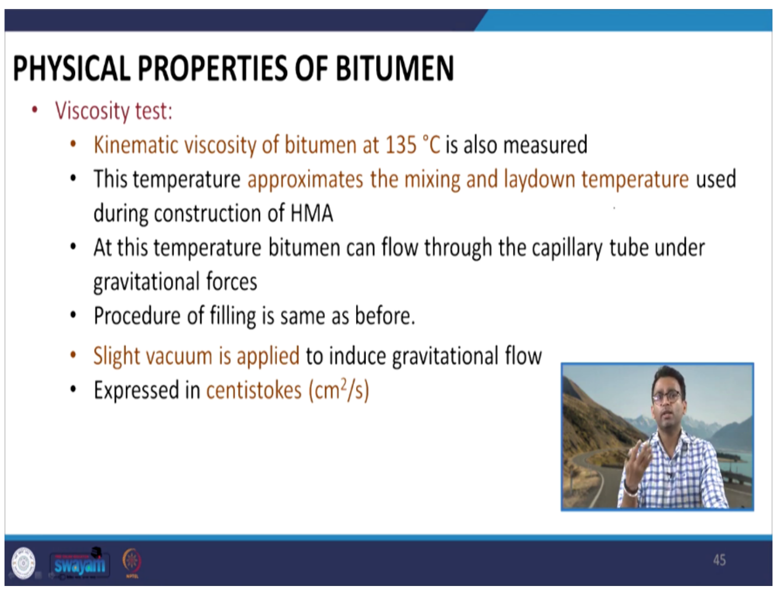
Pavement Materials
Professor. Nikhil Saboo
Department of Civil Engineering
Indian Institute of Technology, Roorkee
Lecture No. 24
Physical Properties of Bitumen (Part-2)

Hello everyone, welcome back. If you remember, in the last class, we have started our discussion on the Physical Properties of Bitumen. We have discussed various physical properties under the consistency tests, such as penetration of bitumen, softening point of bitumen, ductility of bitumen, and we started also our discussion on the viscosity properties of bitumen.

And before ending, we discussed that under the viscosity test, how the absolute viscosity of the bitumen can be determined in the laboratory using a cannon manning viscometer or a capillary viscometer. Let us continue our discussion from where we ended in the last presentation.

(Refer Slide Time: 01:23)



In addition to the absolute viscosity of the bitumen, which can be determined using a capillary viscometer we can also assess the kinematic viscosity of bitumen especially at higher temperatures. So, this temperature of interest is 135 degrees Celsius. Again, the basic question which we have to answer is that y 135 degrees Celsius is used to determine kinematic viscosity of the bitumen. So, if you remember that, when we talk about bitumen, we have to see how the bitumen undergoes various temperature ranges from the production to the in service life.

During the production period bitumen is exposed to very high temperature at this particular period or at the mixing plant, we have to ensure that the bitumen is fluid enough so, that it can be pumped and it can be mixed with the aggregate particles at such high temperatures even higher than 135 more than 150 degrees Celsius. The bitumen is also mixed with the heated mineral aggregates, where we have to ensure that sufficient coating of the bitumen takes place to ensure proper workability and homogeneity in the mix.

Later, when this particular mixture which is prepared at elevated temperatures of greater than 150 degrees Celsius is taken to the site where it is laid and compacted again at a higher temperatures which is typically more than 100 degrees Celsius. And at this temperature we again have to ensure that the bitumen has sufficient workability characteristics such that it can be compacted to the required density in the field.

So, talking about the viscosity test, at 135 degrees Celsius this can be performed using again a capillary viscometer typically at this temperature the bitumen is fluid enough so, that it can flow under gravity, which means, the requirement of applying pressure separately which we did in case of determination of viscosity at 60 degrees Celsius is not required the process of filling the tube the cannon manning tube or the U-tube remains the same here.

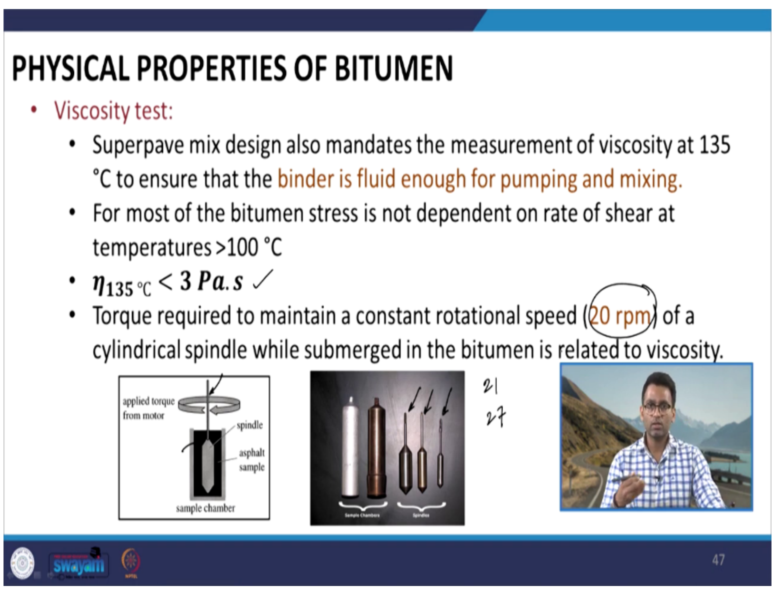
So, which means we have to fill it from the larger side opening and we have to fill it up to the filling mark then we apply a slight vacuum this slight vacuum is required just to start the gravitational flow. Now, if we are testing bitumen have different consistency having different viscosity having different density under the gravitational flow depending on the property or the viscosity of the bitumen, the time to cross this timing marks will be different. And here also the time is noted and this time is multiplied by the calibration factor of the U-Tube viscometer to calculate the viscosity of the bitumen.

Now, since here we are using the gravitational characteristics of the bitumen, we are actually measuring the kinematic viscosity in units of centistokes. Typically, if we are interested to find the absolute viscosity of the bitumen, then this kind of metric viscosity can be multiplied with the density of the bitumen to calculate the absolute viscosity.

(Refer Slide Time: 04:31)

This picture which you see on the screen is a typical picture of a U-Tube which is used during the determination of the absolute and kinematic viscosity of the bitumen in the laboratory.

(Refer Slide Time: 04:46)



Moving on, there are other methods also which are available to determine the viscosity of the bitumen at elevated temperatures. Now, the capillary viscometer they have some difficulty when we do a test on modified bitumen or crumb rubber modified bitumen. Because of the stiffness of the mix, there are chances that the flow inside the tube will not be proper, the tube may also get choked, sometimes giving us erroneous results. In such a case, if we are interested to assess the viscosity of the bitumen at temperatures greater than 100 degrees Celsius, we can use a Rotational Viscometer.

Now, in the Superpave mix design process, which we will be discussing later in our presentations, we will see that one of the requirement under the binder testing category is to ensure that the viscosity of the bitumen at 135 degrees Celsius is less than 3 Pascal second and this is required to ensure proper pumping and mixing characteristics in the bitumen.

Now, here a Rotational Viscometer is used, if you try to understand the working mechanism of a Rotational Viscometer it is simple, we have a mold which is filled with bitumen which you can see here and then we have a spindle which we insert inside this mold filled with bitumen and once the temperature at which we are interested to find out the viscosity is arrived, we will rotate the spindle inside the bitumen sample at a fixed rate of rotation or at a fixed shear rate or rotations per minute.

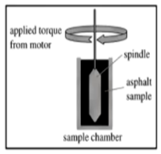
So, in the standard process which we use to determine the viscosity of the bitumen using a Rotational Viscometer a rotational speed of 20 rpm is typically applied. And here we can use several spindles to determine the viscosity of the bitumen, typically the spindle number 21 and 27 they are popularly used however, the choice of the spindle is a function of the required torque or the minimum torque which is required we have to ensure that during the testing at least greater than 10% torque is applied. So, as to calculate the viscosity of the bitumen.

So, here what we are basically doing we are trying to measure the torque which is required to rotate the spindle inside the bitumen sample at a fixed shear rate. Now, try to understand it in this way that depending on the viscosity of the bitumen, the torque required to rotate the spindle at a fixed shear rate will be different for different types of bitumen. So, this torque indirectly represents the resistance which is offered by the bitumen sample to rotate the spindle inside the mold and this torque is used to calculate the viscosity of the bitumen.

(Refer Slide Time: 08:14)

PHYSICAL PROPERTIES OF BITUMEN

- Viscosity test:
  - Superpave mix design also mandates the measurement of viscosity at 135 °C to ensure that the binder is fluid enough for pumping and mixing.
  - For most of the bitumen stress is not dependent on rate of shear at temperatures >100 °C
  - $\eta_{135\,°C} < 3\ Pa.s$
  - Torque required to maintain a constant rotational speed (20 rpm) of a cylindrical spindle while submerged in the bitumen is related to viscosity.



So, the actual calculation of the viscosity is applies some mathematical functions some calculations to be done. So, let us try to understand how the calculation is actually performed to assess the viscosity of the bitumen using the value of torque and the value of shear rate which we apply.

So, try to imagine in this way that we have a mold or we have a cylinder which is filled with bitumen and we have a spindle here say that the length of the spindle is l say the radius is r_s and this radius or the inner radius of the cylinder is r_c and we are applying a rotational speed of ω here. So, using these variables, we can calculate the viscosity at any radial distance from the center of the spindle. So, at any radial distance x, if you are interested to find out the viscosity of the bitumen, so, viscosity is basically defined as stress by shear rate. So, this is the basic definition.

Here, the shear rate which is applied can be calculated as $\dot{y} = \frac{2\omega r_c^2 r_s^2}{x^2 \times (r_c^2 - r_s^2)}$. So, x is the distance from the center of the spindle at which we are trying to find out the $viscosity \times (r_c^2 - r_s^2)$. So, this shear it can be derived and stress, so, we have torque, torque is $force \times distance$. So, distance will be r_s here and force can be written as $stress \times area$ stress or sigma into the area, which will be equal to $\sigma \pi r_s \times l \times r_s$.

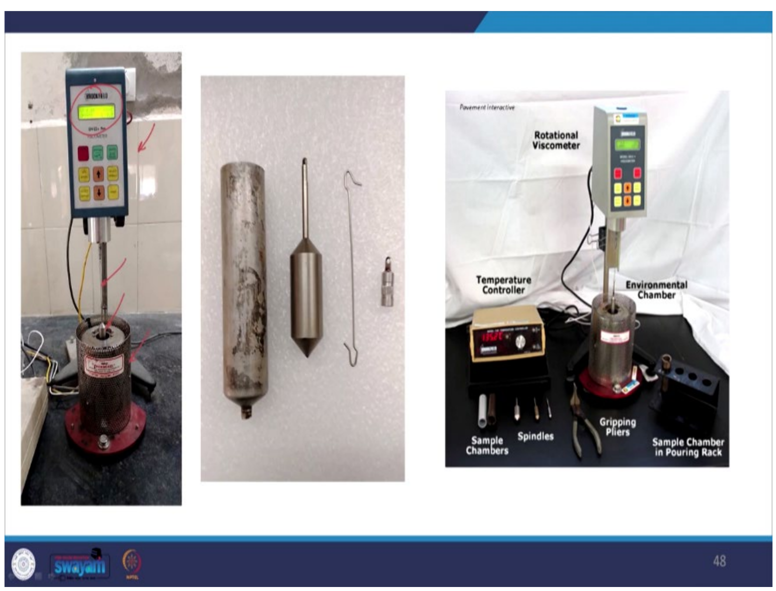
So, here $\sigma = \frac{T}{2\pi r_s^2 l}$. So, you see here that the shear rate is a function of the rotational speed which we are applying which is fixed the value of r_c. So, for a given setup which we have the value of r_c will be fixed r_s. So, this is the radius of the spindle which we are using. So, depending on the type of spindle, the radius r_s is also fixed x is any distance we are interested to assess the viscosity.

So, if you are trying to assess the viscosity at the edge of the spindle, so, the value of x will also be equal to the value of r_s and these are again constant torques, coming to the stress which you see here, it is a function of torque. So, talk the instrument is measuring it is an indirect representation of the power which is actually required to rotate the spindle r_s is the radius of the spindle which is fixed and l is the length of the spindle which is again fixed.

So, basically if we know the torque and if we know the rotational speed and if we have the geometrical attributes or geometrical parameters of the instrument, we can actually calculate the viscosity. So, this viscosity can be thus assessed using the readings of the Rotational Viscometer. Now, how the spindle looks like and how the mold inside which we put this bitumen looks like. So, this is a mold which is typically used in a Rotational Viscometer.

So, you can see here we can fill the bitumen sample which is required and then we have the spindle which will be dipped inside this mold. So, the spindle has a holder or a pin which can be used to hold the spindle and then we have an attachment which goes inside the viscometer or inside the viscometer motor which is the main part and this goes inside the thermocell at which we will maintain the constant temperature or the temperature which at which we desire to measure the viscosity and the spindle is put and it is rotated inside it is rotated at the given shear rate and depending on the torque which is required to rotate the spindle as we discussed, the viscosity can be calculated.

(Refer Slide Time: 13:02)



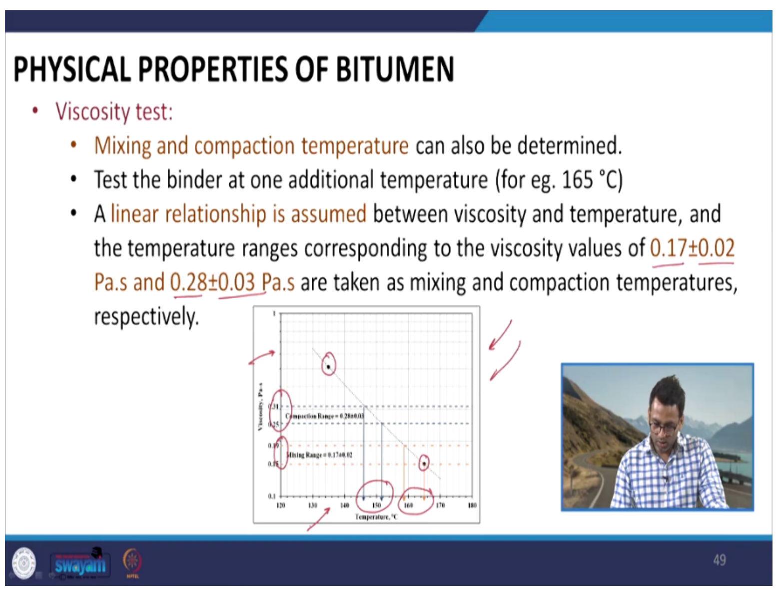
So, these are some typical pictures of Rotational Viscometer in the laboratory. So, you can see here we have a Brookfield Viscometer which is a type of Rotational Viscometer. Here we have a thermo cell at which the temperature is maintained. We have the pin and spindle arrangement here. And then we have a display which tells you that what is the shear rate we have applied what is the corresponding viscosity and what is the percentage torque which is achieved with the given spindle we have used to determine the viscosity.

The use of Rotational Viscometer is not only to determine the viscosity at a temperature of 135 degrees Celsius, Rotational Viscometers are also used to determine the mixing and compaction temperature of the bituminous mixture or the hot mix asphalt at such a higher temperatures typically 100 degrees Celsius, we assume that bitumen behaves mostly as a Newtonian fluid and therefore, the stress is independent of the shear rate.

So, therefore, the viscosity of the bitumen can be taken as an indirect representation of the workability characteristic of the mix. Now, this is our assumption that we are defining the workability attributes are the characteristics of the bituminous mixtures as a function of the viscosity of the bitumen. So, higher is the viscosity of the bitumen, more stiff is the mix less will be the workability if the bitumen viscosity is low enough, we are able to properly import the bitumen particles with the aggregates with much ease which means we have better workability

So, studies have shown that temperatures at which bitumen attains some specific viscosity that particular temperature can be considered as the mixing temperature. Also, there are some other criteria related to the viscosity, which is required at the compaction temperature.

(Refer Slide Time: 15:06)



So, here what we have to do in the Rotational Viscometer in addition to doing the test at 135 degrees Celsius, we do the test at one additional temperature let us say 160 or 165 degrees Celsius, and then we plot the relationship between viscosity and temperature.

So, if we plot it in a semi log graph where the y axis is log of viscosity and x axis is in the arithmetic scale the temperature you will see and we are doing the test at two different temperatures and we join this point using a straight line and then we will find out that what is that particular temperature range at which the viscosity is in the range of 0.17 ± 0.02 Pascal's second and the temperature corresponding to this viscosity range is considered as the mixing temperature of the bituminous mixture.

Similarly, we will see that what is that temperature range at which the viscosity of the bitumen is 0.28 ± 0.03 Pascal seconds and the temperature at which the bitumen attains this range of viscosity is termed or is denoted as the complexion temperature of the bituminous mixture. Now, though this is a typical method or typical standard which is used, this particular method may not actually work for many types or different types of bitumen.

So, this method is more suitable if the bitumen is a normal viscosity graded bitumen or an unmodified bitumen. So, researchers have shown that for modified bitumen for crumb rubber modified bitumen and also for bitumen with additives such as warm mix additives, this particular method which is called as the equi viscous method fails to give appropriate ranges of mixing and compaction temperature. In case of modified bitumen even at such high temperatures, they may not be purely Newtonian in nature.

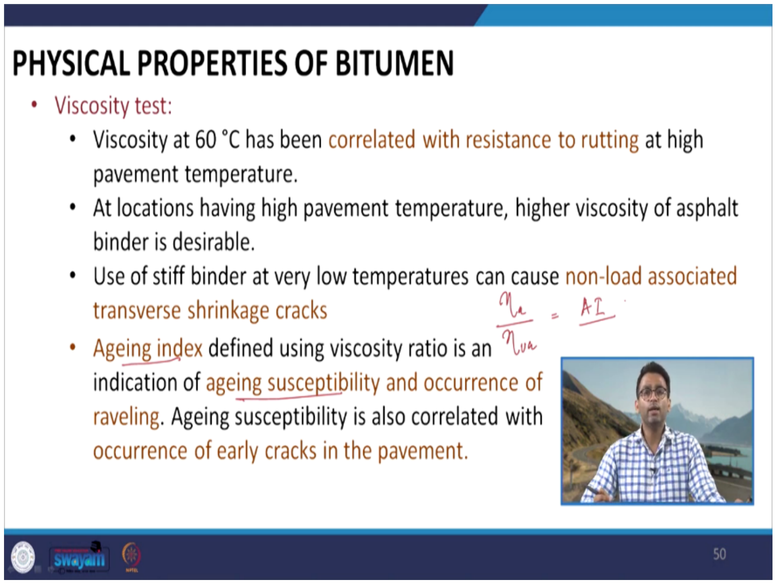
So, their behavior can be dependent on the shear rate and because of this property, this non Newtonian property, the equi viscous method may not give a true replication of the workability characteristics, which is achieved in the mixing plant in case of warm mix binders or warm mix additives, some of the warm mix technology then do not necessarily reduce the viscosity of the bitumen.

Now, talking about warm mix technology just to give you an idea, why omics technologies refer to those technologies, where we attain at least 10 to 40 degrees' Celsius reduction in the mixing and compaction temperatures of the bitumen. So, there are certain additives which are available, which we can mix either with the bitumen or directly in the mixture and this will improve the workability characteristics of the mix such that the temperature requirements for mixing and compaction goes down.

Now, some of these technologies works on the principle of reducing the frictional forces between the bitumen and the aggregates. So, as to achieve better workability but, in this particular test method, which we have discussed, we are trying to relate only the viscosity with the workability and therefore, this method fails for such type of additives or such type of modified binders.

So, this again is applicable mostly for the unmodified bitumen. So, under the viscosity test, we have discussed about various methods which can be used for example, there are capillary viscometer based methods, there are rotational viscosity based methods.

(Refer Slide Time: 19:12)



So, if we see the importance of the viscosity test and try to relate it with the performance here, the viscosity at 60 degrees Celsius the absolute viscosity of the bitumen has been correlated in various literatures with the resistance to rutting. And here the logic is that rutting resistance can be improved by improving the stiffness of the mix. So, in the mix, we have mineral aggregate particles and we have bitumen and this bitumen helps in keeping the aggregate particles together in a dense mass and bitumen being viscoelastic in nature, it becomes soft at higher temperatures.

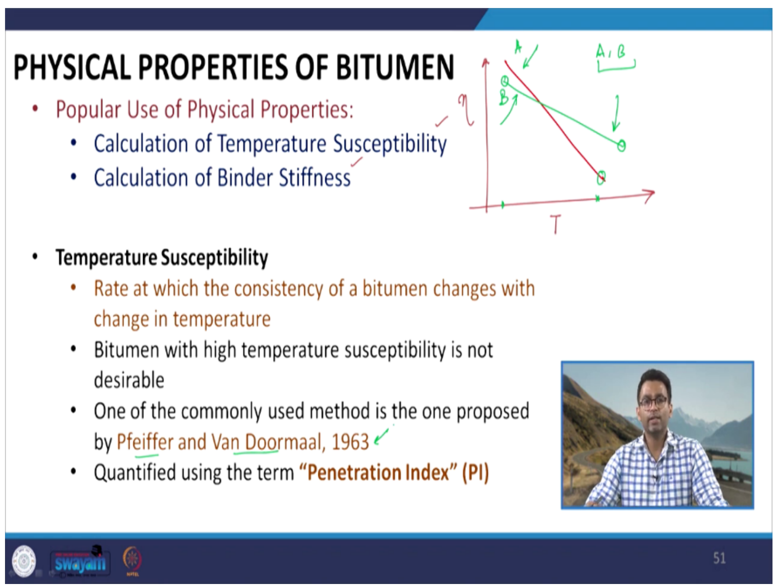
So, if at the in-service temperature at the maximum in-service temperature at any given location, if the bitumen becomes too much soft, the cohesion which is imparts will break down and permanent deformation can occur. Therefore, higher is the viscosity of the bitumen, typically at the average maximum temperature, more resistance it will offer to permanent deformations. So, at locations where we have high pavement temperature using a bitumen with higher viscosity is more desirable.

However, if the viscosity of the bitumen is high at lower temperatures, this may cause a negative effect it can lead to non-load associated transfer shrinkage cracks or temperature related cracks. Another parameter which can be calculated using the viscosity of the bitumen is its aging index. And aging index is a parameter which is used to assess the aging success, stability of the mix, about aging, we will start our discussion in the next class.

So, this is just to inform you that the viscosity which we are measuring can be also used to assess or to determine the aging susceptibility. Here the viscosity of the bitumen in an aged condition is first measured, then the bitumen is subjected to aging condition and after aging again we determine the viscosity of the bitumen and the ratio of the viscosity in aged condition to the unaged condition is denoted as the aging index and the aging index or the aging susceptibility is also an indication of the occurrence of early cracks in the pavement.

So, we want our bitumen to be less age susceptible in order to prevent the occurrence of these cracks. So, this tells us about the importance of the viscosity in relation to the actual performance of the pavement. So, now, let us see that how these consistency properties which we have discussed that is penetration, softening point viscosity and ductility they have been very popularly used to determine other properties or other performance related properties of the bitumen.

(Refer Slide Time: 22:14)



Two of the popular use of these physical property is in the calculation of temperatures susceptibility and in the calculation of binder stiffness, temperatures susceptibility is the rate at which the consistency of a bitumen changes with change in temperature. So, if we try to see the variation of the property of bitumen at different temperatures, let us say in the y-axis we have viscosity and in the x-axis we have temperature.

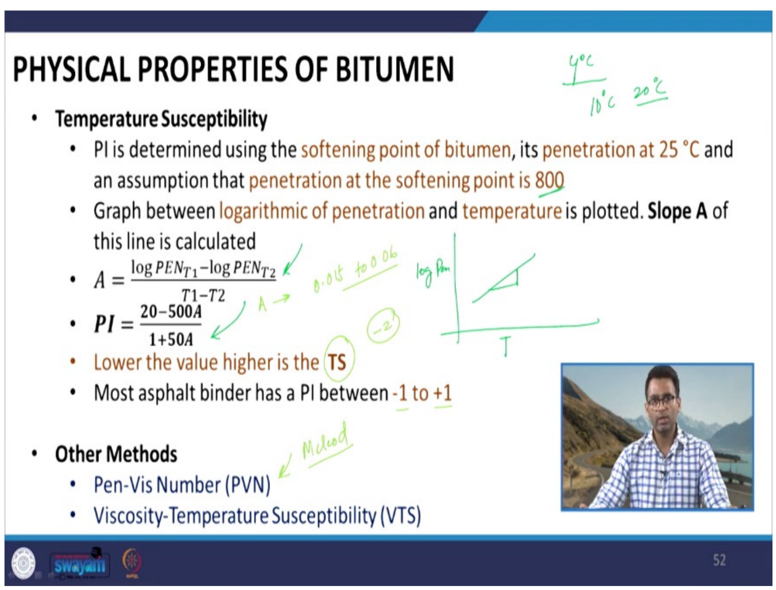
Let us say you have two bitumen for one bitumen, the variation of viscosity which temperature is something like this and for another bitumen, the second bitumen which we are trying to study the variation of viscosity with temperature is something like this, let us say this is bitumen A this is bitumen B. So, in case of bitumen A you will see that at lower temperature, it has very high viscosity, but at higher temperature, it has very low viscosity which means the viscosity drops at a much faster rate.

On the other hand, in case of bitumen B, the viscosity at lower temperature is lower than the viscosity of bitumen A and it higher temperature, the viscosity of bitumen B is higher than the viscosity of bitumen A. So, if you are given a choice to choose between A and B, which bitumen are we going to choose or are you going to choose? So, you have to understand that at low temperature, we desire lower viscosity, why because, if the stiffness of the bitumen is very high at lower temperature this can lead to temperature induced crack or non-load associated shrinkage cracks.

On the other hand, at higher temperatures, we want the viscosity of the bitumen to be higher. The reason being that if we are talking about let us say the higher temperature is 60 or 70 degree in service temperature, then we want stiffness in the bitumen in order to resist the permanent deformation or rutting failure in the bituminous mixture. So, therefore, bitumen A here will have higher chances of low temperature cracking as well as rutting. On the other hand, bitumen B has lower chances of low temperature cracking and also lower chances of high temperature rutting or permanent deformation.

So therefore, temperature susceptibility gives us an indication about the change in the property of the bitumen when it undergoes it a range of temperature change. Though there are various methods by which we can determine the temperatures susceptibility of the bitumen. One of the commonly used method is the one which was proposed by Pfeiffer and Van Doormaal 1963 and they proposed the term penetration index to assess the temperatures susceptibility of the bitumen.

(Refer Slide Time: 25:31)



Penetration index can be determined just by using the softening point value of the bitumen and the penetration value of the bitumen at 25 degrees Celsius. Additional assumption here, which they have taken for assessing the penetration index is that the penetration at the softening point is approximately 800.

Now, this may not be always true, therefore, researchers have suggested that instead of assuming the penetration of the bitumen at softening point as 800, we can also determine the penetration at any other temperature then 25 degrees Celsius. If you remember, when we were discussing about the penetration test, we also discussed that few specifications required that the penetration of the bitumen to be done at 4 degrees Celsius.

So, we can do the penetration test at 4 degrees Celsius or 10 degrees Celsius or 20 degrees Celsius, any other temperature then 25 degrees Celsius and then use this concept to determine the penetration index. First what we do that we plot the variation of log of penetration with temperature.

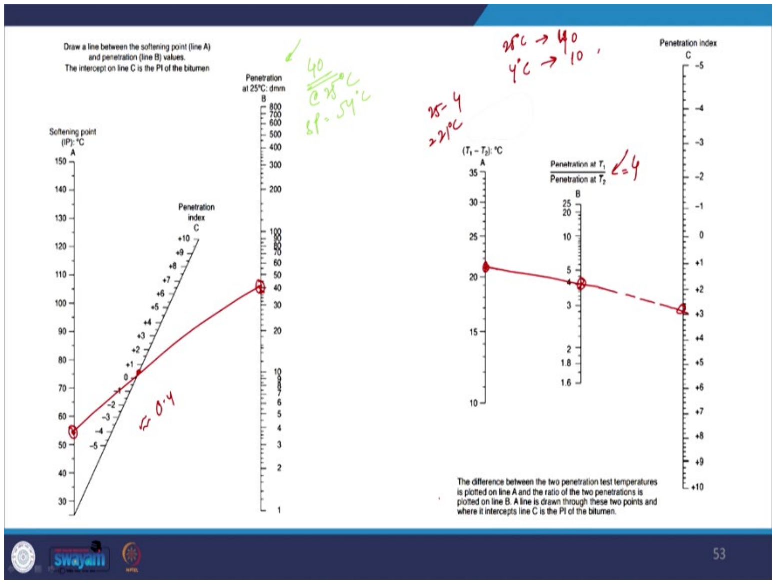
So, with increase in temperature the penetration value will increase. And then the slope is calculated for this particular variation. And the slope which you can see is calculated as $\frac{logPEN_{T1}-logPEN_{T2}}{T1-T2}$ is used in this particular formula to calculate the penetration index of the bitumen. So, $PI = \frac{20-50A}{1+50A}$.

Here the value of A it typically ranges from 0.015 to 0.06 which indicates that bitumen from different sources can have a very wide range of penetration index and therefore, temperatures susceptibility lower is the value of the penetration index higher will be the temperature susceptibility of the bitumen. So, for most typical bitumen's the penetration index it ranges from minus 1 to plus 1 it has been found that bitumen whose penetration index is as low as minus 2 can be very high low temperatures acceptable.

Well, there are other methods also, as I said, which can be used to determine the temperature susceptibility, though they are not very popularly used one of these methods is the penetration viscosity number, which was proposed by Mcleod and in this particular method to in order to assess the temperature susceptibility, we calculate the penetration viscosity number.

So, the penetration at 25 degrees Celsius and the viscosity value either at 135 degrees Celsius or 60 degrees Celsius can be used in a formula to calculate the temperatures susceptibility in the viscosity temperature susceptibility VTS what we do a double log viscosity is used and it is plotted with log of temperature. So, we have log viscosity and its variation is plotted against log of temperature which is used to assess the temperatures acceptability of the bitumen, but as I said mostly penetration index has been used popularly to determine the temperatures susceptibility of asphalt binder or bitumen.

(Refer Slide Time: 29:22)



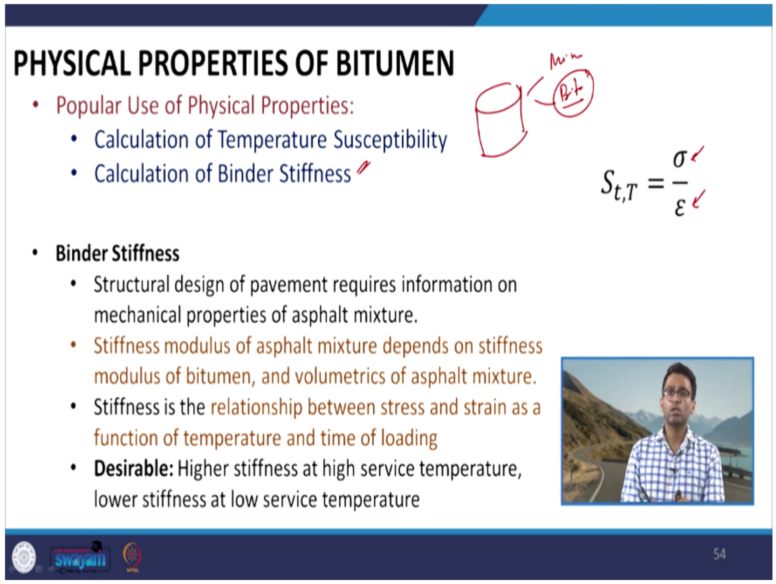
Now, since penetration index as I said is popularly used let us try to find out the temperatures susceptibility using these nomographs. In the first nomograph, which is plotted here they have assumed that the penetration value at the softening point is 800. So, let us say that we have a bitumen with a penetration value of 40 at 25 degrees Celsius and the softening point of this particular bitumen is 54 degrees Celsius. So, how do you use the first nomograph? First we will mark the penetration value.

So, this is 40 the softening point is 54 somewhere here and now, we just have to join these two points. So, you can see that if you join these two points the penetration index value, I am not sure if it is a very straight line, but the penetration index value is a little higher than 0 maybe 0.4.

Coming to the second nomograph, here, we have to measure the penetration value at two temperatures, let us say we have done it at 25 degrees Celsius, which is 40 and we have also measured at 4 degrees Celsius and the value came out as 10. And then therefore, the $\frac{PEN_{T1}}{PEN_{T2}} = 4$ in our case and (T1 - T2) is (25 – 4) which is 21 degrees Celsius.

So, let us mark this in this nomograph. So, $\frac{T1}{T2}$ is 4, which we have marked here and (T1 - T2) is 21 degrees Celsius which is marked here and then we will join this to line and we will extend it here. So, you can see that here the penetration index value of the bitumen is somewhere near to 3. So, this two nomograph can thus be used to determine the temperature susceptibility of the bitumen in terms of penetration index.

(Refer Slide Time: 31:45)

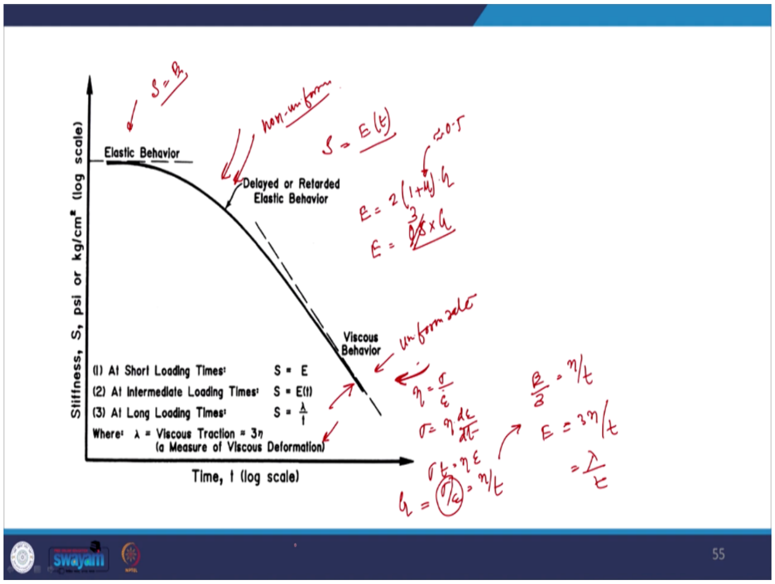


Now, let us see how the binder stiffness is calculated using these physical properties. Let us first try to understand why we are interested in buying the stiffness. We will see later in our presentation that for the structural design of pavement, we need to input the values of the mechanical properties of the asphalt mixture and one of these mechanical property is the stiffness of the mixture.

So, stiffness modelers or stiffness of a asphalt mixture is basically the ratio of the stress and strain, which is a function of time and temperature. So, we are using the term stiffness which is analogous to elastic modulus, but stiffness here refers to the ratio of stress and strain, which is a function of time and temperature typical for viscoelastic materials. If you try to imagine an asphalt mixture or a bituminous mixture, what it is composed of it is composed of mineral aggregates and it is composed of bitumen and if you see the response of the bituminous mixture to any given loading condition, it is time dependent and temperature dependent which means it acts like a viscoelastic material.

Now, this characteristic of viscoelasticity is actually imparted by the presence of bitumen. Therefore, we can agree to the fact that the stiffness of the mixture will be a function of the stiffness of the bitumen and the volumetric parameters of the bituminous mixture in question. Therefore, if we can evaluate or if we can determine the stiffness of the bitumen, we can indirectly predict the stiffness of the bituminous mixture as well from the bitumen what do we desire, we desire that, at higher surface temperature the stiffness should be high and at lower surface temperature the stiffness should be low so, that we can have good resistance to permanent deformation as well as to low temperature cracking.

(Refer Slide Time: 33:53)



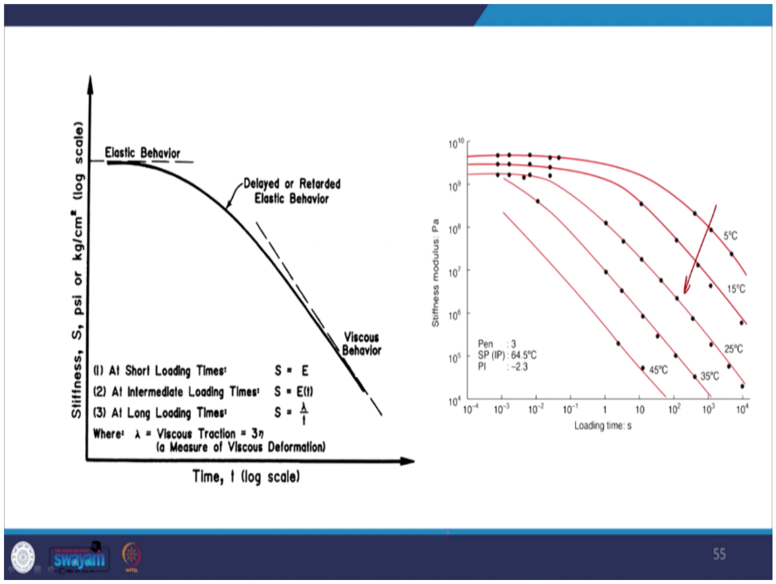
This graph shows the variation of stiffness of bitumen with time at one particular given temperature, let us try to understand the variation of the stiffness with temperature. If you see that at the short loading time, the stiffness is time independent and approaches the elastic modulus. So, here the stiffness is time independent and it approaches the elastic modulus. If you see at longer loading times, here, the stiffness reduces but at a uniform rate and the response is mostly viscous in nature at the intermediate time range, the responses mostly delayed elastic in nature. And here the variation of viscosity is non uniform with the increase in time.

So, you can see that the stiffness here is a function of time and here the if we try to find out the stiffness in some form let us try to understand what happens here. Here you see since the response is more viscous in nature, so, we can write that viscosity is stress upon shear rate for instantaneous loading sigma is equal to bita de upon dt for instantaneous loading, we can write that sigma t is equal to Nita e.

So, $\frac{\sigma}{\varepsilon} = \frac{\eta}{t}$ and here this $\frac{\sigma}{\varepsilon}$ is equal to a representation of the shear modulus let us say, and if you remember that, in mechanics of solid, you must have learned that $E = 2(1+\mu)G$. So, if we assume that the value of mu is approximately 0.5, we can say that the elastic modulus is three times the shear modulus. So, if we replace the value of Gand try to find out the stiffness in terms of E, then we can write that this is equal to $\frac{E}{3} \times \frac{\eta}{t}$.

So, $E = \frac{3\eta}{t}$. or we can say $E = \frac{\lambda}{t}$. Here this λ is basically a measure of the viscous deformation of the bitumen sample. So, as I said this picture or this graph is at one particular temperature.

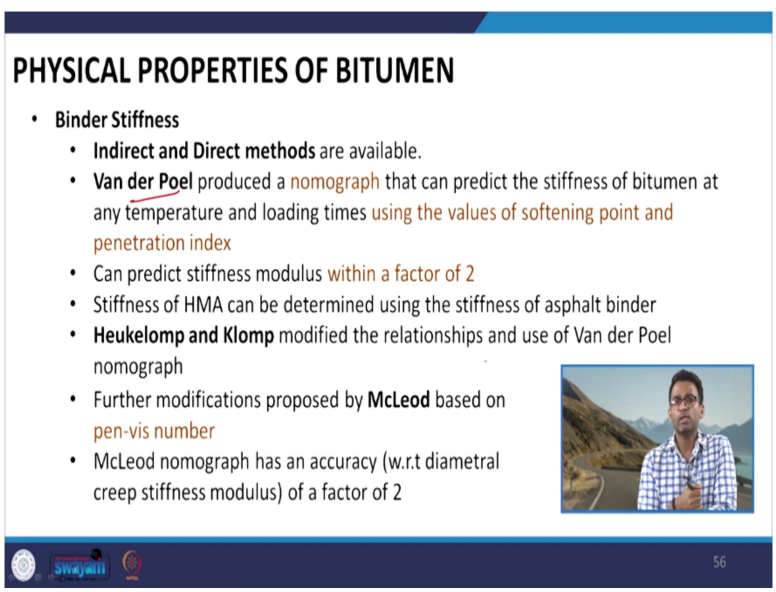
(Refer Slide Time: 36:34)



Similarly, we can have the variation of stiffness with time at different temperatures and it is obvious that with increase in temperature, the stiffness of the bitumen will reduce and different bitumen can have different variation in the stiffness versus time graph. Of course, this picture which we are seeing on the screen is a simple representation of the stiffness.

If we consider the 3D stress strain system or 3D stress system, the response or this particular variation will be more complex in nature. So, however, for most of the purposes, it is found that uniaxial stress system is adequate to study the response of the bitumen and therefore, the bituminous mixture.

(Refer Slide Time: 37:19)



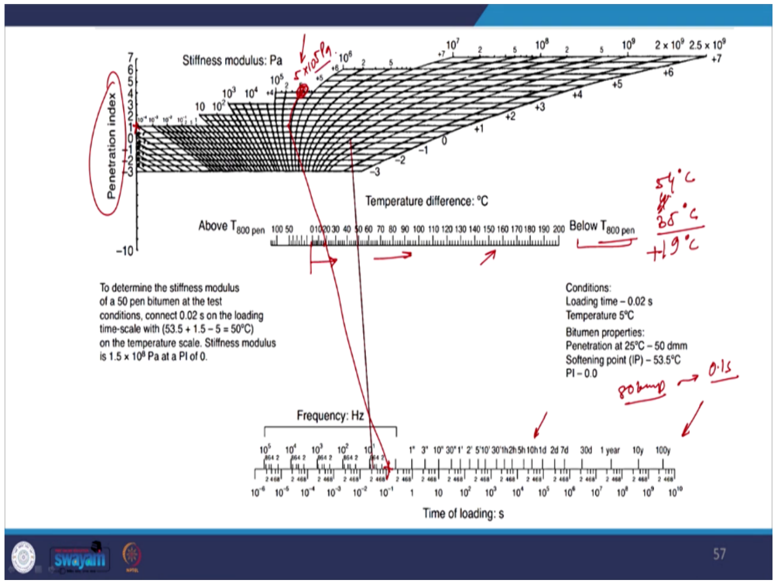
In order to determine the stiffness of the bitumen, which we are interested in, we can use indirect methods as well as direct methods. In the direct methods, we actually test the bitumen using some instrument and then try to find out the stiffness of the bitumen, which we will be discussing when we will talk about the rheological tests on bitumen. Since now, we are interested to study that how the physical properties can be used to derive the stiffness of the bitumen we are basically interested to see the indirect method.

Now, one of the most popularly used indirect method is the nomograph proposed by Van der Poel. So, Van der Poel proposed a nomograph which can be used to predict the stiffness of the bitumen at any temperature and loading time using the values of only the softening point and penetration index.

Now, this seems to be very interesting because, if you have only simple properties or simple tests done on bitumen, you can actually find out a complicated or a more exact behavior or you can predict the more exact behavior in terms of stiffness, which is actually a function of time and temperature. Studies have found that this nomograph can predict or the accuracy of this normal graph has a factor of 2. After finding the stiffness of the bitumen, we have another chart which can be used to find out the stiffness of the bituminous mixture, depending on the stiffness of the bitumen and the volumetric properties of the bituminous mixture.

Later studies were also done to modify the nomograph proposed by Van der Poel for example, Heukelomk and Klomp they did some modifications to the relationships and use the Van der Poel nomograph to refine the prediction later on Mcleod are also refined the prediction given by Heukelomp and Klomp by adding the penetration viscosity number in the prediction chart and Mcleod nomograph also has an accuracy of a factor of approximately 2.

(Refer Slide Time: 39:23)



Now since Van der Poel nomograph is more popular and has been successfully used in various research, let us try to see how this nomograph we can use to calculate or to predict the stiffness of the bitumen and the bituminous mixture. So, first I will try to explain what are the different parts of this particular nomograph.

In the lower part, you have a scale which tells you the time of the loading or frequency for example, and this frequency is actually a replication of the speed of the vehicle. So, for example, if we are interested to find out the response of the bitumen in a bituminous mixture, which is placed in a pavement where the average speed of the vehicle is let us say 80 kmph.

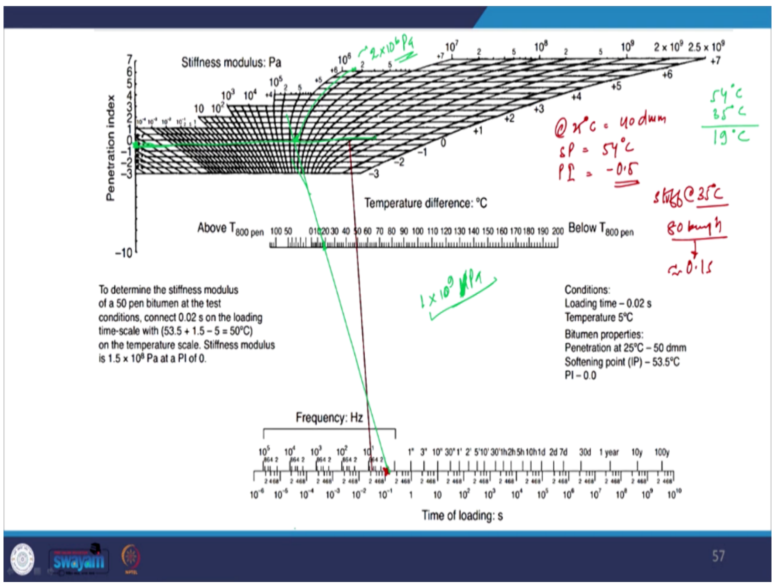
So, if you try to further derive will see that this approximately represents 0.1 Second loading time or 10 hertz is a frequency. So, the first axis which you see on the lower part basically can be used to select the time of loading or the frequency of loading at which we are interested to find out the stiffness of the bitumen coming to the second scale.

Here we have the temperature difference between the temperature at which we are interested to find out the stiffness and the softening point of the bitumen, which is represented as T 800 Penetration because, as we discussed previously that there is an assumption that at the softening point the penetration to the viscosity is approximately 800. So, let us say that the softening point is 54 degrees Celsius and we are interested to find out the stiffness of the bitumen at 35 degrees Celsius. So, this gives us 90 degrees Celsius.

So, therefore, these 90 degrees Celsius is plus So, we are looking at a temperature which is lower than the softening point. So, we will see in this part of the scale which is on the right side of the 0. So, we have to mark that particular point here or whatever value which comes at the temperature at which we are interested to find the stiffness of the bitumen, this particular scale on the upper part, it gives us the stiffness of the bitumen, if we know the penetration index value.

So, if you know the penetration index value, we will just mark it let us say that if the penetration index is 1 and we are interested to see at 0.1. So, we will just extend this graph to this particular point, we are we are interested to find out the stiffness and then we can read the particular stiffness in terms of Pascal's. So, let us say if this is the point then it says this is 2×10^5 Pascal's. So, this is the stiffness of the bitumen.

(Refer Slide Time: 42:26)



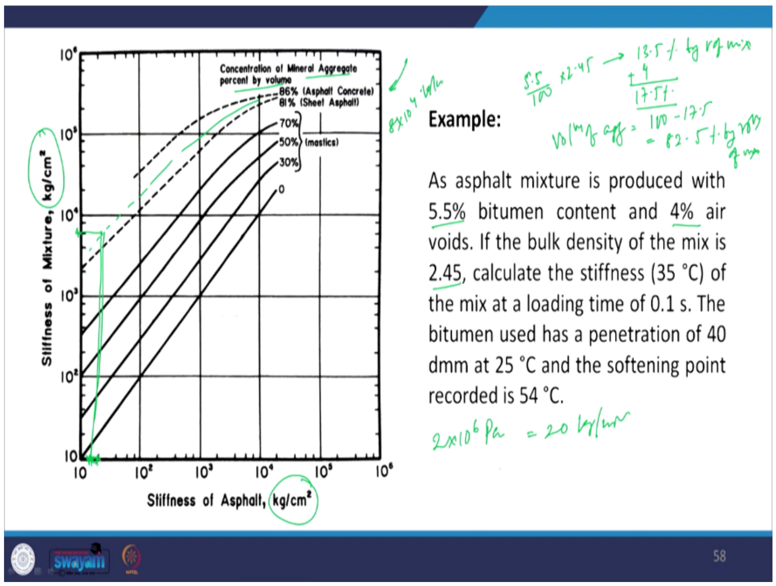
Let us try to understand the use of this chart with an example. So, we will use the similar example, which we discussed while deriving the penetration index. So, let us say that the penetration at 25 degrees Celsius is 40 dmm the softening point is 54 degrees Celsius and let us say that the penetration index which we calculated was around minus 0.5. And we are interested to find out the stiffness at 35 degrees Celsius, which let us say is the average in service pavement temperature in tropical climates looking at a pavement where the vehicle is moving at a speed of 80 kmph.

So, we are looking at the loading time of 0.1 second approximately we will first mark the 0.1 second here, so, I think this is 0.1 second, this has been marked here, then, we have to see the temperature difference. So, it is 54 degrees Celsius 35 degrees Celsius we are interested in so, this is 19 degrees Celsius. So, let us mark these 19 degrees Celsius here. And now, the penetration index is minus 0.5 as we calculated which is somewhere here.

I will draw a straight line first from minus 0.5, then I will join this two points and extend this line to intersect the penetration index line which I have just drawn. So, this is 1 and I am just extending it. So, it meets somewhere here. And if you see this is somewhere here, let us say that this is approximately 1 point something let us say this is 2×10^6 Pascal's. So, 2×10^6 Pascal is the stiffness of the bitumen, which we just predicted from this particular nomograph.

Another important point to mention here that is that usually at lower temperatures and very high frequency, all bitumen it approaches a limiting value of stiffness of approximately 2×10^9 Pascal's approximately. So it is around like 1 Giga Pascal.

(Refer Slide Time: 45:11)



So, let us now proceed and see further that how the stiffness of the bituminous mixture can be determined from the second graph or the nomograph which we have this is also the nomograph which was proposed by Ven der Poel and here you see on the y axis we have stiffness in kg per centimeter square, this is the stiffness of asphalt in kg per centimeter square and here we have different lines corresponding to the concentration of mineral aggregate percent by volume of the mixture.

So, in this example, which we are doing, let us say that we are looking at a mixture which is produced at 5.5 percent bitumen content by weight of the mix has a here air void of 4 percent and the bulk density of the mix is 2.45. So, if you try to find out what is the volume of bitumen in this particular mixture, so, it is how much $\frac{5}{100} \times 2.45$. So, you will get as approximately 13.5 percent by volume of mix and we have 4 percent here white, so, adding the 4 percent air white we have 17.5 percent by volume of the mix.

So, the volume of aggregates is basically (100 -17.5) which is 82.5 percent by volume of mix. So, here you see we have 86, 81 so, maybe one graph will be somewhere here somewhere 82. And the stiffness of the bitumen, which we predicted using the previous nomograph 2×10^6 Pascal's which is actually 20 kg per centimeter square. So, this is 40 Maybe here 20 And then we have to extend this graph to particular dislocation somewhere here is not it.

So, this is what you get here. So, if you extend this you will get that this is somewhere between 468 8×10^4 kg per centimeter square just an example. So, in this way using both these nomographs we can predict the stiffness of the bituminous mixture. So, this shows that how strong this particular nomograph can be, when we only have limited data available with us definitely, this will not give us the exact value of the stiffness, but this can give us at least a rough idea of the first estimate of the stiffness of the bituminous mixture. And very interestingly only with the help of simple physical properties such as penetration and softening point.

With this we will stop here today and in the next presentation, we will continue discussing the physical properties of the bitumen and we will start discussing about the durability aspects of the bitumen where we will talk about the short-term aging and long term aging characteristics of the bitumen. Thank you.