Pavement Materials
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Lecture 47
Characterization of Bituminous Mixtures (Part 1)

Hello everyone, Today, we are going to start discussing about Characterization of bituminous mixtures. The entire contents of this presentation may not be very-very useful to those learners who want to learn only about pavement materials, but the learners who have previously taken a course on pavement analysis and design or will be taking a course on pavement analysis and design in the near future, these contents will be very useful to them.

So, few of the things we will go very quickly considering that the audience for this particular subject do not require exposure to those concepts, but I have kept it in the presentation just as a reference so that tomorrow when you are going to see these presentations parallel to the notes on pavement analysis and design it may be useful to you.

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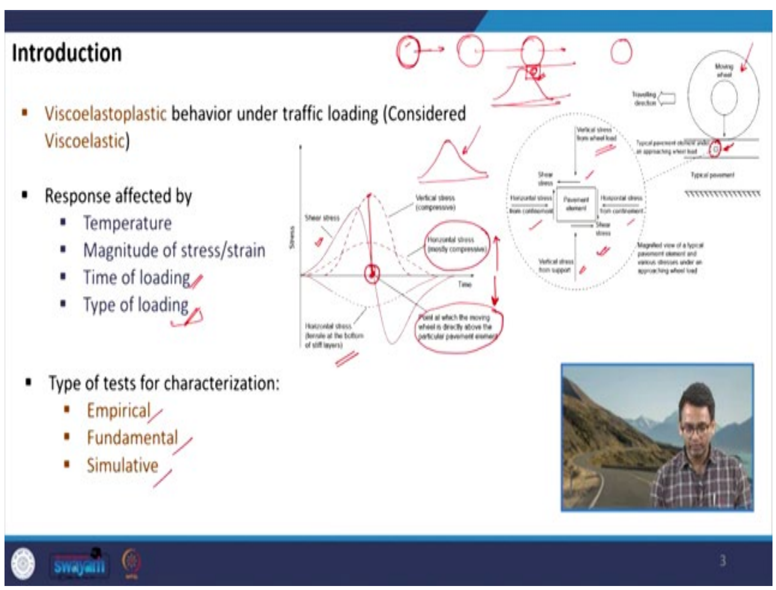

Talking about bituminous mixtures, by now, we understand that the response of a bituminous mixture is a function of both time and temperature. In general, the response is defined as or the bituminous mixture is characterized as a Visco elastoplastic material for a given a traffic loading, but for the learning purpose for most of the practical users, we characterize the behavior of the bituminous mix as a viscoelastic material and by now, we already know what do we mean by viscoelasticity and how a general viscoelastic material behaves under a given loading condition, which includes a loading from the traffic as well as the temperature.

So, if we see an element of a bituminous mixture, that is the, which is placed as the surface layer of the pavement, and if we want to see that how or what types of stresses will be induced in that particular element. So, this picture tries to highlight these stresses which are generated. So, this is the element here, this is a moving load, and this is the element whose magnified view has been shown here and various stresses have been identified.

So, one stress will be the vertical stress from the wheel load this is what we understand, there will be a support from beneath the layer which is below. So, this is also something which we understand, because it is a 3 dimensional structure and the loading is placed over it. So, there will be a generation of shear stress, which is shown here.

And of course, because of the confinement from all the sides, there will be horizontal stresses which will build up in this particular material. Also you have to understand and this is something which we have again discussed in the third module specifically, suppose, I am looking at this particular element of the bituminous mixture in the pavement and the load is much far from this particular element right now.

When the load is here, practically, this particular element is not subjected to any stress. So, when this load will move towards the element and it will come somewhere probably let us say to particular distance stresses will start generating in this material and when this load is directly placed over the element the stresses will be maximum and further than this load move away again the magnitude of stress will gradually decrease and at a particular time the stress will be almost equal to 0.

So, there is a variation of the stress which can be represented more as a haversine or sometimes as a considered as a triangular form of loading, this tells that the magnitude of stress gradually increases, it reaches the maximum when the load is placed exactly on the over the element. And then when the load moves away, it decreases.

So, researchers have tried to, give different forms of equation for this particular shape, mostly in the form of a sinusoidal wave. But again, the equation differ in many cases, so, we are not going in detail about those equations. This is just an idea how the element will be stressed when the load approaches that particular element in the bituminous mixture.

Now, this is again the variation of stress with time for this particular element when the load approaches that particular element. So, you see that this is the point at which the moving load is directly above the element. So, here, we are going to expect the maximum vertical stress, and here you see the shear stress is 0, because this is the axis of symmetry, where the shear stresses will cancel out and it will be equal to 0.

So, this is the variation of shear stress, this is the variation of horizontal stress which is compressive and because, here we are talking about compressive stresses and below this we have tensile stresses and of course, there will be tensile stresses at the bottom of the bituminous layer, which will also build up when the load approaches that particular element.

Now, when the load approaches that particular element or in general, when a bituminous mixture is loaded, it will respond to that particular load. Now, this response of the material to that particular load and this material being viscoelastic, which we are considering will depend on the temperature at which we are loading the material, it will also depend on the amount of load may it may be in terms of stress on strain, which is applied to the material, it will also depend on the time of loading we have discussed that how frequency affects the viscoelastic material.

So, of course, the time of loading in here when I say time of loading, it actually means that when we talk about practical consideration a time of loading is nothing but a representation of the speed of the vehicle. And also the type of loading this type of loading means the form of loading which we are giving in the laboratory specifically, whether we are loading the material in or giving a uniaxial load to the material, whether we are loading the material in shear, whether we are loading the material in a tension, whether we are loading the material in an indirect tension mode and so, on. So, the type of loading which we give will also affect the response of the material.

Now, various tests in the literature have been proposed to characterize bituminous mixture, and we are not going to discuss about all those test methods in detail in this particular lecture. However, we will try to have an overview of these test methods and then most importantly, we will talk about the use of these test methods for pavement design because, ultimately when I do a testing of a material, one thing is to understand the behavior of the material and the other thing is to use those properties in designing the pavement as a composite structure, if you talk about the type of test is it can be divided as empirical tests, fundamental test and simulated test.

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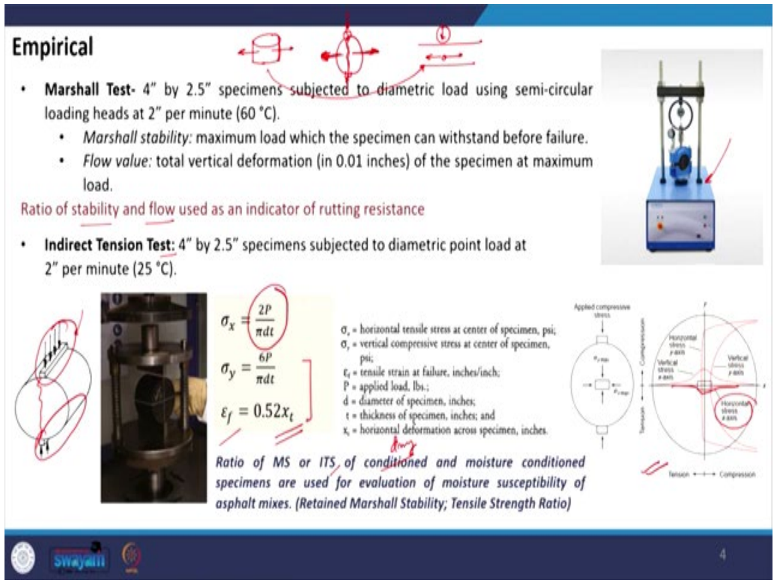

So, let us first start talking about empirical test methods and these test methods we have already discussed. So, I will not spend much time in, discussing in detail about this test method, we will just go through them, we will just try to see, these are the test methods, which we call as empirical. The first test is martial test in this particular module just before few lectures we have discussed about the martial test method in the mix design process.

So, A tests which is carried out using a martial stability and flow machine, we prepare specimens it can be either 100 mm in Dia or it can be 150 mm in Dia and then the standard height can be either 63.5 or 90 plus and then the load the material diametral plane and the test temperature is taken as 60 degrees Celsius and using this machine we measure the martial stability value which is nothing but the maximum load at which the specimen fails.

And at this load we also measure how much deformation or vertical movement has taken place and that is denoted as the flow value in the martial test. As I mentioned during our discussion on mix design, that both martial stability and Flow are empirical test, they are mostly used only as a check parameter in the martial mix design. But studies have not found good correlation with the occurrence of the stress and the values of martial stability in flow.

However, in the initial time when people studied about martial stability and flow and then tried to see its correlation with the occurrence of distresses, so, the ratio of martial stability and flow has been taken as an indicator of rutting resistance, but, not many literature's claim or agree to this particular parameter.

Then we have indirect tension test, again we have discussed about indirect tension test when we discussed about moisture sensitivity. So, here what we do, we load the specimen along the diametral plane again, but using a rectangular element, so, the area of loading is small. So, you can see in this particular picture that this is the area of loading using a rectangular strip, we provide the load on both the sides and then we are expecting that the material will crack along this plane.

One thing many times student ask that why we are loading the specimen in the indirect mode. And we will see later also when we measure the resilient modelers for example, we again load the material in the indirect tension mode. So, what do you mean by indirect tension mode. What so, what in the pavement we are expecting that when the pavement is subjected to a load, because the horizontal tensile strain is considered as a critical parameter for bituminous mixture, because this leads to fatigue cracking.

So, we are more interested to see the horizontal stresses and strains that get generated in the mixture. So, this is what we are interested in. So, when you load the material in the indirect mode and why we call it as indirect tension, because, you see, we are applying a compressive load here, then why do we call it a tension we call it as tension, because when you load this material, here the material is split along this plane.

So, there are forces acting in this direction and this is shown here, if you see that how the horizontal stress act along the materials, so, you see the horizontal stress is maximum along this plane and this is shown here in tension. So, this acts in this direction and this is what we are trying to evaluate.

So, if you try to see the specimen in the uniaxial form, this particular stress is basically along this plane and that is what we are interested in and therefore, we load the material in indirect tension mode though we are giving the compressive stress, but we are trying to measure the tensile stresses in that particular element.

So, we do an indirect tension test the method is very simple, we can use the martial stability machine here we provide the similar rate of loading or 50 mm per minute the same which we apply for martial stability test and then we measure the indirect tensile strength and the indirect tensile strength can be calculated using $\frac{2P}{\pi dt}$, this is the standard formula where P is the load at failure, d is the dia of this specimen and t is the thickness of the specimen and using the other formulas you can calculate the vertical compressive stress also during the indirect tension test, and you can also calculate the tensile strain at failure.

And you can see that the tensile strain at failure is a function of the horizontal deformation across the specimen. So, these formulas can be used to calculate the indirect tensile strength. Again, indirect tensile test is sometimes considered as a representation of fatigue cracking, but this may not be true however, the use of indirect tension test is prominent, specially when we are trying to measure the moisture susceptibility because we use the tensile strength ratio as the parameter and also in the conventional resident modelers test that we carry out the load which we apply to the specimen is taken as a percentage of the load we get in the indirect tensile strength test. So, that is also an use of this particular test method.

So, as I mentioned, the ratio of Marshal stability or the ratio of ITS of condition and moisture of basically dry and moisture conditions specimens are used for the evaluation of moisture susceptibility. So, this is again one of the use of martial stability in indirect tension strength with and both of these tests are empirical.

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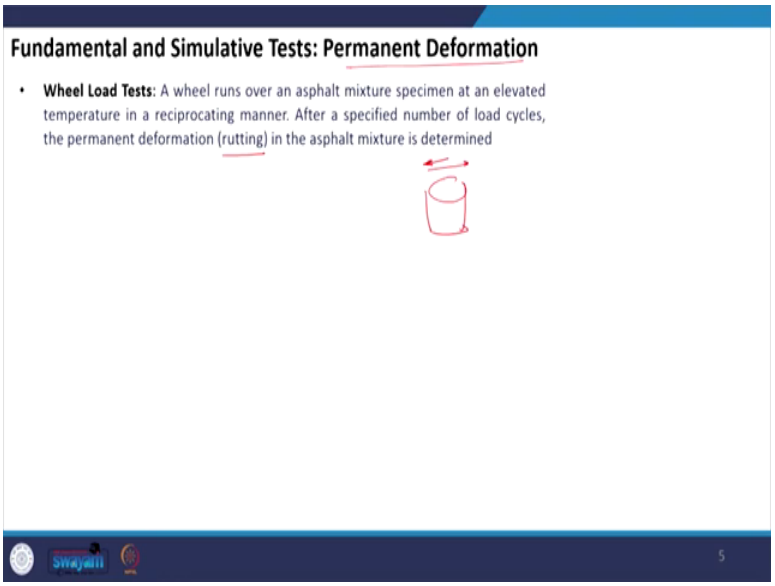

Then let us talk about fundamental and simulative test. So, fundamental tests are those tests which tells us something about the fundamental property of the material. On the other hand, simulated tests are those which may not tell us exactly about material properties, but will give us an indication of how the material will perform when it is subjected to similar level of loading as we see in the field.

So, we load test for example, this is a simulative test now, we are talking about permanent deformation or rutting we will take up the distresses one by one. So, in this particular presentation, we will talk about permanent deformation and then fatigue cracking.

So, talking about permanent deformation, one of the very popular tests is the wheel load test where there is a wheel that will run on a prepared sample of asphalt mixture, we will carry out the test at an appropriate temperature, this temperature can be the maximum payment temperature of that particular location, where we are going to use the mix or the specification may always tell us that you have to do the test at a fixed temperature. So, it depends on the specification and the agency.

So, there is a wheel which will continue to move on the specimen. So, we will have the specimen here and the wheel will continue move on this and after a specified number of load cycles. The amount of rutting in the in terms of rut depth, how much the wheel has rutted the specimen is basically measured.

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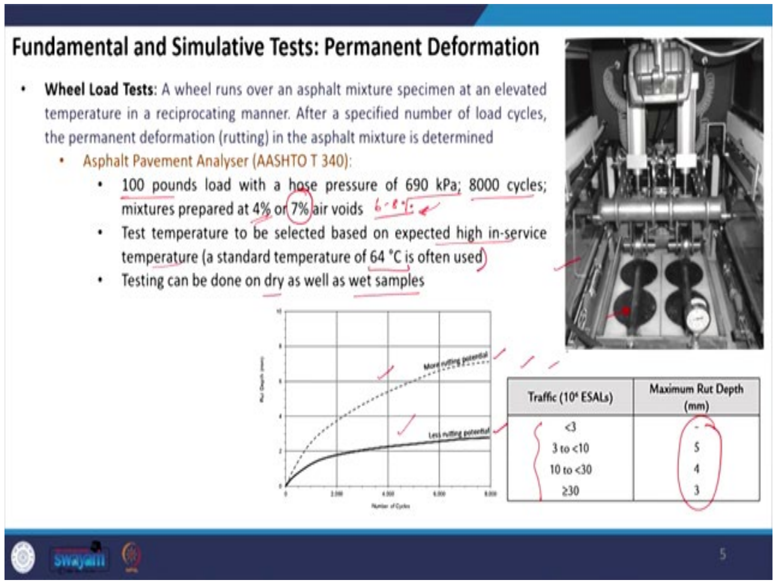

So, there are various type of wheel load test, one of the type is the use of asphalt pavement analyzer. So, APA is one of the common or popular test method or evaluating rutting resistance using a wheel load setup, you can see an image here that has been taken from MS 2. So, here, we will first prepare cylindrical specimens and then we will subject the specimen to the load in the machine and typically 100 pounds of load is applied with a host pressure of 690 k Pa.

So, these are the specification we allow the load to move for 8000 cycles and the mixtures which we use here, they are either prepared at 4 percent air voids or some specification said that they should be prepared at 7 percent air void, the reason of using 7 percent air void is that if you are anticipating that the mixture is to fill in rutting in the field and when we put the mixture in the field that time the air void in the mixture just after placement is somewhere in the range of 6 to 8 percent and this is what we have discussed.

And we are expecting that rutting in the bituminous mixture, if there has to be any, should occur within a few years or immediately after opening the pavement to traffic after movement of some amount of repetition of load. Because with time the mix will become stiff and the chances of rutting will reduce and therefore, some of the specification says that it is more logical if you want to see the susceptibility of the mix to rutting it is better to prepare it 7 percent air voids and 4 percent is considered because this is the design air void content.

Test temperature to be selected based on expected high in service temperature or some of the specification says that you can use a standard temperature for example 64 degrees Celsius testing can be done on dry as well as wet samples, which means both dry rutting and wet rutting can be evaluated.

So, a typical graph is shown here that these are let us say 2 different mixes and you can see that with the increasing number of load cycles. Of course, the rut depth is going to increase you can see that this sample is having a higher rate of development of a permanent strain in comparison to this particular sample which has less rutting potential.

So, this is just a typical picture, which you get after doing the test. Now, we also have specifications available related to the limiting values and this is a table which shows that for different levels of traffic, what should be the maximum allowable rut depth and for example, this table can be used as a reference when we are talking about performance based mix design also which we have discussed in the last presentation. So, specification table are available for the asphalt pavement analyzer test presently.

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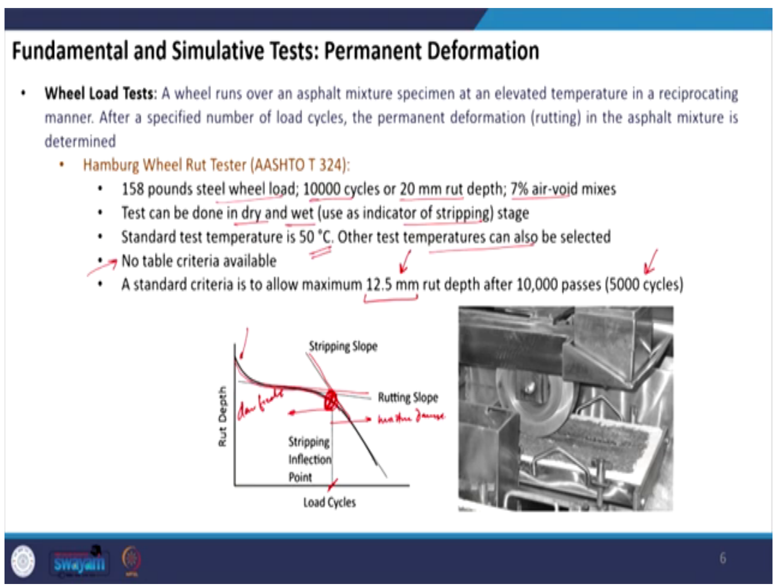

Another test, which is also a wheel load test is the Hamburg wheel load test again one of the popular test methods, it is almost similar to the asphalt pavement analyzer only the values of number of load cycles or the temperature or the amount of load we are putting may change. So, here we have 158 pounds of steel wheel load which will move on the prepared bituminous mixture sample typically 10,000 cycles is considered as the end of the test.

Alternatively, we can also see what is the number of load cycle taken by the sample before reaching 20 mm rut depth, both the parameters can be considered as the less criteria are the samples are typically prepared at 7 percent air void in the Hamburg Wheel load tester. This test can be done again on dry and wet condition. And when the test is done in wet condition, we can also have an idea about the stripping inside the bituminous mixture. So, the standard temperature is 50 degrees Celsius as I mentioned other tests temperature can also be selected.

Unfortunately, for Hamburg wheel load test, we do not have any table criteria similar to what we saw for asphalt pavement analyzer. One standard criteria however, says that you can allow a maximum of 12.5 mm rut depth which is sometimes also the limiting rut depth for pavement design after 10,000 passes or you can say 5000 cycles.

So, after 10,000 passes or after 5000 cycles, if the rut depth exceeds 12.5 mm, then it can be considered as a pass or fail criteria. So, this is a typical picture of how the sample will behave with increase in number of load cycle sometimes you must be wondering that why the rut depth shows that it decreases because here they are measuring the change in the thickness of the sample.

So, you can see that with increasing in load cycle when the rut depth increases. So, the thickness of the sample decreases and that is why the curve goes down. And to identify if you are doing this in wet condition how to identify the occurrence of stripping here. So, these are 3 stages. So, the curve will move like this and this is called as the inflection point.

So, beyond this point all the failure that has occurred or all the rut depth that has accumulated is because of the densification in the mix and beyond this point the rut depth that has occurred is attributed to the moisture damage in the mix and you can find out the stripping inflection point, this will be a point of intersection of the slope of the densification part and the slope of the moisture damage part.

So, stripping slope and rutting slope the intersection of both the slope will give us the stripping inflection point.

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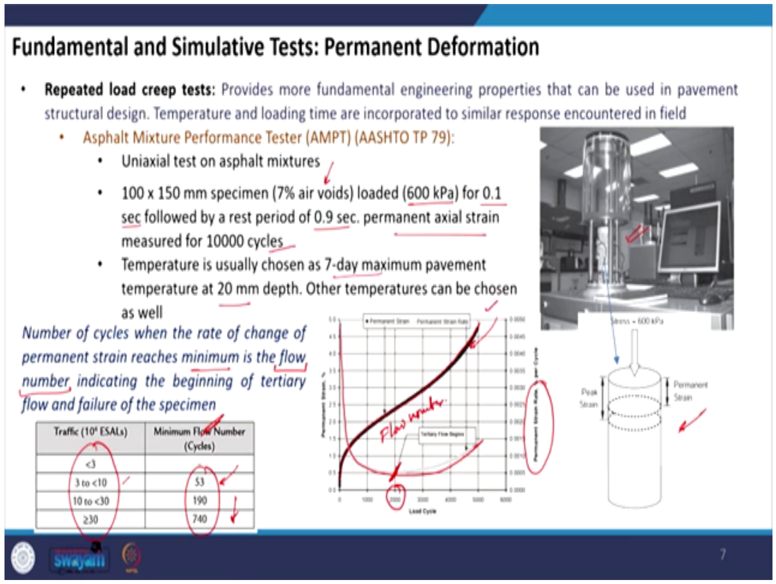

So, moving further the other test method under permanent deformation category is repeated load creep test. Now, repeated load creep tests are fundamental test because they will provide fundamental engineering properties that can actually be used in the structural design of the pavement, we will talk about that, temperature and loading time are incorporated similarly to what the response that is encountered in the field.

One of the test method under the repeated load creep test is the asphalt mixture performance test, we call it as AMPT. So, this is a an example of the sample placed in the AMPT machine. And you see the sample is loaded in the uniaxial direction here. So, what we do here we perform a uniaxial test on asphalt mixtures, we have cylindrical specimen prepared at 7 percent air void and they are loaded at using 600 kPa of pressure and the load is given as 0.1 second of load followed by a rest period of 0.9 seconds.

So, you can see this is more of a representation of what is happening in the field when a point is subjected to a load and the load moves away from him. So, this is a loading and unloading test and in this particular test, we measure the, or we keep on monitoring the permanent axial strain for 10,000 cycles.

So, we see how the strain accumulates in the material up to 10,000 cycles, the temperature at which you have to do the test is typically chosen as 7 day maximum pavement temperature taken at 20 mm depth from the surface of course, other temperatures can be chosen for the test method. This shows a typical output from the test method you can see that the permanent strain increases gradually with increasing number of load cycles. And you also see here the strain rate that how the slope of the permanent strain is changing with time and this is shown here.

This is shown here and the point corresponding to the minimum value of the permanent strain rate is noted down and the number of cycle at which the permanent strain rate is minimum is termed as the flow number of the sample and this is where it is assumed that tertiary flow in the material has started. So, there is we have primary flow, we have secondary flow, and then we have tertiary flow. So, this is the location where the tertiary flow starts.

So, number of cycles when the rate of change of permanent strain reaches minimum is denoted as the flow number which is one of the parameter to quantify rutting resistance and this indicates the beginning of tertiary flow and failure of the specimen. So, we also have a specification table here depending on the level of traffic. So, this is a good thing it can be used in performance basic design and the criteria is that what should be the minimum flow number which means, the cycle at which this tertiary flow will actually start.

So, at least for 3 to 10 MSA traffic for example, at least the sample should have undergone 53 number of cycles before the start of the tertiary flow and so on. So, this is one of the specification that is available, then we will also discuss that this particular curve can be very again very useful to quantify the total plastic strain or the magnitude of rutting in the mixture, which can be directly used as an input in pavement design we will discuss about this in some time.

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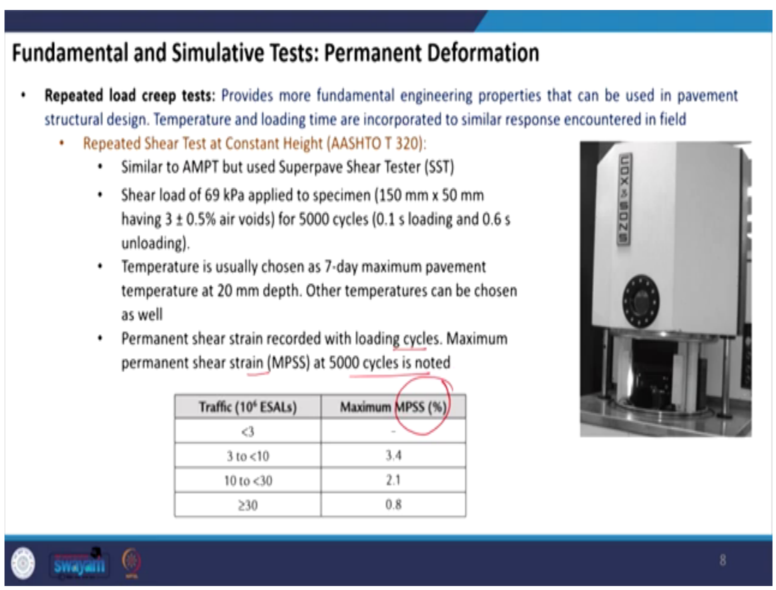

Then we have repeated load creep test under repeated load creep test we have the next test is repeated shear test at constant height. This test is almost similar to AMPT, but the machine used here is different we use a Superpave shear tester and the loading used here is a shear load instead of a uniaxial load.

So, we apply a shear load of 69 kPa to the sample which is prepared at the error void of 3 plus minus 0.5 percent air void. So, you see the average air void is 4 percent and the sample is loaded for 5 seconds and the loading and unloading given here is also a little different from what we give in AMPT it is 0.1 second of loading with 0.67 rest period.

So, loading is given in this form. So, you have the loading and then you have the rest period or if you want to see the loading, then you have a loading cycle and then you give rest period you have loading cycle and you give rest period and then the if you see the response of the material, it is in this form that the strain will increase after recovery they will be recovery in the material again the strain will increase again they will be recovery in the material and so on.

So, what we do here we record the permanent strain with loading cycles and the maximum permanent strain at 5000 loading cycle is noted, and here also we have a specification table available corresponding to different level of traffic, what should be the maximum permanent shear strain accumulated in the material after 5000 cycles for different levels of traffic.

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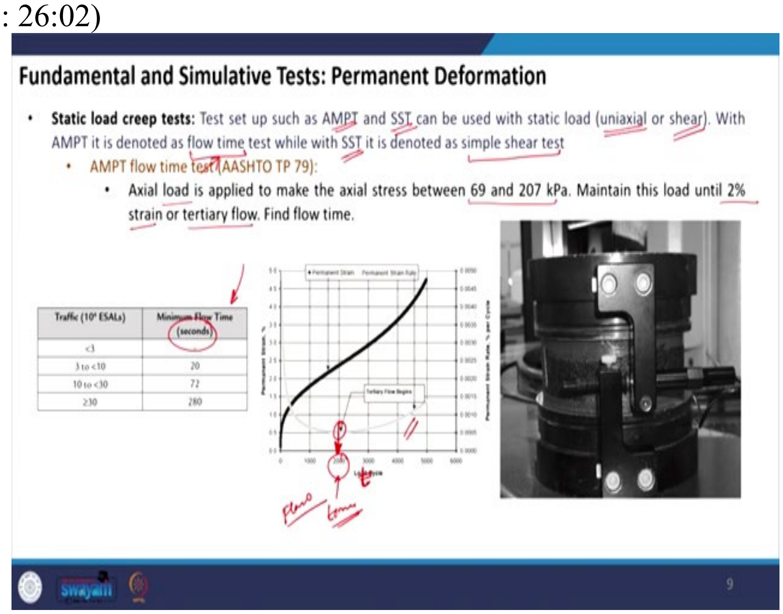

Then, we also have static load creep test now, just the previous slides, they were talking about dynamic creep, we are giving a loading and unloading, but here we have static creep that we do not load and unload the sample using a dynamic load. Rather we use a static load, we keep that load on the sample for a certain period of time. And we see how the sample response to that particular static load.

Therefore, the same machines like AMPT and the Superpave shear tester, they can be operated even in the static mode. As I said the only difference is if you are using AMPT, you will use a uniaxial static load, if you are using a Superpave shear tester, you will use the shear static load. For example, if you are using AMPT the response is denoted in terms of flow time, there we had flow number here we have flow time.

While when we are using superpave, here tester test is denoted as simple shear test. So, I have just taken the example of AMPT to explain what is the specification difference. So, the type of curve which will be generated will be same. So, here what we do, we apply an axial load so, that the stress is somewhere between 69 to 207 kPa and then we, you maintain this load.

So, how long you have to maintain this load until 2 percent strain is generated in the material or the material starts showing tertiary flow and then you find flow time so, the curve will almost be similar and here this particular time period we will see at different times with increasing time how the permanent strain changes and this particular point will give us the time.

So, this is time and this is termed as the flow time and the specification gives minimum flow time, there we had minimum flow number in terms of number of cycles here we have minimum float time in terms of the magnitude of time period. So, this is the only difference and it depends again on the specification that which test method we are going to use.

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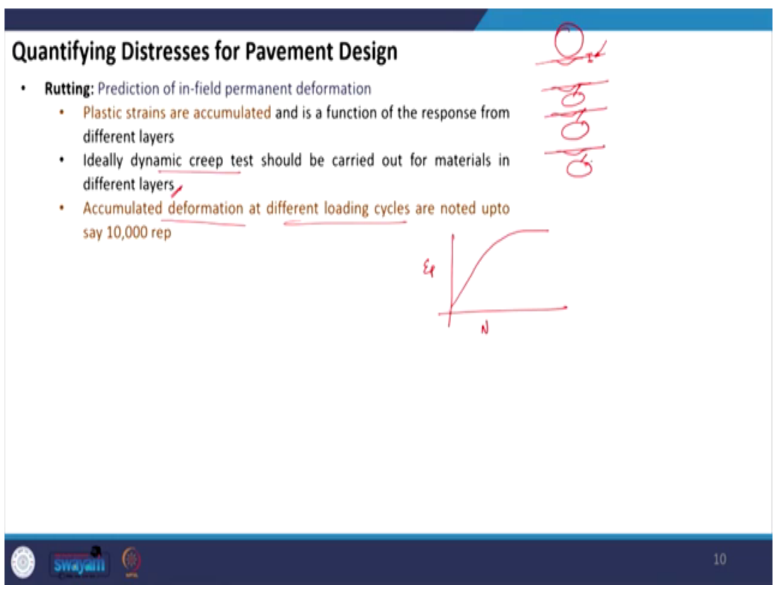

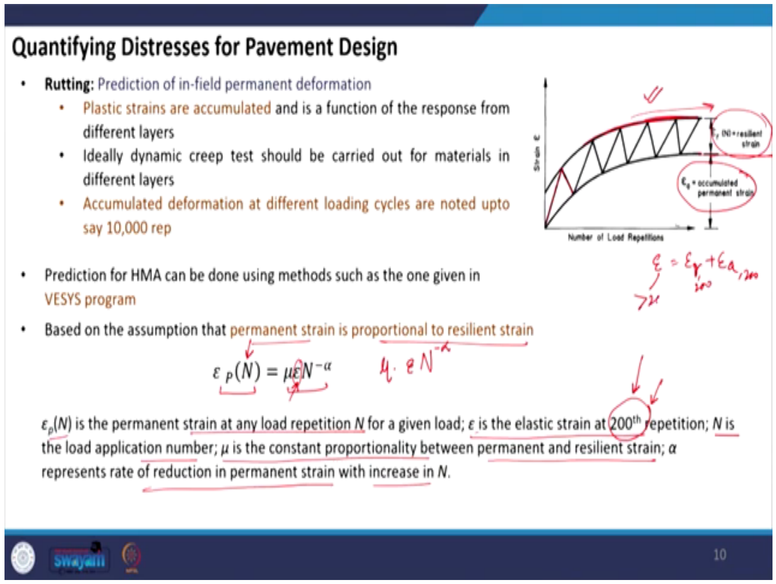

Talking about the infield behavior and then quantification of rutting. In infield, this is not very straight forward when you talk only about asphalt mixtures, because rutting is a phenomena which is attributed to the development or the accumulation of permanent strain in different layers.

For example, if you talk about a layered system, and when you apply a load and you want to quantify rutting, so, this layer must have deformed this layer must have deformed this layer must have deformed and then this layer must have deform. So, the total strain or the total deflection here or permanent deformation here is a function of the deformation in all the layers. So, this is an accumulated permanent strain, not only the permanent strain in the HMA.

Therefore, these dynamic creep test which we say is a fundamental test to quantify the occurrence of rutting in the pavement or is tell us about the material property should actually be carried out in materials from different layers. So, you have to take material from subgrade you have to take material from granular layers and then you have to carry out dynamic creep tests in all these materials. And then you have to note down the material properties corresponding to the dynamic creep test.

Usually in the test what we do, we will keep a note on the accumulative deformation at different loading cycles. So, when we do that test, we keep on monitoring that with increase number of loading cycle, how the permanent strain is generating at different values of n. And then we sum up the value of permanent strain from different layers to get the total deformation in the surface.

So, again as is said that this moment it may not be very clear when I talk about these concepts, but it will be very clear when you see how a pavement design is basically done. Anyways, few of the general things we can of course, understand from material perspective. For example, if you do carry out a dynamic creep test with number of loading cycle, we expect that when we load the material unload the material, some amount of permanent strain will be generated and we keep going on and after a particular number of load repetition, the amount of permanent strain will stabilize.

So, we will have resilient strain in the material or recoverable stream and we will have some amount of permanent strain in the material. So, we keep a note of both the resilient strain and permanent strain while doing the experiment.

So, let us talk about a methodology which is very commonly used and has been very popular also for prediction of permanent deformation in hot mix asphalt or even in the entire pavement layer, I will discuss the general concept here just to explain how we can calculate the total permanent strain in a flexible pavement.

So, this program, this method was given in the VESYS program and it is based on the assumption that permanent strain is proportional to resilient strain, the assumption is that the permanent strain is proportional to resilient strain and the relationship between permanent strain and resilient strain with the number of load repetitions can be written as follows. So, you see, the permanent strain = $\mu\epsilon$, epsilon is basically the strain. So, permanent strain at any N th number of load repetition, $\epsilon_P(N) = \mu\epsilon N^{-\alpha}$.

So, here $\epsilon_P(N)$ is the permanent strain at any load repetition and for a given load, ϵ is the elastic strain at 200 repetition, please note down this. So, this is talking about the elastic strain in the material, which is this is not the total strain as I mentioned, this is the elastic strain or the recoverable strain and n is the load application number mu is a constant of proportionality between permanent and resilient strain.

So, you can say this is a correlation factor and alpha represents the rate of reduction in permanent strain with N increase in N and so, in this curve also you see with increase in N, there is a rate of reduction in permanent strain, the permanent strain decreases with increasing number of load cycles and we are assuming that after 200 load repetition, most of this curve will stabilize here and then we will have a constant value of permanent strain and resilient strain. So, after the 200 reputation, we can say that ϵ = $\epsilon_r + \epsilon_a$ at 200 repetition. So, ϵ at greater than 200 repetitions. So, this is what is the assumption here.

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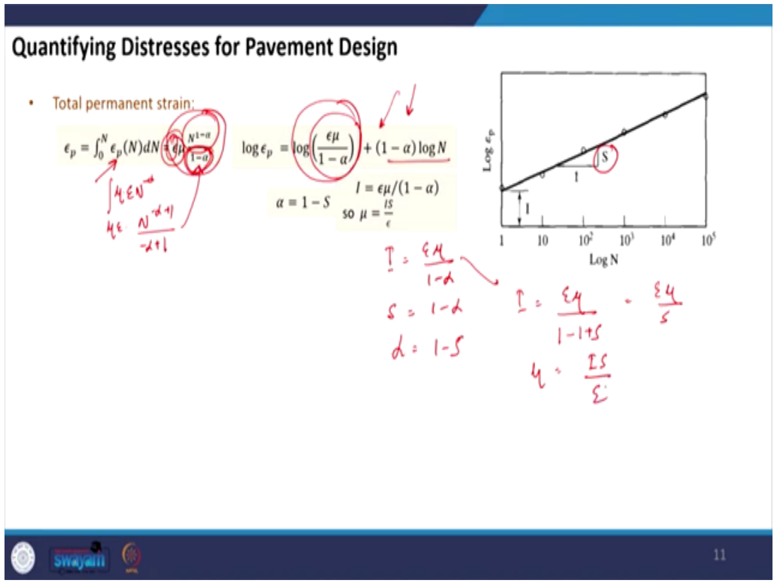

Then what we do so, using this equation, if I want to calculate the total strain after n number of nodes reputation, what I need to do, I will just integrate everything from 0 to n, this is what I am going to do. So, this is what is done here the previous equation has been integrated to calculate the total accumulated strain after all the reputations.

So, if you just put ϵ_P here, which was given in previous equation, this was if you see here this was $\mu\epsilon N^{-\alpha}$, if you just integrate this will be $\frac{-\alpha+1}{-\alpha+1}$ and this is what is written here. So, the permanent strain can be written in this form the total accumulated permanent strain, if you take logarithmic on the both sides this will give you a linear equation in this form, because this $\frac{\epsilon}{1-\alpha}$ can be separated $\frac{\epsilon\mu}{1-\alpha}$ a constant.

So, this is separated and $N - \alpha$ becomes $(1-\alpha)LogN$ here if you take log on the both sides, so, this is a straight line equation of $Log\epsilon_P$ versus $LogN$, where this is the constant the intercept here. So, intercept becomes equal to in the log scale $\frac{\epsilon\mu}{1-\alpha}$ and then the slope is basically equal to $(1-\alpha)$ here.

So, therefore, alpha becomes equal to $1 - S$ and if you put alpha here then it becomes equal to $\epsilon\mu$ $(1 - \alpha)$ is $(1 - S)$, so, this is $(1 + S)$. So, this is $\frac{\epsilon\mu}{S}$. So, therefore, $\mu = \frac{IS}{\epsilon}$.

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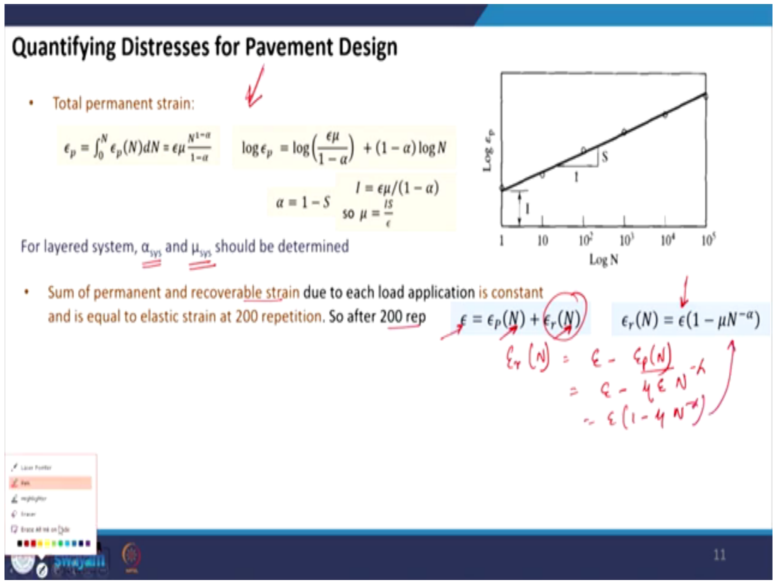

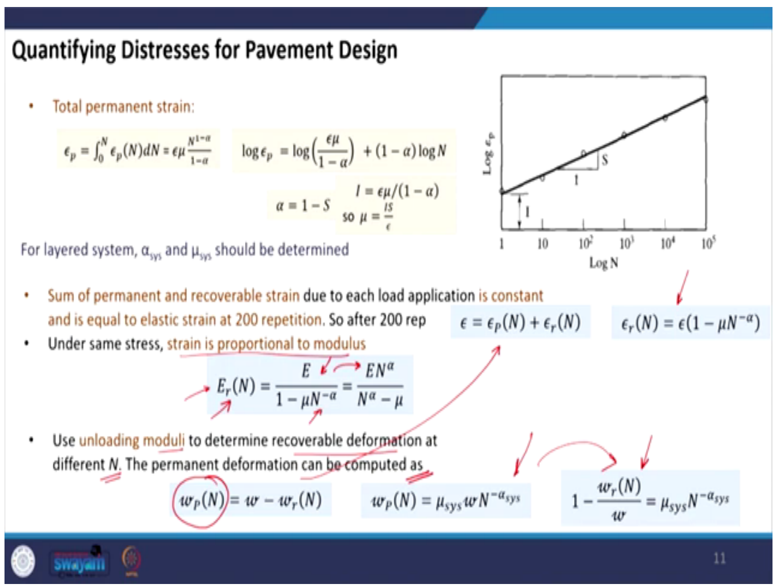

Now, we are discussing about only one layer where we are talking about these concepts, but in order to, find the accumulated strain in the pavement, we have to find out alpha system and μ system not only α for one layer and μ for one layer rather α for system and μ for system.

So, what we do in the next step will sum up the permanent and recoverable strain due to each load and we are seeing that after 200 load repetition it is constant. So, after 200 Load repetition what you get $\epsilon = \epsilon_P(N) + \epsilon_r(N)$, ϵ_r is the resilient strain.

So, this is equal to ϵ and $\epsilon_{p\,V}$ already have said that it is equal to if you see in the previous 1, it is equal to $\mu\epsilon N^{-\alpha}$ and this is what we have put here, if I want to calculate ϵ or N, so, this is $\epsilon - \epsilon_P(N)$ So, it is $\epsilon - \epsilon_P(N)$ is nothing but $\mu\epsilon N^{-\alpha}$ here.

So, this becomes equal to $\epsilon(1 - \mu N^{-\alpha})$ and this is what is written here. So, I hope this is clear. Now, if the stress remains the same, then of course, we know that from the general concept of elasticity, we know that strain is proportional to the modulus.

So, this equation can now be transformed in terms of modelers that $\epsilon_r(N) = \frac{\epsilon}{(1-\mu N^{-\alpha})}$ using the same concept we can write this and this is just rearranged in this form $\frac{\epsilon N^{\alpha}}{(N^{\alpha}-\mu)}$ and this is called as the unloading or the recoverable module. So, using the recoverable moduli we can determine the recoverable deformation at different values of N.

And this can be done using the linear elastic analysis and finally, the permanent deformation can be calculated as in terms of deflection or in terms of deformation as $\omega_P(N)$ and here we are using the same form $\omega_P(N)$is equal to $\omega - \omega_r(N)$ then further $\omega_P(N) = \mu\omega N^{-\alpha_{sys}}$ this talks about all the layers and this can further be arranged in this form and using this you can calculate the total accumulated deformation in the mix. This may not be very clear when I talk verbally about these steps.

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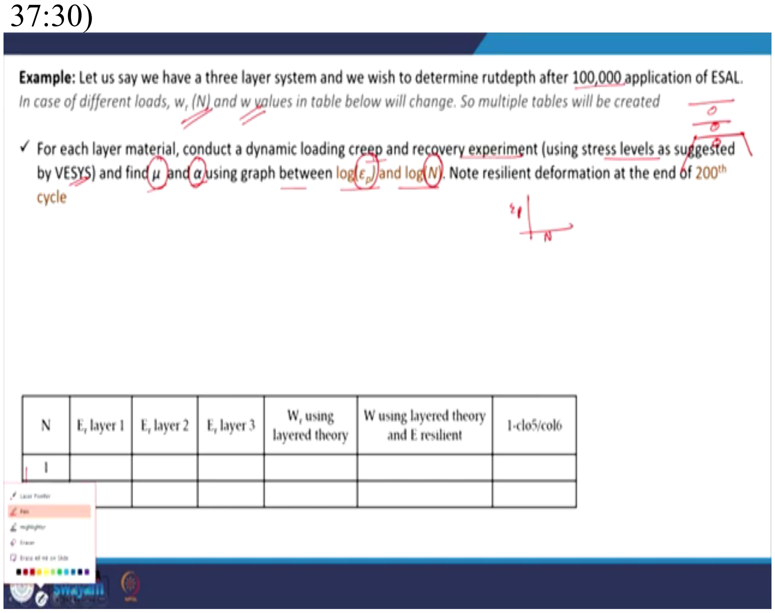

So, I have just taken an example are here to explain how to use these steps. So, let us say that we have a 3 layer system, we have a 3 layer system and we wish to determine the rut depth after 100,000 application of equivalent standard axial load. Now, in case of different loads, which means after 1 load after 2 loads after full loads, after 10 loads after 100 loads, every time the recoverable total at $\omega_r(N)$and ω values will change. So, this is the table where I am going to note down all the values. So, multiple tables will have to be created.

So, I have created from here N to N 100 Probably then it is 1000 then it is 10,000 and so on. And then these are the steps for each layer. I will take this layer, this layer this layer for each layer material conduct a dynamic load creep and recovery experiment and our stress levels which I am going to use it is given in VESYS program I am not going to talk in detail about which stress method you have to use during the test.

Let us say you have done the test as per the standard and then you will find μ and α using the graph between $Log\epsilon_P$ versus $LogN$ for so for each material, we are monitoring ϵ_P versus N and we can use that particular variation ϵ_P versus N variation and then using this I can find out the value of μ and α using the slope and intercept.

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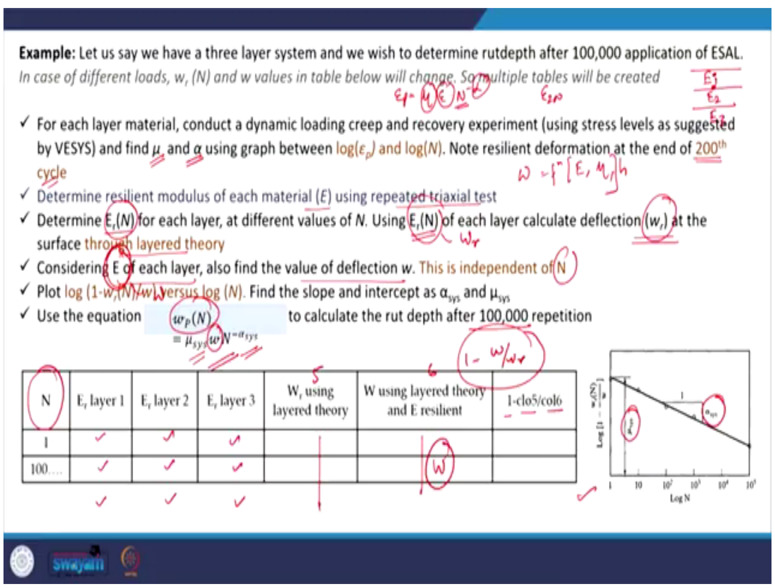

So, this is what we have discussed in the previous slide that how the slope and intercept can be used to calculate μ when α and why you need μ and α because ϵ is taken as ϵ_P is taken as $\epsilon\mu N^{-\alpha}$).

So, here ϵ is known N is known, you need α and μ to quantify the behavior of the material. So, note the resilient deformation at the end of 200 th cycle. So, you note that after 200 cycle, what is the total value of strain. Determine the resilient modulus of each material using a repeated triaxial test or by using some correlations. So, for each layer you will also need the value of N, using the value of ϵ you calculate $\epsilon_r(N)$ for each layer.

So, how you will calculate $\epsilon_r(N)$ using the previous slide using this formula. So, $\epsilon_r(N)$ is equal to ϵ of the material and you already know and you already know α you have just computed using the slope and intercept μ you have just computed using the slope and intercept. So, using this you can calculate the value of $\epsilon_r(N)$. So, $\epsilon_r(N)$ will be a function of the value of N. So, for different values of N, you will have $\epsilon_r(N)$ values here then using $\epsilon_r(N)$and using the linear elastic theory, you calculate the value of deflection. So, you compute the deflection based on the linear elastic theory.

Now, as per the linear elastic theory the deflection is a function of the modulus of the layer and the poisons ratio of the layer. So, using the linear elastic theory and of course, the thickness of the layer, so, you calculate the value of $\omega_r(N)$ in each layer probably at the middle or probably at the surface.

Now, consider each of each layer and also find the deflection value. So, using $\epsilon_r(N)$ you get ω_r and using the value of ϵ you get ω and this is independent of N because ϵ does not depend on N, ϵ is independent of N. So, you get $\omega_r$and then you get ω this ω is basically only one ω here, then what you do you just do $\frac{1-Column\ 5}{Column\ 6}$. So, this is column 6 this is column 5. So, you just do $\frac{1-\omega}{\omega_r}$ and you plot $\frac{1-\omega}{\omega_r}$ versus N.

So, you do this you get the slope this is μ system by α system, once you have the μ system α system, you use this particular formula that ω permanent which means plastic strain is equal to μ system $\times$elastic ω which you get from the linear elastic theory into $N \times N^{-\alpha}$ to calculate the total rut time. So, I hope that with this you get an overview on how VESYS has describe the steps to calculate the rut depth in a pavement system using you do not do dynamic creep experiment.

So, with this, we will stop here today and in the next presentation we will continue discussing about the further test methods and we have completed the test methods and discussion on test methods on rutting today. And in the next presentation we will start discussing about stiffness and fatigue cracking. Thank you.