Mechanical Characterization of Bituminous Materials
Prof. Dr. M.R Nivitha
Department of Civil Engineering
PSG College of Technology-Coimbatore

Lecture-55
MSCR Analysis Using Matlab

Hello everyone, so in this lecture, we are going to talk about the MSCR analysis using Matlab. We all know what MSCR is, it is multiple stress creep and recovery test, which is mostly used for modified bitumen to capture it elastic recovery properties, right. So, we know how the test is also performed. I will do a small recap of the test procedure before beginning to analyze the data. So in this lecture, we will see how to import MSCR data into Matlab and how to calculate the parameters which are specified in ASTM D7405.

So, they ask us to calculate percentage recovery at 2 different stress levels, non-recoverable, creep compliance at again 2 different stress levels and the percentage recovery difference between the 2 stress levels and the non-recoverable creep compliance difference between the 2 stress levels. So, these are some of the parameters which are specified in ASTM D7405.

So, in this lecture we will see how to import the data in Matlab and calculate all these parameters using Matlab.

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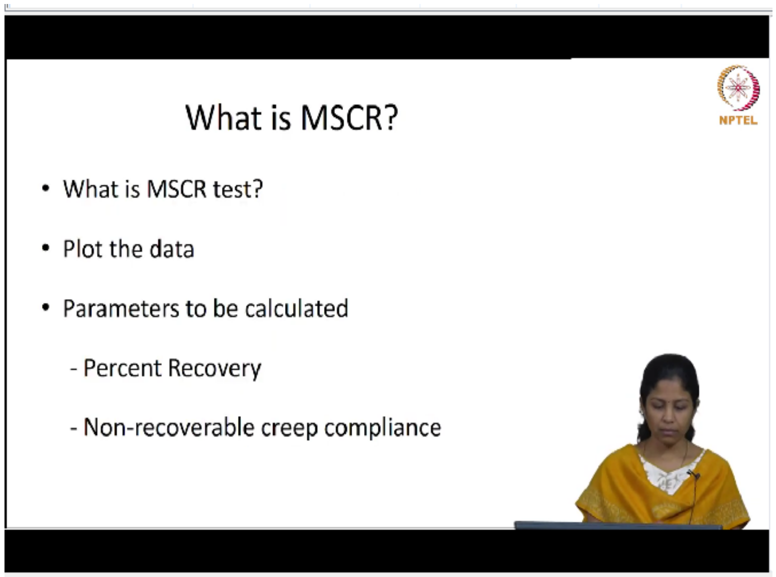

So, this is the outline; we will first talk about what is an MSCR test and then we will see how to plot the data which we get from an MSCR test and then we will see what are the parameters that are required to be calculated, how to calculate percentage recovery and then how to calculate non-recoverable creep compliance. The first one is what is an MSCR test.

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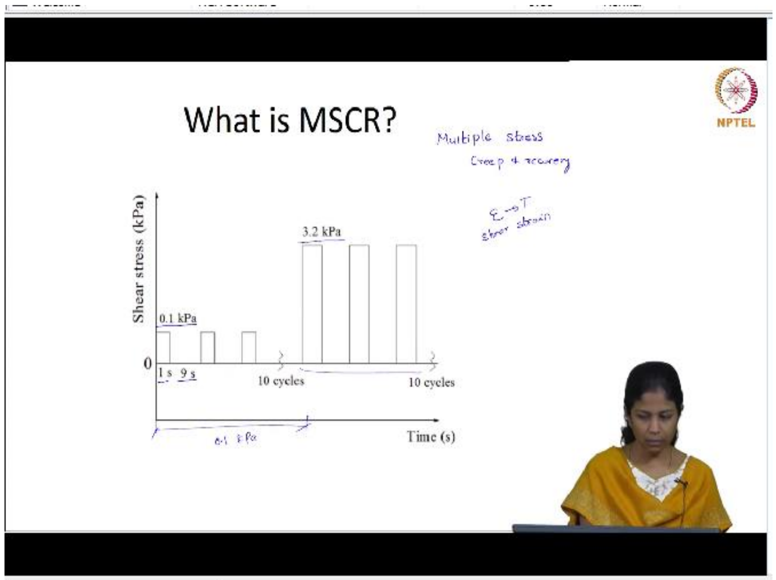

So, what is an MSCR test, we can see here, so an MSCR test is a multiple stress creep and recovery. It is a multiple stress creep and recovery test, we perform the test at 2 different stress levels 0.1 kPa and 3.2 kPa. And then we know that we apply a loading for 1 second, and we measure the recovery for 9 seconds. So, we have a loading which is applied for 1 second, and the recovery is measured for 9 seconds.

We have 10 cycles at 0.1 kPa and we have 10 cycles at 3.2 kPa. So, this is a schematic of the MSCR test. Now, using this data, for this experiment, what we get is the strain values, how the strain, so they call it as shear strain since we do an oscillatory test. So we will see how the strain varies as a function of time right. So, this is how the experiment is done.

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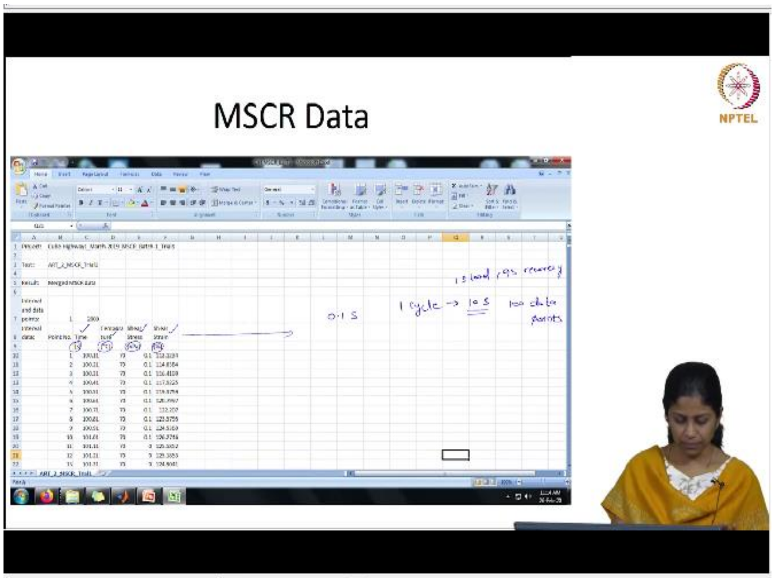

Now, this is the data which is generated. So, we have done some trial in a laboratory and captured the MSCR data. So, previously when I showed you the amplitude sweep, you saw a number of variables which are listed here, again you can modify that, you can specify what are the variables which you are required to see. So, for this experiment, we have collected only or we have imported only few variables, one is time, the other one is temperature, shear stress and then shear strain.

And you can also see the units here, time is given in seconds, temperature again degree Celsius, shear stress is kilo Pascal and shear strain is in percentage, right and you can see here that every data point is collected for 0.1 second because here you see 100.11, 100.21, 100.31. So, like that the data collection point is varied right. So, we have collected data for every 0.1 second. So, for 1 cycle which is for 10 seconds.

Because we saw that we have 1 second loading and 9 seconds recovery, so, 1 cycle is for 10 seconds, so, here we will have 100 data points right. So, this is the data which we have collected.

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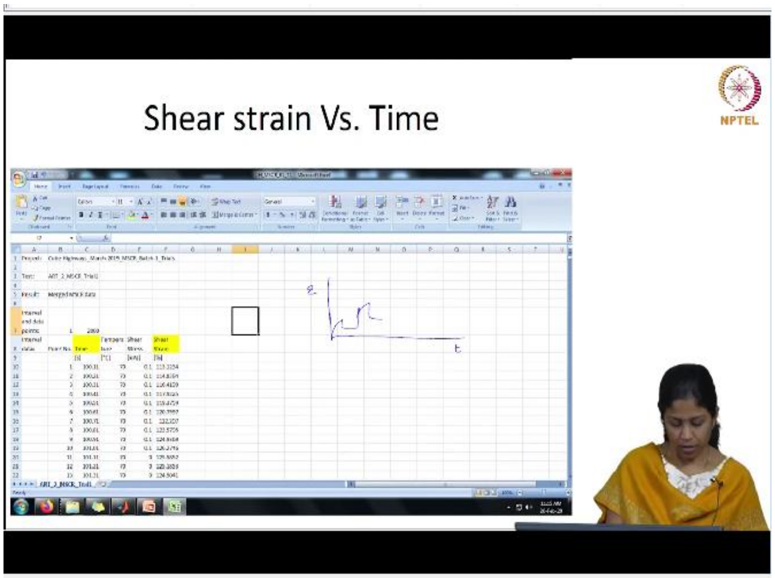

What we are interested is the plot of shear strain, how the shear strain varies as a function of time right. So, we will have some creep; depending upon the material, we will have some recovery and then they will shoot up to the next strain level, some recovery, so that it will keep going on. So, this is what we are interested in.

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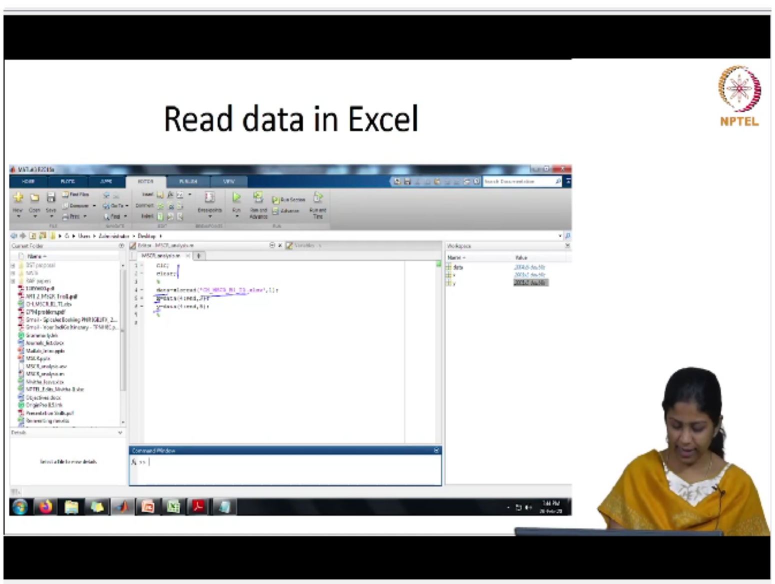

So, we have to extract these variables into Matlab. So, by this time you know how to read only these 2 variables into Matlab. So, like I mentioned in my previous lecture, you can see that we have added to clear the command window and the workspace and then we have imported the data. So, data is xls read of the particular file name along with the sheet number, and we have also extracted x data and y data.

So, it is data from 4 to end of the second column and y data is 4 to end of the fifth column. So, here you can see, second column is time which we want in our x axis, and sixth column in fact is shear strain which we want in our y axis.

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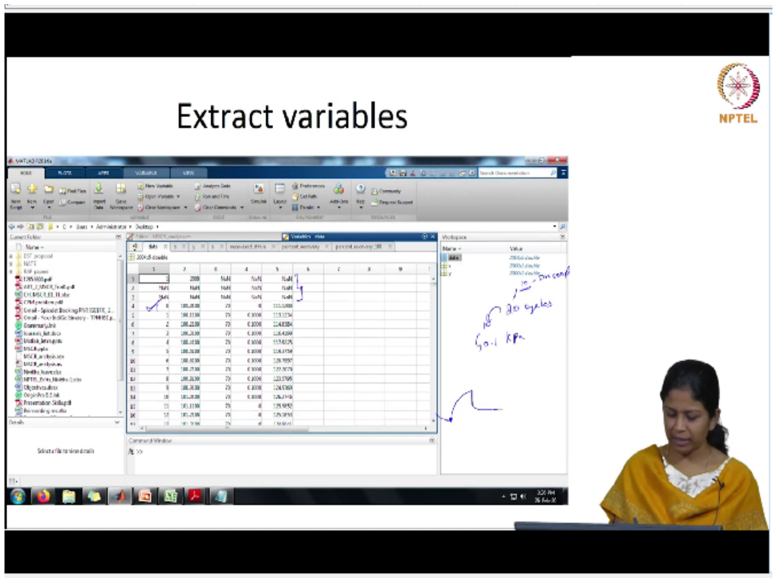

But when you are importing you can see that in data, you will have only 5 columns because it has neglected this column which does not have any data. So, that is why we are seeing only 5 columns in our data which is shown here. The first 3 are not a number which has some information strings about the experiment and the data starts here right. So, I have added one more point. Generally in a multiple stress creep and recovery test, we will perform some pre-shearing, say we have 10 cycles in 0.1 kPa and 10 cycles in 3.2 kilopascal; that is what we have said right.

But the AASHTO code suggests us to do some 10 cycles as pre-conditioning cycles at 0.1 kilo Pascal. So, instead of the 10 cycles in this stress level, we will actually be doing 20 cycles, the first 10 will be taken as pre-conditioning and the next 10 is what the experimental data is. So, the strain corresponding to the recovery of the 10th pre-conditioning cycle will be the 0th point for the subsequent cycle.

So, that data is not represented here and hence, that data is added to this. I have done it manually generally when you collect data from DSR you will get this by default. So, you have to take this as the initial value because see, when we have our creep and recovery test, so, this is the initial portion, which will be the last data point corresponding to the recovery of the previous cycle. So, this would have been the previous cycle would have been recovering something like this.

So, this will be the initial portion for the next cycle. So, this data point we need and that is shown here right. So, this is for the creep and recovery data; we have to ignore all these things and read it from the fourth line.

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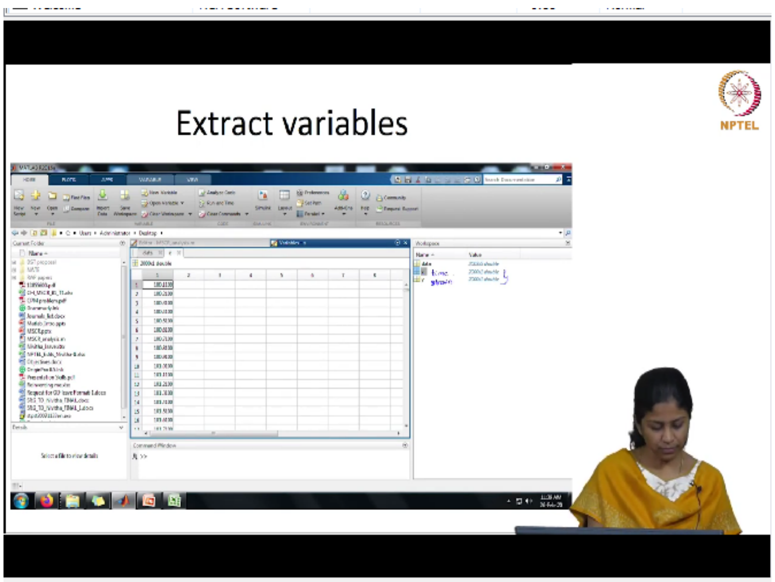

So, we have extracted and you can see here this is our x variable and this is our y variable, I can alternatively save this as time and this as strain, I can name it this way also there is no problem, because all of them are just variable names.

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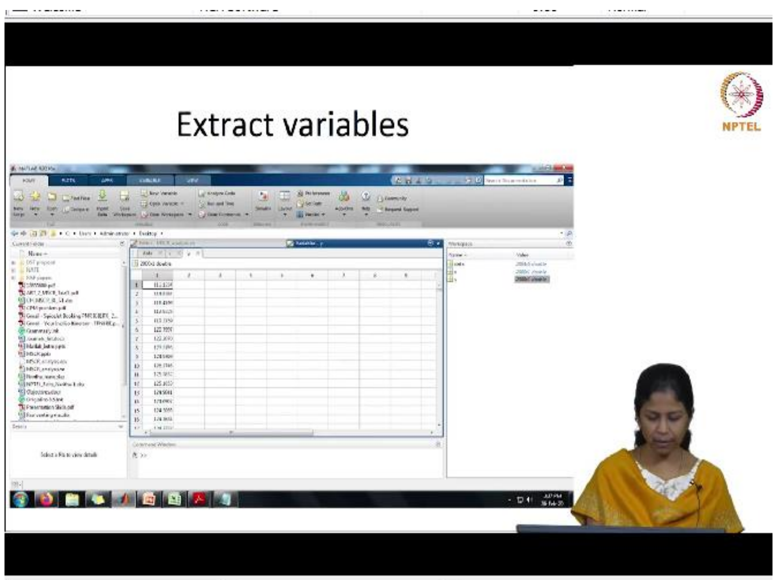

So, you can see we have our y data also which is given here. Next is how to plot this data.

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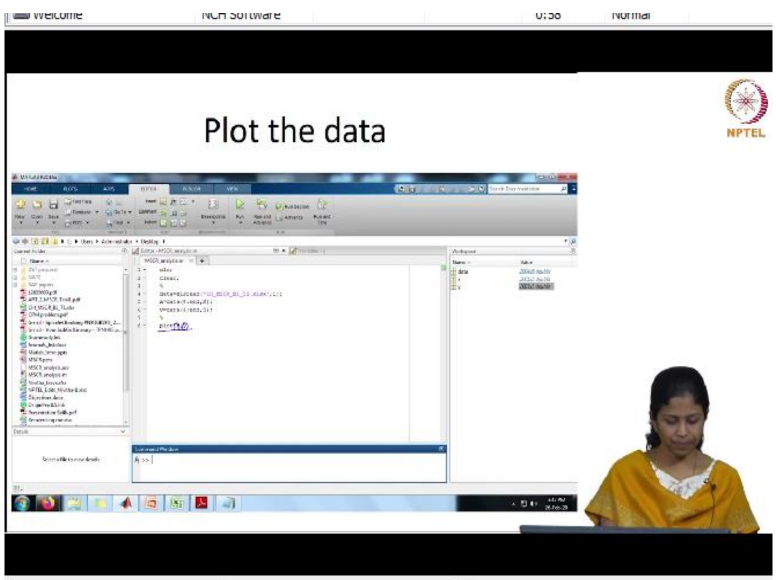

So, the syntax for plotting is just give plot x, y right. So, which means that this one will be ,whatever be the name, will be on the x axis and this one will be on the y axis right. So, we have generated a plot x, y.

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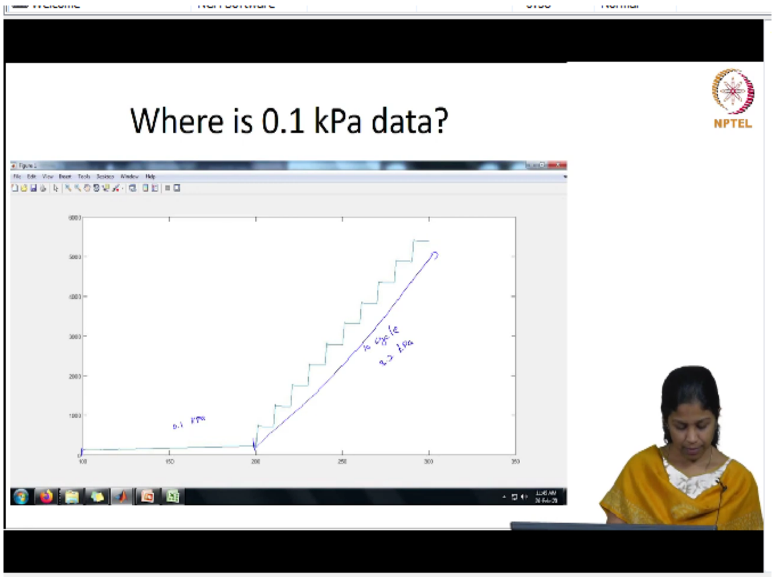

And you can see that this is the data which is plotted right. So, we have time which is given here since we have not given any label, it has not shown it and here also we do not have any label. And you can see here that this is the first 10 cycles corresponding to 0.1 kilopascals and these are the, from here to here are the, 10 cycles corresponding to 3.2 kilopascals right. But here we can see that we are not even able to see the creep and recovery. For a first look, you will see that it almost looks like a straight line.

The reason is the scale because the strains are substantially higher. Again depending upon the material the scale will vary for a higher stress level of 3.2 kilopascal compared to a lower stress level of 0.1 kilopascal. So, the magnitude of strain is also different and that is why we are not able to see the creep and recovery part at 0.1 kilopascal and that is why we have to use a log scale.

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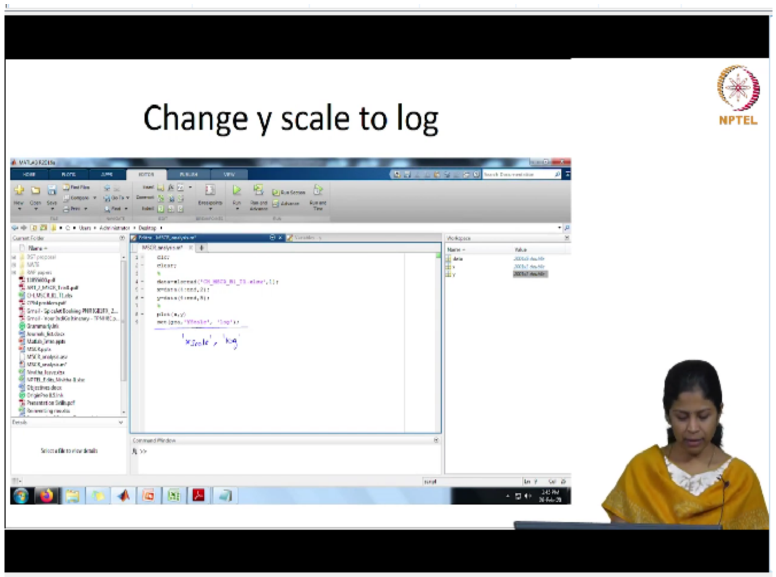

So, here we define some attributes. So, you can just use the syntax for now, you give set GCA and then you put y scale within quotes and then you say log, if you want to change x scale, you just put x scale log. So, then the x scale will be automatically changed to a log scale, but since we want only the y scale to be changed into log scale, we have just given here y scale comma log.

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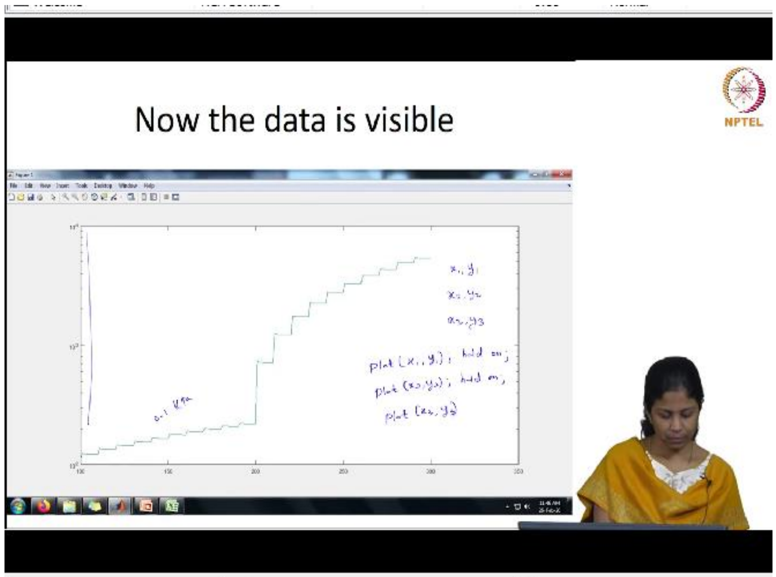

And then you can see that this will be changed into a log scale you can see it here. Now, this is in the log scale and then now the creep and recovery portion for 0.1 kilopascal is very evident, right. So, this is how you plot if we have different materials, we can plot different plots on the same figure. And then we will be able to compare the creep and recovery or the strain levels for different materials.

So if you want to make that plot, let us say we have 3 sets of data, x1, y1; x2, y2; x3, y3. So then we first plot x1, y1, you specify, hold on, so that it will re plot in the same plot. And then you give plot x2, y2, hold on plot x3, y3, then we will be able to get all the 3 plots in the same figure. And then we can compare across, right. So this is possible.

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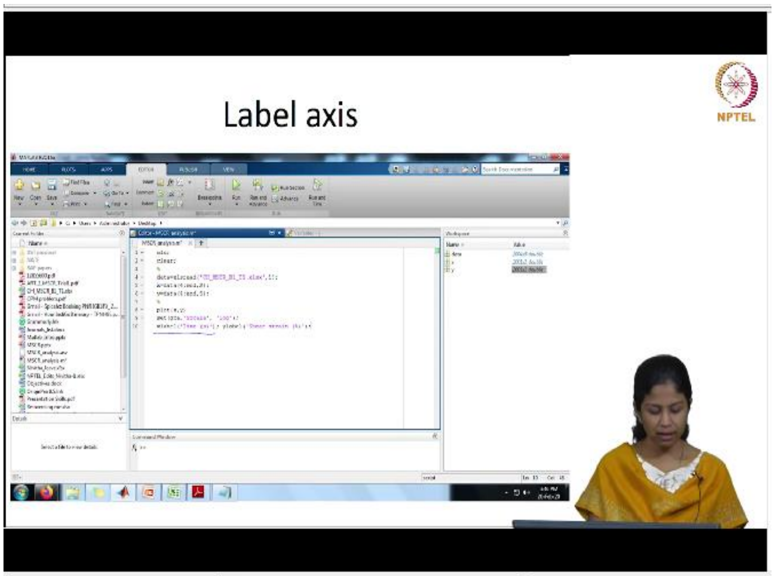

And then we want to change the label. So, if you want to add it in the code, you just say x label within braces, you put time in brackets seconds within single quotes. So, then the x label is now changed to time in seconds and similarly you give y label within braces we specify the name right.

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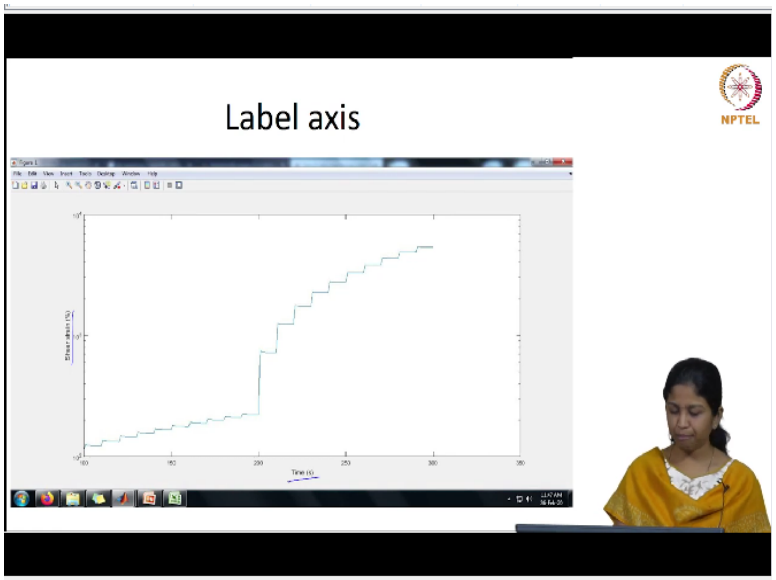

So, then we will be able to see that the axis labels are also now generated. So, it is a plot of time versus shear strain right. So, this is how we make plots using the data. Next, we start calculating some parameters using this particular data. So, the 2 parameters which we are going to see here are percentage recovery and non-recoverable creep compliance.

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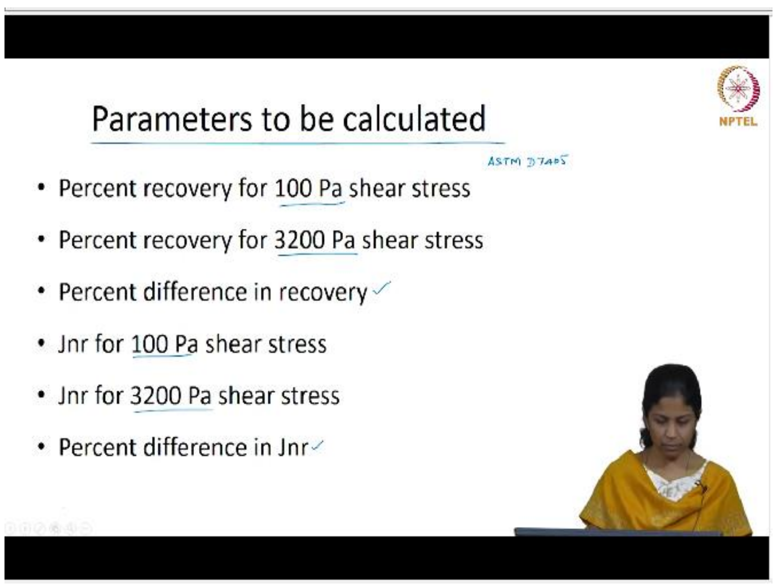

Now, these are the parameters to be calculated based on the specification provided in ASTM D7405. So, we can see that we calculate the percentage recovery for 100 Pascal shear stress and 3200 Pascal shear stress and the percentage difference in recovery. Similarly, Jnr for 100 Pascal and 3200 Pascal shear stress and the percentage difference in Jnr.

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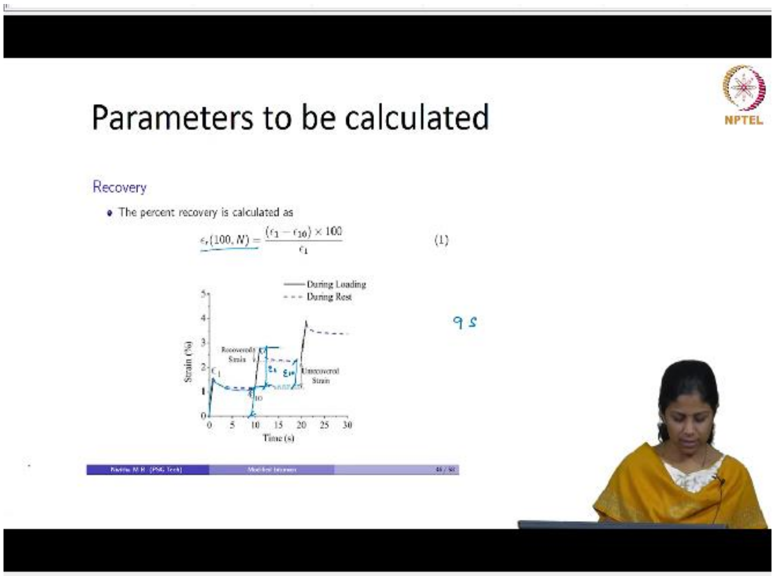

So, this is a snapshot from a previous lecture in which I explained what an MSCR test is and what are the parameters to be calculated. So, the percentage recovery ε_r is calculated as $(\varepsilon_1 - \varepsilon_{10}) / \varepsilon_1$. So, what are these variables ε_1 and ε_{10}? So, ε_1 is the total creep strain that is from my 0th time to the end of 1 second. So, when I start the test, when 1 second of loading is completed, how much of strain is accumulated in the material, so, that is my ε_1.

So, when we have to do this calculation, the last value of strain from the previous cycle will be ε_0 for the current cycle. So, like I previously explained, you have to take that into consideration and then this strain at the end of 1 second loading can be taken as ε_1 and then ε_{10} is nothing but the strain at the end of recovery. So, we allow the material to recover for 9 seconds.

So, at the end of 9 seconds recovery the strain which is accumulated in the material, right, so, this is ε_{10}, so, for the next cycle, this will be my ε_1 and so, I have to take this as the baseline and this will be ε_{10}. So, this is how we have to calculate these parameters when we are using the code. So, we have to be clear about these things. So the first one what we will look into is percent recovery.

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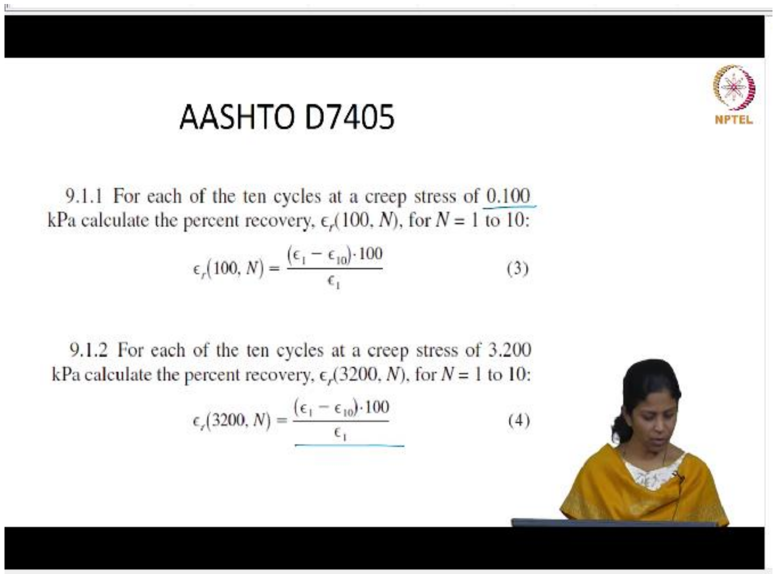

So, for the 10 cycles, so, this is the snapshot from ASTM D7405. So, they have specified that for 10 cycles, at a stress level of 0.1 kilopascal, we calculate percentage recovery like this. And for the 10 cycles at 3200 Pascals or 3.2 kilopascal, we calculate the percent recovery using this formula, the formula remains the same. What they mean here is you have to calculate it separately for the 2 different stress levels.

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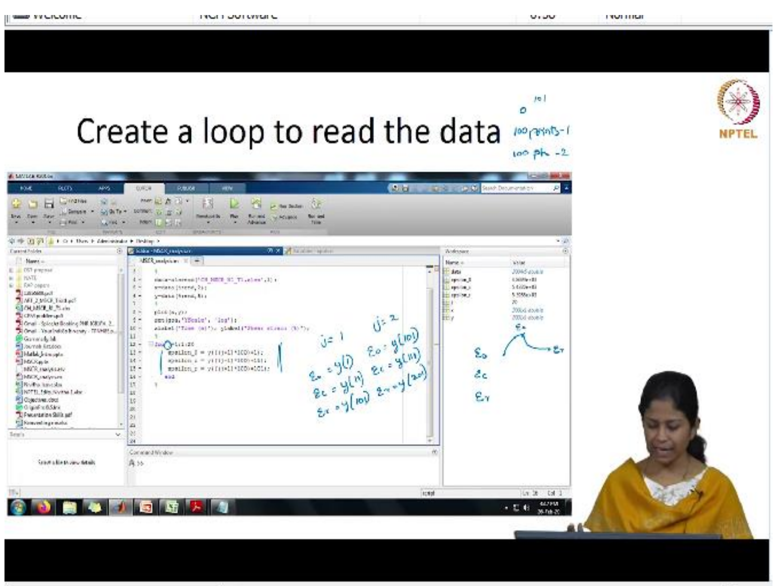

Now, let us see how to do that. So, this is the code which is written related to that. So, we have to create a loop to do that for all the 20 cycles. So, how do we read the data? because in our data is started from 0.0, which is the last point from the previous cycle, and then we will have 100 data points in a cycle. So, including this it will become 101 data point and then we have the next 100 data points for the next cycle. This is cycle 1.

So, this is 100 points for cycle 2. So, like that it keeps going on, it is a continuous data. Now, we have to separate that data to calculate your ε_0, ε_c and then ε_r. So, ε_0 will be the time in which I start, ε_c will be this strain and then it starts recovering. So, this is ε_r right. So, we need to identify this for each and every cycle right. So, a loop is created. So, I have used the same names to avoid confusion.

And whenever I need to call these variables in future, it will be helpful. So, I have ε_0, ε_c and ε_r. So, what do I mean by a loop? So, when it has to do the same function a number of times, then we create a loop and the loop here is defined using another variable j. So, when j varies from 1 to 20. So, this will be executed 20 times, so, j will vary 1, 2, 3 like that from 1 to 20. So, when j is varying from 1 to 20 how do we get it?

So, ε_0 is nothing but y because y is our strain value right. So, y of j – 1 × 100 + 1. I have defined it this way. Let us see why it is defined in this manner. I will show it with an example, then you will be able to understand clearly. So, ε_c I have explained as y of j – 1 × 100 + 11 and y is ε_r is y of j – 1 × 100 + 101. Now, let us take the first cycle. So, for the first cycle j will be equal to 1 right.

So ε_0 is nothing but y of j – 1 is 1 – 1 which is nothing but 0, 0 × 100 will be 0, right + 1. So the first data point which is there for y, so in the excel sheet, we saw that we have added one point which is the information related to the last data point of the previous cycle. So that is the first point here, which is ε_0, the starting point for the next cycle. The next variable is ε_c. See, this ε_c is again y of j – 1 × 100 + 11.

So which is nothing but 1 – 1 is 0 × 100 + 11th data point right because 0 is corresponding to the previous cycle and we said we are collecting data for every 0.1 second. So, the eleventh point will be the maximum point otherwise if we do not have information related to the previous cycle, actually 10th data point should be the maximum point right, because we said we are loading for 1 second.

And since, we are collecting data for every 0.1 second, we will be having 10 data points for this creep portion, but since that data point is included here, I have to make it as 11. So, which will correspond to this peak strain here. So, that is why it is given as y of 11 and ε_r is y of again 0 + 101 because we said we have 100 data points for every cycle plus the first data point. So, we have 101. So, this 101th point will be the ε_r right.

So, we have calculated, so, this is how so, when we go to the second cycle right, we will see what happens; now j will be 2 right. So, ε_0 should be the 101th data point because that is the last point of the previous cycle. So, you read here j will be 2, 2 – 1 will be 1, 1 × 100, 100 + 101. So, it will be y of 101 right. So, we have taken for the next cycle, the last data point of the previous cycle that becomes ε_0.

Then ε_c is nothing but 2 – 1 is 1, 1 into 100 is 100, 100 + 11. So, y of 111, similarly we will get ε_r as y of, so, it is 100 + 101 which will become 201 right. So, like that we will calculate the points for each and every cycle. So, it will do this for all the 20 cycles right. So, we will get ε_0, ε_c and ε_r separately for each and every cycle.

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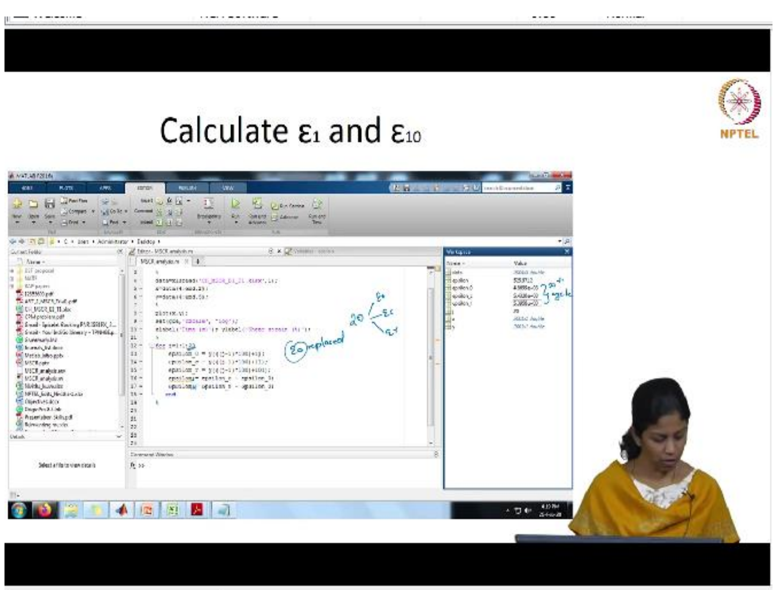

So, here we can see the values are specified here, ε_0 is given here, ε_c is given here and ε_r is given here. So, now, using these 3 things we have to calculate ε_1 which is nothing but ε_c - ε_0 and then we also have to calculate ε_r which is nothing but ε I am sorry ε_{10}, which is nothing but ε_r minus ε_0 and that is how we have defined it as.

So, now we have to calculate these 2 parameters and for that the code which is written here is ε_c. This should be actually ε_1. This is ε_10. So, this should be ε_c minus ε_0 and this is ε_r minus ε_0. But what we have done here is that we have 20 cycles, right we have 20 cycles, and we should have had actually 20 points for ε_0, 20 points for ε_c and 20 points for ε_r.

But we can see here that for all these 3 parameters, we are only getting one value that is because we have defined this as numbers rather than an array. And what happens is, every time the second cycle, see for the first cycle it would have calculated an ε_0, right some value and when we go to the next cycle, this value will be replaced by the value of the second cycle. So, it keeps replacing, and what we get here corresponds to the 20th cycle, right.

So, we should actually define this as an array. So, that we will get all the data points individually. So, how to do this?

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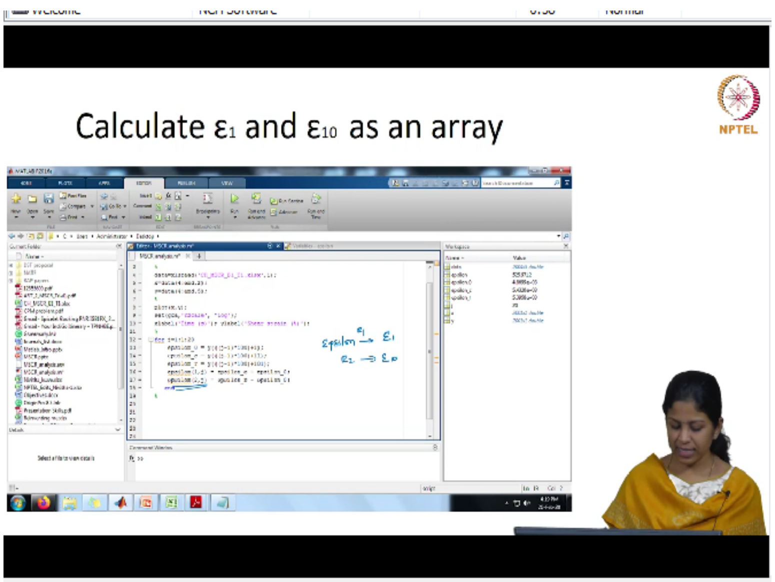

So, here we define them in the form of an array. So, this we say epsilon (1,j) and this epsilon is epsilon (2,j). So, we say for every cycle, we ask Matlab to calculate ε_c and ε_r and save that in a file called epsilon where the first row will be the ε_1 value and the second row this is row 1 and this is row 2 will be ε_{10} value right. So, then next time if it is replaced there will not be an issue because it is already saved here in this epsilon matrix, right.

So, instead of using epsilon so instead of defining epsilon underscore separately and ε_{10} separately, if we do this in the same matrix, we will be able to do all the subsequent calculations in an easy manner. So, that is the reason behind saving these 2 variables ε_1 and ε_{10} in the same variable epsilon as 2 different rows right. So, here we can see, we have epsilon, the first one j will be replaced.

So, the first cycle will be the first column, second cycle will be the second column. So, like that all the 20 values will be saved as different columns and we will see get epsilon as I mentioned earlier, row 1 will be ε_1 and row 2 will be ε_{10} right. Now, let us see what is the output.

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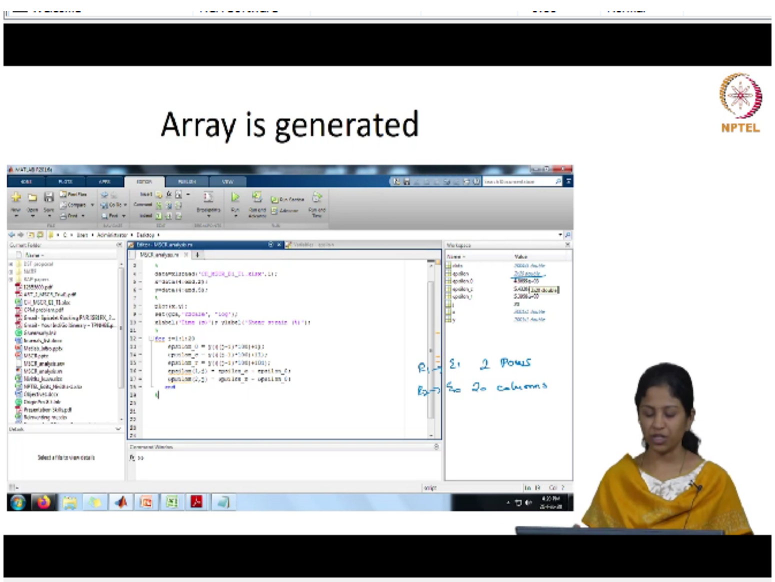

So, when we run this we see that epsilon matrix is generated as a 20 by 20 2 by 20 right. So, which has 2 rows and 20 columns, so, that is how we have specified it as right. So, the first row will be ε_1, second row will be ε_{10}. So, this is row 1 ε_1, row 2 will be ε_{10} and we have got it for all the 20 cycles at one shot.

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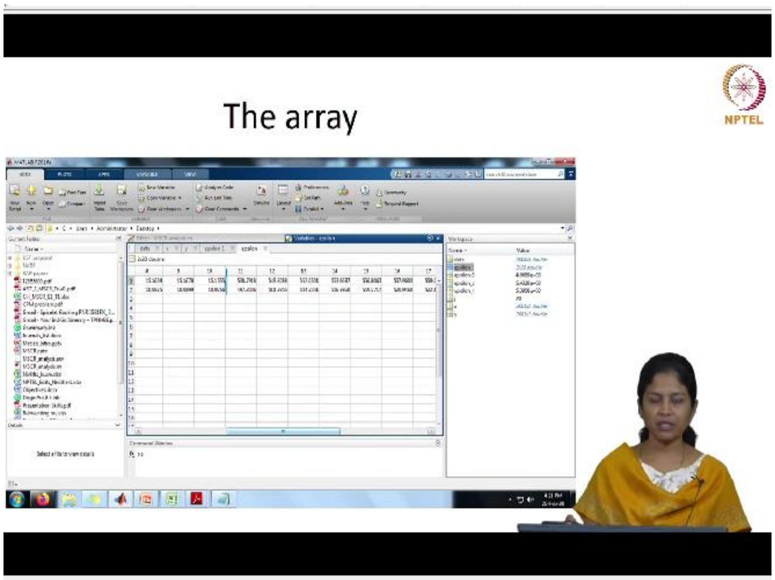

So, we can have a look at the data, this is the epsilon, we can see that after the 10th cycle, the strains have increased substantially, because the stress level has increased right. So, you can see the difference in your ε_1 and ε_{10} between 10th cycle and 11th cycle.

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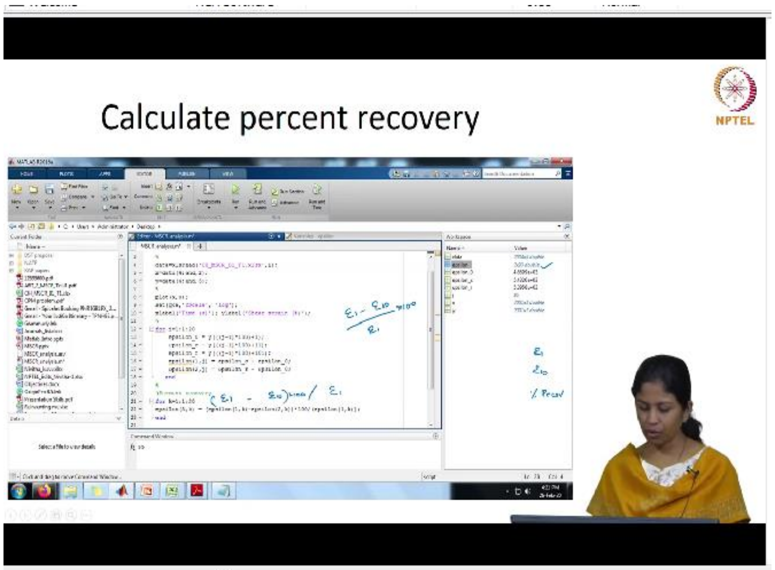

Next, we will start calculating the parameters. So, the first one is how to calculate percentage recovery. To calculate percentage recovery, we have written this code. So, first we will define what percentage recovery is, we will write it down here. So, your percentage recovery is $(\varepsilon_1 - \varepsilon_{10}) \times 100 / \varepsilon_1$ right. So, this is how percentage recovery is defined. Now, we calculate this simultaneously for all the 20 cycles. So, for your k which is varying from 1 to 20 and this epsilon and this parameter percentage recovery is calculated as the third row to our epsilon matrix.

So, this epsilon matrix is already defined; row 1 is ε_1, row 2 is ε_{10}, row 3 will be percentage recovery right. So, this epsilon (3, k) is nothing but ε_1 - ε_{10} right. So, into 100 is specified here divided by ε_1 right. So, that is specified here. So, then we will get the third row as the percentage recovery.

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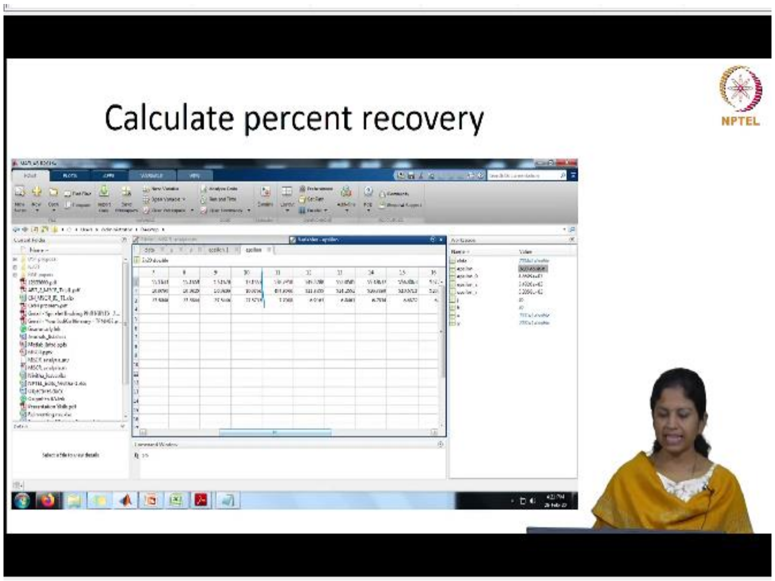

And here you can see the third row is calculated, we can see the percentage recovery till the 10th cycle again it is about 27% is recovered, whereas after the higher stress level is applied, only 7% of this strain is recovered. So, we will be able to get this information using percentage recovery.

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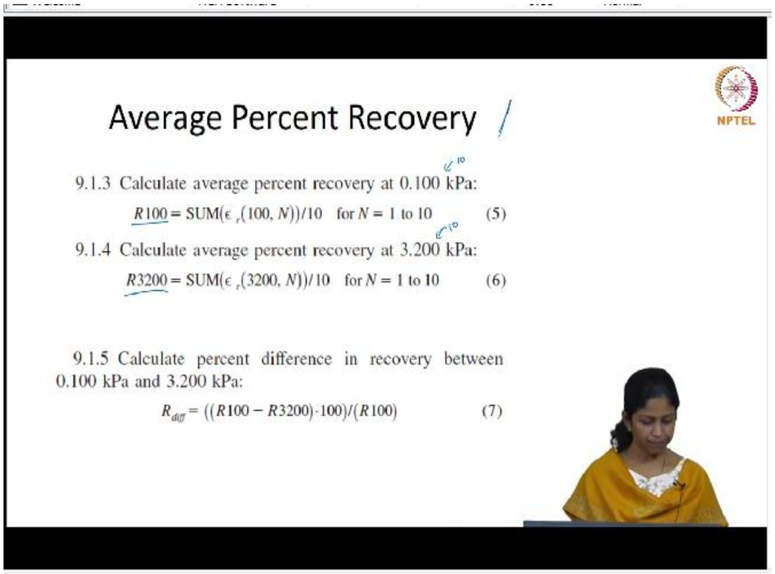

The next parameter that we will calculate is average percentage recovery. So, we said we calculate percentage recovery for all 10 cycles individually. So, for every cycle we will have 1 percentage recovery. So, for 0.1 kilopascal we will have 10 values and here we will have 10 values. So, we need to average all these 10 values and that is called this R100 or R3200 depending upon the shear stress level.

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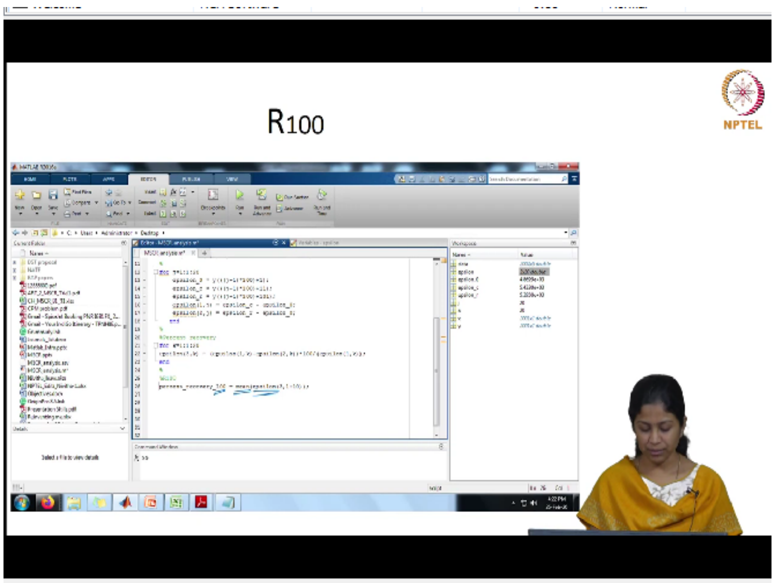

So, how to calculate R100? So, this percentage recovery 100 I have named it that way for easy understanding. So, percent and so you should not write this with space percent space recovery is not possible, but you can write it using an underscore. So, percent recovery for 100 Pascal shear stress is mean of epsilon 3 from 1, 10. So, what does this mean? So, the percentage recovery for

100 Pascal shear stress is the mean, here we calculate the average value of what? the epsilon array for what? the third row and 1 to 10 column.

Because we said we are calculating it for 100 right. So, we have to take the first 10, the remaining 10 are for the 3200 Pascal shear stress. So, we calculate mean of epsilon of the third row for 1 to 10 columns.

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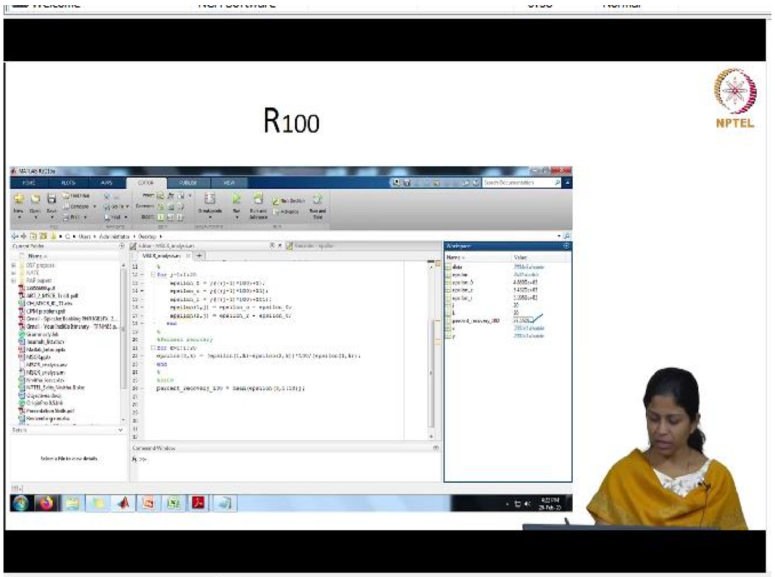

You can see here the percentage recovery value is displayed here. So, this is calculated for all the 10 cycles and this is only one number because we are averaging all the 10 cycles. So, we get as a single number here.

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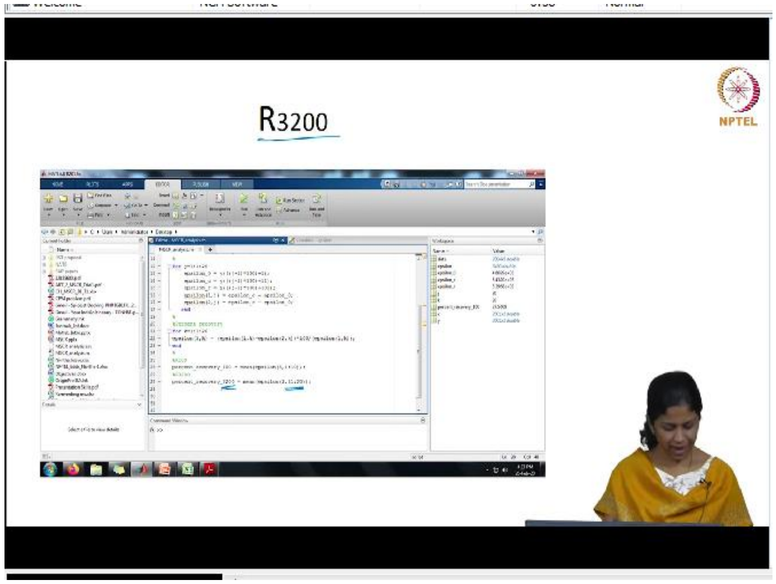

So, similarly, we can calculate R3200 also. So, this is nothing but percentage recovery at 3200 for the next 10 cycles. So, first we took the first 10 cycles, now, we are going to take the next 10 cycles. So, it is mean epsilon 3 from 11 to 20, remaining things will remain the same. So, it is mean of epsilon, third row from 11 to 20 columns.

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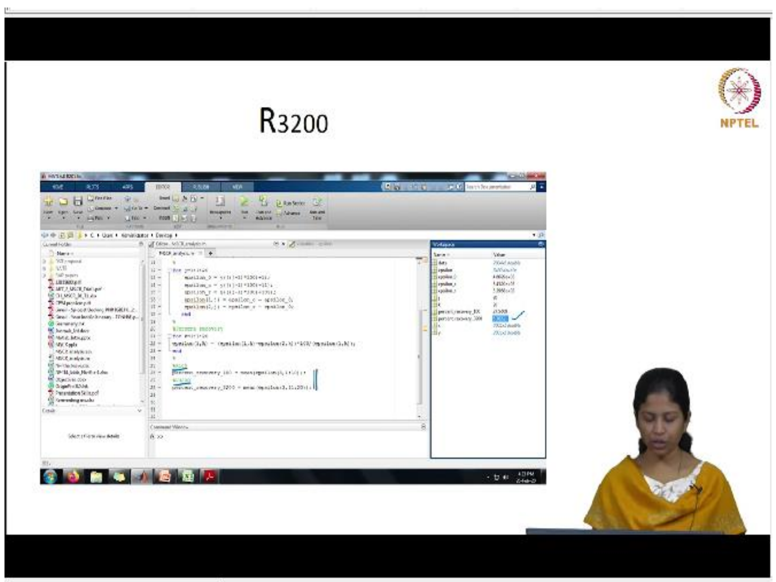

So, it will calculate the mean value and you can see that the percentage recovery has reduced as we had seen earlier. So, this is how we calculate the percentage recovery for these 2 cases, the average percentage recovery which is specified as R100 and R3200.

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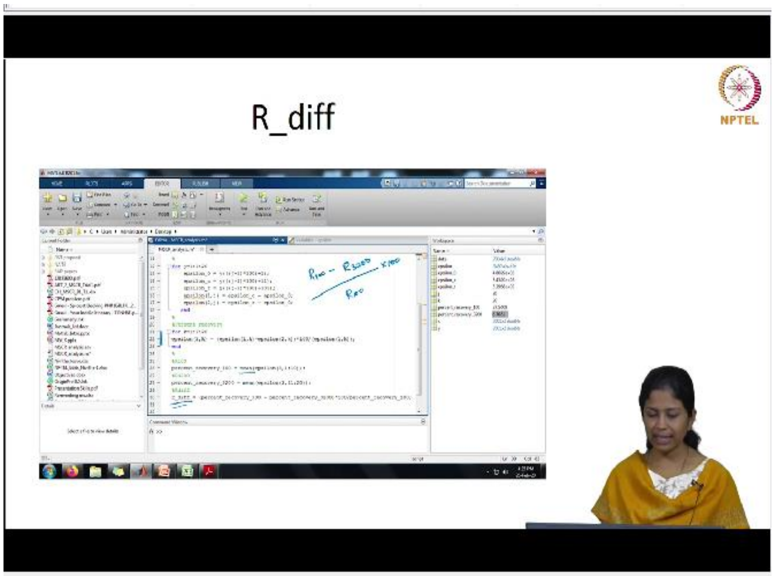

And we are also required to calculate R difference which is percentage recovery at 100 minus percentage recovery at 3200 divided by percentage recovery at 100 which is nothing but R100 minus R3200 divided by R100 into 100. So, this is R difference. So, this you can straight away calculate because these are 2 numbers. So, you can specify it in the same manner, you have to note that here we are giving it as a loop because we have to calculate this individually for all the 20 columns.

Whereas here it is only one number, we are calculating one number here and we are calculating this for 2 different numbers. So, there is no need to give a loop here right. So, next is we can see the R difference value, it is about 75.45% right so, this is the R difference value. Next, we will calculate non-recoverable creep compliance.

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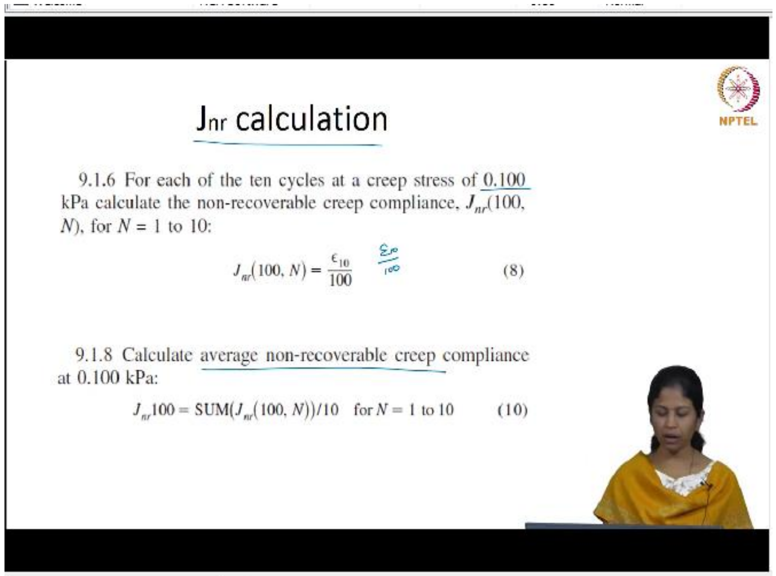

So, this Jnr right, it is said as Jnr. So, this Jnr is calculated separately for the 2 different stress levels as we have mentioned earlier, so we calculate Jnr as $\varepsilon_{10}/100$ so that is how this is calculated, and we kind of average it out to get the average non-recoverable creep compliance. So, this is for 100 Pascal shear stress.

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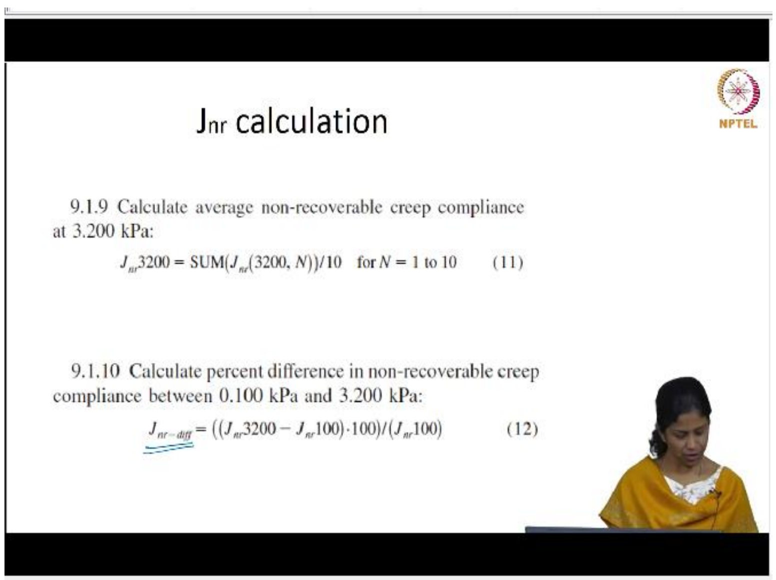

And this is for 3200 Pascal shear stress and we also calculate Jnr difference, which is (Jnr 3200 - Jnr 100) × 100 / Jnr100 as a percentage.

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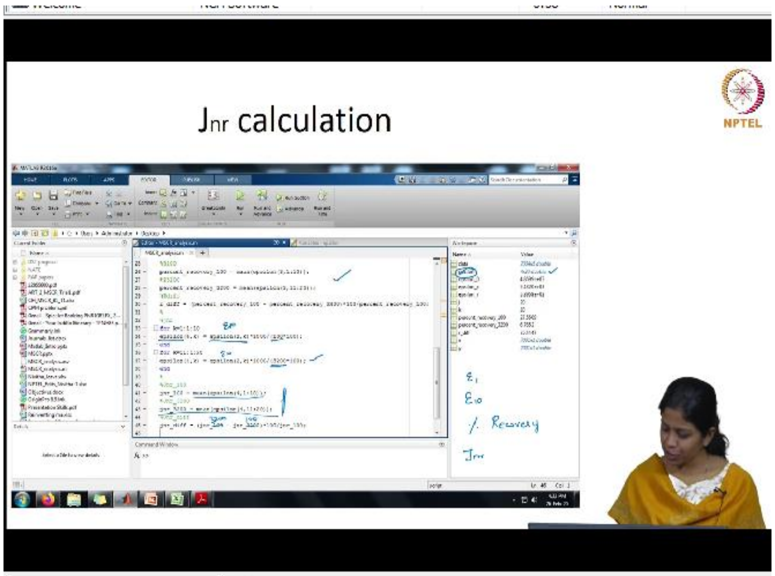

So, how do we calculate this Jnr? we calculate this Jnr as another row to the same epsilon matrix what we have defined earlier, but we need to make a note here, the denominator is different for the 2 stress levels. For the first case it is divided by 100 whereas, for the second case it is divided by 3200. So, you can also do this in the same loop, but for the sake of simplicity, I have splitted into 2 different loops.

So, in the first loop we calculate for the first 10 cycles. So, which is epsilon (4, k) is epsilon (2, k) which is nothing but our ε_{10} divided by 100. They have added these for the conversions right divided by 100. Similarly from the 11th to 20th cycle, the denominator here is 3200. So, we have calculated ε_{10} divided by 3200 for this case, so, we have the 2 Jnr values.

But both of them are calculated in the same fourth row. So, the calculation will be different, but both the numbers will be displayed in the fourth row and then we also calculate Jnr 100 which is nothing but mean of epsilon the fourth row 1 to 10 similarly, Jnr at 3200 which is mean of epsilon fourth row from 11 to 20 right. So, this is similar to what I have explained here for percentage recovery.

And finally, we calculate Jnr difference, which is Jnr 100 minus Jnr at 3200 divided by Jnr 100 into 100 right. So, now we have got all these things we have saved all the information in one matrix which is epsilon. So, this has 4 rows, the first row will be ε_1, the second row will be ε_{10}, the third row will be percent recovery and the fourth row will be Jnr right. So, these are the 4 rows you can see it is a 4 by 20.

And then we have calculated some average values and then calculated the percentage difference. So, this Jnr difference is this should be other way around: Jnr at 3200 minus Jnr at 100 divided by Jnr at 100 right. So this is the Jnr difference that we have calculated. Now let us see what are the values which have got.

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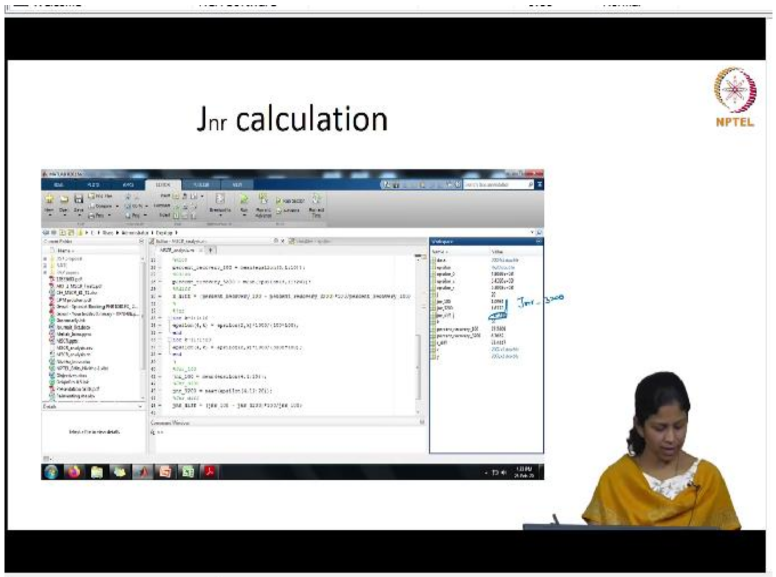

Ignore the Jnr difference, we can consider Jnr at 100 and Jnr at 3200. So based on the Jnr value at 3200, the grades of binders are specified.

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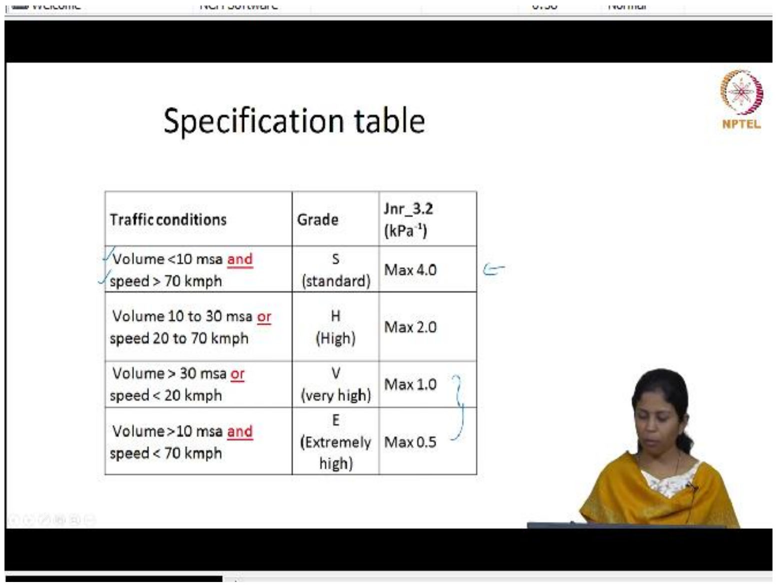

So we have seen this specification table also in our previous lectures. So, we see that for different traffic volume and speed conditions, the grades are specified using the Jnr value. So, here we can see that standard or high case, the Jnr value should be a maximum of 4 or a maximum of 2 whereas for these 2 cases, it is maximum of 0.5 and maximum of 1. Now let us go back and look at our Jnr at 3200.

You have to see here that though we have calculated a number of parameters, this table is specified only based on Jnr at 3.2. So from here we can see that the Jnr at 3200 is 1.6 right. So when we come back to this table, we can see that these 2 cases should have a maximum of 1 only, but we have a value of 1.6. So, this can fall under this grade or this grade.

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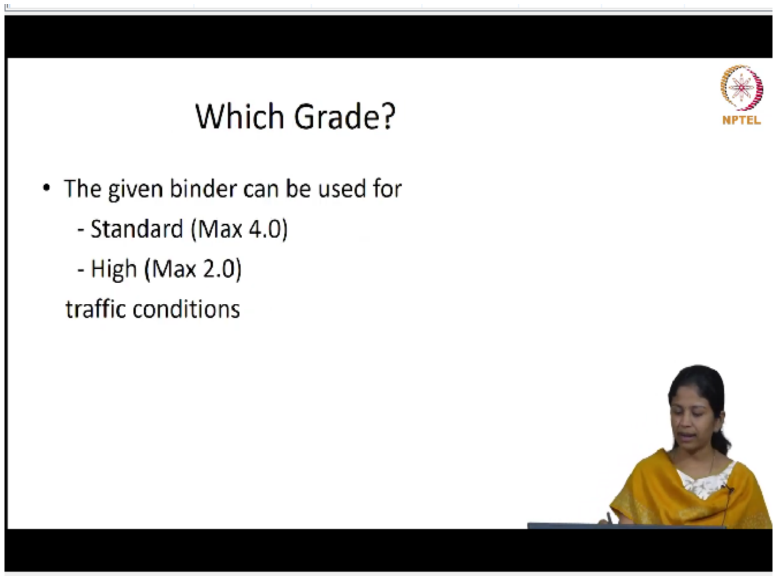

So, the conclusion what we derive here is the given binder can be used for standard or high traffic conditions. So, this is how we analyze the standard multiple stress creep and recovery data to arrive at conclusions regarding the usability of this binder for different traffic conditions. So, this is the analysis which I have shown for a standard MSCR test. You can also do a number of customized tests, you can increase the load level to you know the loading from 1 second to 10 seconds or we can do a lot of variations on this data. And for all such calculations, we can use this methodology to calculate the different parameters.