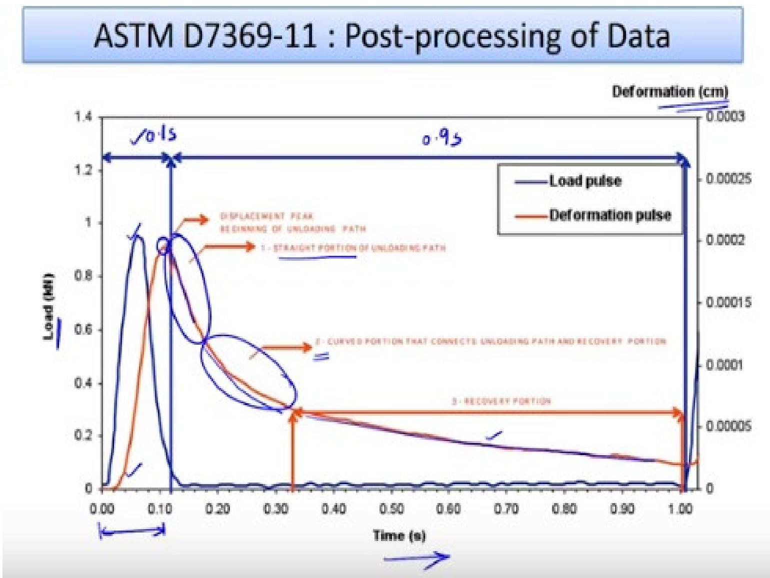

Now let us see how this is post processed to arrive at the resilient modulus and the Poisson's ratio okay. So as you can see here, this blue line indicates your load pulse and the orange line indicates the corresponding deformations. So this is load marked here on this y axis and this is deformation marked here on the right y axis and this is time on the x axis.

So as the load is applied for 0.1 second duration, this is the load duration of 0.1 seconds and there is a rest period of 0.9 seconds, you can see that the strain reached a peak value and after that your load unloading starts and then there is a rest period. So during this period there is a recovery of the deformation.

So recovery initially there will be a sudden recovery which will follow somewhat like a straight line path as here. Thereafter, you see that there is a curved portion and then it comes down like this. So essentially you can fit three different curves for this portion of recovery.

Say for example, in this first region, you can fit a straight line curve or a straight line and this is one region which is actually connecting the unloading path and the rest period path. So you have a recovery during the unloading of the load and a recovery happening during the rest period. So a curve connecting these two portions is shown here, this is the second portion.

And the third portion is ofcourse your recovery portion. So you can consider three different curves for all these three portions.

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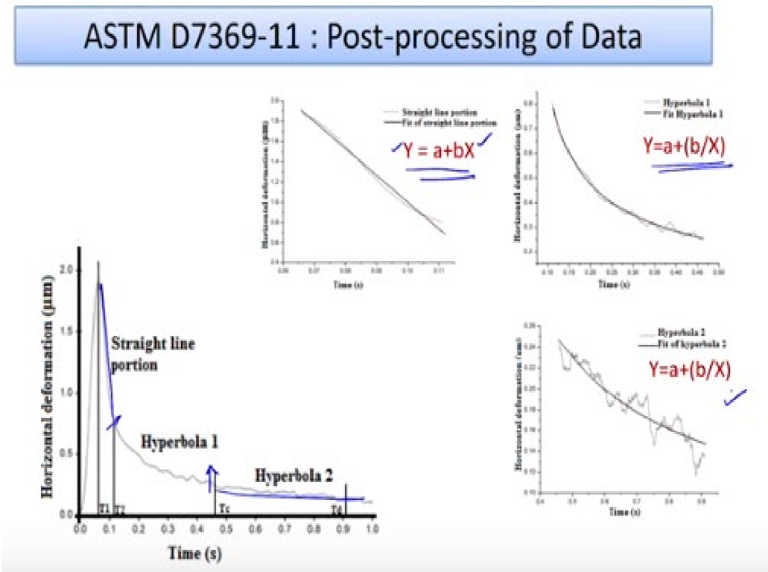

So you fit a straight line for the first portion. As I said this straight line portion in the recovery will be considered. And you fit a straight line equation as Y = a+bX, where Y is the deformation and X is the time and a and b are the regression coefficients, okay. And for the second region, from here to here, you can fit a hyperbola of the form Y = a + (b/X), again a and b are the regression coefficients.

And during the last portion also you can fit another hyperbola Y = a + (b/X). Now this whole procedure is done to identify the two variables, which is one is your instantaneous recovery and the second one is your total recovery. So you essentially want to find out what are these two recoveries and based on which you are going to find out what is the resilient modulus and the Poisson's ratio okay. So this is how you split the curve into three.

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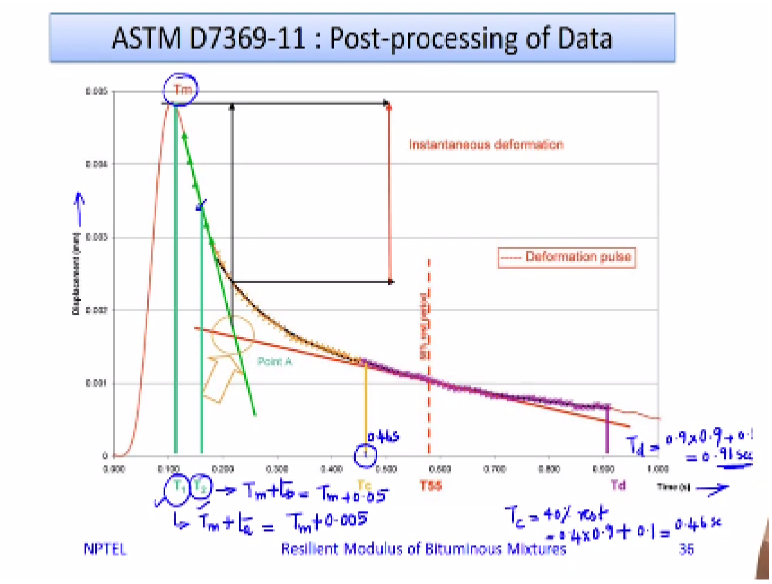

So let us see how this instantaneous deformation is identified. So first of all you have to get that straight line potion as I mentioned. Now from where to where is this straight line portion? So that is identified like this. Let T_m is the maximum displacement or deformation. So here it is written as displacement and this is the time in the x axis. So this is one pulse of your deformation that is plotted here.

So as you can see, slightly after the maximum load pulse your or whenever the load is unloaded, it starts recovery okay. So that straight line starts just after your top point or your maximum point is reached. So let the maximum deformation is marked as T_m

and the time corresponding to them that is marked as T_m. So the first point of start of the straight line is marked as T 1 as a sum of $T_m + t_a$.

Now t_a is a small time that is provided so that to ensure that the straight line portion has just started from that maximum point. So that is given as 0.005 seconds. So the first point which is the start of the straight line is T_m + 0.005 seconds, where T_m corresponds to the time of the maximum deformation. Then the last point here is noted as T_2, that is when the unloading is over, where the rest period starts.

So T_2 you can denote as $T_m + t_b$, where T_m is as I said when the maximum is reached and t_b is a half of your load pulse. So your load pulse is for 0.1 seconds so half of it is 0.05 second. So this becomes T_m + 0.05 okay. So your straight line is identified as from T_1 to T_2 which is as defined like this. Now the second portion is from T_2 to T_c. You will mark it as the point marked as T_c. That is a hyperbolic portion.

So that portion is identified as when 40% of the rest period is taken as that point when your hyperbola reaches somewhat as a somewhat a coinciding point. So in order to identify point T_c, as I mentioned, T_c is at 40% of the rest period. So you can mark it as 0.4 times of 0.9 is your rest period plus your initial loading time which is 0.1. So this comes to around 0.46 seconds. So 0.46 seconds in this noted here will mark your end of the secondary stage or the second hyperbola. Now coming to the third hyperbola you can consider a distance from T_c which is your 40% of the rest period to around 90% of the rest period. So when it reaches almost the 90% of the rest period you can assume that it has reached a steady state.

So the last point T_d is marked as 0.9 of your rest period which is your 0.9 seconds is your rest period plus the initial 0.1 seconds so it comes to around 0.91 seconds. So the tertiary is or the third stage of hyperbola is from a time of 0.46 seconds to a time of 0.91 seconds.

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ASTM D7369-11 : Post-processing of Data

TABLE 3 Time Recommendation for Resilient Displacement

NCHRP Research Results Digest January 2004, No. 285 Project 1-28A recommendations		Considering a load pulse of 0.1 s and a rest time of 0.9 s, the total cycle time for curve estimative are	
t_c	40% rest period	t_c	0.46 s
t_d	90% rest period	t_d	0.91 s
t_{55}	55% rest period	t_{55}	0.595 s
t_e	85% rest period	t_e	0.865 s
t_f	95% rest period	t_f	0.955 s
T_1	Tm + Ta	t_a	0.005
T_2	Tm + Tb	t_b	½ $t_{load\ pulse}$ (when $t_{load\ pulse}$ equal to 0.1 s, t_b = 0.05)

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So this is provided here. These are the recommendations that are given by NCHRP. So as you can see here, this is t_a and t_b is noted here and also this 40% rest period time and the 90% rest period time is noted.

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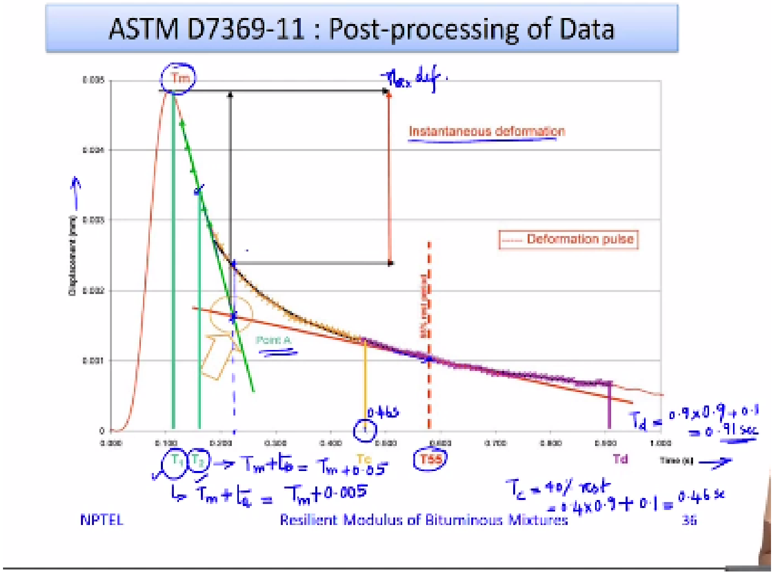

Now in order to determine this instantaneous deformation as I said it is the point when that instantaneous deformation happens before that slow deformation continues. So in order to identify that point, this is the procedure. So first of all you will drop a tangent through that straight line you extend the straight line from the first portion and you drop a tangent from the third portion at a time of T_{55}.

Likewise 55% of your rest time that is 0.9 seconds plus the initial 0.1. So this comes to around 0.595 seconds. So at that 0.595 seconds you draw a tangent. So both these tangents will meet at this point which is marked as A here. This points corresponds to the point of instantaneous recovery. So what you have to draw is that draw a vertical up. So this point where it meets with the recovery or the deformation graph, that point will be taken as the deformation correspond to point A. Now subtract it from the maximum deformation. So you subtract this value from the maximum deformation, which will give you your instantaneous deformation.

I will repeat. You have a straight line dropped, extended and you have a straight line marked from T_{55}. They meet at a point A. You can just drop a vertical down. Note what is the time there and find out what is the deformation at that time. And that deformation subtracted from the maximum deformation will give you actually the instantaneous deformation. So this is how the instantaneous deformation is noted.

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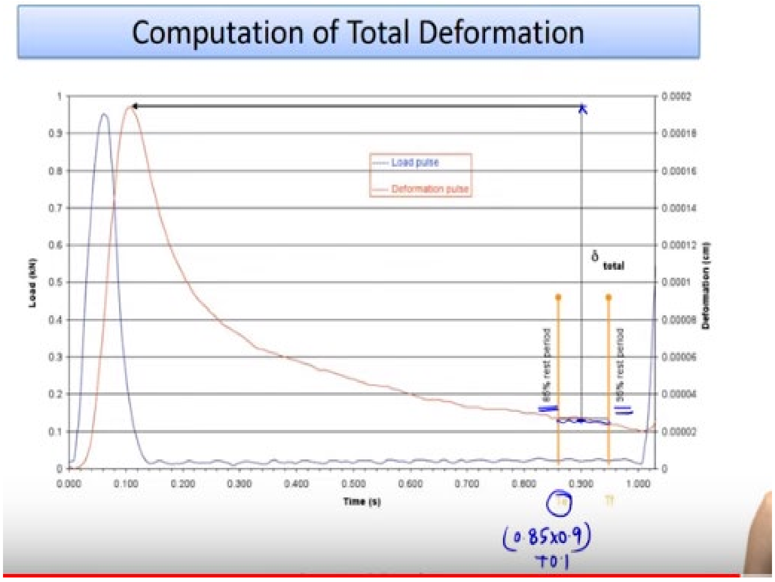

So the total recovery is from the T_{max} that is the maximum deformation and almost when it reaches the complete recovery. So it is expected that somewhere around the end of the test cycle your recovery is over okay. So what is done is that you consider two points towards the end. One is corresponding to the 85% of the rest period and the other one is corresponding to the 95% of the rest period.

So how do you arrive at these points is that you take 85% of rest period which is 0.9 plus your initial time. So this will give you this time of T_e. Similarly, you can take the 95% of rest period time and you find the deformations at these points and take an average. So this will whatever irregularities here will get averaged out. You note that deformation subtract it from the maximum deformation.

So that will give you the total recoverable deformation. So maximum minus whatever deformation is there at the this averaged out point. So that will give you the total recovery. So we have determined what is the instantaneous recovery and also what is the total recovery.

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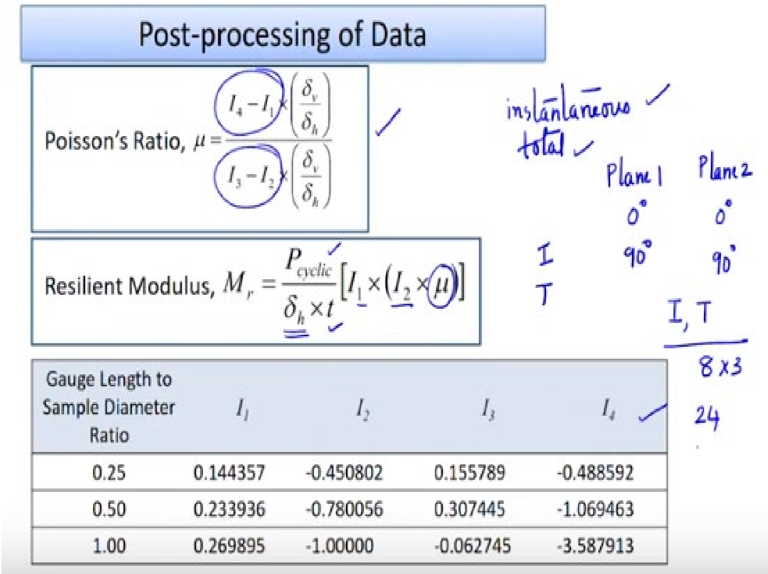

Gauge Length to Sample Diameter Ratio	I_1	I_2	I_3	I_4
0.25	0.144357	-0.450802	0.155789	-0.488592
0.50	0.233936	-0.780056	0.307445	-1.069463
1.00	0.269895	-1.00000	-0.062745	-3.587913

Now we will use this information to find out the Poisson's ratio as well as the resilient modulus. As you can see here the Poisson's ratio is given by this expression δ_v/δ_h and also there are four parameters I_1, I_2, I_3 and I_4, which are given here. This is based on the gauge length to the sample diameter ratio. Say for example, you are doing a full gauge length, quarter gauge length or half gauge length, accordingly these parameters are provided here or the constants are provided here.

You can substitute and δ_v corresponds to the deformation or the recovery that is measured from the vertical LVDT and δ_h is the recovery that is corresponding to the horizontal LVDT. And I said you have two measurements. One is the instantaneous one, okay. And second one is the total recovery. So in this expression if I substitute the instantaneous recovery part, I will get one Poisson's ratio and if I substitute the total recovery value, I will get another Poisson's ratio.

So similarly, you come to the resilient modulus okay. The resilient modulus is given like this P cyclic as I said is the maximum load minus the contact load is your cyclic load that you have applied. T is the thickness of the specimen and the δ_h here is the horizontal recovery. And I_1, I_2 as I said are the constants for the arrangement and μ is the Poisson's ratio that you compute from earlier equation.

So here also if we use instantaneous μ that is the μ that is captured using instantaneous recovery values, we will get one resilient modulus. And if we are using the total recovery value, then we will be getting another resident modulus. So we have two planes, say on the both sides of your specimen, you have plane one and plane two. And in each plane, you have a zero-degree alignment and the 90-degree alignment as I said.

You will keep the two LVDTs like this. In one position, you will test it and then 90 degrees you will turn and test it. So you have two alignments of zero degree and 90 degrees. And at each alignment, we will have an instantaneous value as well as you have a total value, okay. So altogether you are going to get 8 resilient modulus values being measured from one set of data as discussed here.

And we have to have three replicate testing to be done in three specimens. So altogether, you are going to see 24 resilient modulus measurements which is made for one particular specimen okay.

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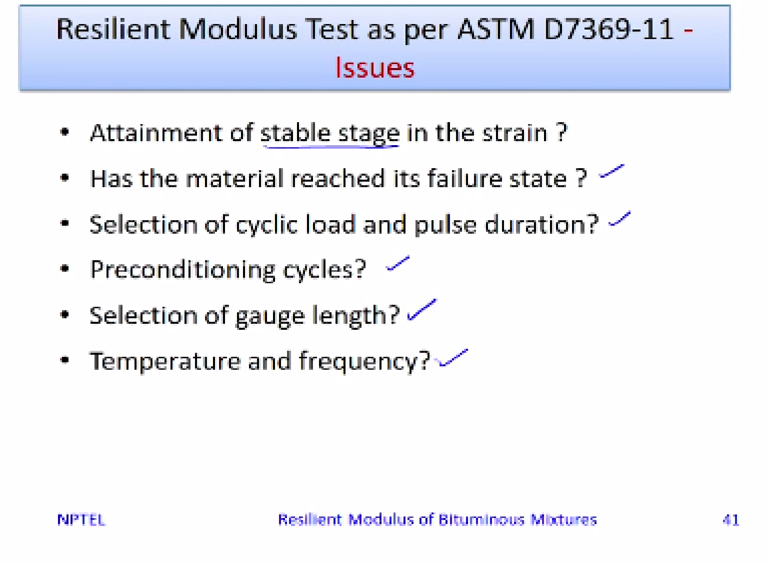

So you can average out this 24 resilient modulus value, so that most of the irregularities associated with the specimen or in the test procedure or in the gauge length fixation may get canceled out and you are supposed to get a reasonably good estimate of the response of the material using this resilient modulus value, okay.

Now again, there are certain issues associated as mentioned here is that the gauge length is mentioned as you can choose either full length or quarter or half gauge length. So which one to choose and how it actually affects the performance is something that they have to be, it has to be investigated.

And second is regarding the conditioning cycles. It is mentioned that hundreds of conditioning cycles is enough for the material to reach that stable state. But it is not clear whether for all that kind of materials and all for every test temperature if I am if you are trying for different temperatures, will this conditioning cycles be enough for that attainment of steady state is second thing.

And the second one is the and the next point is the cyclic load and the pulse duration. As clearly mentioned you should go from 10 to 20% of ITS as the load and pulse duration as 0.1 seconds. It may happen that in a very stiff material this load is not sufficient to create certain amount of deformation that can be measured, especially when you are going for a very small gauge length. Because if you go from a larger gauge length to a smaller gauge length, the deformations are going to be very small. So you may require a larger load to produce certain amount of deformation which can be actually noticed.

And sometimes it may happen that in the larger gauge length for a particular mixture these load itself can create an excessive deformation happening in the material. So whether this choice of one cyclic load and pulse duration for every type of material is also questionable. And another aspect is that within this load range as I mentioned, whether the material will go to a failure stage or it is still in the that elastic stable stage is there or not is another thing.

So as I said the stable state whether this conditioning cycles is enough for the stable state and also you do the test at 25 degrees Celsius though other test temperatures are also suggested. As you see in IRC 37 the test is being conducted from 20, 25 and 30 degrees as well. So it is not clear whether it will be possible for you to conduct that the test at that kind of a temperature especially when you are dealing with materials which are less stiff at that kind of a temperature range.

So these are some of the issues that are to be investigated and fine-tuned if you want to use this method to determine the modulus value of the material. Thank you.