Mechanical Characterization of Bituminous Materials
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Lecture 30
Performance Grading- Part 2

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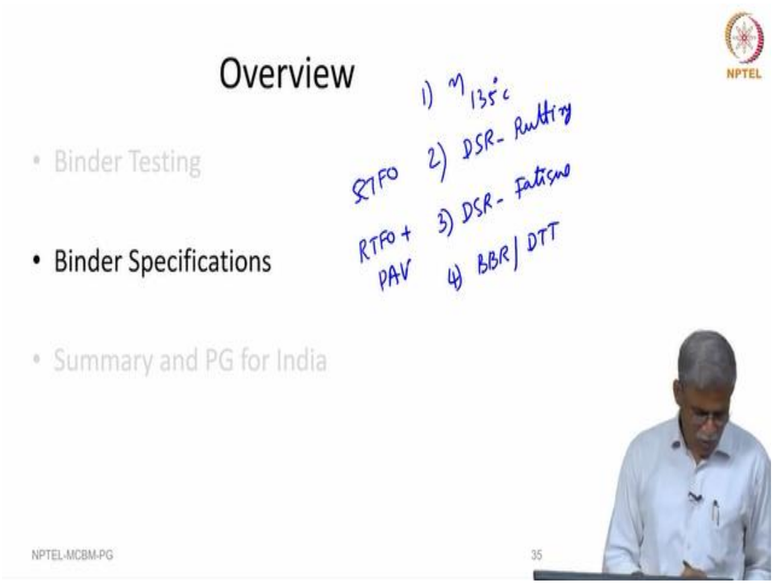

So now what we really understood was we need to do many tests on the bitumen, in fact if you say the recap quickly related with the viscosity grading in viscosity gradient, we measured penetration at 25 degree centigrade softening point, viscosity at 60 degrees centigrade and kinematic viscosity at 135 degree centigrade. Viscosity at 60 degree centigrade was performed by you using a vacuum capillary viscometer.

You subjected the sample to short term aging and ductility test was carried out as well as penetration was carried out and then the viscosity at 60 was measured and all of them were measured at a fixed temperature and depending on the grade values were given here. Now let us take a look at what we discussed till now for the PG, first and foremost thing is as far as the construction operation is concerned, we are still going to do the test at 135 degree centigrade but instead of using a kinematic viscometer, we are going to use a rotational viscometer and record the absolute value of the viscosity that is number one.

Then after that for rutting we are going to measure the rheological properties at unaged and short term aged conditions depending on the geographical locations where you are going to construct.

And in fact, if you notice it these values 1 kilopascal or 2.2 kilopascals were fixed and you are expected to find out the temperature at which these values will be met. Then after subjecting the sample to short term aging we also subjected to long term aging and we are going to do it for fatigue and then for low temperature we are going to do a BBR or a direct tension. So there is going to be RTFO aged sample, there is going to be an RTFO + PAV aged sample.

So looks like we have a complex set of testing that needs to be done not only that we also need to spend some time thinking about the maximum intermediate temperature as well as the minimum pavement temperature where you are going to construct a road. When we talk about the viscosity, I gave you an indication about which grade should be used depending on the geographical location. But here it is lot more specific. Right?

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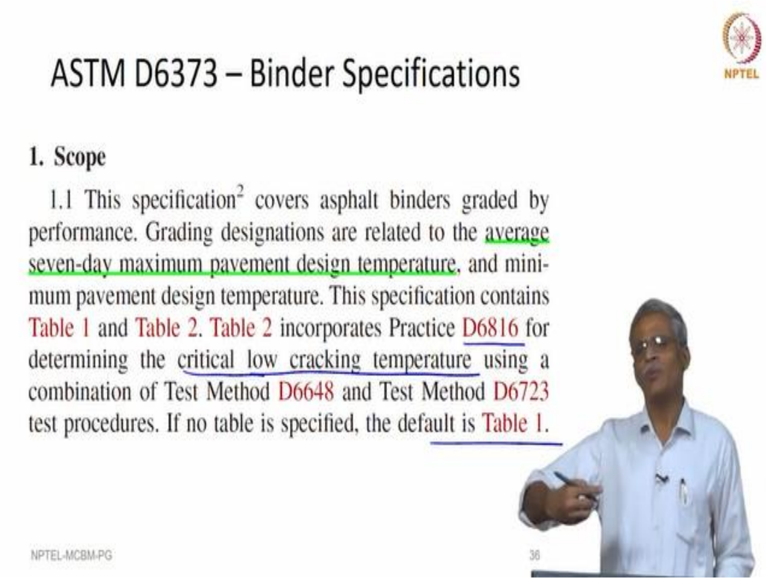

So I am just going to read out few sentences from the ASTM D6373 binder specification and the most important is the grading designations are related to the average 7 day maximum pavement design temperature and minimum pavement design temperature. In the earlier version, there was only one table that was given but in the recent version of ASTMT 6373, two tables are given.

There is a procedure that is given as using 6816 in table 2 and that tells you how to find out the low critical low cracking temperature using a combination of test methods. But if we will be discussing it as we go along but if there is no table that is specified, Superpave says you just take table 1. This is more or less similar to the ASTM D3381 in which there was 2 table that was mentioned in which the default was taken as table 2, if you recollect the discussion we have right?

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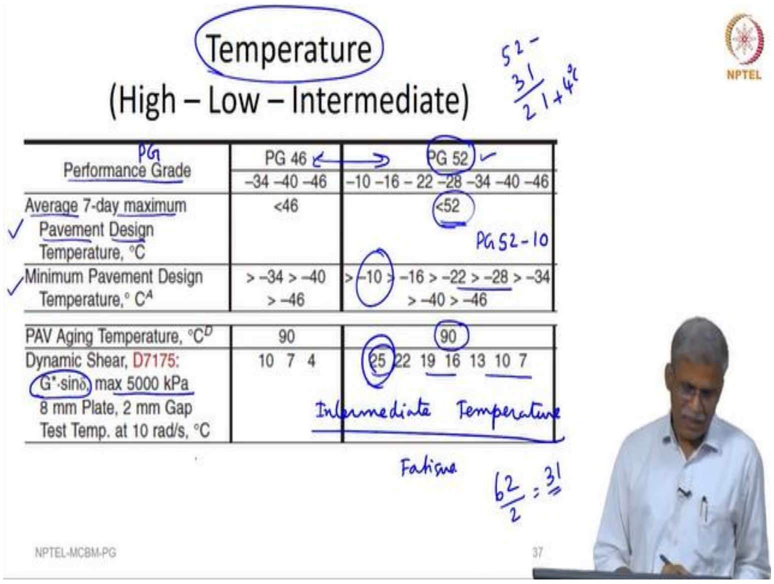

Now, this is the crux, this is the table that you need to see here very carefully. So I have split the specification and to do portion here. What you see here is performance grade, PG and it is 46 or 52 on the table is quite long it will be given some given to you as part of the course material, so you can take a look at it. So this says average 7 day maximum pavement designed temperature should be if it is less than or equal to 52, you take a PG of 52 centigrade. Okay?

So what you should do is to guess get some idea about the expected air temperature for the next 10 years. Use some kind of an algorithm to find out what will be the pavement temperature and knowing the pavement temperature, find out what is the average 7 day maximum pavement to design temperature and for instance if it is less than 52 then you take a PG-52.

Now, you will also notice that there are some values that are given here -10, -16, - 22 to - 28, -34, -40 and - 46. These are the minimum pavement design temperature. So that means if you write PG 52 - 10. So this corresponds to this value. So it this particular grade of bitumen can be give a satisfactory performance if the 7 day maximum pavement design temperature is less than 52 and it is up to - 10 degree centigrade, Okay?

Now for this particular location ASTM prescribes that you should do the PAV aging temperature at 90 degree centigrade and you also see that there is an intermediate temperature that is prescribed here. So this is for the fatigue part. So after doing the short term aging and when you do the long term aging at 90 degree centigrade and when you measure the G star sine delta values here, you are expected to if the value that you measure is around maximum of 5000 kilopascal, when you heat it at 25 degrees centigrade.

So that any for any temperature above 25 degrees centigrade it is fine, but if it is going to be below 25 degrees centigrade you are going to have a problem with this, so this is the limiting value that is given here. So how do we get this 56, 10 and 25, in fact if you actually take a look at it, it is a very empirical algorithm that is used, so 52 and 10. So the difference is going to be 62, Right? And 62 divided by 2 is 31.

So if you take 52 - 31 you are going to get 21 and they add 4 degree centigrade here to get this 25, okay? So that is the way in which these things are computed. The reason why they are computed like this depends on a detailed weather analysis as well as the use of the master curve also. For instance any binder that passes G star sign delta at less than 52 degrees centigrade should also show a G star times sine delta of a maximum of 5000 kilopascal at a less than 25 degrees centigrade, so this is understood okay?

So you have to notice few other things there is a 6 degree difference between each PG 46 and 52. Originally it was 3 degrees centigrade but when the binder manufacturers expressed objection, it was contracted into the 6 degrees centigrade, you will also notice that there is another 6 degree difference in the lower temperature, but even you look at the intermediate temperature the same 3 degrees centigrade is maintaining here, okay?

So to summarize this is a very important table to summarize you have to find out the air temperature, you have to find out the pavement temperature, knowing the pavement temperature compute the average 7 day maximum pavement temperature, right. And then check for what is the PG that you will use. Now if you know, what is the PG that you are going to use, you will be able to prescribe limits for rutting as well as fatigue.

On the minimum pavement design temperature will also be given by the depending on the weather conditions and then the temperature at which you have to age your binder to simulate the long-term aging is also prescribed by this and in fact what you see here is temperature plays a very, very critical role in PG unlike viscosity grading in which we did not worry about anything associated with temperature, we just measured one at 60 one at 20 degrees centigrade and a softening point of temperature and we just moved on.

But here you are worried about all these temperatures and you also need to understand that from G star sine G star by sine delta rutting which is at high temperature to the appropriate value of G star times delta for the fatigue you have to understand that these numbers have been worked out based on the manner in which the master curve of the material exhibits its behaviour, okay? Right?

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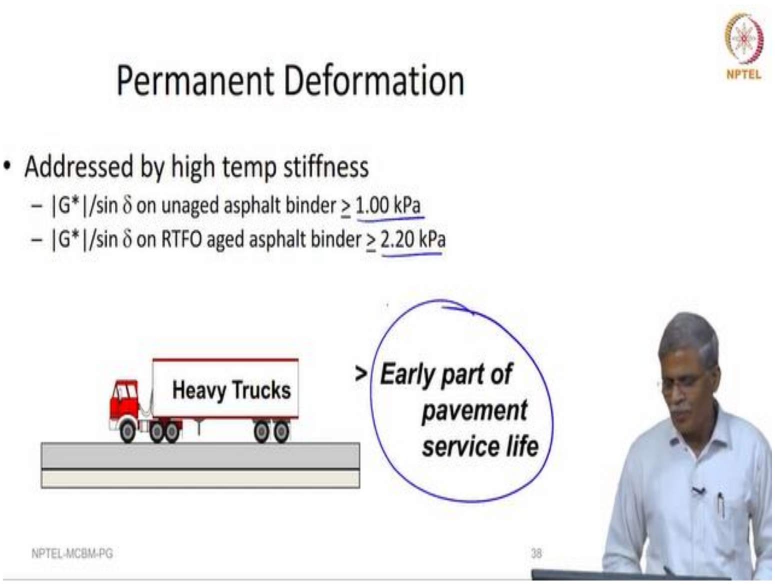

So what is the reason for this? So this G star by sine delta of value that is given here as 1 kilopascal and 2.2 kilopascal is related to the early part of the pavement service life.

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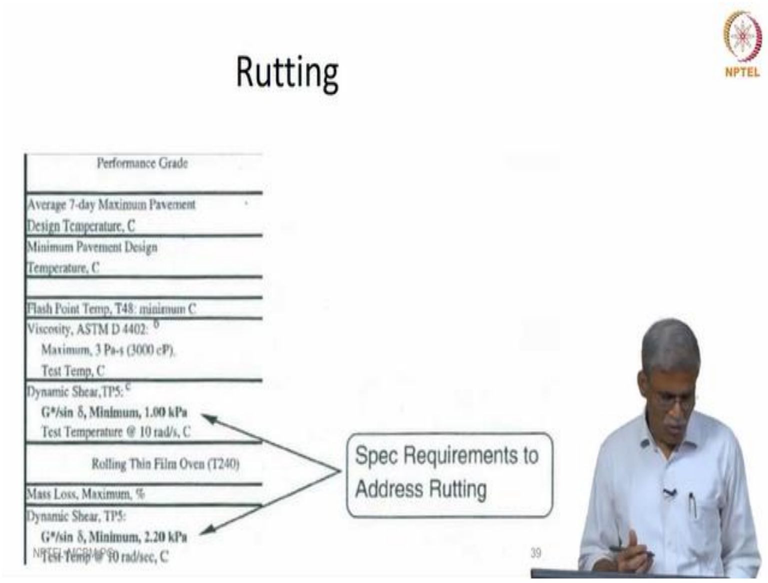

And how it is written here, please understand this carefully look at this here in performance grade specification, the spec parameters come to the left hand side, on the temperature is listed in the main table, so it says G star by sine delta minimum 1 kilopascal reminds the same. That is the most important thing, whether you construct the road in Chennai or in Nagpur or in Srinagar the parameters related to rutting remain the same, only the associate temperature changes. That is not the same case when we did the viscosity grading in which we kept the temperature constant and we only vary the viscosity but here we are keeping the rutting parameter constant and we are only looking at the variation associated with the temperature.

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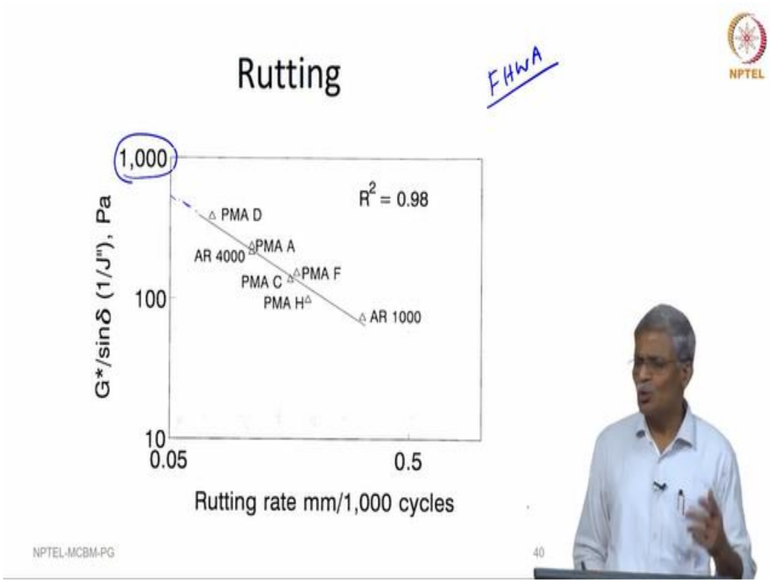

So in fact this is a very interesting graph you will see it in the FHWA report that I referenced in the earlier you can actually see how one got this 1 kilopascal, lot of data was collected and in fact what you see here is only a snapshot, so they were trying to see whether the rutting rate versus G stars by sine delta can have some relation so when they extended this it came somewhere below 1 kilopascal and they kept it as 1 kilopascal for the rutting requirement.

And there is always an idea that when the material ages the viscosity of the material for most of the binders if it is a good performing material which is not having a very high aging susceptibility, the viscosity increase will be in the order of 2 to 2.5 for reasons this known to them, they took it as 2.2. So that is why you also get that as 2.2, right?

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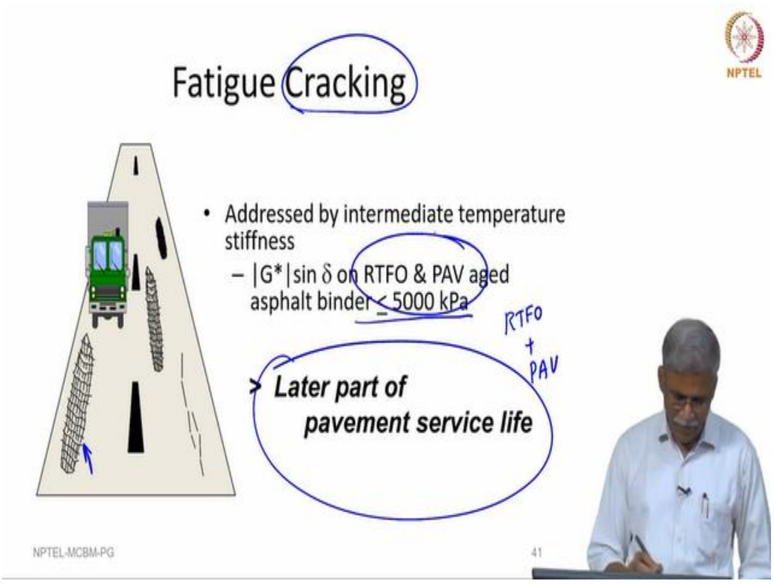

So as far as the fatigue is concerned one needs to understand this very carefully always the terminology of fatigue cracking is used when it is specified because in the field what you see here is something like this your map cracking or alligator cracking. But when we do that test in the laboratory, we never crack the sample, the bituminous binder is subjected to only a testing at the particular intermediary temperature.

So what we are doing is we are actually making a jump here, finding out what is the damage or the energy that is dissipated in the material during that particular temperature and then making a connection with what can happen if the binder is used and how it can lead to cracking at the intermediate temperature. So again lot of statistical analysis field data laboratory data have been used before this parameter has been worked out in fact and this is more or less at the later part of the pavement service life. So that is why we do the RTFO + PAV aged material here, okay? Right?

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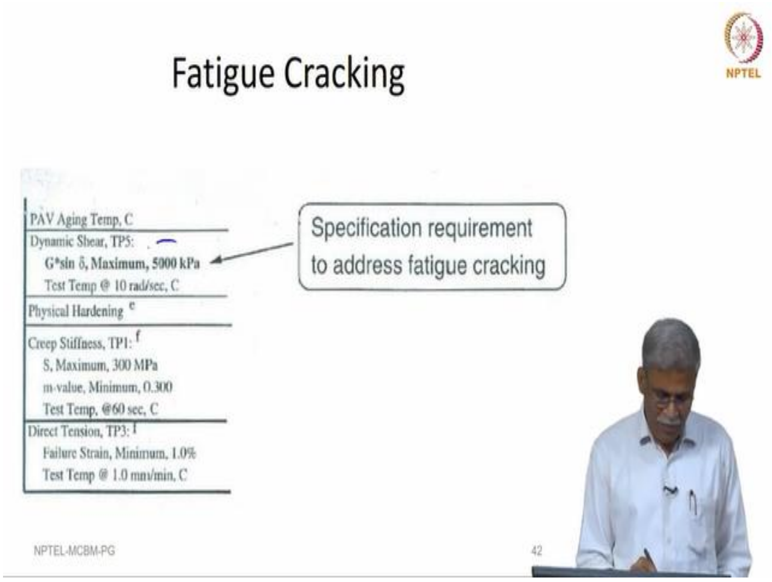

And in fact, if you look at it from the fatigue damage perspective the specification requirement address fatigue cracking is kept at 5000 kilopascal.

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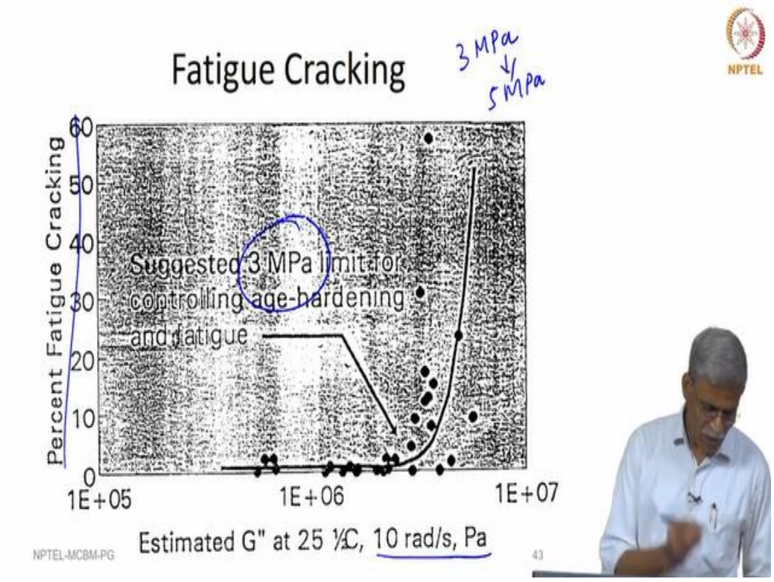

And if you actually see the old graph, I could not get a better graph than this in the olden days; they used to believe only in 3 megapascal, Okay? So this is the estimated G star at 10 radians per second, so this is what was carried out on the percetage fatigue cracking. Basically you see a very good functioning pavement a test track try and collect find out what is the crack intensity that has happened there.

Try to collect the binder from there under two are testing and then try and see whether you could come out with parameters that could be related with the fatigue that you are seeing that.

So this was taken as a suggested 3 mega Pascal limit for controlling the age hardening as well as fatigue but later it was moved into 5 MPa, Okay? Right?

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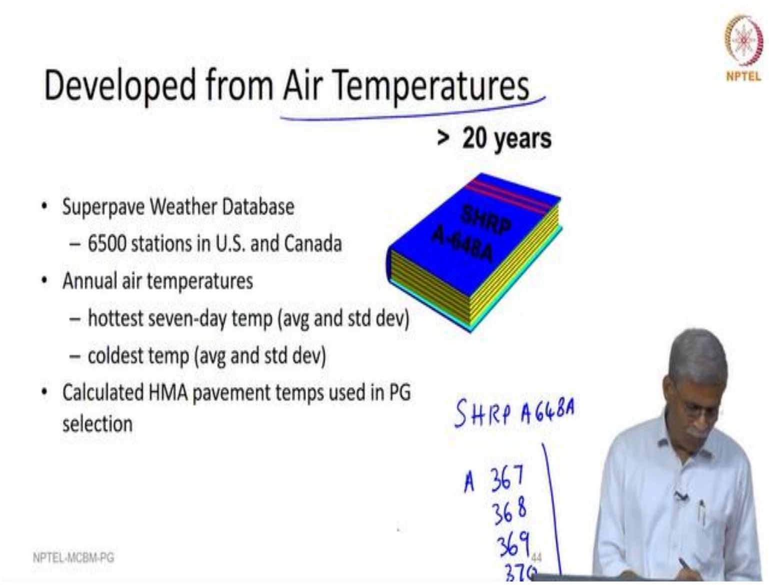

So how do we do this go about doing this so we need to get lot of air temperature data and in fact what is given here as SHRP A648A has that. Then you also have various SHRP reports of 367, 368, 369, 370 more or less list how this performance creates specifications came out, you can actually go search for A367, you will be able to get this details, okay? Right?

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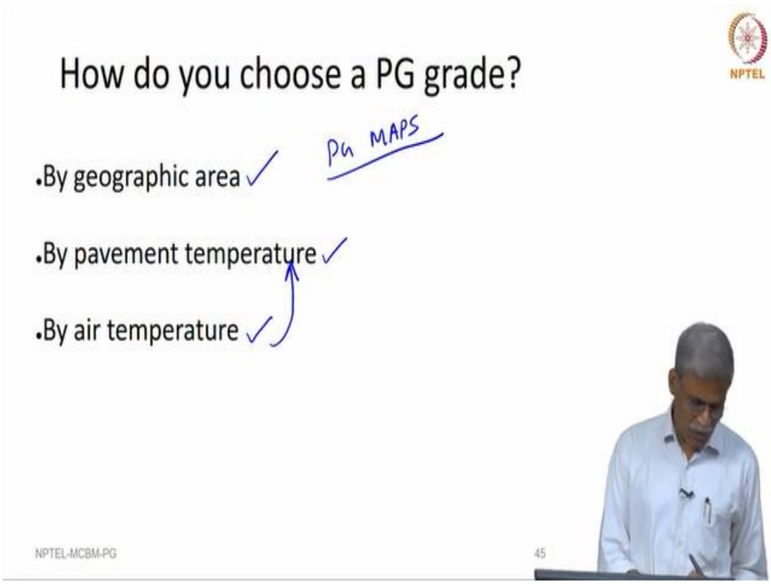

How do we finally choose a PG grade? We if you know the geographical area you can choose it. If you know the pavement temperature you can choose it or by means of an air temperature, if you do not have any access to any of the algorithms that are used there are PG maps or given in which you can look at your district and then find out what is the PG that is needed.

But if you have the pavement temperature data with you the well and good you can choose the PG or if you say no, no, I do not have the pavement temperature data. I have the air temperature data then I could calculate the pavement temperature data from the air temperature and then I could do it, of course whatever I am discussing is valid, mostly further North American on the European countries, we have not complete stage in India in which we can actually show this kind of weather map.

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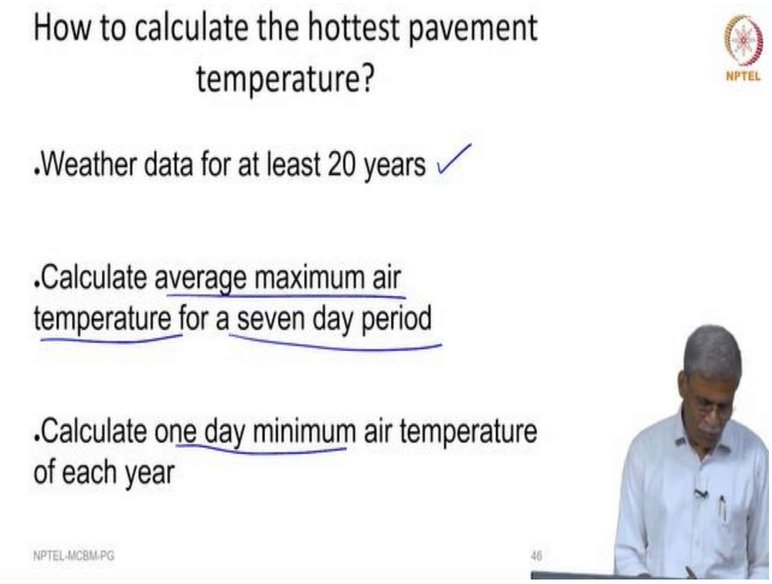

So how do we really compute the hottest pavement temperature? We need at least weather data for 20 years and we calculate the average maximum air temperature for a 7 day period and then we compute, the calculate the one day minimum at temperature for each year.

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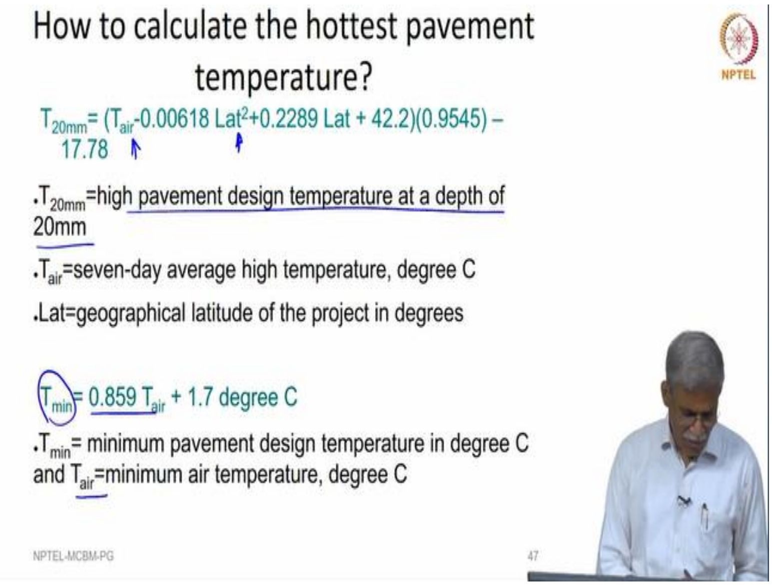

So this is the empirical expression that was given by FHWA you can actually see that T 20 mm of is the high pavement design temperature at a depth of 20 mm. This is the air temperature this is the latitude. We have a similar expression that we have developed at a IIT Madras for Indian conditions the details have already been explained in few other lectures and this is the minimum air temperature. It is the given, this is the minimum air temperature and this is the minimum pavement temperature, right?

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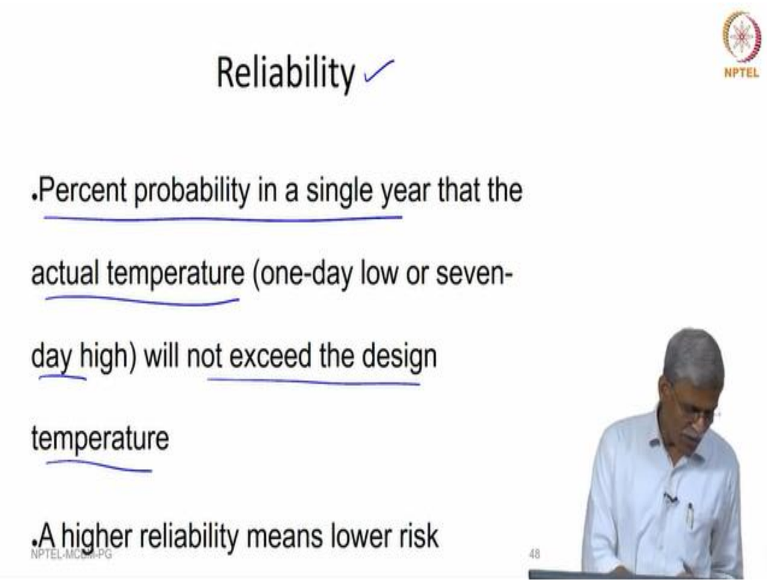

So now, when we are going to get into all these things we also need to understand that whether prediction is always subjected to it associated variability, so one cannot really design on a PG grade without understanding what is really called as the reliability. So what exactly is defined as the reliability and this is something well known to all of us but I will just state this percentage probability in a single year that the actual temperature either 1 day low or 7 day high will not exceed the design temperature. So if I am going to use 90 % or 95 % reliability, then I am really talking about the lower risk here.

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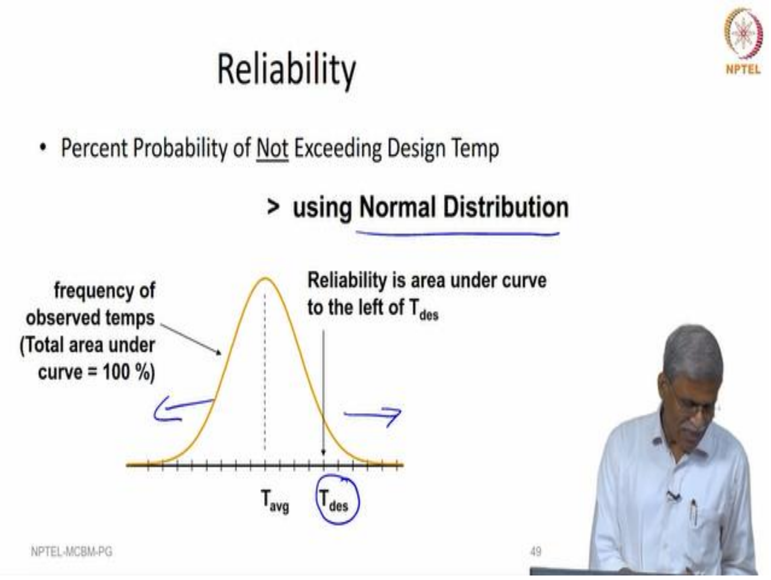

So how do we do it? So if you typically assume that the data is normally distributed, so you are talking about picking something as the design temperature on either side. In fact, what we will do for higher temperature, we will go to this side and for lower temperature will be going to the other side. I am going to illustrate it with a very simple example;

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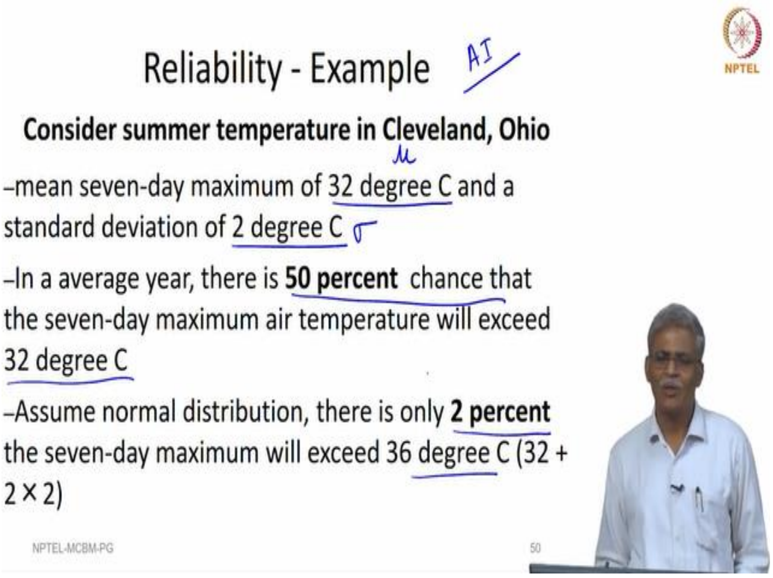

And in fact this example found in the Asphalt Institute superpave manual. So, let us take one particular case of we have mean 7 day maximum air temperature as 32 degree centigrade and the standard deviation is so this is Mu this is sigma 2 degree centigrade. So, what this basically means that there is a 50 % chance that the 7 day maximum air temperature will exceed this 32 degrees centigrade.

So if I assume normal distribution and then what I am going to do is, so 36 degrees centigrade so that means that 36 Mu + 2 sigma will give me a 2% that the 7 day maximum temperature will exceed 36. So I am looking at a 98% okay?

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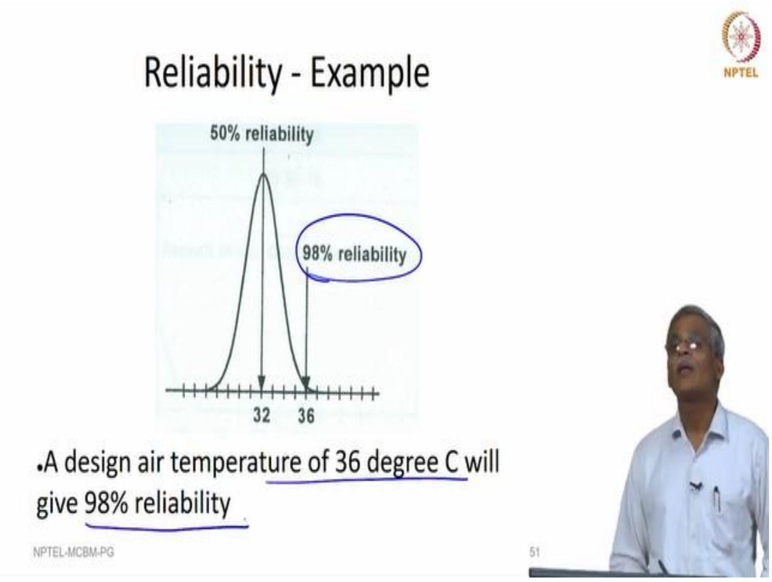

So 32 are the air temperature, standard deviation is 2 degree centigrade. So 36 is the 98 % reliability that I am going to give, so design air temperature of 36 degrees centigrade will give me the, 98 % reliability.

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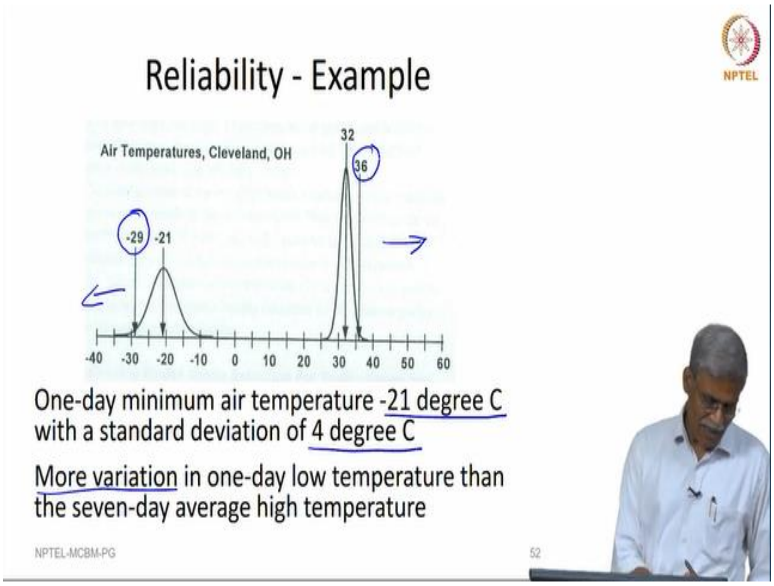

So similarly what we do is, we take the minimum air temperature is - 21 degree centigrade understand a deviation is 4 degree centigrade. So 2 into 4 is 8, 21 + 8 is 29. So it is going to be - 29 here and + 36 here, of course since this is high temperature we go in this direction and not in this direction and for low temperature we go in this direction and we normally see that there is more variation one sees in the low temperature, when it comes to the 7 day average high temperature and it is more or less the same.

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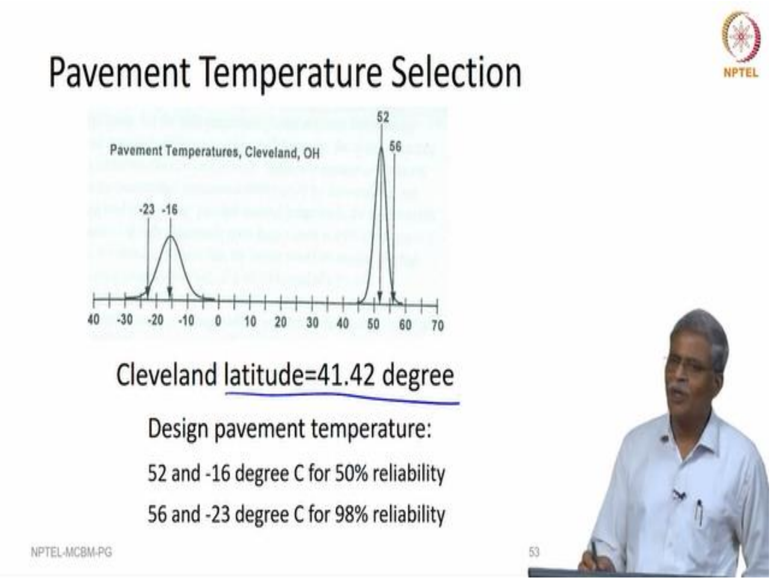

Once you know, what is the air temperature and knowing the latitude of a specific location and using the empirical expression that was given earlier you can actually find out what is the pavement temperature?

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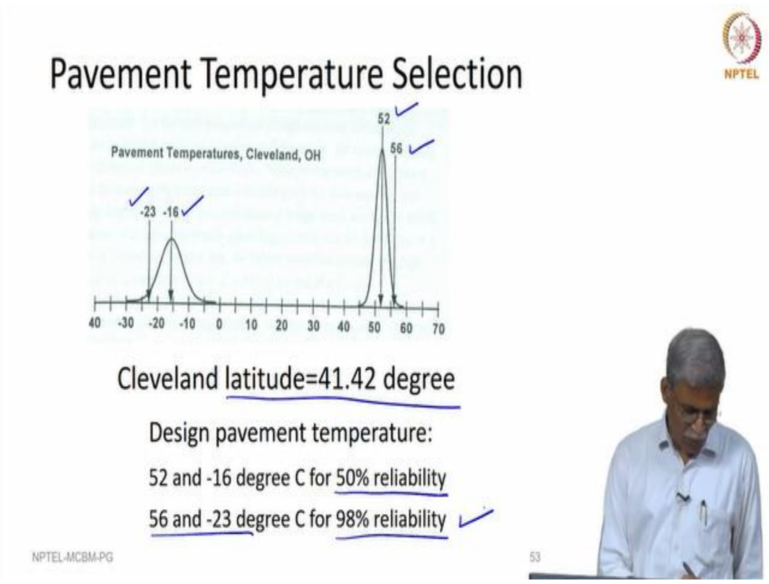

So if you know for instance if this was 32 and - 21, so if you use 32 degrees centigrade or 36 degrees centigrade and knowing the latitude and if you use the expression, you might get 56 degree centigrade as well as - 23 degree centigrade or 52 degree centigrade and - 16 degrees centigrade. So if you use 52 to - 16 the reliability here is only 50 % but if you use 56 and - 23, the reliability is now going to be 98 % reliability or going to get the, Okay?

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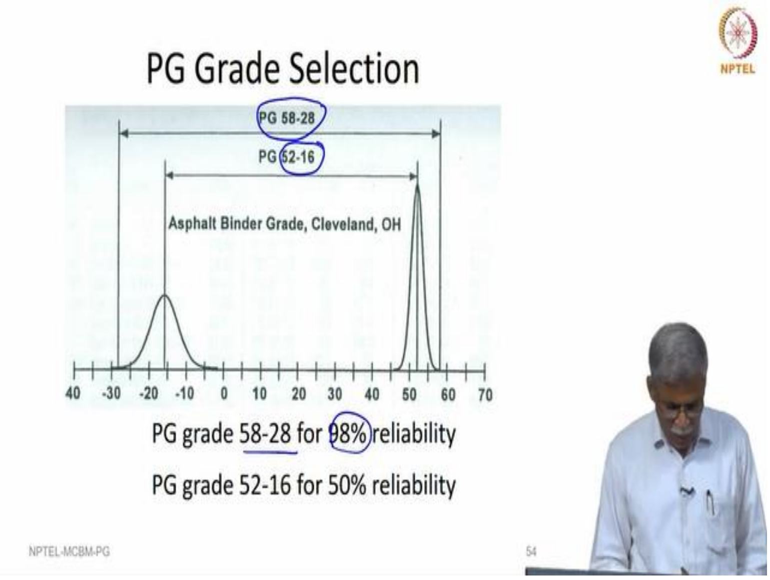

So now the interesting part is, if you remember the table that I showed you there is not going to be anything given as 56 in the table because the next one that you are going to see is only 58 degrees centigrade. So the actual PG that you are going to see will be 58 - 28 or 52 - 16, so the actual PG grade that will be using is 58 to - 28, so since you are trying to fit it to the PG table the reliability that you are going to see here in this specific case is going to be little higher than what we actually calculated here. I hope it is very clear;

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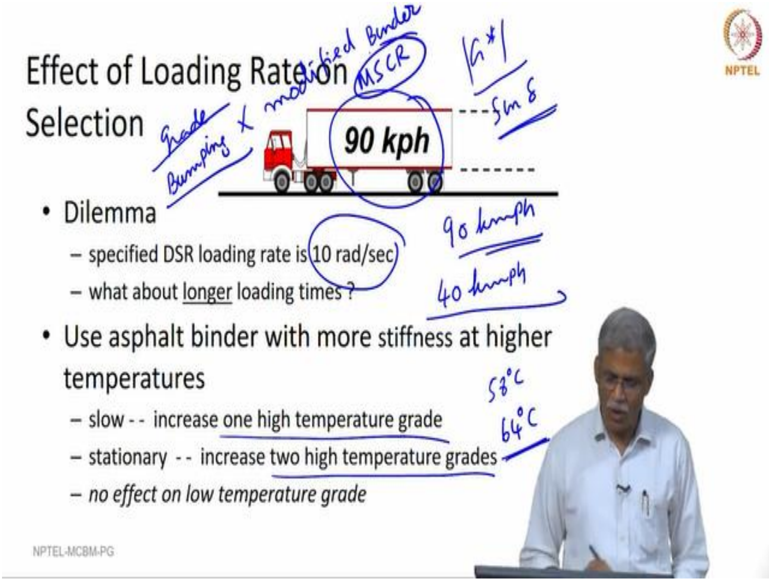

Now the interesting part about the PG grading is in fact we will discuss this assumptions associated with the G star by sine delta in a separate lecture all these were calibrated for the 90 kilometre truck speed okay? And there were some issues related to converting this 90 kilometre per hour to the angular velocity so they took it as 10 radians per second and in fact FHWA describes in detail some of the small errors that have script into the specification formulation.

So what will really happen for instance if instead of 90 kilometre per hour, if the speed of the representative truck in that location is going to be 40 kilometre per hour what will really happen. Since, all this calibrations are 1 kilopascal or 2.2 kilopascal or 5,000 kilopascal are based on this particular speed and since we know already that as the frequency varies changes the viscoelastic properties also changes, so we should be able to do some corrections here.

So this basically is given a name of what is really called as grade bumping. So if you are going to have 40 kilometre per hour in here highway what you are going to do is you are going to increase this by one high temperature three and if you are going to let us say will be a yard in which most of the vehicles are going to be stationary you are going to have a two high temperature grades.

So that means if you got something like 58 degrees centigrade and if it is going to be a slow moving traffic the move to 64 degrees centigrade what is the tacit assumption that we have made here when the bump the grade to 64 degrees centigrade the more or less assume that the PG properties the G star by sine delta will also hold good as the speed reduces. So in essence you are invoking equivalence of time and temperature as you increase the temperature and reduce the frequency.

It may work it may not necessarily work and in fact grade bumping has never worked for modified binders and that is why we started using multiple stress creep and recovery which was discussed already, right?

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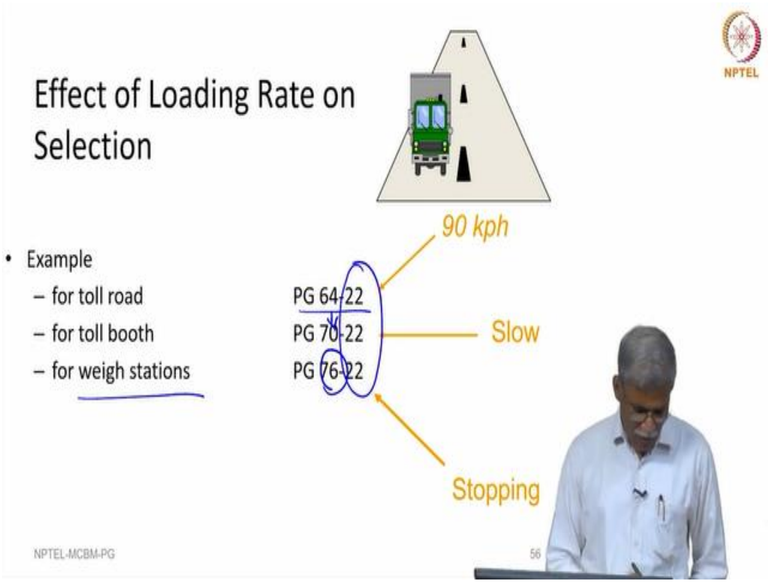

So if you are talking about, for instance, if you are talking about a toll road where it is 64 - 22, if it is going to be a slow moving traffic you increase it by 1 greater 70 and if it is going to be weigh station, it is going to be 76 you will also notice that nothing has actually changed in the low temperature, right?

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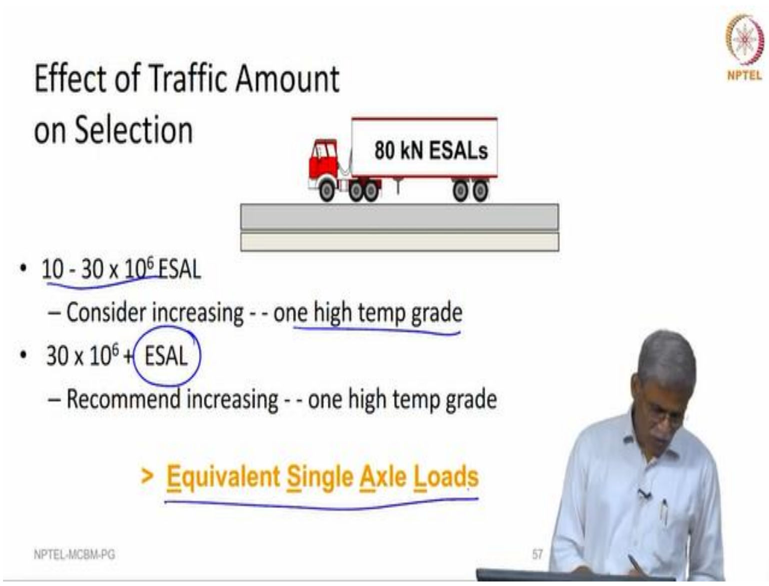

What about the traffic amount because the original grading that was carried out was typically for 10 million standard axles, okay? So I will we will explain in an actual what exactly is this standard axle, later when we have a course on advanced pavement analysis and design this issue should be discussed with that but if it varies from 10 to 30 million standard axles, we have to increase it by 1 high temperature grade.

And if it is more than that we recommend increase in one more, so that is what we are really going to do it and what exactly is this ESAL, ESAL is nothing but Equivalent Single axle load.

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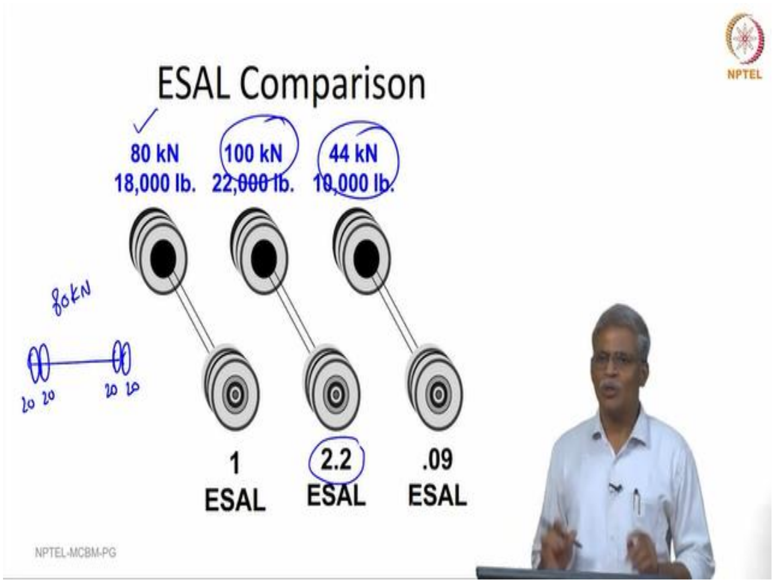

So what is this ESAL? So this is your 80 kilo Newton, so you have a single axial with the two wheels on a that side 20, 20, 20, 20 so if and you can actually see there is another axial that is shown here which is 100 kilo Newton another axle that is shown here which is 44 kilo Newton. The concept of this is essentially tells you that one application of 80 kilo Newton is equivalent to 2.2 application of 100 kilo Newton as well as the damage is concerned.

Now, it is not very clear whether the damage is in terms of rutting or fatigue because the damage will be completely different when you are talking about rutting as well as fatigue is concerned but alright now as far as this particular topic is concerned we will assume that both are the same. So this is the concept that is used;

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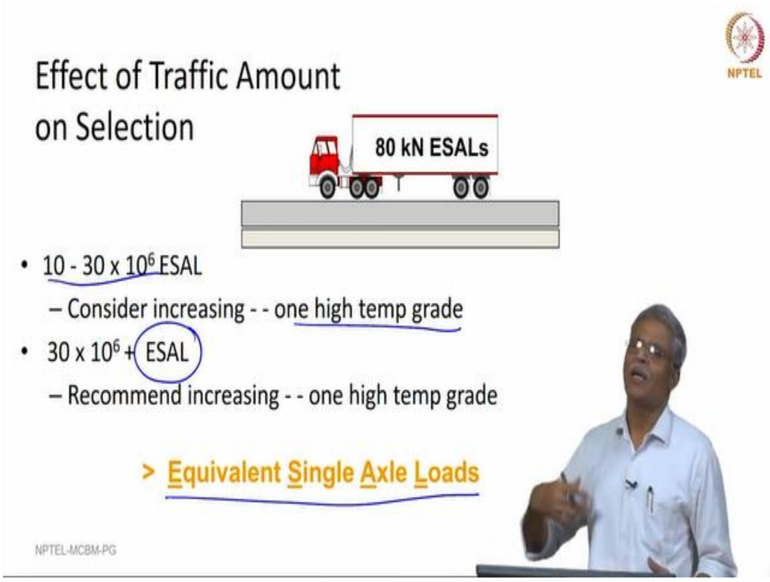

And now normally what we do is, if we have a very small truck this is how you will be computing the ESAL, so for a 27 kilo Newton axle will correspond to 0.01 and 67 kN will correspond to 0.48 ESAL, so when you add the you are going to get 0.49 and Similarly this is for a big truck you get 2.39. so what you do is wherever you are going to construct your pavement you have to find out for your design period, what is the axle load in terms of the standard axle

And then find out whether for that particular design period if you will be between 10 to 30 million standard axle, or it will exceed and appropriately we have to also increase the grade of it.

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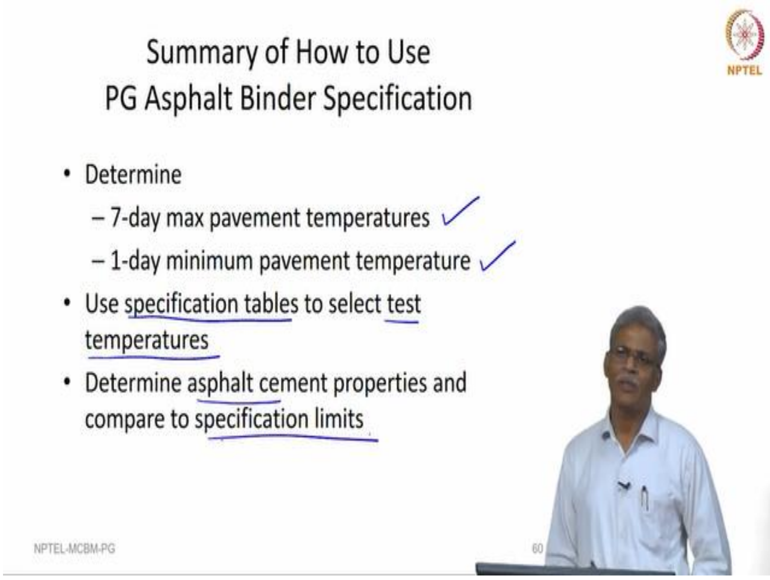

So finally how to use this specifications we need to find out the 7 day maximum pavement temperature, we need to find out the 1 day minimum pavement temperature and then we have to use the specification tables to select the test temperature and basically then we have to find out the bituminous binder properties and compare it with the specification limit. So this is the whole crux of it.

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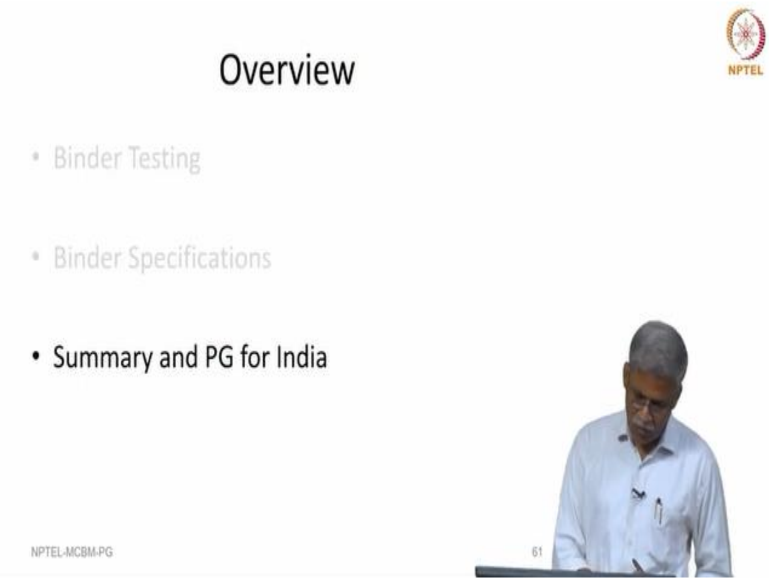

Now if we want to use PG for in India, how do you think for proceed? What are things we need to understand?

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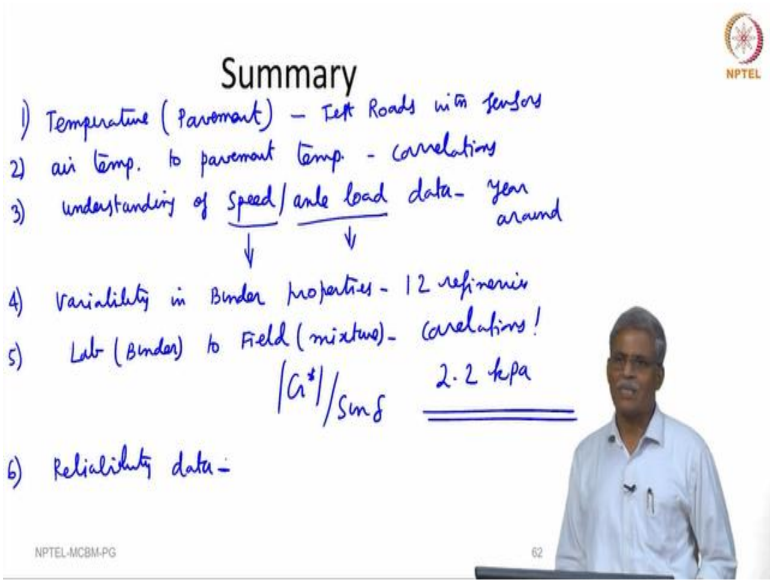

So first and foremost thing is we need the data related to temperature and what we are talking about we are talking about Pavement temperature, so that means we need to have test roads with sensors how to be used to collect 24 by 7 pavement temperature data and we need to establish air temperature to Pavement temperature correlation. Without that we cannot really proceed. Because most of these correlations that are available as part of the AASHTO or superpave more or less correspond to what is available for North American condition.

The next thing that we need to do is to have understanding of Speed, Axle load data, we need it for all year round. In fact, most of the time what we see here is before a new pavement is constructed or rehabilitation is carried out for a old pavement we only collected 24 by 7 data and we do not actually have the complete data.

So we need to have full data on only then we can actually find out what is the representative speed and what is the axial load spectrum because when we know the axial load spectrum, we will know, what kind of corrections has to be done and when we know the speed we will also know what exactly needs to be done here. Then we also need to find out the variability in the binder properties.

So roughly we have around out of the 23 refineries in the country we have 12 refineries which produce bitumen and each of them use different process, so we do not really know what exactly is the variability that one can expect in this, so this is something that we need to do and later lab, that is binder to field which is the mixture correlations have to be worked out a fresh.

It is not very clear, whether the G star by sign delta of 2.2 kilopascal will indeed work for the Indian conditions, so this also need to be understood and finally we also need to spend some time looking at the reliability data and what kind of risk that we are trying to take when we design a pavement. So these are some of the issues that we need to keep in mind.

In the next lecture, we will talk about the theoretical basis of G star time sign delta G star by sine delta, the testing conditions as well as how to find out the low temperature performance grading, thank you very much.