Mechanical Characterization of Bituminous Materials
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Lecture - 46
Laboratory Investigation for Rutting of Bituminous Mixtures - Part 1

Hello everyone, today we are going to discuss the laboratory investigations for rutting of bituminous mixtures.

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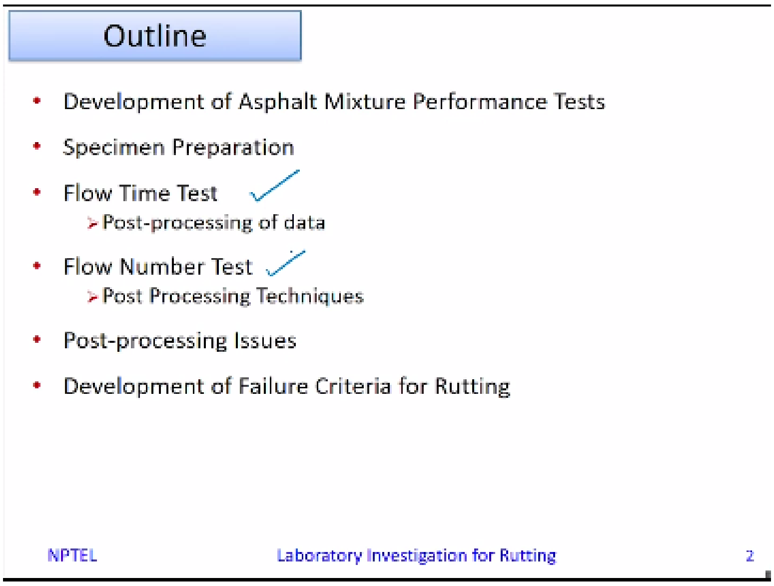

So this is the outline of this lecture. I will give you an outline about the development of asphalt mixture performance test, what is the motivation for that. And then we will be discussing two mixture performance tests such as one is a flow time test and second one is a flow number test. How the specimen is to be prepared for this test? what are the testing protocols? and what are the post processing techniques?

All those will be discussed in this lecture. And also we will see what is the failure criteria as far as rutting is concerned is determined based on these tests.

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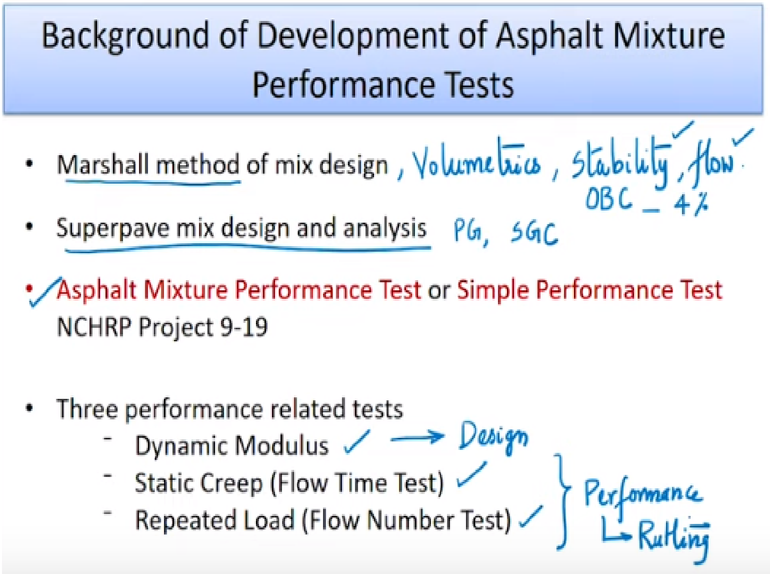

So let me give you an overview of what is the background of development of these asphalt mixture performance test. As we all know we design bituminous mixtures in India and in many other countries, we follow the Marshall method of mix design. The basic concept of Marshall method is that you select the aggregates and the binder for a particular mixture say bituminous concrete or bituminous macadam, and then we look at the volumetrics of these mix.

When I say volumetrics it means the voids in mineral aggregate, voids filled with bitumen, voids in the mixture. All these parameters will be looked into after casting a specimen using the aggregate and the binder with different binder contents with a compactive effort given using the Marshall compactor. Then for the prepared mix, then you see what is its stability and flow.

So these are the two parameters that you will see to determine what is called as the optimum binder content for the mix. So in this case the optimum binder content is decided based on a target air voids say 4% and considering the volumetrics of the mix and also the stability and flow of the mix which is determined using the Marshall apparatus.

But in this case, what is lacking is that the stability and flow are not directly correlated to the strength of the mix or the property of the mix to resist deformation such as rutting, fatigue etc. is not captured using such parameters such as stability and flow. So understanding this and to be used along with a mechanistic empirical pavement design, the superpave method of mix design was developed by the Strategic Highway Research Program.

And in Superpave method of mix design also the volumetric part remains more or less the same. But the main aspect is that the properties of the binder as well as aggregate is linked together in this mix design procedure. You use PG graded binders, and then the compactive effort that is given to the mixture to prepare the specimen is also changed to mimic what is actually happened in the field.

So you cast specimens in the Superpave mix design using the Superpave gyratory compactor wherein a shear compaction is given in the specimen which reflect more or less the kind of compaction that is happening when you lay and compact your bituminous mixture in the field. Based on this analysis, Superpave method, you decide what is the optimum binder content.

But then later when this mechanistic empirical design of pavements was introduced they realized the fact that this method of mix design also lacks any kind of mechanical test that will actually determine the performance of this material in the field. So in order to introduce that factor also or in order to capture the response of the material in the field, this Asphalt Mixture Performance test, or Simple Performance tests were developed as part of the National Cooperative Highway Research program.

So in this program, three different tests were identified or and developed. One is a dynamic modulus test. And the second one is a static creep test, which is called the flow time test. And the third one is a repeated creep test or a repeated creep and recovery test. You call it as a flow number test. The first dynamic modulus test is related to the determination of dynamic modulus for this mixture which will be used in the design of flexible pavements.

Whereas, the other two tests which is the flow time test and the flow number test is related to the performance of the mixture as far as rutting is concerned. So it is related to the rutting performance. So in this lecture we will see what is a flow time test and what is a flow number test.

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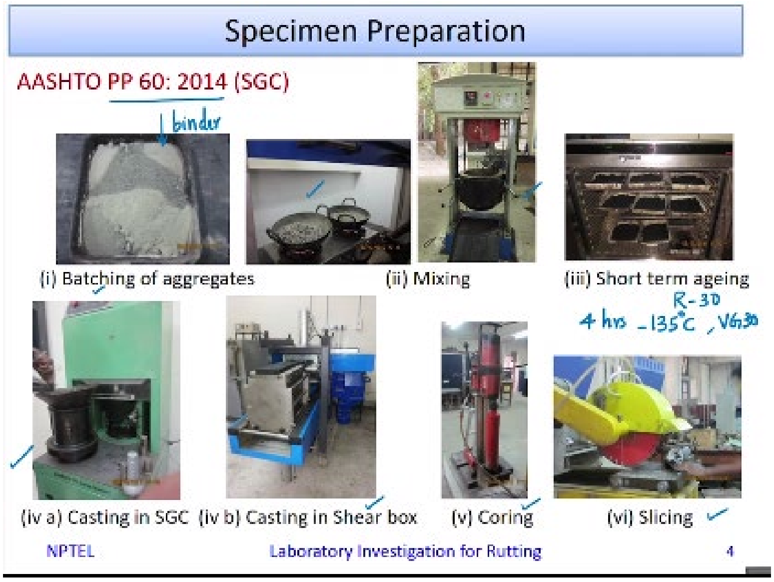

So for both these test, I will discuss how this specimen is prepared. The specimen is a cylindrical specimen of 100 mm diameter and 150 mm height. This is prepared as per the AASHTO protocol AASHTO PP 60. You decide the mix then you batch the aggregate first as per the required gradation.

Then you choose the binder and decide the binder content based on your mix design and then the mixing of the aggregates and the binder can be done either manually or you can do it in a mixer, mechanical mixer. Then you do a short term aging of the prepared mix as per AASHTO standards R-30. This is a conditioning of say 4 hours at 135 degrees Celsius. If you are using an unmodified binder say VG30.

Whereas, if you are using a modified binder for this mix, then you have to choose the conditioning temperature as per the manufacturer's recommendations. So you will keep it in trays at small depths and this will be placed in the oven and condition for at least 4 hours. This ageing of bituminous binder as well as mixtures are discussed in detail in Professor Nivitha in her lecture.

So next is casting of the specimens. Now this mixture will be cast in cylindrical specimens, either in a Superpave gyratory compactor or you can cast as slabs or prisms in a shear box. Then the required specimen will be cored and sliced to get the required dimensions.

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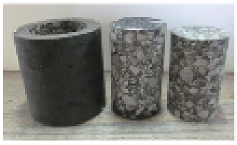
Specimen Preparation

Shear box				
Full beam size (mm)	Vertical stress (kPa)	Shear angle (°)	No. of specimen	Size of cylindrical specimen (mm)
450×150×160	600	4	3	100×150
Superpave Gyratory Compactor				
Full cylinder size (mm)	Vertical stress (kPa)	Angle (°)	No. of specimen	Size of cylindrical specimen (mm)
150×160	600	1.25	1	100×150



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Now the difference is that when you are using a shear box compactor, you can have a specimen of a larger beam size from which you can cut specimens of at least three numbers of the required dimensions. Whereas, in the case of Superpave gyratory compactor, the specimen is cast as a cylinder from which you can core out only one cylinder for your test. So this is the picture showing a prism from which three specimens are cored out.

Whereas, this is a picture showing Gyratory compacted specimen from which one cylindrical specimen is cored out and your final specimen size is, 100 mm diameter and 150 mm height. Again, this casting of specimen using a shear box as well as Superpave gyratory compactor is explained well in the lecture by Professor Murali.

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Outline

- Development of Asphalt Mixture Performance Tests
- Specimen Preparation
- Flow Time Test
  - Post-processing of data
- Flow Number Test
  - Post Processing Techniques
- Post-processing Issues
- Development of Failure Criteria

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Now let us discuss first the flow time test. I will discuss what are the test protocols and how the data is processed.

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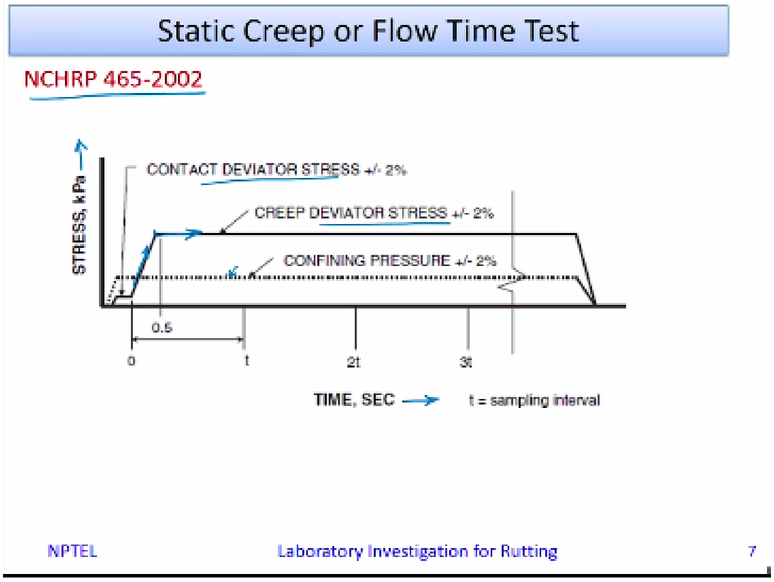

Flow time means a static creep test. When I say a static creep, it is a static load which is applied on the specimen for a sufficient long time. That is called a static creep test. Now this actually reflects or represents the kind of loading of a stationary vehicle on your pavement surface. Now this protocol is taken from the National Cooperative Highway Research project report NCHRP 465. And this shows the test protocol.

You can see this is time in the x axis and stress in the y axis. You apply a creep deviator stress. So this is a stress that you apply, which is constantly applied on the specimen. Now it is very difficult to apply a certain stress suddenly on a specimen. So it will take some time to reach that. So this is the time to reach the required deviator stress. Then that stress is kept constant.

Now for this specimen you need certain amount of contact stress to be given or a seating load has to be given. Normally, 2 to 5% of the deviator stress will be given as the contact stress. And also this test can be conducted in a confined condition or in an unconfined condition. I will come to that later. So if the confinement pressure is given, so this marked here is the confinement pressure which is also a static compressive load on the specimen. So this is the whole loading protocol.

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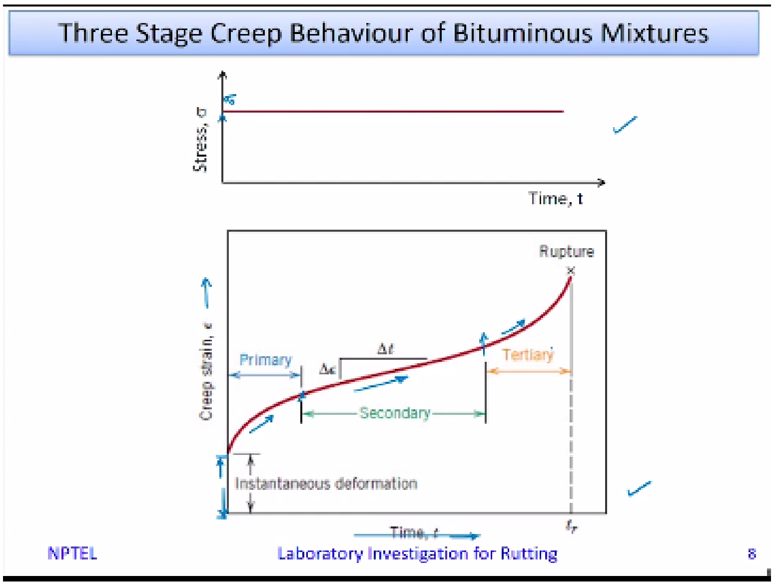

So what you are looking at is, see here you have the stress which is constant over a period of time. You expect that the material behaves in a ductile manner and it is well established that a ductile material responds in a three stage creep behavior. So what you see here is a three stage creep response of a material.

You can see time in the x axis and the creep strain or deformation is marked in the y axis. When you load a material suddenly, say here I have shown it as a sudden loading of σ or σ_0. When the load is applied suddenly there will be a sudden instantaneous deformation in the material. So this is marked here as the instantaneous deformation.

Thereafter, what you can see is that there will be an increase in strain, but this will happen at a decreasing rate. So in this region you say that, the strain is increasing but the rate of increase of strain is actually decreasing. And a point will be reached thereafter, the increase in strain will be at a constant rate. So here it is more or less at a constant rate and later on at certain stage will be reached when the strain starts increasing at an increasing rate.

So this is the third stage. So these three stages you call it as primary, secondary and tertiary. So in the primary stage there is a gradual increase in strain. Then there is a constant increase. Then thereafter there is a sudden increase in the strain.

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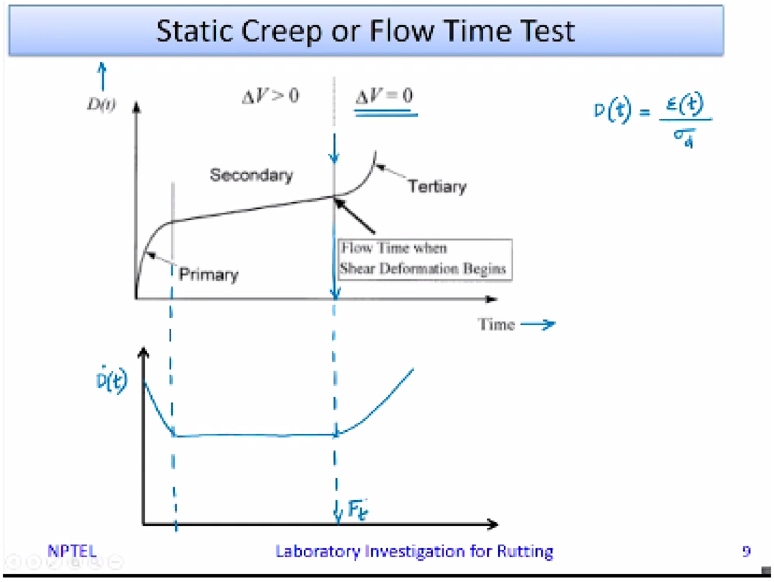

Now, the definition of flow time is that the time period when the material starts flowing or it is the time when which the material or shear deformation begins to happen in the material or you can say that, when the tertiary stage begins you say that the material has failed and that point is called as flow time for the specimen. So what you see here is first is the time versus compliance is plotted here.

When I say compliance, this is creep compliance, which is the strain per unit stress applied. So it is if ε_t is the strain at a time divided by σ_d is the deviatoric stress that you have applied, that will give you the compliance or creep compliance. So here creep compliance is in the y axis and time in the x axis. You see there is a primary stage then the secondary stage and the tertiary stage is shown here.

Now you know that bituminous material is a heterogeneous mix of an aggregate matrix and a bituminous mastic. Now when it is loaded and it contains certain amount of air voids. So when you load it during the initial stages, there could be a rearrangement of particles or the deformation which will actually densify the material. So there could be a change in the volume of the material.

But after a certain point of time, you see that the material flows without any change in volume. So this is the stage where which the change in volume becomes zero and that point corresponds to the flow time of the material. Now how to determine this flow time is that from the creep compliance or creep strain graph, you can find what is the rate of change of strain and you can identify that point which is the minimum rate of change of strain.

So you can see, I will just plot the primary, secondary stage in this bottom graph. So in the primary stage, let this is the rate of change of creep compliance. I have marked it as the D dot (t). So you know that as I said, the rate decreases as the time increases. So you can see that the rate goes down like this, and in the secondary stage it remains more or less constant.

And when it reaches the tertiary stage it starts again increasing. So this is the rate of change of strain. So that point which is the minimum rate of change of strain or when the increase in strain happens, that point is marked as flow time or F_t.

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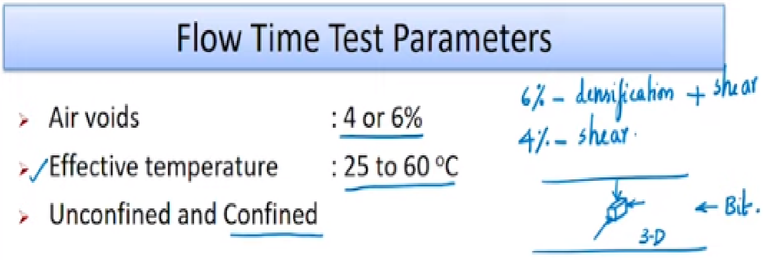

State of Stress	Stress	Range
Unconfined	Design stress	69 to 207 kPa (10 to 30 psi)
Confined	Design stress	483 to 966 kPa (70 to 140 psi)
	Confinement	35 to 207 kPa (5 to 30 psi)

You have to do the test at an air void of 4 or 6%. This is what the protocol says. Now why 4 and why 6? When I say 6%, you know that you in the field you lay and compact a bituminous mixture to an air void of 6 to 7%. So if you have to represent that material in the laboratory, you have to test it at 6% air void.

So when I test it at 6% air void, what you can see is that there could be deformations due to densification in the material as well as there will be deformation due to shear. Whereas if it is a 4% air void material it is it might have already reached its almost refusal air void content. So there will be less amount of densification in the material. There will be mostly shear deformation.

So depending upon what is that what you want to capture, you can do the test at a 4% or a 6% air void sample. Now the temperature at which you have to do the test is, you can test it at any range of temperature from 25 to 60 degrees Celsius. But what the code says is that you should choose the effective temperature of the region in which you are going to use the material.

When I say effective temperature, it is that one temperature which will give you the same amount of deformation in the pavement or in the material as if you have considered all the seasonal variations for a year. So if I consider one representative temperature that temperature is called the effective temperature.

But what you know is that during lower temperatures the deformations that may happen or rutting that will happen in a material will be very less because this is a high temperature phenomenon. At high temperature the material will be less stiff and the chances of deformation will be more.

So mostly your effective temperature will be the higher temperature prevailing in the region. So you can test it at say 50 or 60 degrees Celsius suppose you are doing a test for the Indian conditions.

And the next aspect is that you can do the testing in an unconfined condition or a confined condition in the specimen. Now why this is so? See if I consider a pavement structure, any element inside the pavement layer say suppose this is the bituminous layer and in the bituminous layer if I consider one element inside that.

We know that it is not only subjected to an axial load, but it is subjected to stresses from all around or it is a three-dimensional state of stress that is which the material is subjected to. So suppose you want to reflect this in your test protocol, you have to do the test in the confined condition. When I say confined condition you will be applying stress not only from the top, but from all around the materials will be subjected to stress.

Now the stress levels that you have to apply as per the test protocol is if you are testing in the unconfined condition, you have to give a deviatoric stress or a design stress of 69 to 207 kPa. That is 10 to 30 psi. You can choose the load according to the kind of traffic that you are expecting in the field. And if you are testing in the confined condition, you can have a design stress of 483 to 966 kPa that is here 70 to 140 psi.

And the confinement you can give as 5 to 30 psi or it will be 35 to 207 kilo Pascal will be the confinement pressure that you have to give.

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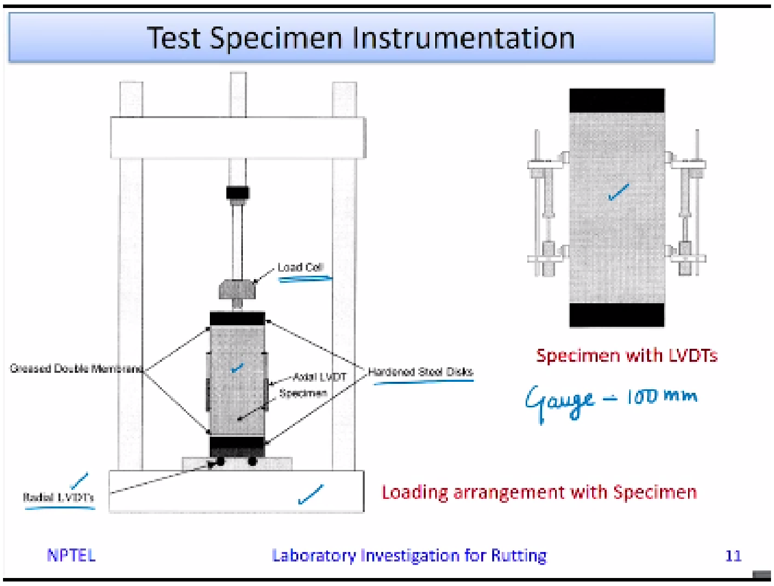

How the material is set up for the testing is shown in this figure. You can see that this is a loading frame. You apply the load using a load cell and this load cell captures the load and this here is the specimen. The specimen is kept in between a bottom platen and a top platen and there are two hardened steel disks which are provided at the top and the bottom and it is through this disk that the load is applied uniformly on the specimen.

And then to capture the deformation, the axial deformation you use linear variable differential transducers or LVDTs. Now what I have mentioned so far is the linear deformation of the material. Now suppose you want to capture the radial deformation that also can be done by the use of radial LVDTs. But which will give you information about the Poisson's ratio of the material and all.

But this may complicate, it will be highly complicated to collect information in the radial direction as well. So what I am discussing here is the collection of deformation in the axial direction alone. So as you see here, this is your specimen, you will collect the deformation as I said using LVDTs. Now it is not that you will collect the deformation of the entire specimen because there could be end effects at the top and bottom.

So you will collect the deformation of certain gauge length in the middle of the specimen. So the gauge length that we normally provide is 100 mm. And again the specimen deformation can be collected at 100 mm in the specimen. You use three LVDTs which are equally spaced that is at 120 degrees apart on the surface of this specimen, so that any variability due to non-uniformity of the material or non-uniformity of the specimen will get cancelled out when you use three LVDTs.

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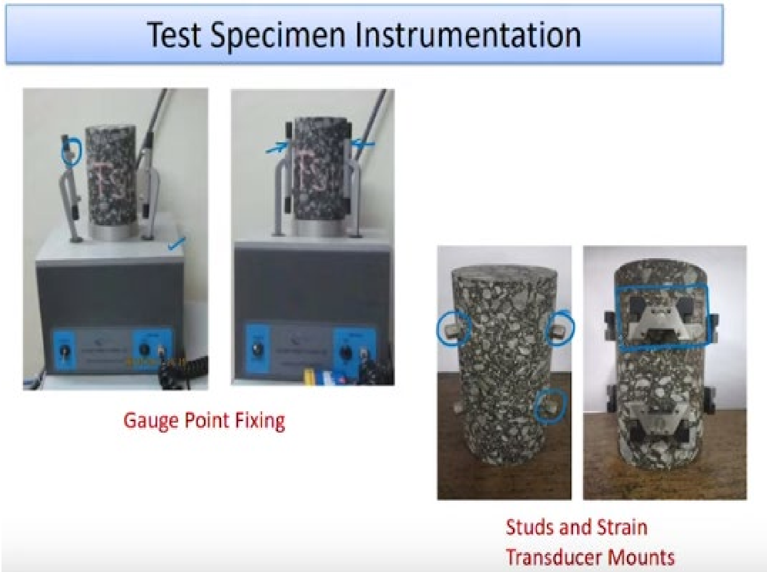

So now how to fix the LVDTs on to the specimen. This is done using certain studs fixed on the specimen. So as you can see in this figure, this is an apparatus wherein there are three holders in which what you see here is a stud and the glue is applied on the stud and this attached to the specimen so that all the six studs will get glued to your specimen. So you can see here these are the studs which are glued to the specimen.

So for three LVDTs you have six studs in the specimen. And in the in this studs you will attach this which is your transducer mount. So you have two transducer mounts, one at the top and one at the bottom for one LVDT.

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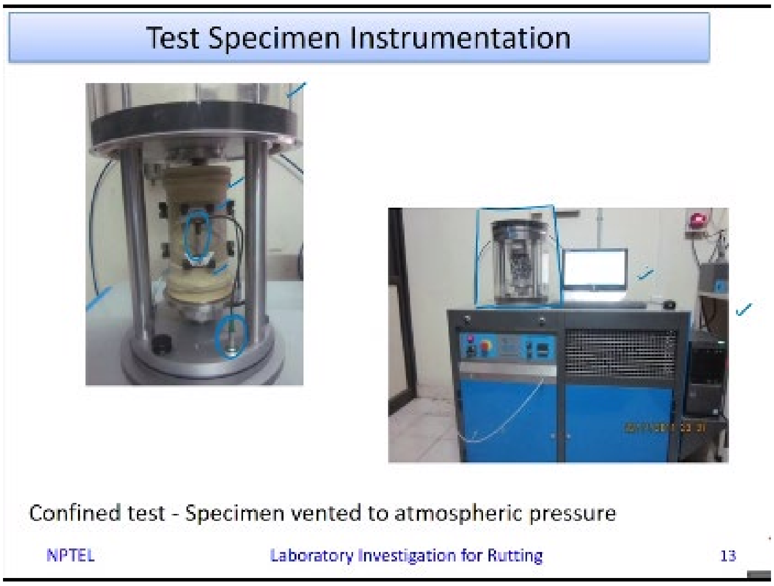

Now as you can see here, this is a top mount and this is a bottom mount and this rod here is LVDT which is connected to the specimen and then to the data acquisition system. As I mentioned that you have you can do the test in the confined condition as well as in unconfined condition. So when I say confined test, you have to apply a confining pressure from all around on this specimen.

But since this is a specimen which contains air void inside that you have to cover it with a rubber membrane if you have to do a confined test. So what you see here is that your entire specimen is covered with a rubber membrane. And this membrane is actually attached to the top platen as well as the bottom platen and it is fixed using O-rings so that there is no leakage through the top and the bottom platens.

And another important aspect is that suppose you are doing a confined test you want to have an atmospheric pressure to be maintained inside the voids of the specimen. So what you have to do is that this has to be properly vented using, see, what the pipe that you see here, is a venting pipe to keep the air inside the specimen in the atmospheric condition. Whereas the pressure will be applied from all around.

Now what you see here is an asphalt mixture performance test apparatus. You can see there is a closed environmental chamber inside which the specimen is placed here and this is the top cover of the chamber which can be closed so that you can do the testing in a closed chamber and this is a data acquisition system.

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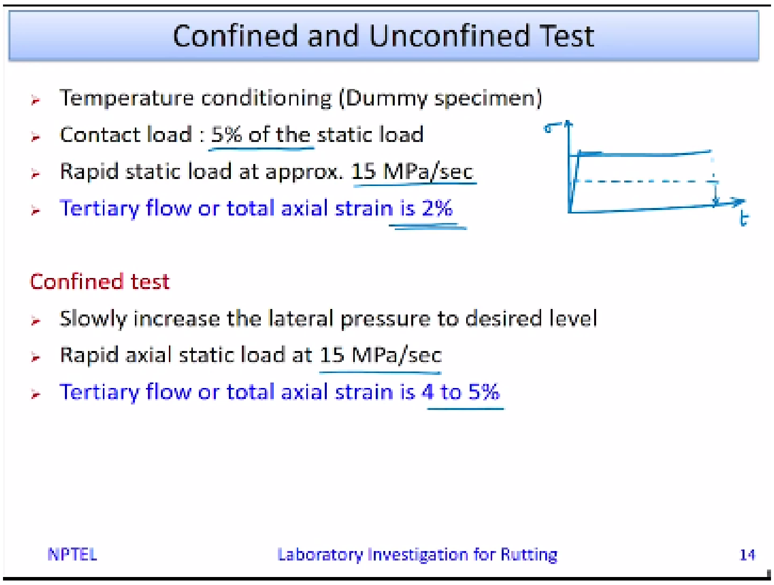

Now the temperature of testing as I said has to be done at an effective temperature. Now this is a specimen of size 100 mm dia and 150 mm deep. And every point in this material has to reach the test temperature before you can do the testing. So what you normally do is that, if the environmental chamber has sufficient space, you can keep a dummy sample along with your actual test sample.

You can put a temperature probe inside the specimen, you can cut a groove and put it temperature probe inside that and note how much time it takes in the conditioning chamber for the specimen to reach the temperature. And once it reaches the test temperature, you can remove the dummy sample out and you can do the test in the actual test specimen.

If it is not possible, then by trial and error, you can determine how much is the time that is required for each specimen to reach the required test temperature. Then only you will start the testing. And the contact load as I said is 5% of the deviatoric stress or the static load. And then when you apply the load, what you are trying to achieve is this thing. That is, you have to apply a load or a stress instantaneously on the specimen.

But this may not be possible because of the equipment capability. So in that case, you have to apply it rapidly so that at least at 15 Mega Pascal per second should be the rate at which you have to take the load. So it will go like this and then the required stress will be reached. Now you will continue this test till a time you see the tertiary flow in the material or a failure in the material by tertiary flow or till the axial strain reaches a value of 2%.

Now if you are doing the confined test, then you have to apply the pressure also. That is a confinement pressure also. So first you will keep the specimen then apply the confinement pressure. Again that is slowly applied. Once the confinement pressure is completely applied, see here, see this will be the confinement pressure that will be applied completely and then the deviatoric stress or the static load will be applied.

Again the static load will be applied at the rate of 15 Mega Pascal per second so that it reaches immediately on this specimen. And the confined test you will do it till a tertiary flow is reached, as you can observe from the material, or the material fails or up to an axial strain of 4 to 5%.

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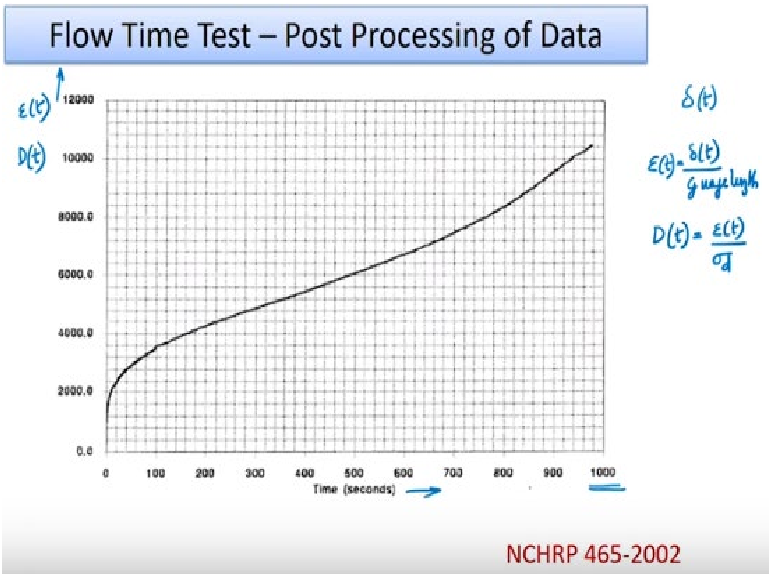

Now let us see how we process this data. So as I said what we are collecting is that we are applying a static load on the specimen and the creep in the material is being collected or you say the creep deformation. So what you are collecting is a deformation say δ. Now this deformation with time, this δ with time can be divided with the gauge length.

So here the gauge length is 100 mm, you will get the creep strain. Either you can represent it in terms of creep strain or you can represent it as creep compliance. So when I say creep compliance, is this creep strain per the deviatoric stress. So what you see here is the creep compliance or it could be creep strain also either ε_t or it is D(t) which is marked in the y axis. And this is time in seconds which is marked in the x axis.

So this is a typical output from the flow time test. You can see that this test continued till 1000 seconds and it has more or less followed a three stage creep behavior.

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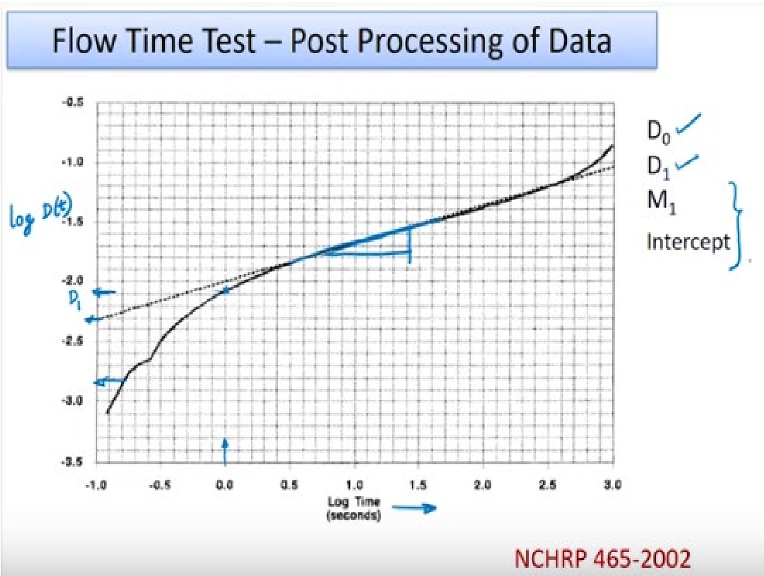

First of all, you will plot it in a log-log scale. So it is much easier to do the computation in a log scale. So this here is a log D(t). So the strains or compliance are in the order of 10 raised to -2 or -3. That is why these are negative values here in the log scale and here log time in the x axis. So I have plotted log time versus log compliance.

And then you identify various factors, one parameter as I said is the flow time and NCHRP has suggested several other parameters also to be identified from this creep compliance curve. Let us see one by one. The first one is D_0. D_0 is called the instantaneous compliance or what is the compliance at the very first instant of load application.

But you cannot take it at the 0^{th} time because as I said, it will take some time for you to reach the required load application. So for example, if you have taken 50 microseconds to reach the load application consider the first point as say 100 microseconds. So you note what is the creep compliance corresponding to that first point which is denoted as at that time corresponding to 100 microseconds. So that is the instantaneous creep compliance.

And another one is the creep compliance at one second or it is actually in the log-log plot where does the creep compliance curve intercept. So that value is called the creep compliance corresponding to one second. So when in the log scale this becomes as the 0^{th} point so where it intercept is this point. So this point corresponds to, so this compliance value here or somewhere here, this corresponds to D_1.

So this is another parameter that you can estimate from the creep compliance curve. Now the next two parameters are M_1, that is a slope and intercept of the linear portion of your creep compliance curve. So as I as drawn here, the secondary stage of the creep compliance curve, if you can identify, is draw a tangent to that line, the intercept here is one parameter and the next is the slope of this straight line portion in the creep compliance curve.

So these are the four parameters that you can estimate from the creep compliance curve and the next one is the flow time.

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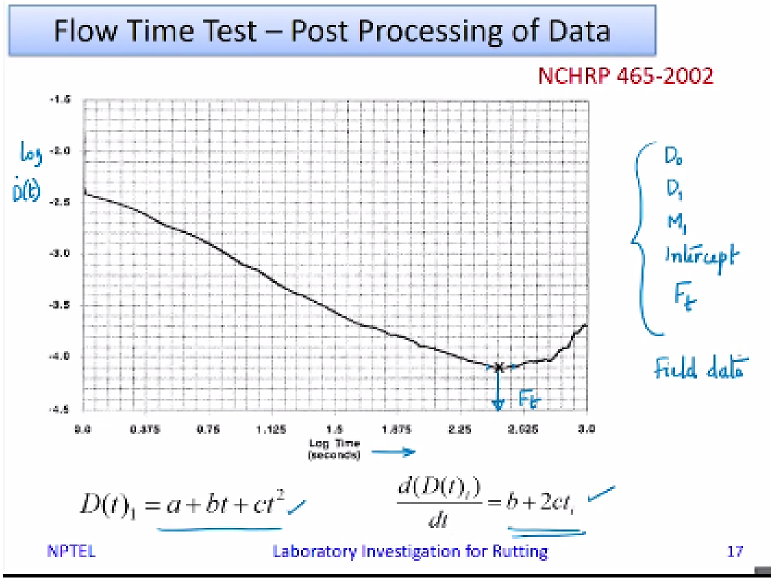

So in order to estimate the flow time, as I said, you have to get the rate of change of creep compliance. So what is drawn here in the y axis is D dot t, which is the rate of change of creep compliance and time in the x axis both in the log scale, so this is also log scale. So how to get this data is that what you normally do is that. identify one point every point in the compliance curve, take two points to the left, two points to the right. So you can have five data points corresponding to one time. And then you fit a polynomial for that. So here at any time, at any data point, you have five points to which a polynomial is fitted. You can use any regression tool to fit this equation. So a, b, and c are the coefficients of this fitting. Then you take the rate of change.

So it is d(D(t)/dt, which will be equal to b + $2ct_i$ where i corresponds to the i^{th} position or the i^{th} time. So at every time point in the creep curve, so every point in the creep curve, you choose five data points fit a curve and then take the rate. So that will be easier to draw the rate of change of creep compliance. So then you can plot this and you can identify where you get the minimum point.

So this point is here is denoted as the flow time. There could be a problem that you may find many points which are lying at the same with the same minimum value. Then what you can do is that you can choose certain points in and around the minimum point and then fit another polynomial for that to identify the exact minimum value in this curve. So that is how the processing is done.

So as I mentioned, as in the NCHRP study, they have identified various parameters such as D_0, D_1, slope of the linear portion, intercept of the linear portion and the flow time. So this many parameters were identified in the study to find out which one mostly correlate to the performance of the material in the field.

So in order to get such an information, it is required that you need field data or any other simulative tests which can relate, which you can directly relate to the field performance.

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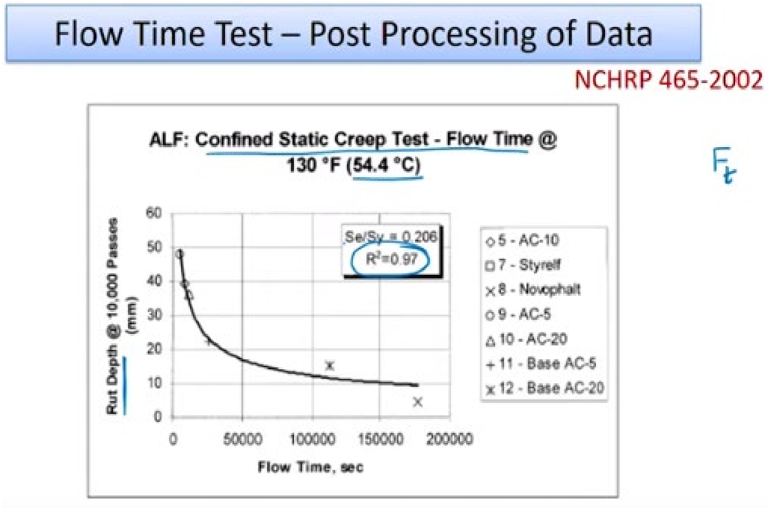

Figure 39. Rut depth versus confined flow time for the ALF test sections.

So in NCHRP study, what they have done is that many accelerated loading facility studies, test tracks studies where there. All the information that is collected from this these test stretches were tried to be correlated with the flow time data that is captured in the laboratory on that particular mix.

And then correlations were tried to be established between these and it was identified that among all the parameters that we have estimated, flow time is the one which is seemed to be more correlating to the field rutting. So this is one such correlation which I have taken from the NCHRP report. As you can see that this is from an ALF accelerated loading facility test section.

And, as far as the material is concerned, it was a confined creep test that was done or a flow time test that was done at 54.4 degrees Celsius in the laboratory. And the same mix which is used in the accelerated loading facility and the rut depth at 10,000 passes of a wheel in the accelerated loading facility is tried to be correlated. So it is flow time versus the rut depth at 10,000 passes.

And it was found to be very much correlating with each other or it is related to each other. So it was established that flow time is a better estimate of the rutting performance of the mixture in the laboratory.