Analysis and Design of Bituminous Pavements

Prof. M. R. Nivitha

Department of Civil Engineering

Indian Institute of Technology Madras

Lecture – 20

Modulus for Design - CBR

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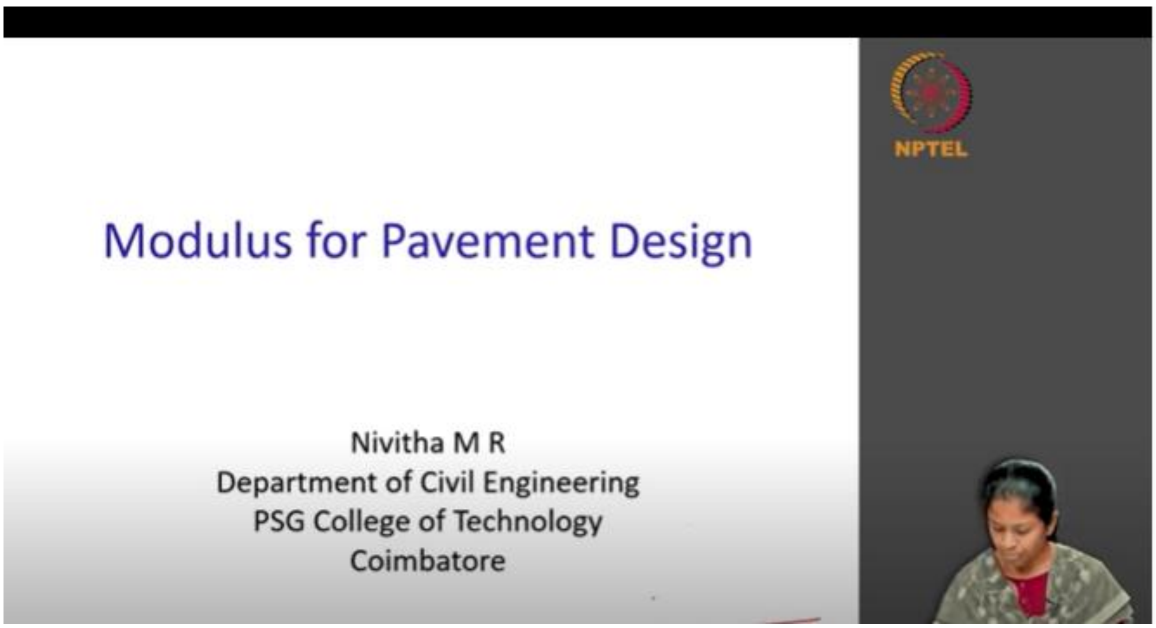

Hello everyone, welcome to this module. In this module, we are going to discuss the impact of climate on the pavement design. So, what is meant by climate? Climate is actually a common term which encompasses a lot of effects. Let us start with the sunshine. So, there is solar radiation which is received from the sun, this solar radiation falls on the pavement. So, the amount of solar radiation that falls on the pavement, is also determined by the cloud cover. Also, the convection radiation other processes that happen on the surface is also influenced by wind speed. Let us take the other case wherein there is some rainfall. So, because of this rainfall, there is water which is falling on the surface of the pavement, it is going to influence the temperature of the pavement. Apart from that, the water is going to infiltrate into pavement and cause some damages.

Let us keep it at a generic level as of now, we will discuss each of them in detail as we go along. Similarly, there is moisture, there is water table underneath my pavement. So, because of this water table, there is going to be some moisture ingress into my pavement and that is going to influence the moisture content of my subgrade and my granular layers. So, there are a number of effects like this which we are going to see in detail and all of them are clubbed together under a common title called climate. So, before quantifying the effect of climate on pavement design, let us start with something which you are already familiar with.

Let us draw a typical pavement cross section. So, in a typical pavement cross section, we have a subgrade, we have a subbase, we have a base layer, we have a binder course and we have a surface course. So, so far what you have learned is that I apply a constant, I apply a load, let us call this load as P and we are going to measure strains at some critical locations for the sake of pavement design. So, let us say that as per IRC, I am interested in measuring strains at the bottom of the binder course and at the top of the subgrade; the horizontal tensile strain at the bottom of the binder course and the vertical compressive strain at the top of the subgrade. So, for a given load P, the amount of strain that I am going to see in these two locations depends essentially on two parameters, modulus and Poisson's ratio. So, these parameters are going to decide the amount of strain that I am seeing at a location for a given magnitude of load. So far, you would have seen that the modulus and Poisson's ratio are one single value. For a given layer, you will use one value of E. But this modulus value is not going to be a constant, it is going to vary because of the effect of all these climatic parameters. So, subsequently I will show you some images, wherein we will be seeing the magnitude of variability in temperature, moisture content and all these things and the influence on the modulus.

So, we have to consider in the effect of variation of modulus over a time period and its impact on pavement. So, having said that, what modulus parameter are we going to use for pavement design? There are a number of modulus parameters that we are familiar with. I can say bulk modulus, I can say shear modulus, I can say resilient modulus, I can say Young's modulus, I can say dynamic modulus and a number of other modulus parameters. So, which modulus parameter are we going to use for a pavement? So, once we identify those parameters, then we will be quantifying what is the effect of climate on those modulus parameters. So, now, this particular part of this module, the first part of the module is going to focus on defining the modulus parameters for different layers in a pavement. Then subsequently, we will be discussing the effect of climate on each of these modulus parameters.

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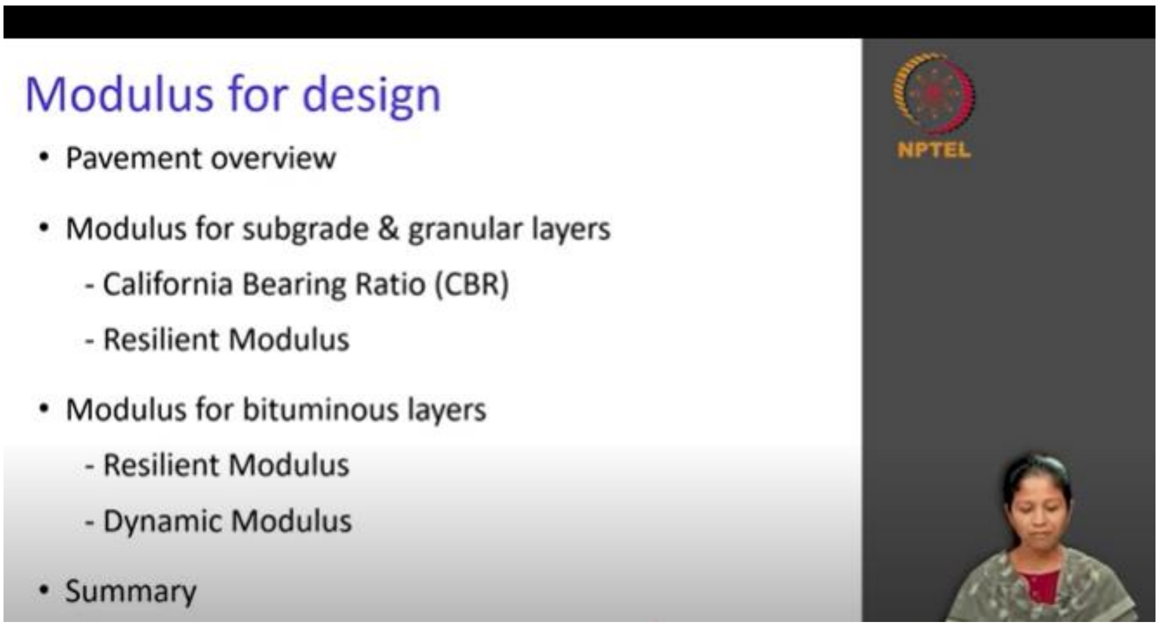

So, this is the overview of this particular module. The first section is the pavement overview, I will be very generically talking about what is a pavement, what material it is composed of and all that. Then we will move into measuring the modulus for subgrade and granular layers. We will be talking about the measurement procedure for CBR. We will be talking about the measurement procedure for resilient modulus. We will first define what is resilient modulus, why it is calculated and then the measurement procedure. Similarly, for bituminous layers, again for bituminous layers, we can measure resilient modulus or we can measure dynamic modulus and then finally, we will summarize.

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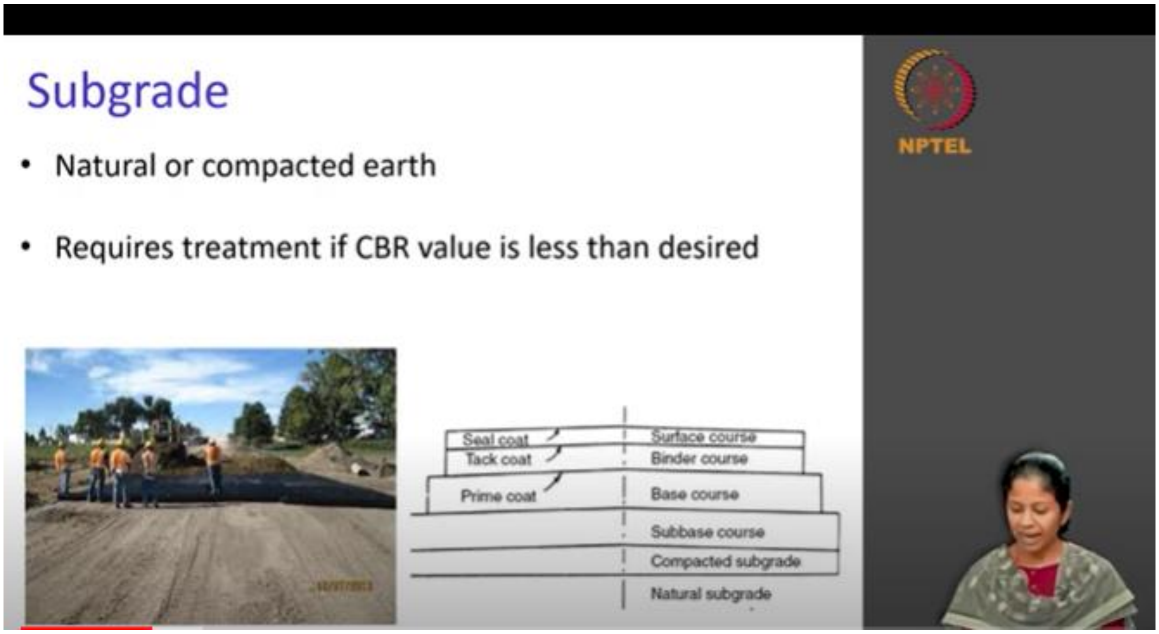

So, to start with the pavement overview, there are a number of layers in a pavement again that you are familiar with, we have a natural subgrade. In some cases, the subgrade would be compacted or it could be treated also to improve the CBR value if it is lower than the required design value. We have a subbase course, we have a base course, binder course and a surface course. So, this you are familiar with. Now, what is this subgrade made of? This subgrade is nothing but natural or compacted earth as you can see here. It is mostly soil and if the CBR is less, it might require some kind of a treatment.

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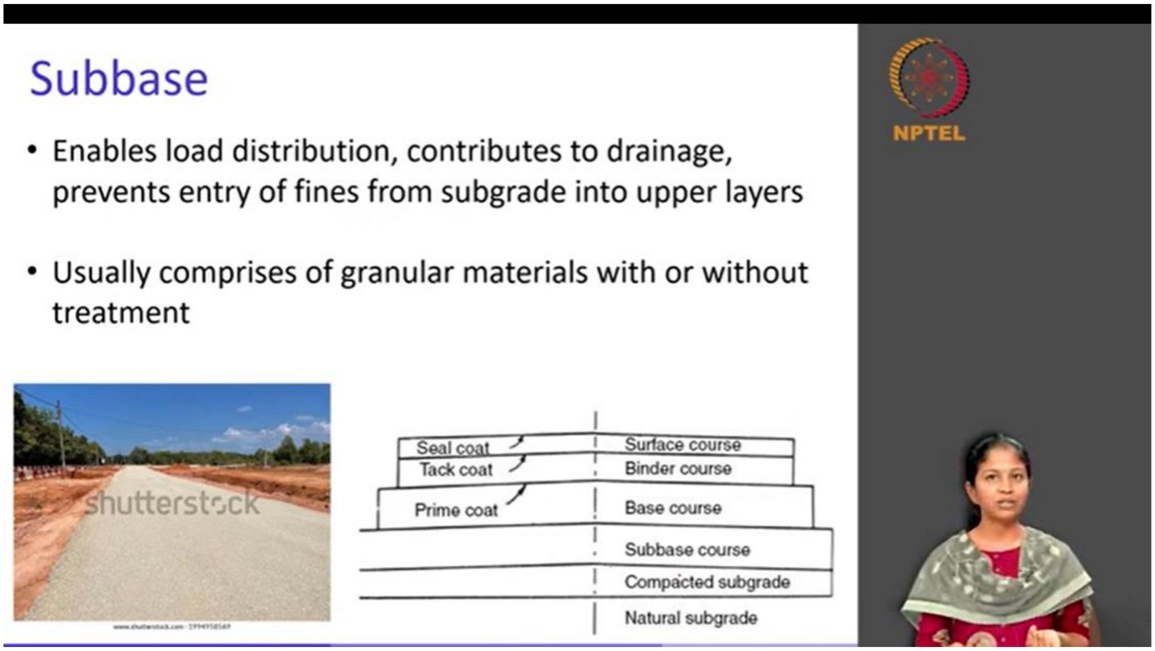

Now, let us move on to the next layer, which is a subbase layer. This subbase layer basically enables load distribution, it contributes to drainage and also it one of the important functions of this layer is to prevent entry of fines from subgrade into the upper layers. Now, what is this composed of? This is also composed of granular material; you can see how it looks like the subbase layer. It is also comprised of granular materials with or without treatment, it can be a cement treated or it can have any other kind of treatment or it could be without treatment also.

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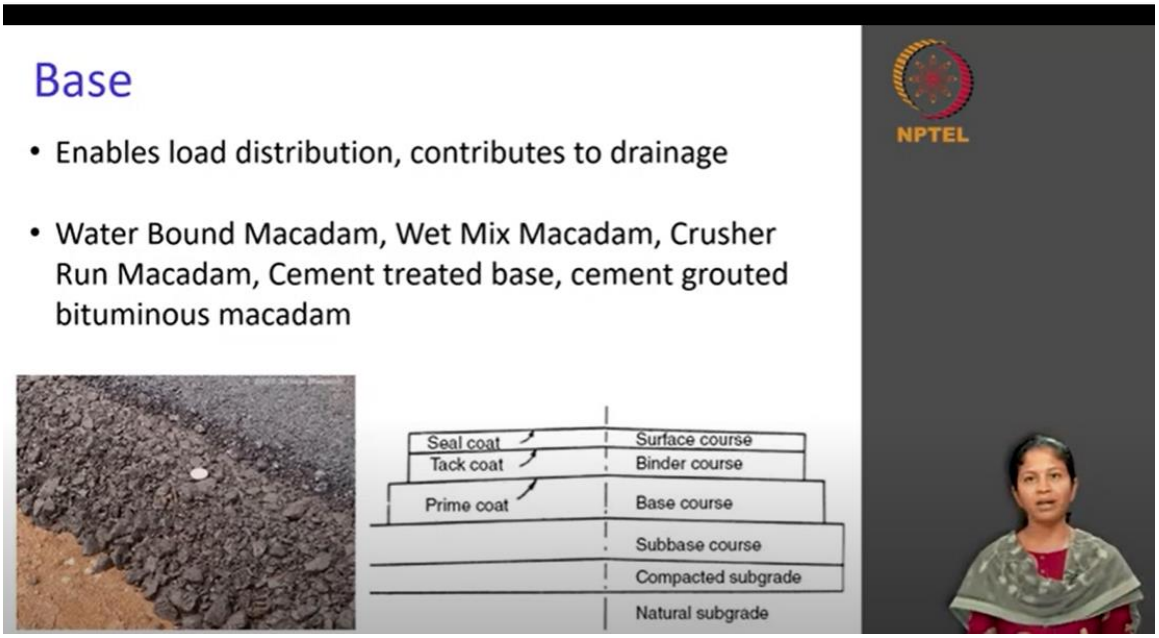

The next layer is a base layer. Again, the functions of this base layer is to enable load distribution and also contribute to drainage. And the typical base layers that you can have are water bound macadam, wet mix macadam, crusher run macadam, cement treated base or a cement grouted bituminous macadam. These are some kind of options which you have for a base layer. Again, if you look at what it is composed of, you can see here it is granular material again, it has quite larger size of aggregates here, but it is again granular in nature.

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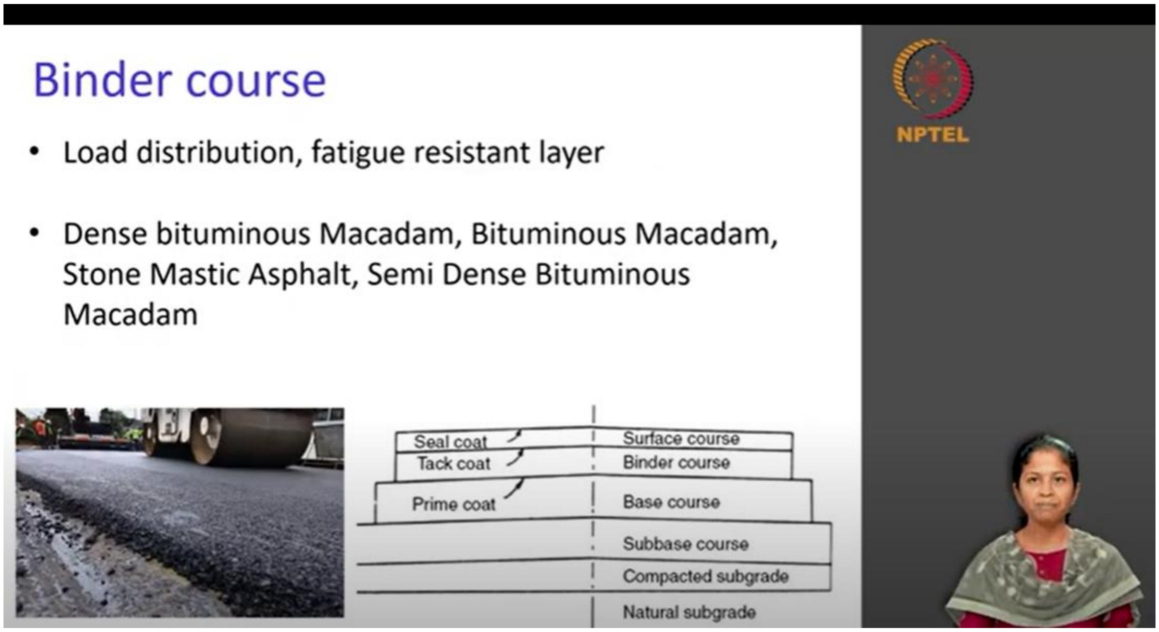

Now we will move on to the next layer which is a binder course. The function of this binder course is again load distribution and sometimes it is also called as a fatigue resistant layer. It has aggregates kind of similar to what you have for your surface course, but larger size of aggregates and lesser bitumen content. And the options that you have for this binder course are dense bituminous macadam, bituminous macadam, stone mastic asphalt, semi dense bituminous macadam and so on. So, this is a bituminous layer, the binder course that you see here is a bituminous layer.

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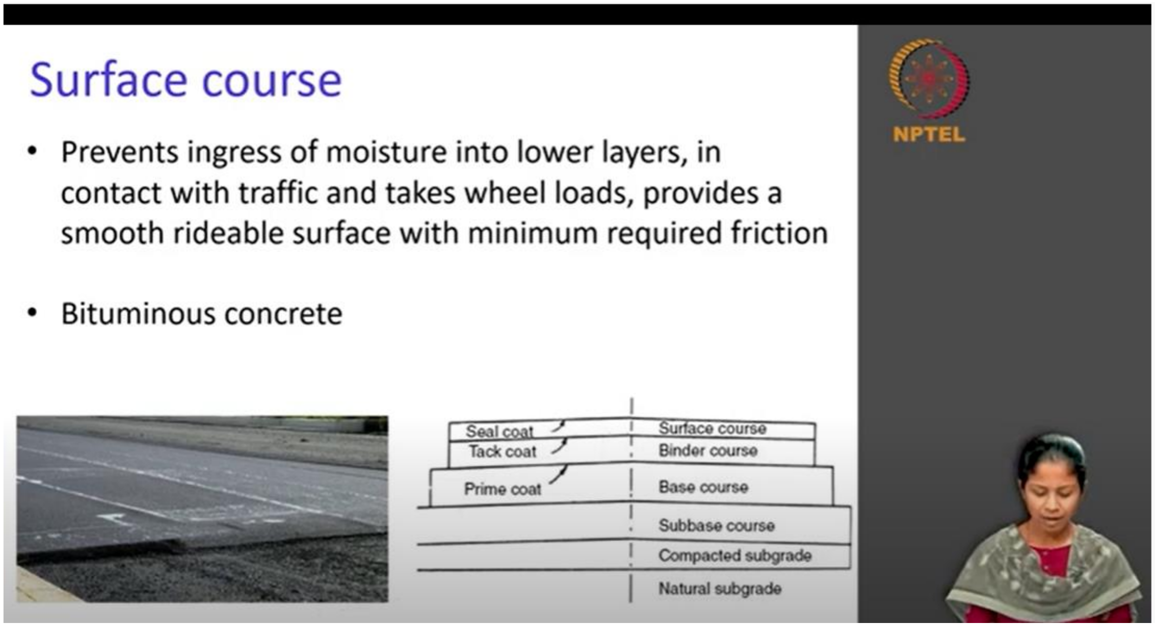

The next is a surface course, which is a bituminous layer, which is laid on another bituminous layer as you can see here. This surface course has a lot of functions. One important function is to prevent the ingress of moisture into the subsequent layers and it is also directly in contact with the wheel load. So, it takes up majority of the wheel load and it should also provide a smooth rideable surface. When I mean smooth, it should have good rideability, but it should also provide minimum amount of friction. And some examples are bituminous concrete and many other options that you have for a surface course. Now when you look into the materials which are used for each of these layers, we see that the base course, subbase, compacted and natural subgrade are typically composed of granular materials, whereas the surface and binder course are composed of bituminous materials.

So, again if you take the granular layers, each of these layers are different. So, subgrade and compacted subgrade are the natural materials which are present there, whereas subbase and base course we bring it and this has to meet a specific gradation and all those things. Similarly, if you look at surface course and binder course, in a binder course, the largest aggregates are present and the binder content is less, whereas in a surface course, the gradation is very tight and also you have a higher binder content. So, for each of these layers, the modulus value is going to be different. Again, what modulus parameter am I going to measure? It is going to be different for a granular material and it is going to be different for a bituminous material. So, now let us see what are the modulus parameters that we are going to measure for each of these layers.

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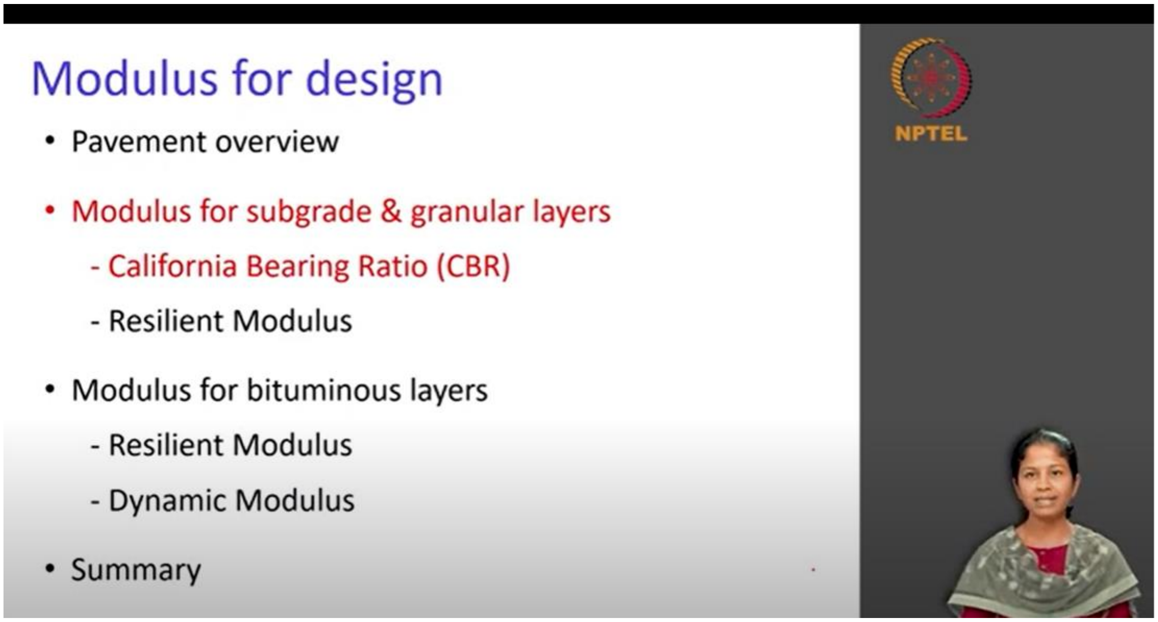

So, that is the next agenda, the modulus for subgrade and granular layers. Here we are going to discuss two test procedures, one is the California bearing ratio or CBR and the second one is the resilient modulus. So, in this lecture, we will focus on measurement of CBR and in the next lecture, we will look into the resilient modulus measurement.

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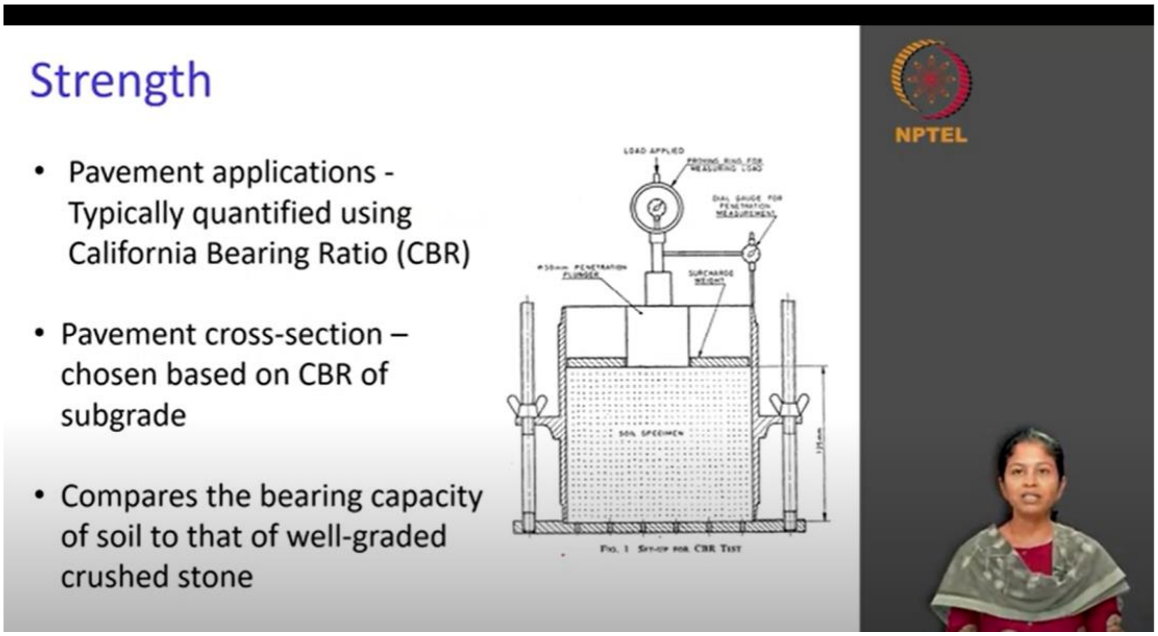

Typically, for pavement applications, the strength of the subgrade is quantified using its CBR value. So, what is this CBR? It is California bearing ratio. I will define in a moment what this is. So, if you look at IRC 37, we have different design templates. So, a particular design template which is the thickness of each of these layers is taken from that template based on two parameters. One is the strength of the subgrade quantified through CBR and the second one is the number of traffic repetitions. So, depending upon the CBR value, the pavement cross section is going to vary. So, if you have a strong subgrade and the thickness can be minimized or if you have a weak subgrade, you have to give a higher thickness to enable low distribution. So, this pavement cross section is chosen based on the CBR value and it what is this CBR value? It compares the bearing capacity of a soil to that of a well graded crushed stone. So, what is the bearing capacity of my given soil that is used in subgrade to that of a well branded stone? So, that is how the CBR is defined. And this is a setup for a CBR test. We will look into it as we go along.

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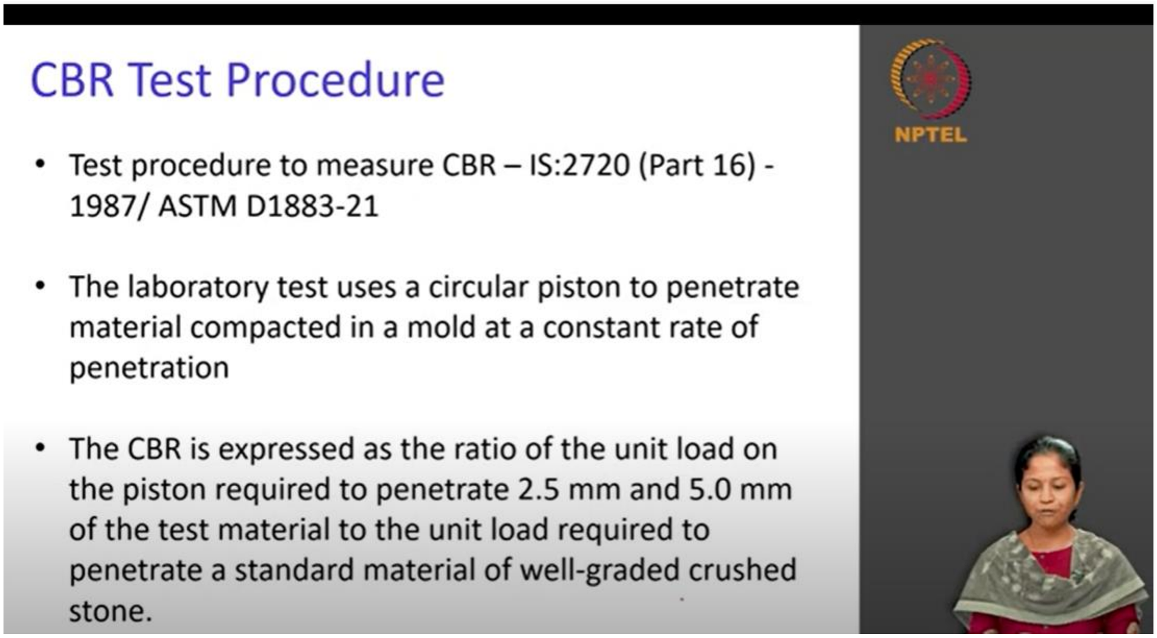

So, the test procedure for CBR is given in IS 2720, Part 16, 1987 and there is an equivalent ASTM standard which is D1883-21. For the purpose of this course, we will be talking about only the CBR measurement procedure which is given in the IS code which is IS 2720, part 16. So, what is this CBR test procedure? There is a laboratory test which uses a circular piston to penetrate the material compacted in a mould at a constant rate of penetration. It is slick, I have a plunger, I penetrate into my soil at a constant rate.

So, how much is the load required to penetrate a given depth? That is what we are going to measure in this CBR test. So, if my soil is very soft or weak, I require less amount of load to penetrate a given depth. If my soil is very hard and stiff, I require more load. So, depending upon the load required, the strength of the soil is quantified. So, this CBR is expressed as the ratio of unit load on the piston required to penetrate 2.5 mm and 5 mm of the test material to the unit load required to penetrate a standard material of well graded crushed stone. So, this is how the CBR is defined. It is basically a ratio. So, it is a ratio of unit load required to penetrate a particular depth. We usually measure it for 2.5 and 5 mm. Let us just take 2.5 mm for discussion. Unit load of my soil to penetrate 2.5 mm depth divided by the unit load of a well graded crushed stone. Unit load required to penetrate 2.5

mm depth of my soil divided by unit load required to penetrate 2.5 mm of well graded crushed stone. So, this ratio is what is quantified as CBR.

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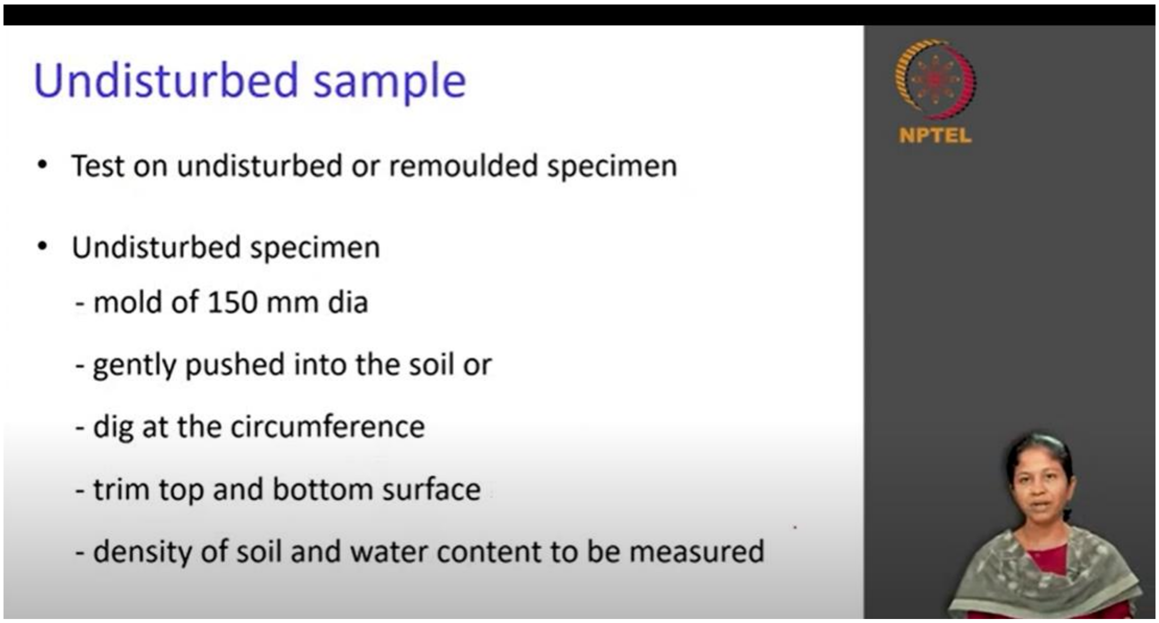

Now, let us look into the test procedure. So, the first part is sample preparation. We can do the test on two kind of samples. So, one is an undisturbed sample which we take directly from field or the other one is a remolded sample which is prepared in the laboratory. So, if it is unmoulded sample, we can take the sample directly from field in its in-situ condition. So, how do we do it? We have a mould of 150 mm diameter. This test is performed usually on a mould which is 150 mm in diameter. There is a standard mould. All the details related to the mould and other apparatus and all other details are given in the CODEL provision. I am not getting into those details.

We will just look into the test procedure and how to measure the CBR alone. So, we have a mould of 150 mm diameter. So, this mould is gently pushed into the soil. If it is easy to push into the soil, we can directly push into the soil. Otherwise, we dig at the circumference. I dig at the circumference, which is at a distance which is larger than the size of the mould, which is greater than 150 mm.

Then I am able to push my mould into the soil and then I can take my soil in the specimen. So, these are two methods by which I can take soil in its in-situ condition. So once you take soil, we can trim the top and the bottom surface to level with the mould and then we can use it for testing. So, once we take soil from its in-situ condition, it is important that we measure density and quantify the water content of soil in its in-situ condition. Now, so this is the sample that we will be using for testing if it is an undisturbed or in-situ sample.

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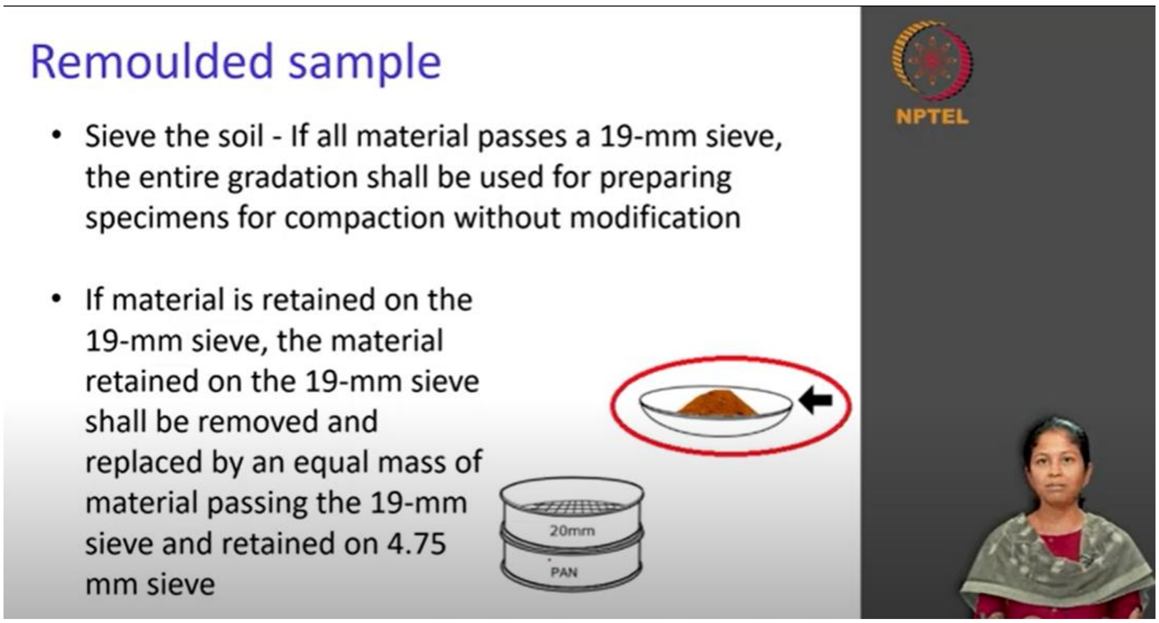

If it is a remolded sample, then we have a certain filtering criteria that we have to do before we use the sample for testing. What is this filtering criteria? We have to first sieve the soil. If all the material passes a 19 mm sieve, then the entire gradation can be used for preparing specimen. If some material is retained on the 19 mm sieve, the material retained on the 19 mm sieve should be removed and that equivalent weight of the material should be put back into the original sample. And you should ensure that whatever material you are replacing, instead of this 19 mm larger particle should be between 19 and 4.75 mm. It should pass 19 mm sieve and retained on 4.75 mm sieve.

So, why are we doing this exercise? Typically, when we have larger particles, which are larger than 19 mm, there is going to be some amount of variability that is induced in the results. So, when we have finer particles, the repeatability is better compared to when you have a larger particle. But now there is a question, if I replace some amount of the larger particles which are present actually in field with a finer amount of material, would not my CBR change? There will be some small variations in the CBR when you change the gradation but just to ensure the repeatability and minimize the variability in the test procedure, this kind of an adjustment is specified. So, the first step, we will sieve the soil, remove whichever is greater than 19 mm, replace it with a material which is between 19 mm and 4.75 mm.

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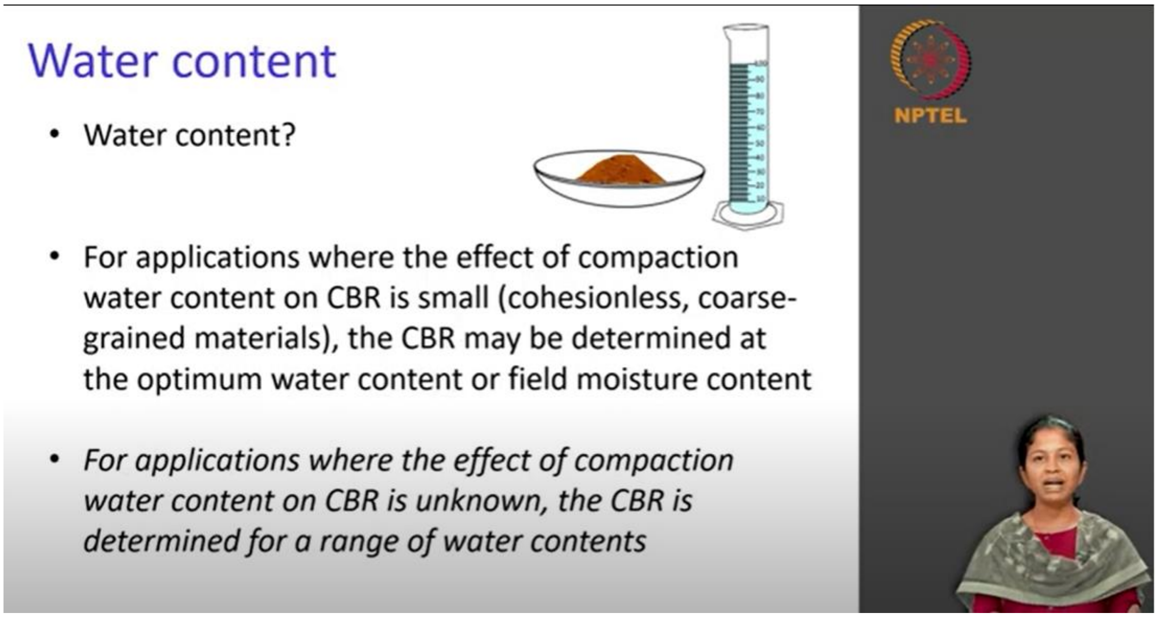

So, once this is done, we have to add sufficient amount of water. So, how much water should I add to this soil? For applications where the effect of compaction on water content is small, say for example, I have a cohesion less soil or I have a coarse grained soil, wherein if I vary the water content, the CBR is not going to vary much. For those cases, we can determine it at optimum water content. IS 2720 specifies to conduct this test at optimum water content or at field moisture content. But you can also do it for a range of water contents in your ASTM D1883, they specify that for cases where the effect of compaction water content on CBR is unknown.

Similarly, when you vary the water content, you do not know how sensitive the CBR value is. In that case, you can carry out the test for a range of water contents. So, even in the previous case, even for a cohesion less soil, if needed, you can do it for a number of water content. So, for each water content, you have to prepare a sample and carry out the test in the same procedure. But ideally, we will be doing it either for the optimum water content or we will be doing it for the field moisture content, one of these two scenarios.

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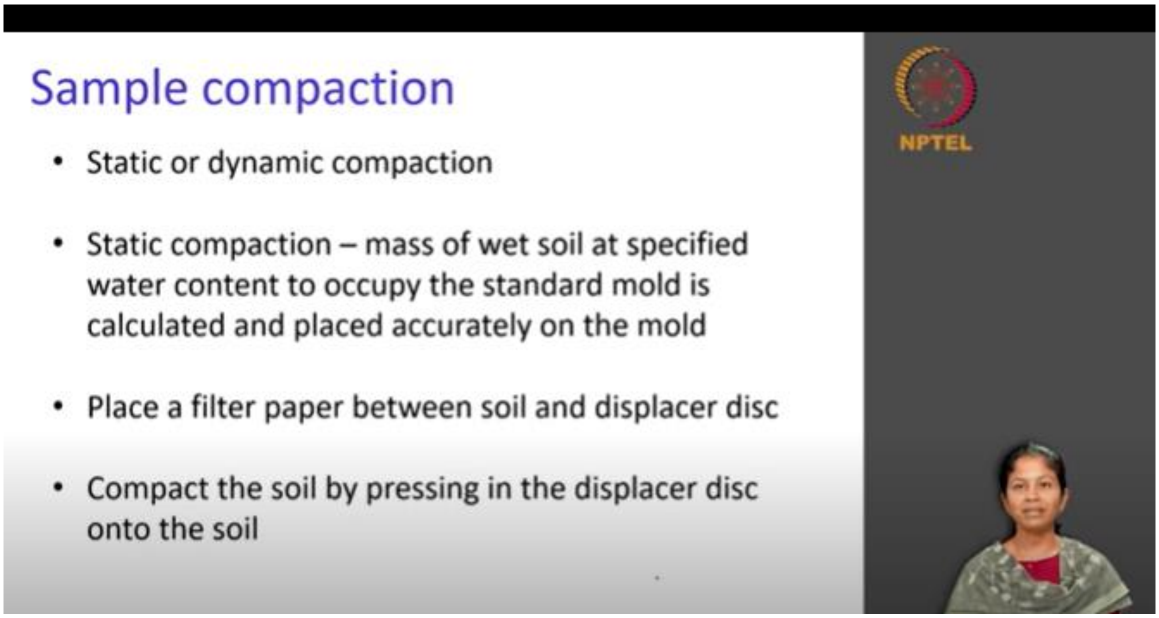

Now, how do we compact the specimen? We have taken the sample, we have mixed water with it and it is now ready. How do we compact the sample? There are two methods of compaction which are again specified in the IS code. One is a static compaction and the other one is a dynamic compaction. So, what is a static compaction? We know the size of the standard mould and we know what is the amount of water content that is to be added. So, I will be able to calculate, this is a standard mould, I can compute the volume. So, I know what is the weight of material that is going to occupy this particular mould. So, I am going to weigh that much amount of material exactly. I am going to calculate and weigh that much amount of material and I am going to place it inside the mould.

Typically, when you are compacting, you usually place a collar on top of it to accommodate the excess soil initially. So, I place w amount of wet soil inside this and I have a displacer. Before you place the displacer, we will be placing a filter paper on top of the soil. Let us say this is my soil, my soil is still here. I will be placing a filter paper on top of the soil, then I will be placing the displacer disc and then I will be slowly compacting until I reach this particular height. So, this is a static compaction, you do not apply any kind of repeated load. So, it is only you take the exact amount of soil and then press it once to fill in your mould exactly. So, this is the static compaction.

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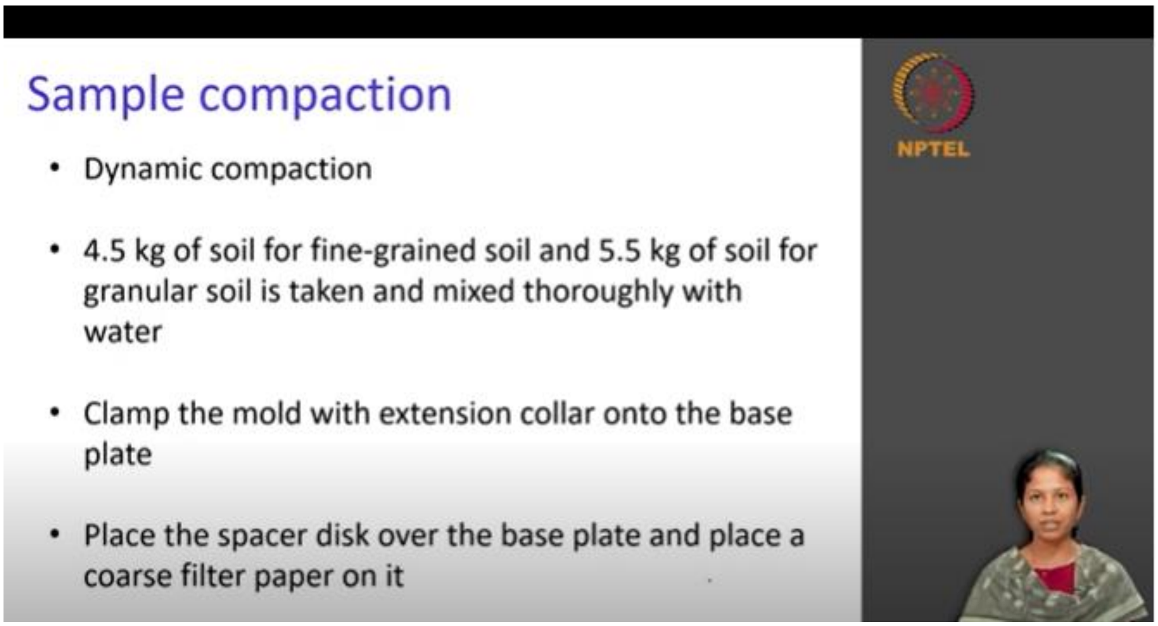

The next one is a dynamic compaction. In dynamic compaction, we apply repeated blows. So, there is a specific weight that is suggested 4.5 kg of soil for fine grained material or 5.5 kg for granular soil and it is thoroughly mixed with water. What is the water content here? It is again the optimum moisture content or it is the field moisture content. So, we mix it with the required amount of water. Then again the similar procedure, you take the mould, you place the extension collar on the mould, place the soil and then here for compacting you need to fix the base plate and the sample mould. So, you place a spacer disc on the base plate. So, there is a base plate on your apparatus. You place a small spacer disc on this base plate. On top of this you place a filter paper. On this filter paper, you put in the soil.

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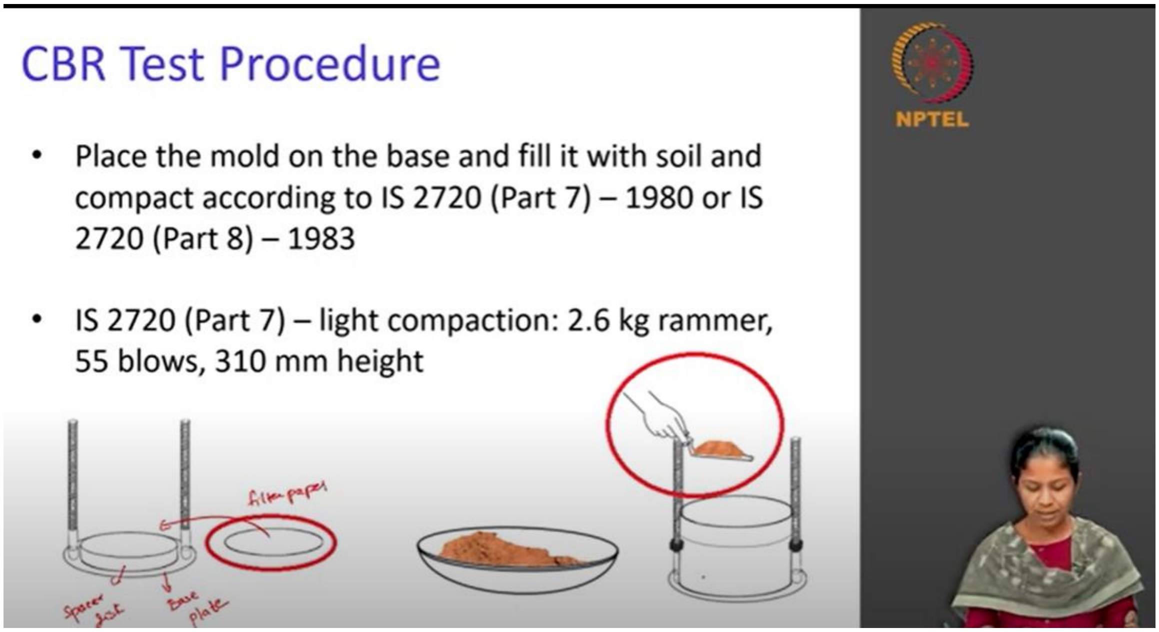

I will show that to you that you can see this is the apparatus. This is your base plate. On the base plate, I place this spacer disc. On top of this spacer disc, I place this filter paper. On this filter, so this is the first setup. On this filter paper, I am spacing the, I am placing the mould and this is my extension collar. On this, once I place this, I am going to put in the soil here. So, this is the setup that we are going to use for compaction. So, how are we going to compact? The compaction procedure is specified in IS 2720 Part 7 or Part 8. So, what are the, what is the difference between Part 7 and Part 8? Part 7 is for light compaction. You use a 2.6 kg rammer here to compact. You apply 55 blows and the height of fall is 310 mm. So, this gives a specified compactive effort. So, this is a light compaction which is specified in Part 7. If you want a heavy compaction, let us say that my field scenario requires a heavy compaction, then I can use the guidelines given in IS 2720 Part 8. This is for a heavy compaction, wherein I will be using a 4.9 kg rammer. In the previous case, it was 2.6 kg rammer. Here I am going to use 4.9 kg rammer and the number of blows is the same. I am going to give only 55 blows here and the height of fall is 450 mm, whereas in the previous case, it was 310 mm. So, we are going to give a heavier rammer and a larger height of fall to increase the compactive effort. So, I will use one of these test procedures depending upon my field requirement and I will compact my sample. In both these cases, the sample will be compacted in 5 lifts.

What is, what do I mean by 5 lift here? First I will fill approximately one fifth of the mould with soil, apply the compactive effort. Let us say I am going to use a heavy compaction. So, I will place one fifth, approximately one fifth of the mould with soil, I will give 55 blows with a 4.9 kg rammer and 450 mm height of fall. So, once I compact the first layer, I will place in approximately the next one fifth and so on. So, this is the third one fifth, this is the fourth one fifth and this is the last one fifth. So, the specimen I have to compact it in 5 lifts for both the cases whether be it light compaction or heavy compaction, I have to compact it in 5 lifts. So, once the compaction is over, we can remove the extension collar because we had placed the extension collar to accommodate the extra material. So, once we have compacted, we can remove it and trim off the sample. If it is an undisturbed specimen that we have got from field, it is, there is a possibility that we will have some larger stones or some kind of irregularities on the surface. So, we have to level off all that before we start the testing. So, once the compaction is over, we can remove these sample from here, we remove the base plate also and then we put back a perforated plate. Once we remove this, you put back a perforated plate, you put in a filter paper on top of it. This mould I will be inverting it. This mould will be inverted onto the setup wherein you have a perforated plate and then you have a filter paper. It is inverted and now it is ready for testing. So, this is the compaction associated with the sample preparation for CBR test.

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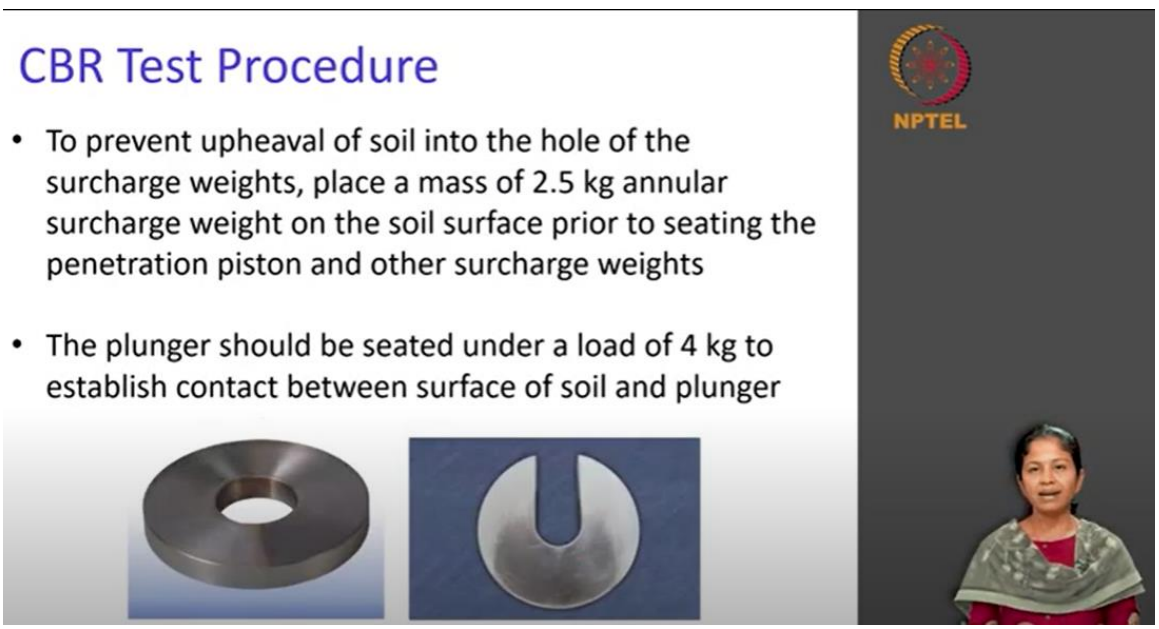

Now before I start the test, let us say that I have a compacted specimen like this. So, once I insert my plunger into this, there is a possibility that soil is going to up heave on all my sides. So, if this is my surface, I put a plunger here, it is going to come like this on the sides, the soil is going to upheave. To prevent this kind of a scenario, it is suggested that you place annular weight like this. This is called as an annular weight and this is called as a slotted weight. So, on the sample, we place this annular weight and then we insert the plunger through this. This is just to ensure that there is no upheaval of the soil. So, there is an annular weight of 2.5 kg. It is called as a surcharge weight because it is an excess load that we are adding to the sample. You place it onto it and then you can start the testing.

So, this plunger should again be seated under a load of 4.4 kg to establish contact between surface of the soil and plunger. Many times you would have heard something called as a seating load. This seating load is provided when this plunger is there, there is a load of 4 kg that is to ensure that there is contact between the plunger and the surface of the specimen. This is also provided before you start the test. So, now once the setup is ready, so we have now placed the annular surcharge and we have also placed the piston on top of it given a seated load of 4 kg.

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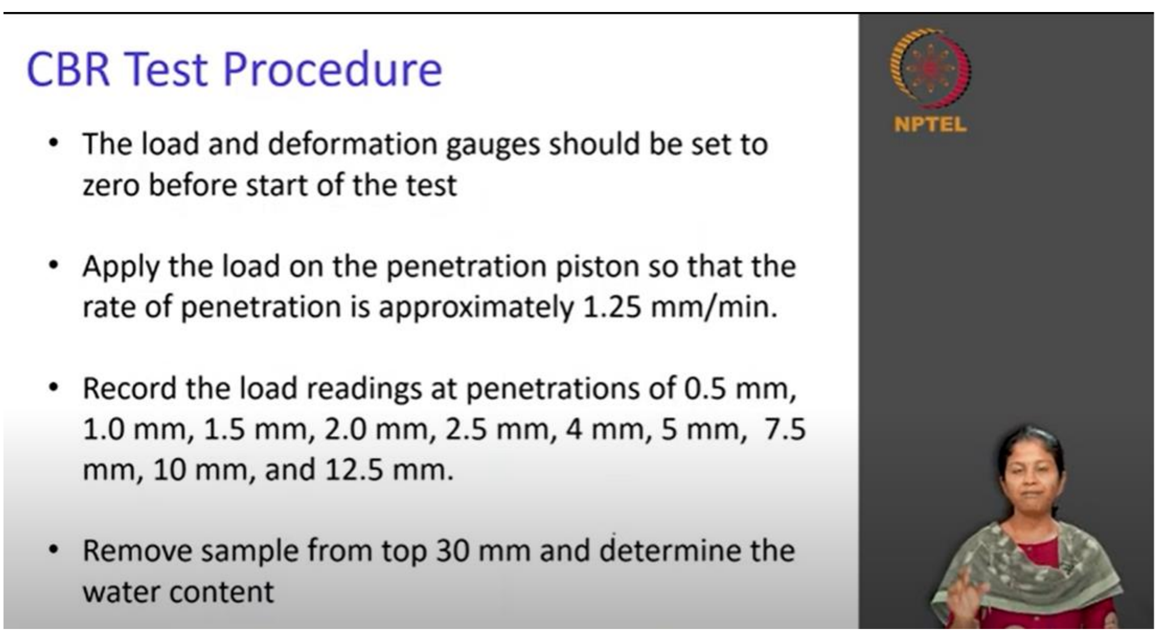

Now it is ready for testing. Before you start the test, it is necessary to ensure that the load and deformation gauges are set to 0 before start of the test. So, now once this is ready, we start the test by applying load on the penetration piston, so that the rate of penetration is approximately 1.25 mm /min. So, the rate in which this plunger is penetrating into my soil is 1.25 mm/min. Now we have to record the load readings, the corresponding load readings for different penetration depth. We start with 0.5, 1, 1.5, 2, 2.5, 4, 5, 7.5, 10 and 12.5 mm. So, for all these depths of penetration, we measure the corresponding load readings. So, once the test is over, we stop with 12.5 mm, once the test is over, if it is required, we can remove sample from the top 30 mm of the compacted specimen and determine the water content. This is an additional step which is suggested, if required it could be performed.

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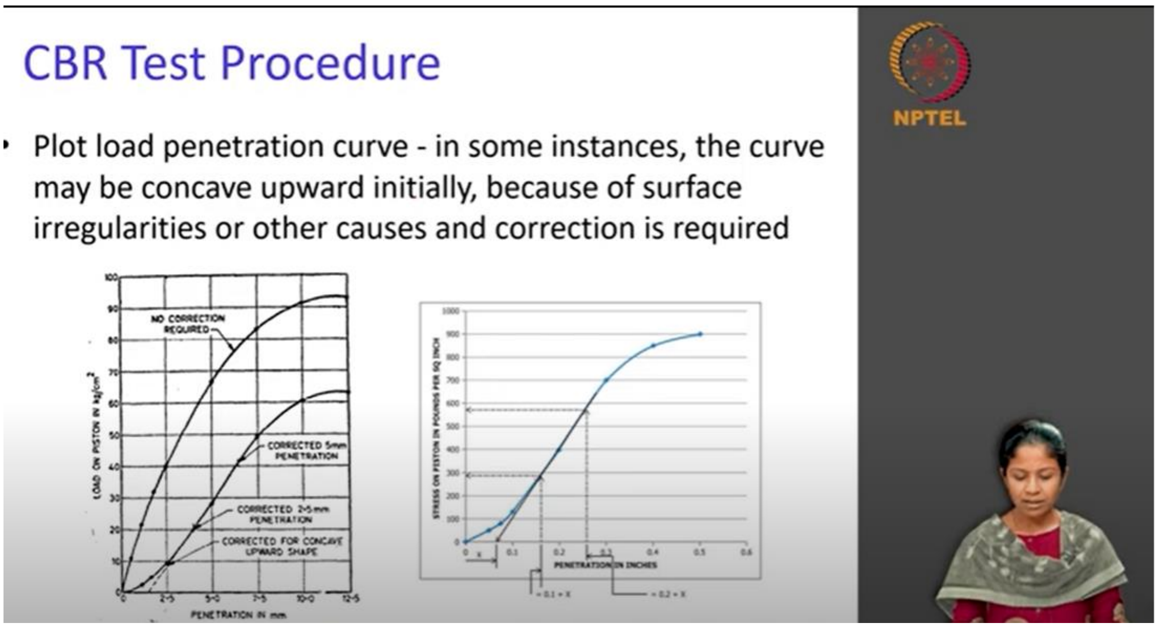

Now let us see, this is how a load penetration curve looks like. So, this is load on the y axis and this is penetration in mm on the x axis. Now we are required to calculate the load corresponding to 2.5 mm and 5 mm depth of penetration. From this curve, we have to calculate the load corresponding to 2.5 mm and 5 mm depth of penetration. Now if you see, this is a correct trend that we see for a load penetration curve. If you look at this one which says no correction, you can see here, it increases like this. So, this is a typical trend that we are supposed to observe for a load penetration graph.

Sometimes we might get a graph like this one also. Initially, there is a concave upward trend and then it kind of begins to become linear. So, this might be because of some surface irregularities or any other cause. So, if you see a trend like this, where there is an initial concave upward trend, it requires correction. So, this plot has to be corrected before we arrive at the load values for 2.5 mm and 5 mm depth of penetration.

So, how to carry out this correction? Let me explain with this graph, which is from ASTM D1883. Again, you should note that they have plotted a stress versus penetration plot. This stress is nothing but they have divided the load by the area of the piston and that is how they got the stress and this is penetration, you should mind the units, it is in inches. Now, so this is a curve which is concave upward initially, I need to correct the curve, how do we correct it? So, after this initial portion of concave upward, we can see that there is a linear portion like this. I draw a line on the linear portion and I extend it, I project it to meet the x axis. At what point it meets the x axis, I am trying to quantify that. So, I can see this I have quantified it as x. This is a point wherein after the initial concave portion, there is a linear portion and I am extending the linear portion and kind of drawing a tangent to this particular area, it is meeting the x axis at this particular distance, I am calling that as x.

So, now, in ASTM, they actually compute it for 0.1 inches and 0.2 inches, which is equivalent to 2.5 mm and 5 mm in IS code. So now, this is the original 0.1 mm. So, I am going to add this x to it, I am going to add 0.1 + x, which is nothing but this point. So, this is 0.1 + x, I get the new position for 0.1. So, at this point, I have to record the stressor load value. Similarly, for the next one 0.2, this is the original 0.2, I offset it by a distance of x, what is this x that is nothing but the difference between this 0 and the point at which this line meets the x axis that we have quantified. So, I take this x offset the 0.2 by this x distance, and then I meet the curve calculate the corresponding y value. So, this is how we carry out correction in case of plots wherein there is an initial concave upward trend. Now, let us come back to this IS plot and see. So, we are here we are required to compute it for 2.5 mm and 5 mm. So, initially this is the offset distance here, this is your offset distance x. So, there is initial 2.5, you offset it by this particular distance. So, this is this x. So, this is your corrected 2.5 penetration. Similarly, this is 5, I offset it by x and this is going to be my corrected value. So, once I arrive at these values, I have a formula, you use the character load values you take from the load penetration curve and you should remember that if you have a trend like this, something like this, there is no need for any sort of correction, you can directly use the values. Otherwise, you have to carry out the correction.

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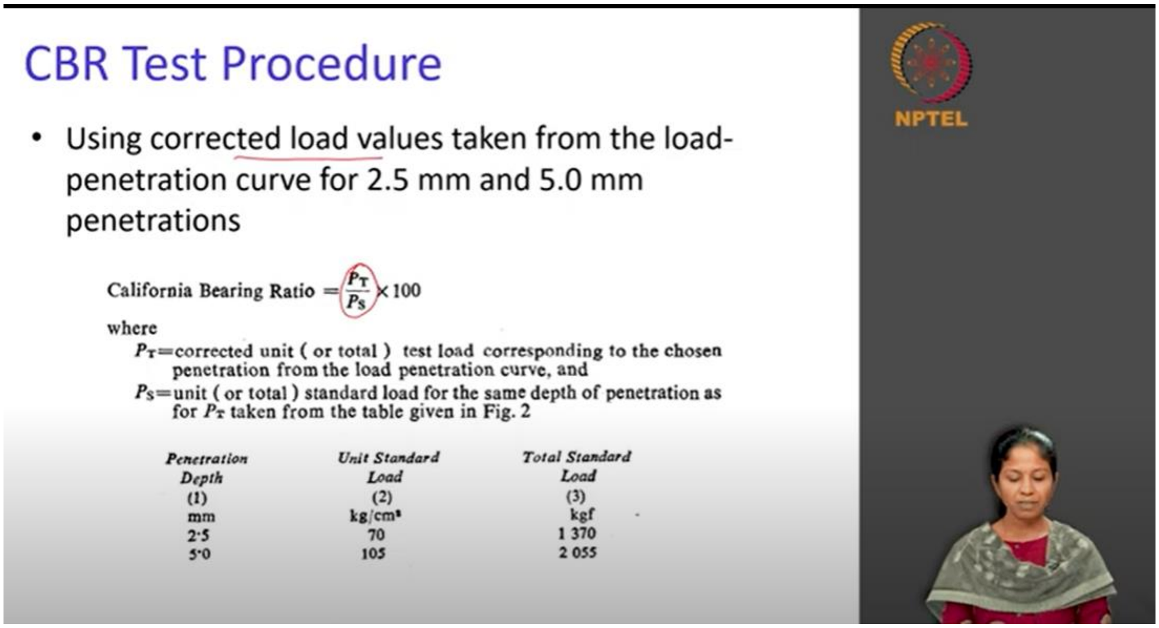

So, once you arrive at the corrected values, you can compute the California bearing ratio or CBR, which is a ratio of P_T/ P_S.

$$California\ Bearing\ Ratio = \frac{P_T}{P_S} \times 100$$

So, what is this P_T? It is corrected unit load or it could be total load, you can compute for any of these things, corrected unit load of the test load corresponding to the chosen penetration again it is for 2.5 or 5 mm penetration. So, that is what is said as the chosen penetration from the load penetration curve. So, let us say this is my load penetration curve, this is the value that I will be taking. And then this P_s is nothing but again unit or total standard load for the same depth of penetration as for P_T taken from the table. So, if this is for 2.5 mm, this P_s also you have to take it for 2.5 mm. So now let us say this is my unit standard load 70 kg per centimeter square and this is my load on piston. So, you can see here from the load penetration curve, we get the load on the piston as 20. Let us compute it for 2.5 mm. This is the original 2.5 mm, but we have corrected this is the new position for 2.5 or corrected position for 2.5 and the corresponding load is around 20. Let us say it is 20. So, for 2.5 mm, it is 20 divided by the standard load unit standard load is 70 kg/cm^2. So, 20/70. So, roughly about 0.3 or so. So, this is for 2.5 mm. So, this is nothing but the ratio of P_T/ P_S, wherein P_T is the corrected load from the load penetration curve which is 20 for 2.5 mm and the corresponding one for a unit standard load which is 70 again for 2.5 mm. Now let us do the same thing for 5 mm. The corrected load from this is about 42, 43. So for 5 mm, it is going to be 43/105. So, roughly about 0.4. So, we get to again you have to multiply into. So, we get this value. Now, there is something which you have to note down.

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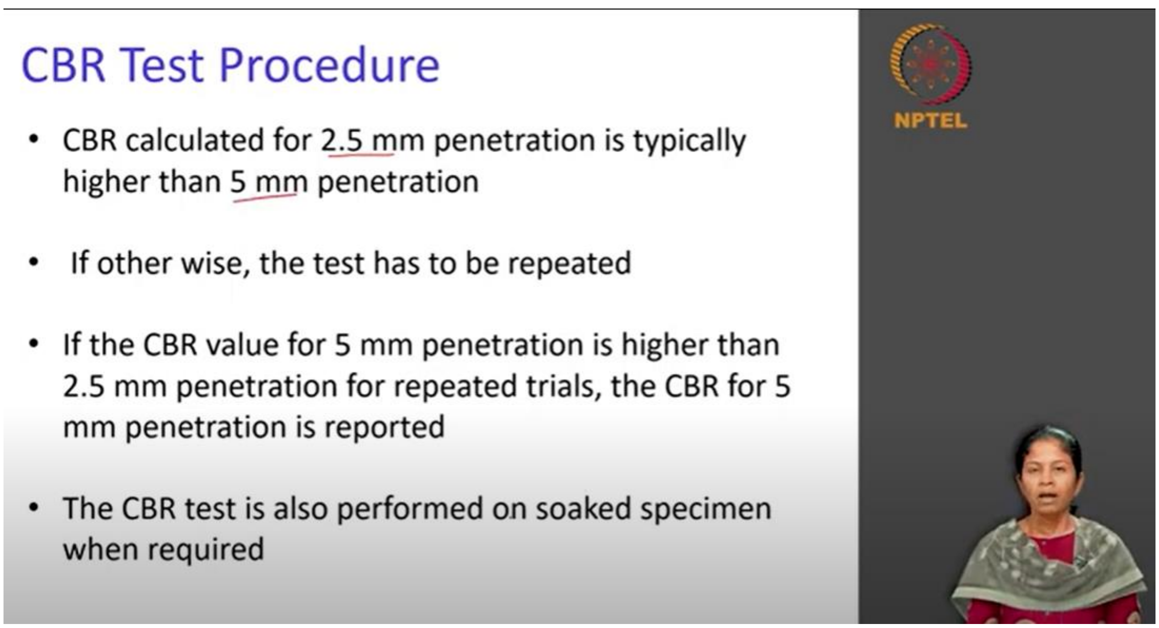

The CBR calculated for 2.5 mm penetration is typically higher than 5 mm penetration. This is a typical case. If not, if we get the CBR value for 2.5 mm to be less than the CBR for 5 mm penetration. In fact, it is a case that even we have got for 2.5 mm we have got the CBR as 30%, whereas for 5 mm we have got it as 40%. So, if we encounter a scenario like this, it is required to repeat the test. So, even after multiple repetitions, even after repeating it many times, if we get the CBR value for 5 mm penetration to be higher compared to the CBR value for 2.5 mm penetration, then the CBR for 5 mm penetration can be reported.

Now, the CBR test can also be performed on soaked specimen whenever it is required, because under the soaked condition the CBR is going to reduce substantially. So, when a case like that is required, we can also carry out the CBR test on soaked specimen. So, if we do the test on soaked specimen, what are the additional steps that are required to be performed?

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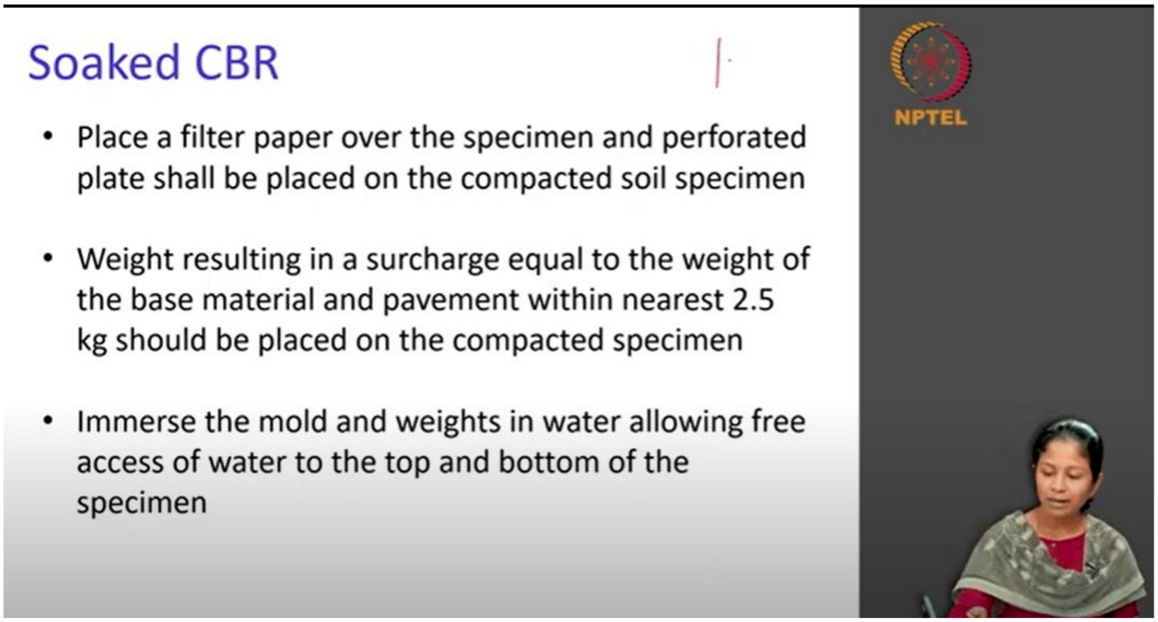

So, we compact the specimen until the compaction procedure, we compact the specimen, it could be an undisturbed specimen or it could be a remolded specimen. So, either way we prepare a compacted specimen. Now, on this compacted specimen, you place a filter paper over the specimen and you place a perforated plate on the compacted soil specimen. Now, we have to place a weight which is like a surcharge equal to the weight of base material in the pavement within the nearest 2.5 kg because these annular and slotted weights are mostly in increments of 2.5 kg. So, whatever is the weight of pavement that we experience in field. So, under a compacted case, how does it react with increase in moisture content? So, that is what we are trying to quantify here. So, we place a weight which is equal to weight of base material and pavement with the nearest to 2.5 kg. So, once you place the weight on the compacted specimen, now you immerse it under water. It should be noted that the sample should be completely immersed in water, there should be free water all over the sample.

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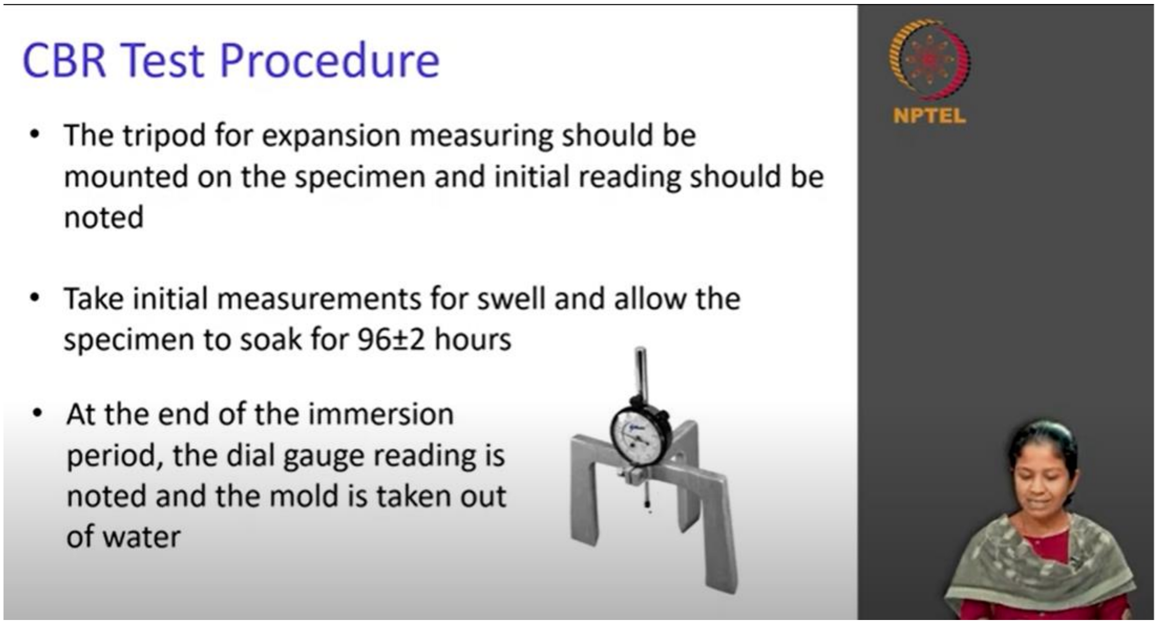

So, once you place it, you also place a tripod which is for measuring the expansion in the sample. If there is any expansion in the sample on subject to moisture content under the compact under the surcharged case. In a typical case the expansion might be different, but when it is confined on top, which is a typical case in a pavement because you have the subgrade on top of it you have all the other layers of a pavement and the weight of all these things is going to act on my subgrade. So, in the presence of this weight, the expansion might be different and that is what we are interested in quantifying. So, that is why we place a surcharge weight when we are measuring the swelling in soaked condition.

So, you have a tripod, this tripod is mounted on the sample. So, this is my sample in the soaked condition. I am mounting my tripod on the sample and I am taking the initial reading. Then once you take the initial reading, it is allowed to soak for 96 $\pm$ 2 hours. This is the standard time which is specified for soaking the specimen. So, you soak it for 96 $\pm$ 2 hours and at the end of immersion period, the dial gauge reading is again noted. So, the initial swell; initial and final reading of this dial gauge is noted, the difference of which is going to tell how much is the swell in the sample.

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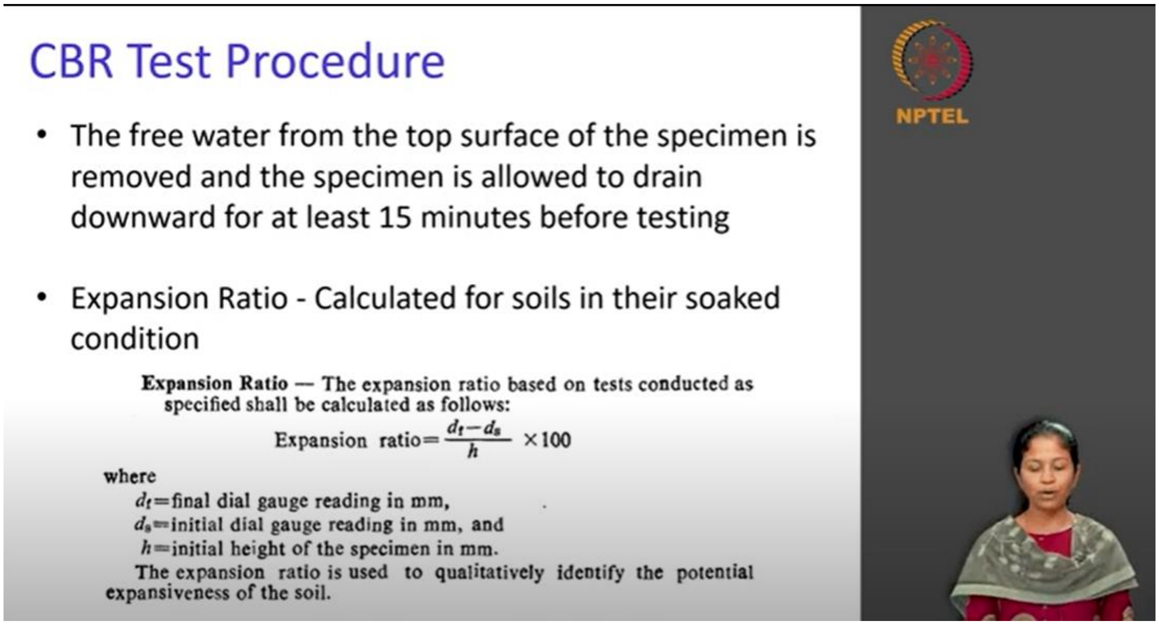

So, now once these readings are noted, you take the sample out of water and then the free water from top surface of the specimen should be removed whatever water is there on the surface and the specimen is allowed to drain downward for at least 15 minutes before you test it. You should let all the water drain from the specimen for 15 minutes before you test it. Once this is done, the same procedure that we had discussed before, the CBR test procedure can be performed on this specimen also. Like you load it there, you apply load penetration at the rate of 1.25 mm per minute, all the procedure that we had discussed before will be applied to this soaked specimen also. The only thing that should be noted here is we have a surcharge weight that is placed on this specimen. Whatever was the surcharge weight that was placed on this specimen during soaking, the same weight should be used during testing also. We are not supposed to increase or decrease the weight during testing in the case of a soaked specimen. So, that is the only point that should be noted. Then we can compute an expansion ratio in addition to the CBR value. So, what is this expansion ratio?

$$Expansion\ Ratio = \frac{d_f - d_S}{h} \times 100$$

It is calculated as d_f - d_s which is the initial reading by h. So, d_f is the final dial gauge reading, d_s is the initial dial gauge reading divided by the height. So, this is going to give us the expansion ratio. This expansion ratio is used to qualitatively identify the potential expansiveness of the soil. So, what is the degree to which the soil will expand on absorption of moisture? So, that we will be able to quantify from this expansion ratio. So, ultimately we will be reporting the CBR value and expansion ratio when the sample is tested in a soaked condition. Again CBR we can specify it for unsoaked and soaked condition.

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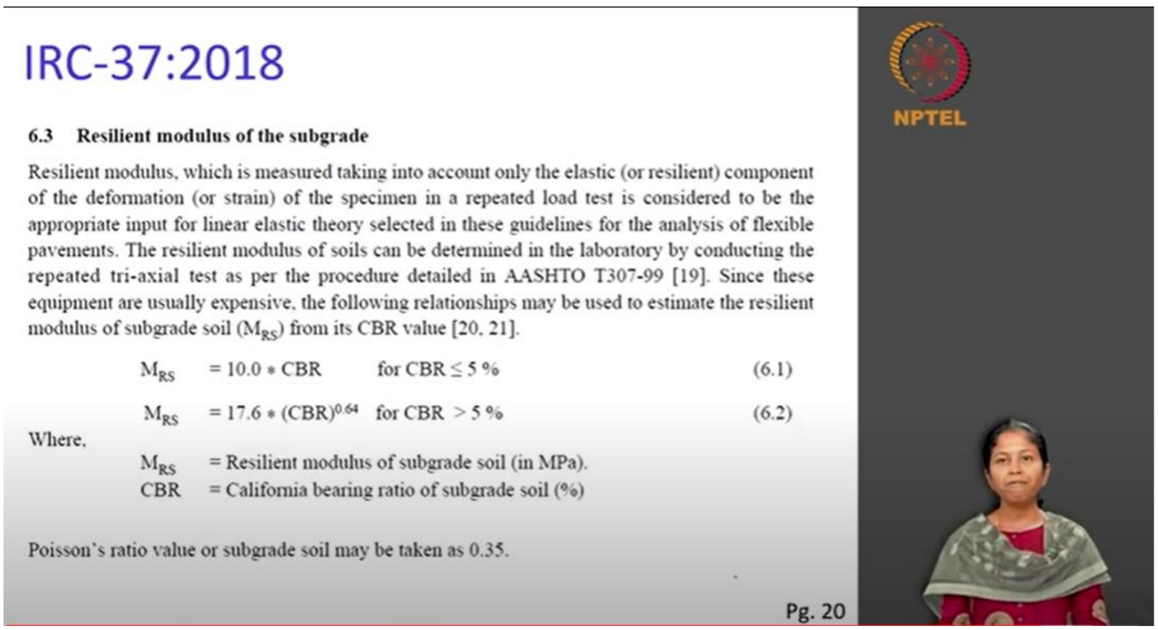

Now, if we look into IRC 37 2018, it uses the CBR value to compute a modulus value. Because ultimately in design when we are giving inputs into the design procedure, what we require is a modulus parameter. But the CBR is not a modulus parameter, it is only a relative variation between the given soil or your soil of interest to that of a standard material. So, we have to now convert this CBR value into a modulus value so as to be used for the design purposes. So, IRC gives two equations, one is for CBR less than 5%, another is for CBR greater than 5%.

$$M_{RS} = 10 * CBR \qquad for\ CBR \leq 5\%$$

$$M_{RS} = 17.6 * (CBR)^{0.64} \qquad for\ CBR > 5$$

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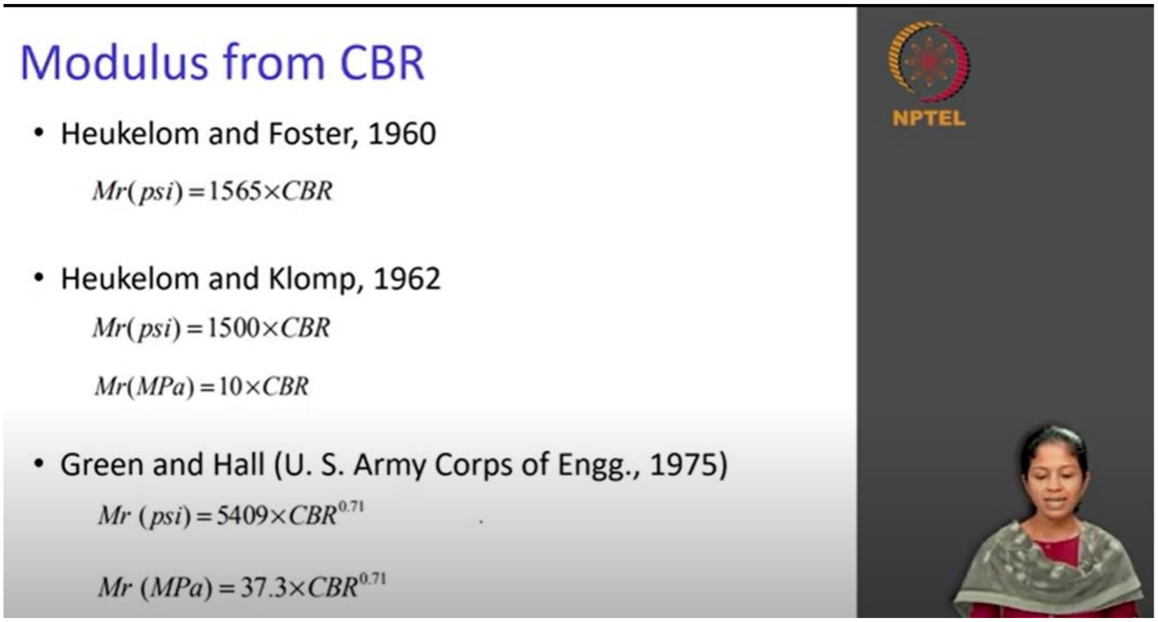

So, typically there are number of studies which have attempted to arrive at these kind of relations. If you see in 1960, the first relation of this kind was proposed by Huckelom and Foster. So, their equation was, this is again you should mind the units, it is all in psi, in some cases it is also given in MPascal. The only thing is that this constant will vary depending upon the unit that we take into consideration. So, the first equation provided the resilient modulus in terms of CBR value.

$$M_{R(psi)} = 1565 * CBR$$

Then in 1960, Huckelom and Klomp provided another set of equation. So, this is for resilient modulus, which is given in terms of psi and MPascal, you can look at the constant values, they have only defined the constants.

$$M_R(psi) = 1500 * CBR$$

$$M_R\,(MPa) = 10 * CBR$$

Similarly, later in 1975, there was another set of equation by US Army cops of engineers. So, you can see here, they have given an exponential value to the CBR. So, this was all one parameter based on one constant, but here we have two parameters that explain the relation between CBR and resilient modulus.

$$M_R\,(psi) = 5409 * (CBR)^{0.71}$$

$$M_R(MPa) = 37.3 * (CBR)^{0.71}$$

And then we have another set of equation given by CSIR. Again, they retained the form of this model which was proposed by US Army cops of engineers and the constant values were changed.

$$M_R(psi) = 3000 * (CBR)^{0.65}$$

Similarly, Powell et al., gave another relation.

$$M_R(ksi) = 2554 * (CBR)^{0.64}$$

The TRRL lab, the transportation and road research laboratory gave another set of equations.

$$M_R(psi) = 2555 * (CBR)^{0.64}$$

$$M_R(MPa) = 17.6 * (CBR)^{0.64}$$

So, all these equations had different set of samples. For one case, they used some fine grained sample, another test they took coarse grained sample. In one case, the soil was of very low strength. In another case, they took a very soil which has a high CBR value. So, depending upon the sample that they took for arriving at the constant, the relationship also varied. So, that is the reason why each of these studies were able to get different constants for this particular relation between CBR and resilient modulus.

So, if you look at this whole lot, we can see that the equation proposed by Heukelom and Klomp was used for CBR less than 5%. They used very low CBR soils and that is why we have borrowed this equation to be used in IRC. Similarly, if you look at this TRRL equation, they had proposed these constants and that is what is used in IRC for a CBR which is greater than 5%. So, you can measure CBR value as a measure of the strength of the soil, but ultimately we have to convert it into some modulus parameter to be used in the design purpose.

Alternatively, we can also measure the modulus directly for the soil and use it for the design. So, that is the next part wherein we will be talking about resilient modulus. So, I will stop this lecture with this content. So, in the next lecture, we will start talking about the resilient modulus measurements for bitumen. Thank you.