Mechanical Characterization of Bituminous Material - Introduction

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Lecture No 1
Linear Viscoelastic Response Part-01

So, welcome you all to this NPTEL course on mechanical characterization of bituminous materials.

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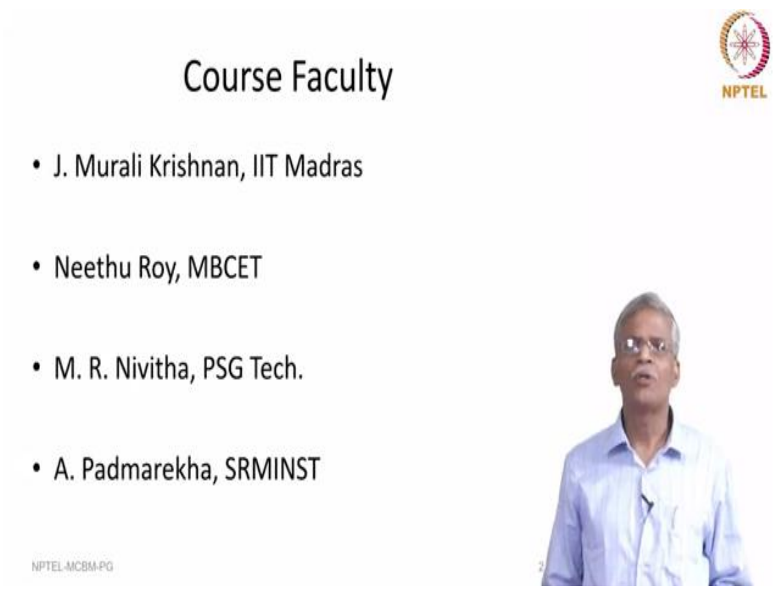

The course faculty for this course will be J Murali Krishnan, that is me, IIT Madras, Neethu Roy from Mar Baselious College of Engineering and Technology Trivandrum, Nivitha from a PSG Tech. Coimbatore and Padmarekha from SRM Institute Kattankulathur. In fact, all of them, graduated from IIT Madras including me, with a PhD in bituminous materials.

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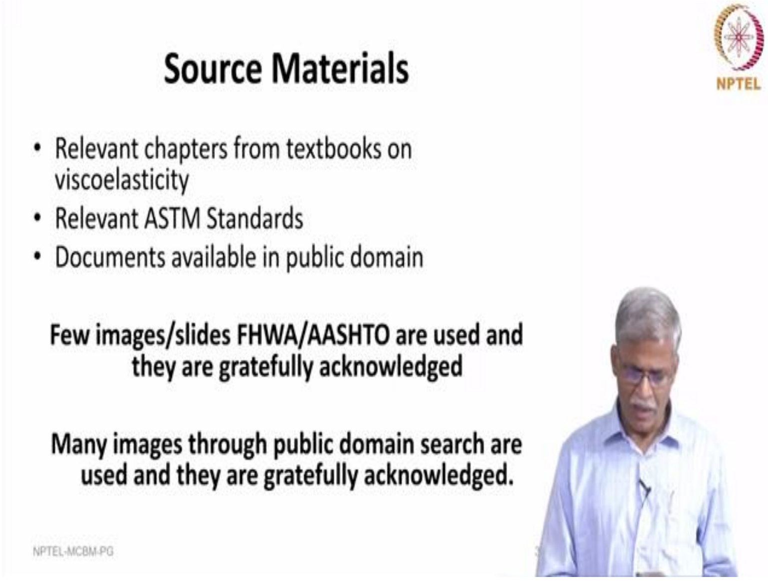

The source material for this course will consist of relevant chapters from textbooks on viscoelasticity. Relevant ASTM standards. In addition to that, links will be provided for documents that are available in public domain. I have used, in fact all of us who are giving you lectures on this course have used images slides from Federal Highway Administration and AASHTO. we have also used images that are available in public domain.

If it is necessary, we have acknowledged it at specific places but other ways, we thank all the people who have provided these images in the public domain, and we will be using them as it is. Right?

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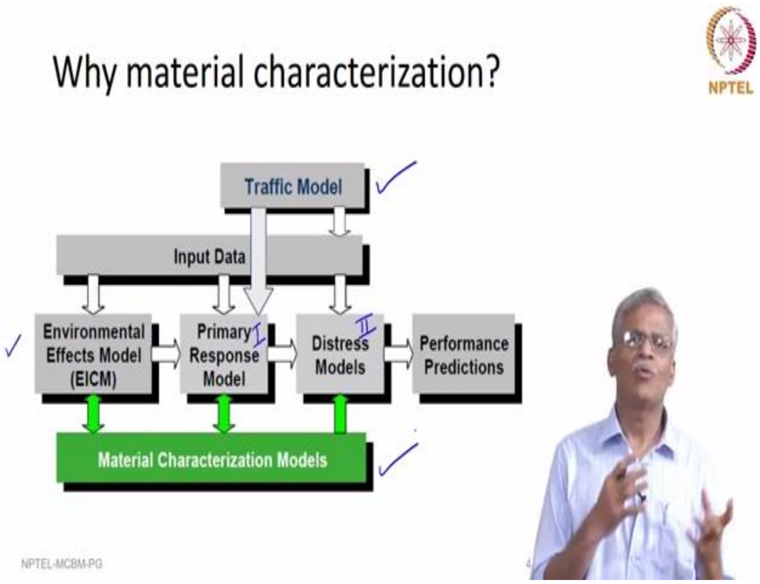

So let’s start talking about the material characterization part, but what is this material characterization, why should we do material characterization? If you talk in terms of bituminous pavement design, there are many aspects to it. For instance, what you see here is a simple overview of where material characterization comes in. As far as the mechanistic empirical design of bituminous pavements are concerned, it need not have to be bituminous pavements even the same thing holds good for the concrete pavement.

So, what you really see is, you see that there is a traffic model, which is the actual load that comes in pavement. And there are different sets of input data that is given. So, one is the environment in which you are planning to construct your pavement. Then there are two types of models that are given. One is the primary response model, and another is the distress model. So, what exactly is the primary response model?

Given any pavement cross section for a given temperature conditions and for given any applied load, what is the stresses- strains- displacements that are induced in the pavement. And that is primary response model. As far as the distress model is concerned, given any pavement cross section, and for any given critical temperature, what really is the mode of failure of the pavement structure? Okay? So that is the distress model.

Now for doing all these things, it is necessary that the characteristic features of the material are known well beforehand. For instance, what is the modulus value should they use for main stress-strain response. If you speak to any pavement engineer, especially when they are talking about bit of pavement, they are going to say that they use layered linear elastic theory for stress analysis.

So, if you are talking to a concrete pavement, they will be talking in terms of the Winkler foundation, or the Pasternak foundation, a dense liquid or solid model. And the slab is assumed to take all the load that is coming on top of it. So, depending on the theory that you use for stress analysis, the material characterization, the material inputs that are needed also is necessary, for instance, it could be Young's modulus, it could be Poisons ratio.

It could be bulk modulus, relaxation modulus, stiffness model, many of these modulus values are needed. So, for all this, the input that is needed is the material characterization. So, unless we know how the material responds for given load condition, in terms of stresses strains for a wide range of time and temperature, we really cannot go forward and design, any pavement.

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So, what are the various steps that normally is followed for any pavement design. In fact, as I have mentioned here earlier, the estimation of the traffic load. The second which are related here is the material characterization, where the pavement is going to be constructed. What is the expected performance? And in case of rehabilitation, how do we really characterize the existing pavement structure.

So, all these factors interlinked play a critical role in the successful design of a pavement and in this the most important link is the material characterization and this NPTEL course will essentially deal with material characterization, and that too for bituminous material. Okay? Right?

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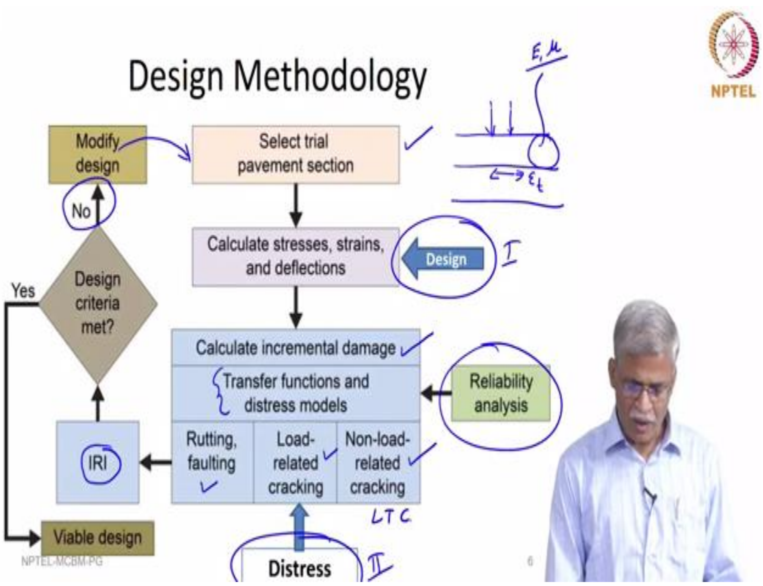

So, having understood that the let us even a little more focus and understand in the nutshell, what is the basic design methodology. So you can actually see that the first thing that we do is select the trial pavement section and in fact, most of the pavement design process that you see here is proof checking of any given cross section, and we do not really go and start playing around with the thickness, or optimize the thickness in the manner in which a typical structural engineering work for your water tank or a multi storage building or any industrial structure is carried out.

Because there are some specific limitations related to the construction of the bituminous pavement, the lift thickness dictates, in a sense, what will really be the thickness that is required. For instance, you can have a pavement thickness of 75mm and if your pavement engineer says, he could do a lift of 45mm.

So, then you are going to be typically looking at two lifts of 45 and 45 equal 90mm. So, the lift thickness as well as the nominal maximum aggregate the size of the material that you use play a complete critical role. So, most of the time, there are some standard trial sections that are known, the thicknesses. The only thing that varies is the kind of material that you use. So, you pick up a material with unmodified bitumen, or with modified bitumen, a bituminous mixture.

Now what we have to do is, take the trial section and calculate the required stresses strains and deflection. And this is where first step the material characterization comes in because if you are really looking at a pavement cross section like this, so let us say and if you apply a load here. And what we really want to know is what is the state of the tensile strength here and for doing them we need material properties.

I am writing in a very simplistic way about E and Mu, but it may not have to be really, it can be as complicated as it can get as you will discover, when you go through this course material. So, calculate the stresses and strains under deflection. So, once it is done for each and every load application, we find out the incremental damage, and knowing the distance transfer functions, we compute the rutting we compute the load related cracking.

And we also come to the non-load related cracking which is nothing but the low temperature cracking and this comes under the distress. So, when I am really talking about material characterization, I am talking in terms of two things. One is material characterization for design purpose. Another is material characterization for distress purpose. What you see here in this chart is the analysis for the pavement structure.

What we will be talking about in this course is the analysis that is occurred for the constituent material that is going to be used in this pavement structure. So, let us understand the distinction, very clearly. So, so if I recap again, you pick a pavement section, and for the material that is used to the compute the stresses and strain and for the load that is expected to come on this pavement structure compute the incremental damage, rutting load related cracking and non-load related cracking.

And we compare it with the and find out what is the IRI if the design criteria is met we proceed, other ways we modify the design. So, when you modify the design, what do you do, you could change the thickness. You could also change the material properties. Here there is also an input that comes in terms of the reliability. Now, this is the overall pavement design methodology that is followed.

And an important input here is the material characterization and the material characterization comes to repeat again for the design and for the distress. Okay?

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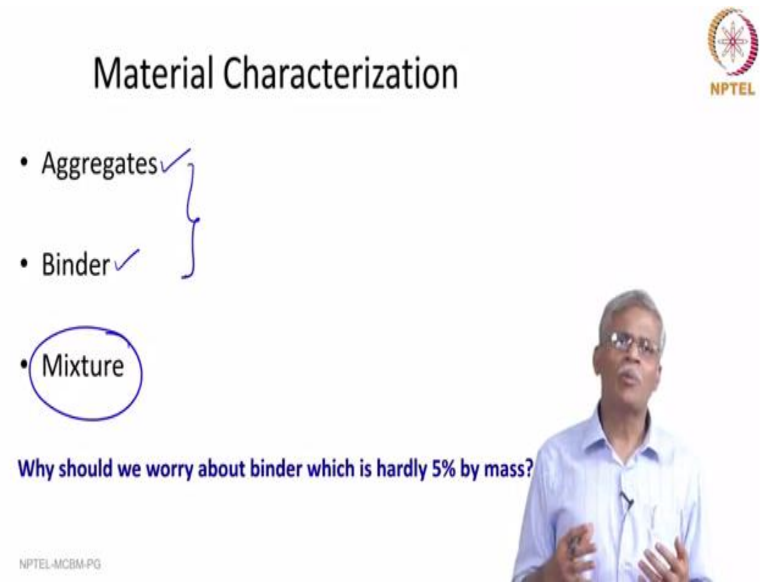

Now, let us look at the various constituents for the bituminous mixtures. So, you have aggregates, you have binder, and these two things are mixed together to get a bituminous mixture. Now, if you look at the mix design that some of you may be very familiar with, you are going to find out that your binder content that you are going to use is hardly 5% or 4%. So why should really be one worried about the binder part.

And that is where the real crux lies. What we do is we take stones of various sizes, shapes, and percentages and mix them together, but if you mix them together, do you really think they will stay there as it as it worked. So, for that purpose, what we do is we add the binder. So, the binder is the one that completely binds all the aggregate particles of various shapes, sizes together. So that, you get one consolidated compacted material that is capable of taking the intended traffic load.

So, what we need to do is we cannot really ignore the influence of the binder and as we will see in the later part of the course, the binder also plays exhibits, different mechanical behavior, depending on the temperature. At very high temperature if your mix design is poor, the binder can start flowing out, in which case the whole aggregate skeleton can collapse. At very low temperature.

When you have used a binder which is extremely stiff, the binder can actually shatter like glass, in which case you are going to have an extreme case of low temperature cracking. So, the choice of the binder plays a critical role, from the time the mix is laid in the field, rolled and compacted to the final design life period.

Okay, So, we need to really understand the binder properties and the mixture properties. If you really want to understand the mechanical characterization of bituminous materials.

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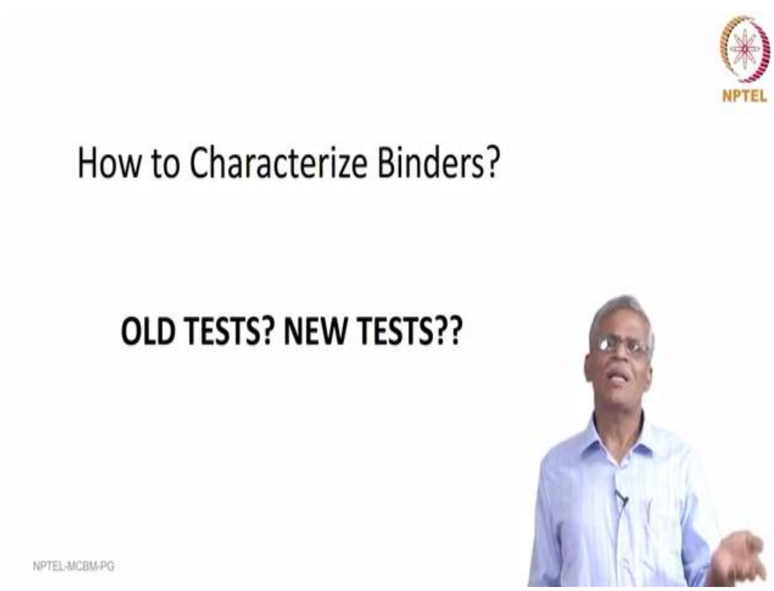

So how do we really characterize this binder. All of you are familiar with the penetration test, the softening point test, ductility, viscosity at 60 and viscosity at 135 degree centigrade. You are also familiar with some new tests that will be discussed in detail in this course. So, what is the sanctity of the old test, what is the sanctity of the new test? Why do we even real need some new test? Right?

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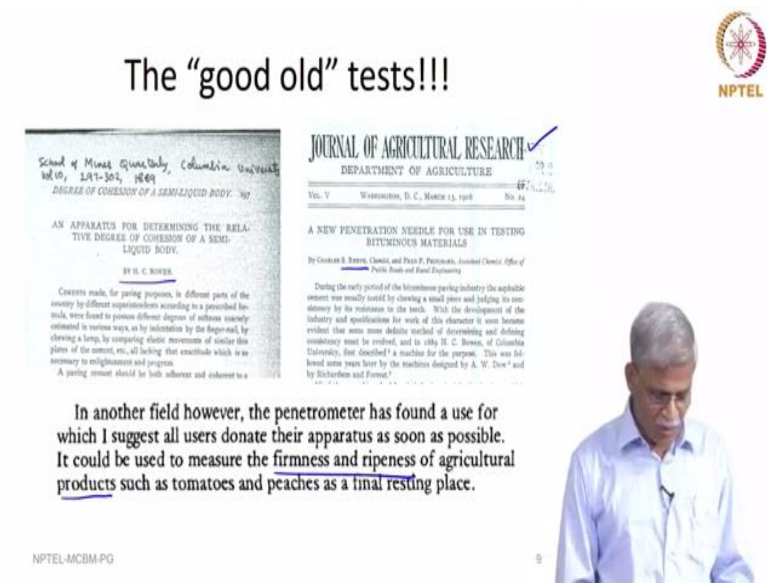

So, these are some of the original papers that were published related to some of the old test for bitumen. In fact, this paper by Bowen, published in School of Mines quarterly, 1889 is the very first paper related to the penetration test, and you can actually see how it is titled. An apparatus for determining the relative degree of cohesion of a semi liquid body and the later on, in during 1916, Charles Reeve improved this test procedure for penetration test

And he titled it as the new penetration needle for use in testing bituminous materials and interestingly this was published in journal of agricultural research, there were criticism related to this test even during the time in which this test were proposed to be used. For instance, very interesting remark by Beckham says that you can use it for determining the firmness and ripeness of agricultural products and these tests have nothing to do with the bituminous material. Right?

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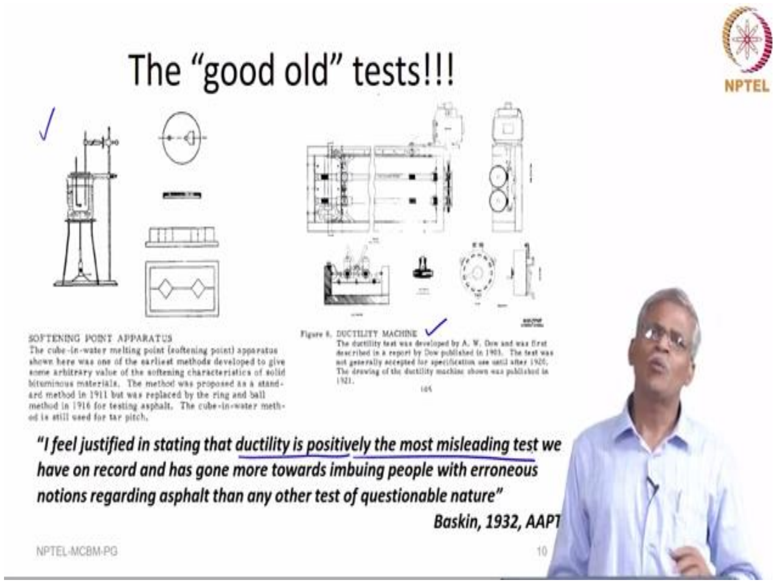

The many other good old tests are for instance, the softening pointers, which we are using till now, even now. The Ductility machine, which is the first machine invented by Dow. And, again, Baskin makes another comment here saying that he says, ductility is positively the most misleading test, we have on record, and has gone more towards imbibing people with erroneous notions regarding asphalt than any other test of questionable nature.

Very strong statements made during the 1932 session of association of asphalt paving technologies meeting, but this test have survived. They are being used. The ductility machine is slowly easing out, but we have started using it for the same machine with the minor changes for the elastic recovery but still this is being used. And most of the time, excepting the softening point and the penetration. Not much information, one can do that.

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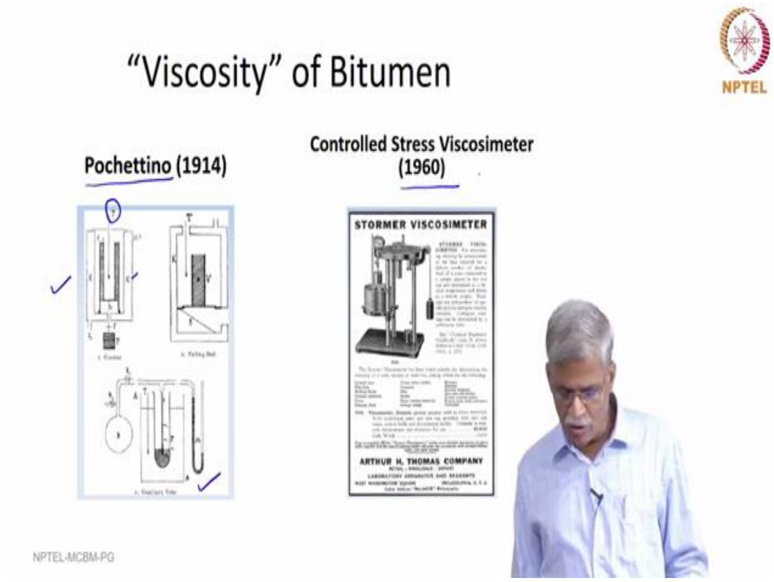

And most of the time we use this for what is really called the consistency. As far as the viscosity of bitumen is concerned. This is one of the very first equipment that you are going to see for the Pochettino viscometer wherein you can actually see that in this case, you can actually see that there is a fixed assembly here and there is a rotor inside which goes inside moves at a constant revolutions per minute.

And the torque is measured and is used to compute the shear stress and the variation is used to compute the shear rate, and the viscosity is measured. You also have a capillary tube viscometer, which is shown here. There were some controlled stress viscosity meters that were introduced, specifically for the purpose of bitumen, this is in 1960s. So, we have some interesting history here, right?

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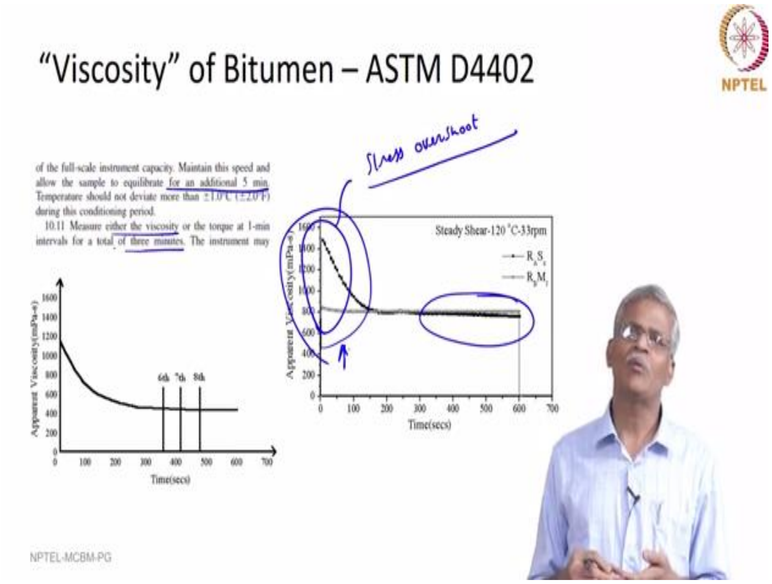

Now, when we look at the ASTM D4402. It talks in a very interesting way about how one should measure the viscosity of bitumen. So, what it says is, maintain the speed and allow the sample to equilibrate for an additional five minutes, and we use measure, either the viscosity, or the total torque for three minutes. So, what it means is you take bitumen at let us say at any given temperature 120 or 135 degrees centigrade.

This is not the vacuum capillary type; this is for the rotational viscometer type. So, when you add the bitumen, and then when you start shearing it. You are going to see, what is really called as a stress overshoot. And ASTM is very clearly aware of such a stress overshoot and that is why they asked you to average, the values for the last two or three minutes, so that the unnecessary influence of this whole shoot can be ignored here.

So, this is that way, which is called city can be measured so as you can see, there are older test. There are new tests, and even in the new test measurement of a simple thing like what we think as a simple thing like viscosity seems to be not simplistic in nature.

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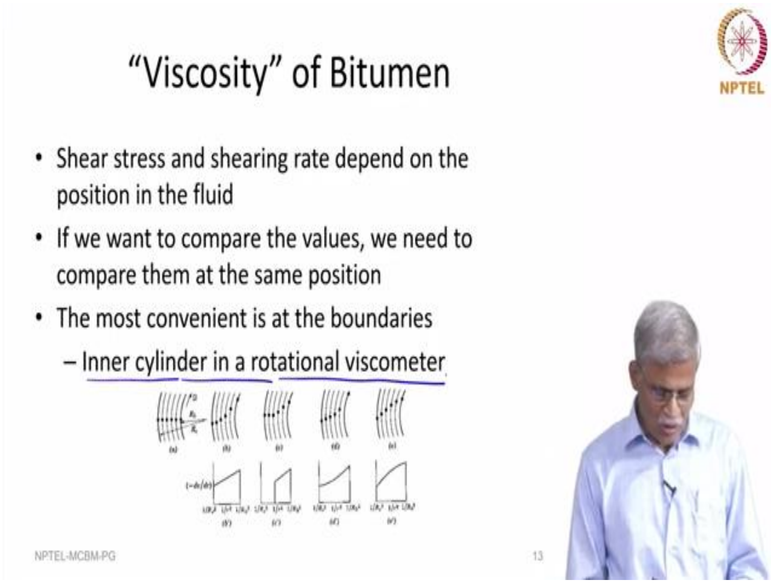

So, if you dwell deeper into the rotational viscometer, the kinematics of the fluid in the rotational viscometer when it is subjected to a constant angular velocity, you are going to see that the variations are going to be completely different. So, the shear stress and the shear rate will now depend on the position in the fluid. And if you really want to compare the values, we need to compare them on the at the specific position.

So, what we do is we compute everything with the inner cylinder in a rotational viscometer right? So that is how the viscosity measurement is made.

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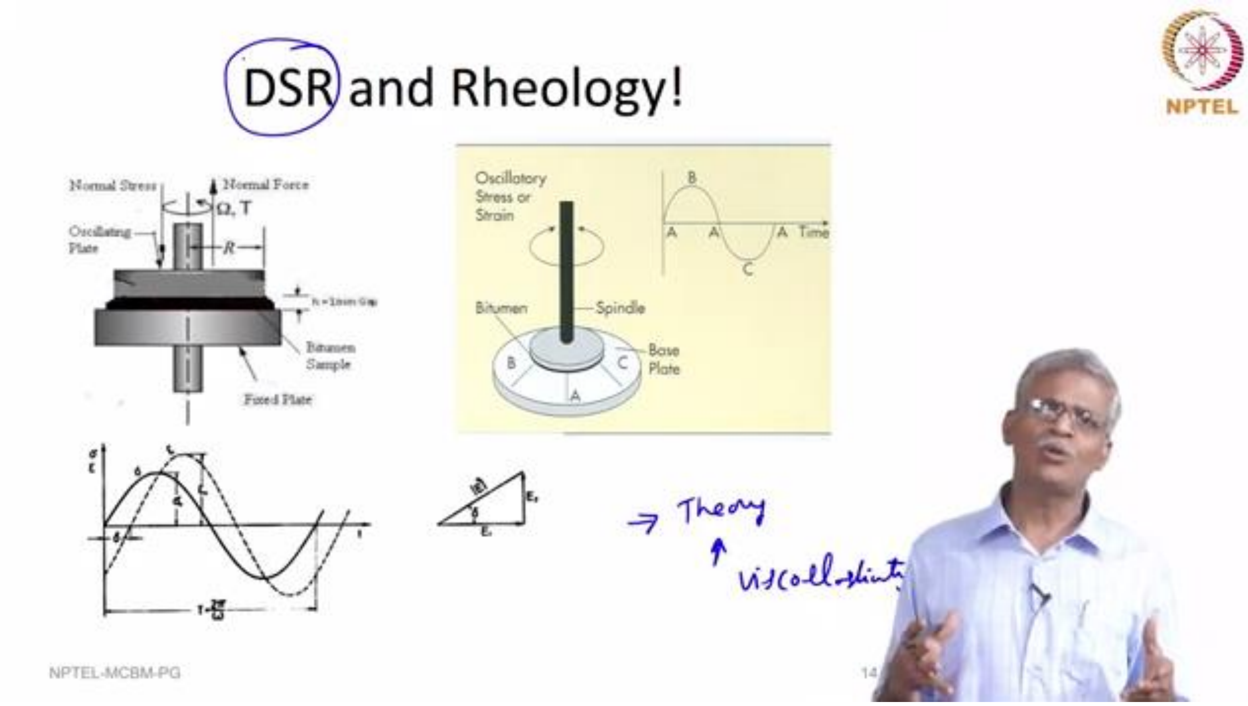

And since these different measurements, be it penetration softening point, elastic recovery ductility, viscosity using capillary viscometer, viscosity using rotational viscometer are not really giving us the correct values, in fact you know you can even go to the extreme of say, if you are familiar with the measurement of viscosity and 60 degrees centigrade. There are a lot of empirical factors that needs to be fixed.

For instance, the temperature at which you are testing 60 degrees centigrade. The vacuum that you are playing 300 mm mercury, and the geometry of the viscometer tube that you use. So, if even that is a minor deviation the values are going to be completely different. So, what this means is when we want to characterize the response of the bitumen. There seems to be different ways of measuring it,

And each of them are very empirical, the empirical factors dictate the response that you are looking at. Is that a correct way of doing it? In fact, when we are looking at an advanced course on bituminous material characterization we would really like to use an equipment that is based on a sound theory, so that we can use the theory, and we can make whatever measurements that we want, irrespective of the testing conditions being enforced.

Use the output that we get from the incumbent and use the theory to come out with the mechanical properties. So, here the theory that we are going to use will be the viscoelasticity and you will hear more about it in the later lectures. Right? So, the equipment of choice that has been identified throughout the world as far as the binder testing is concerned is the Dynamic Shear Rheometer.

Now the working principle of the Dynamic Shear Rheometer will be explained in detail in a later lecture by Mr. Dharmesh Gala from Anton Paar. The theory associated with the Dynamic Shear Rheometer, especially in small amplitude oscillatory shear will also be explained later. The whole idea of this particular lecture is to kind of gently introduce, you to the various characterization methods that will be discussed as part of this course.

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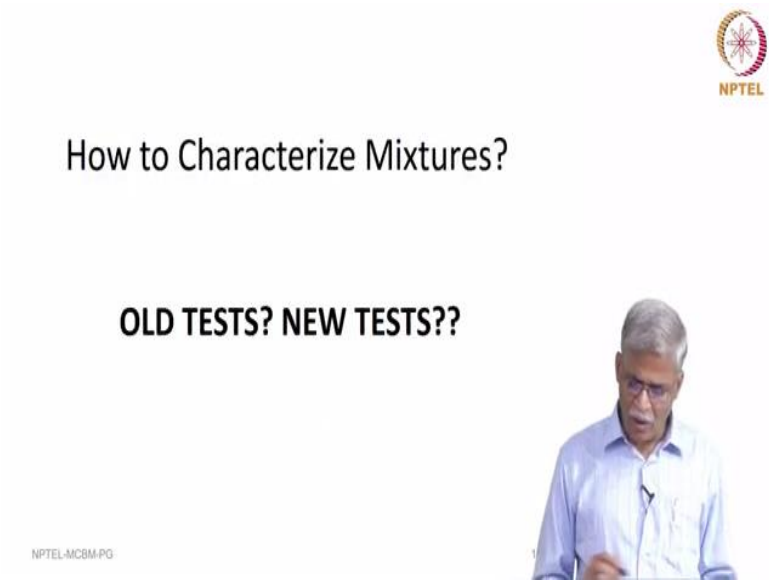

What about mixtures, should I do with old test, should I do with new test. So, this is the next question that we want to ask. In fact, what we have been talking about this, we have talked about why material characterization is important. And when we want to characterize the material, should I characterize the binder, should I characterize the aggregate or is it enough if we just characterize the mixture. Then we mentioned that no, we have to characterize the binder, as well as the mixture.

So, when we looked into some of the characterization methods that are available for binder. They are empirical, semi empirical, and only one or two tests especially the one associated with Dynamic Shear Rheometer seem to have a strong theory, underlining it. So, we will be exploring all those things in detail. Now coming to the mixtures, you are talking about old tests, there are new test. So, what are these old tests.

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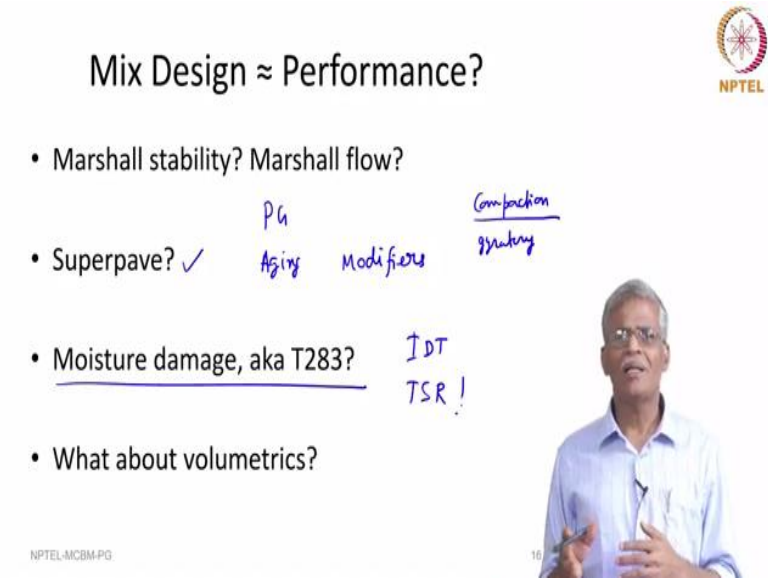

Most of the time, there is always a confusion related to relating the parameters that you get from a mix design, with the performance, for instance the marshal stability or the marshal flow. So, these are basically values that you are going to use for checking the adequacy of the binder content that you are going to use in your mixture, so they do not have any connection whatsoever with the mechanical property of the material.

Some attempt in the literature is available, trying to model the marshal test, but considering the viscoelastic nature of this material. And if the loading rate changes, the response also changes there has not been any recent advances that relates such kind of tests. So, we will not go into all those things. Another example is the superpave, which will be talking in terms of the performance grading, aging, as well as the modifiers.

Okay, so there are many many outcomes that has been come out, because of the superpave superior performance as well. And here also, the interesting part is the compaction, which will be discussed in detail later. And you are going to look into some of the issues related to how to use gyratory compactor, how one could compact a material in the laboratory so that the properties will be identical to that of the properties that you see in the field.

So even superpave, when it came out with this. There were not many interesting outcomes there as far as the performance or as far as the mechanical characterization is concerned, and the initial phases, the one only test to the that was available was using the well-known, T283 AASHTO test for moisture damage in which one measures the IDT, the indirect tensile test and find out what is really called as the tensile strength ratio.

But the interesting thing that one needs to understand as far as the mixer is concerned is the volumetric which play a critical role here. So, if we do not actually understand the role of the volumetric on the mechanic and performance. We will be at a loss to really understand why we are getting variability in the result, just because the voids or the voids in mineral aggregates have changed here by 1% or half percent.

So, I will be giving a very very brief overview of the role of the volumetric. This course is not about mix design. Mix design will not be covered in detail here. So, but we should understand that mix design, as well as the volumetrics plays a critical role in the mechanical characterization. So that is something that we are going to talk in the next few lectures.

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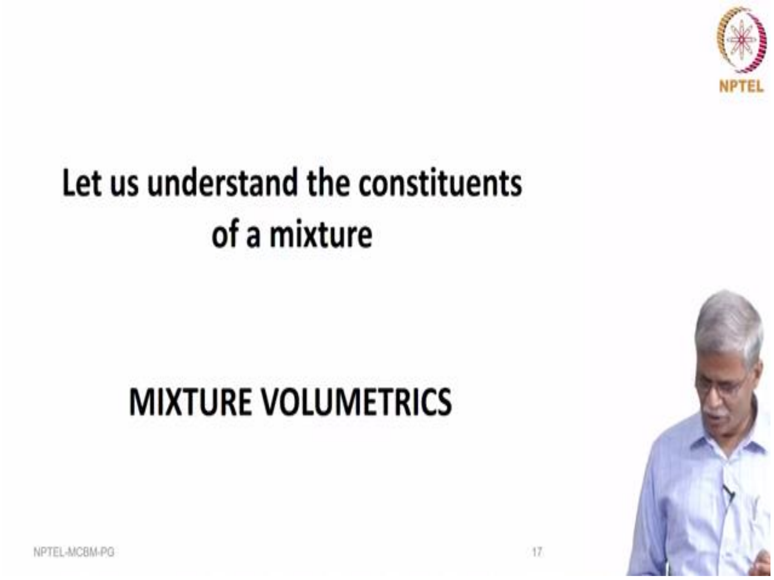

So this is the mixture volumetrics. Right.

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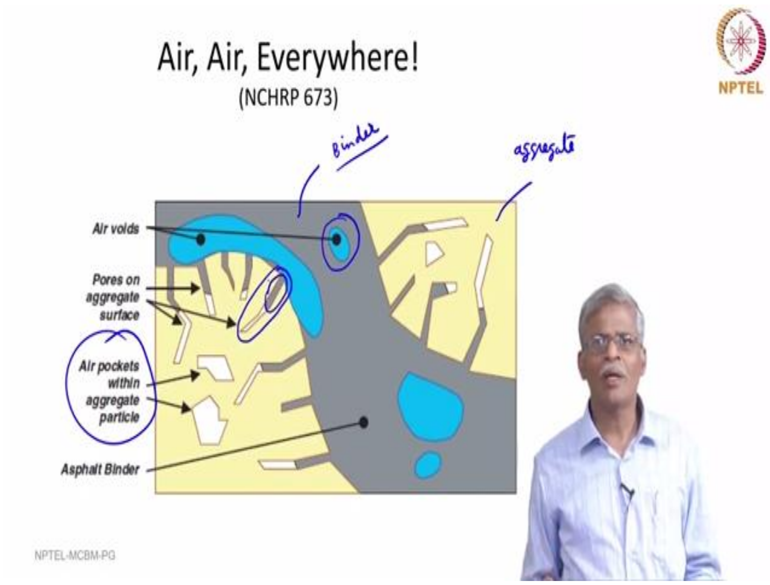

So, the most important point that we need to understand, as far as the bituminous mixtures is concerned is by design, by purpose, you have laid in the field a porous material. Okay, around, when the mixer is laid and compacted you are going to have around 6 to 8% of air voids. This is design, your surface may be impervious such that there will not be any penetration of water inside the mix, but the mixture inside is porous in nature. Okay.

Now, what you see here, this is the aggregate and the gray color is the binder. It is a caricature of what are all the air voids that you are going to see here. So, you could have air voids in the binder. You could have air voids on the surface of the aggregate, you can actually see that. And you can also have air voids within the aggregate particles, you can actually see. Right. The interesting thing that you will see here is, if you take any aggregate look at it very closely.

Use your naked eye or use a microscope there are going to be voids on the surface of the aggregate, some of the voids are going to be permeable only to bitumen, and water. Some of the voids are going to be permeable only to bitumen. Now if you actually take a look at this particular void that is shown here, you can see that the whole thing is permeable to water, whereas only some portion is permeable to bitumen.

So, the air voids, so depending on the amount of bitumen that you are going to apply, depending on the air voids that you are really looking at, the mix design completely changes, and in a sense it influences the mechanical performance of the material.

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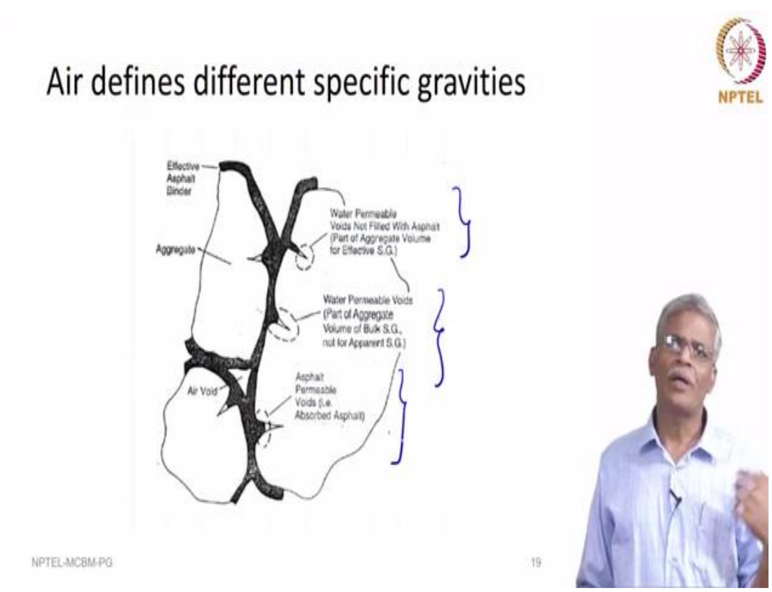

So, this also tells you that the specific gravities need not have to be the same. There are going to be different types of specific strategies, you are going to have what is really called as the bulk specific gravity. There are going to be what is really called as the effective specific gravity. And there is going to be, what is really called as the apparent specific gravity. So, depending on the volume that you are going to compute.

So if you are going to compute volumes that consist of water permeable voids that are not filled with asphalt, the specific gravity is going to be different if you use everything, water permeable voids, including the voids that are going to be permeable to asphalt, you are going to have another specific gravity. And if you are going to have asphalt permeable that is absorbed asphalt there is going to be another specific gravity.

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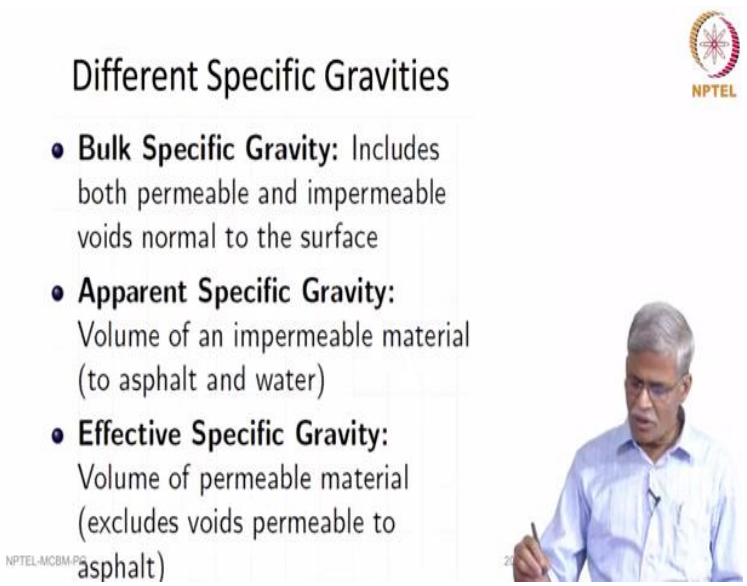

So, this is what is defined here. So bulk specific gravity includes permeable and impermeable voids that are normal to the surface, apparent specific gravity - volume of an impermeable material and effective specific gravity is volume of permeable material which excludes voids that are permeable to asphalt.