Pavement Materials
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Lecture 08
Strength Properties of Soil (Part 3)

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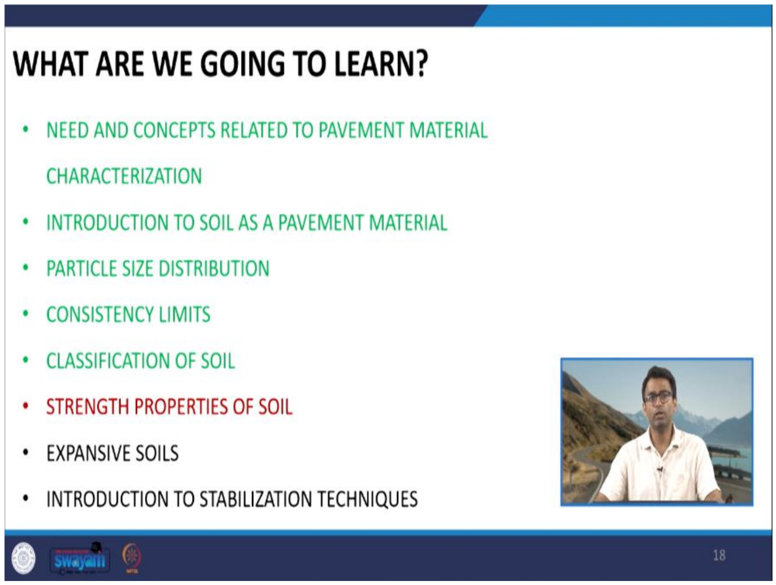

Hello everyone. In the last class we were discussing about the shear strength properties of soil under which we covered different laboratory tests and we also discussed about the fundamental concepts that are related to the evaluation of shear stress and also the normal stress at any given plane on a stressed body.

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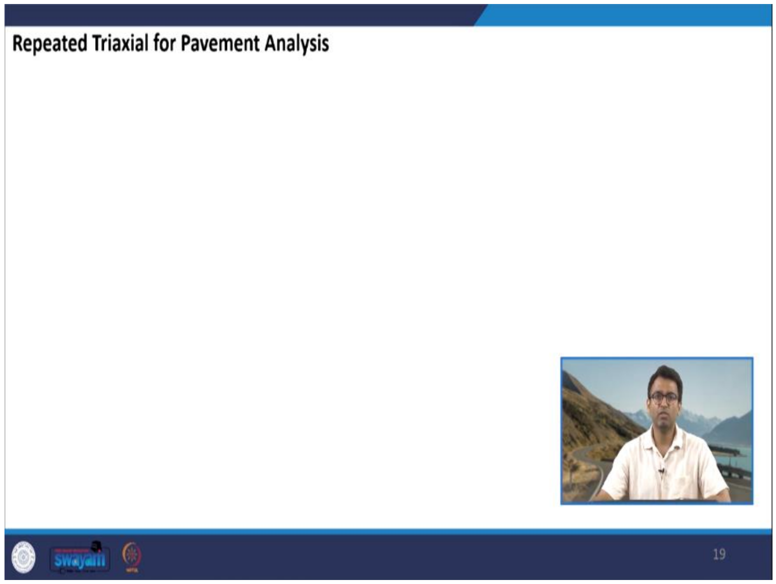

So, today we will continue our discussion from where we left in the last class and if you remember I was telling you just before we concluded the last class that the conventional triaxial test usually is conducted using a static mode of loading. In pavement engineering, we basically have dynamic loads that are applied in the pavement and therefore it is more rational to consider the effect of repeated load to see the properties of soil or any other layers or any other material property which we are dealing with in pavement engineering.

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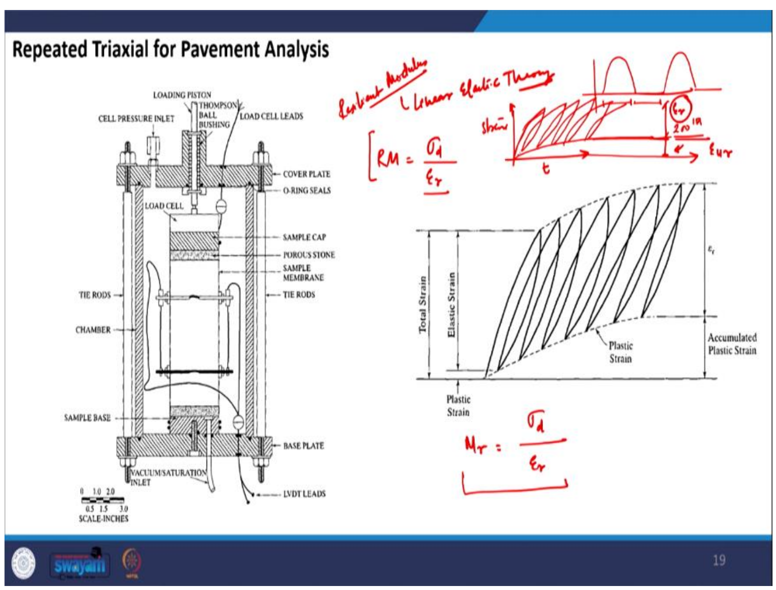

Similarly, in for soil that is the subgrade material also we use the triaxial test, but not specifically to assess the value of c and phi, rather, we perform a repeated triaxial test to get the permanent strain in the material after a few number of load repetitions. So, the same concept will also be covered when we discuss about aggregates in further modules.

But just to tell you that here we are interested to assess the value of resilient modulus. Because the value of resilient modulus is used in the pavement design and the subsequent analysis which is based on the linear elastic theory. So, how do you define resilient modulus? So, resilient modulus is nothing but the ratio of deviatoric stress by recoverable strain.

And the definition of resilient modulus or to determine resilient modulus, we need to perform a repeated load test using any suitable machine or apparatus. For example, for subgrade, we typically use a repeated triaxial test to get or to evaluate the value of resilient modulus. So, what will happen that when we start to give load to this specimen in repeated mode? What we are doing?

We are giving some form of loading. We are giving some form of loading and then we are giving some rest period. And then again we give some form of loading and then we give rest period. So, you see that there is a duration of loading we are talking about, there is a duration of rest period we are talking about. And when this repetition of load occurs, we are trying to see the response of the material.

And when we talk about the repeated triaxial test, we are seeing the response in terms of how the strain is varying with time or with the number of load repetitions. So, what do we expect that when we first give a load, the strain in the material will increase. It may not be a linear increase. It depends on the type of material, how the graph will typically look like.

So, it will increase and during the rest period when we are removing the load, it will try to come back to its initial position. Now, depending again on the material property, it may either come completely to its initial position or there it may not come to its initial position. Which means there will be some accumulation of plastic strain or irrecoverable strain.

Similarly, when we apply the second load again the strain will increase and then after removal of the load, the strain will try to or the material will try to recover. And this loading will go on. And then we will see that after some number of repetitions, the plastic strain or the permanent strain which has been accumulated in the material, it becomes constant.

And this I am talking when we are using lower value of stress for conducting the test. And the lower value of stress is also considered here because the subgrade materials will not be exposed to very high stress because of the vehicular loading because it is at a considerable depth from the surface of the pavement. So, typically in this test, we see that what happens after 200th load repetition.

So, it is expected that after 200th load repetition, the material will become stable and the amount of plastic strain will become constant. So, after 200 load repetition, in this test, what we see that what is the amount of recoverable strain and what is the amount of permanent strain.

And resilient modulus is basically the ratio of the deviatoric stress which I am applying divided by the recoverable strain. Which means this is the recoverable strain; this is the non-recoverable strain. So, I am using the recoverable strain to calculate the value of resilient modulus here.

So, in other terms you can say that resilient modulus is nothing but the elastic modulus in the repeated load domain of the test. So, I hope that this explanation is cleared that what is repeated triaxial test all about and we have already discussed about this setup. The only difference being here, we are applying the load in repetitive mode, whereas in case of a conventional triaxial test we apply a static load without any rest period.

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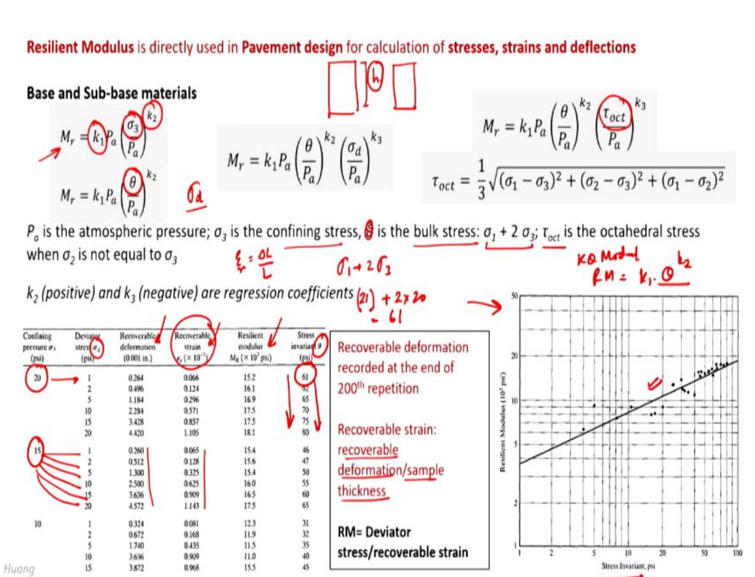

So, as I mentioned resilient modulus is directly used in the pavement design for the calculation of stresses, strains and deflection. And that is why we are interested to find out the resilient modulus. Usually, for base and sub-base material, so, if you see the soil for cohesive material, the response is typically different then what we will expect for a cohesionless soil or granular soil.

So, the soil or the granular materials which we use in the base and sub-base are typically tested using a different mode. When I say mode which means the way I am considering the parameters in the test in comparison to what we typically do in case of cohesive soil. Finally, the resilient modulus, there are various models which have been proposed, depending I mean by various researchers over a period of time. This is to see that how the value of resilient modulus changes with the change in the input parameter during the trial test.

So, here you see for example, this is a typical model, a common model where resilient modulus is related to the value of σ_3, which is the lateral stress which I am applying or the in the triaxial test. And it also has some model coefficients which depends on the response of the material.

Similarly, resilient modulus has also been related to the bulk stress in the material, and not only the lateral stress, there are models which also consider octahedral stresses for modeling the response of the resilient modulus of granular materials. So, in these equations Pa is considered as the atmospheric pressure. σ_3 is the confining stress, this we already know. I think this should be θ. So, θ is the bulk stress. So, what do you mean by bulk stress?

It is the summation of all the stresses. For example, in a triaxial test, since σ_2= σ_3 because σ_3 we are giving it from all these sides. So, the bulk stress= σ_1+2σ_3. And the same can be considered as the octahedral stress in case σ_2 and σ_3 are different from each other.

Usually, the regression coefficients which is shown in in these models that is k2, for example, it is positive whereas k3 is usually negative. Now, let me give you an example that how we are considering the parameter for carrying out this test for granular materials. So, in the test, what we do?

For a given confining pressure, so, we will first fix the value of σ_3 for a given run and at that particular value of σ_3, we apply different values of the deviatoric stress. So, we are applying different values of deviatoric stress here. And then what we do? We have the specimen with us.

So, let us say this is the specimen. I know the height of the specimen. And when I start loading this specimen, the height of the specimen will change. And if permanent strain has to accumulate, there will be permanent change in the height of the specimen after each load repetition which I am giving.

So, taking the height of the specimen initially and then what happens after different load application, I can calculate the amount of recoverable deformation here. And after we get the recoverable deformation, we can calculate the recoverable strain by just dividing the value of recoverable deformation divided by the sample thickness. Because we know that $\epsilon_r = \frac{\Delta L}{L}$.

So, once we have the value of strain, we already know the deviatoric stress here. We have the value of recoverable strain here and we can calculate the resilient modulus just by dividing the deviatoric stress with the recoverable strain. And in this particular experiment, if I am also interested to know the value of stress invariant, I know that this is equal to σ_1+2σ_3. And which means it will be, σ_1= σ_d+σ_3. So, which is 21 here.

Let us say I am looking at the first case 21 +2 × 20. So, this is 61. So, that is why it is written 61 here. Likewise, you can do all the calculations. So, you can also keep a record of, the response corresponding to the change in stress invariant. Then once we complete for a given confining pressure, then we will increase the confining pressure and again at the increased confining pressure, at that fixed confining pressure, we will see what happens when the deviatoric stress value is increased.

And similarly, we will see the change in the dimension of the sample. Using that we can calculate the recoverable deformation. Using that we can see that what is the recoverable strain and we can calculate the resilient modulus. And finally, what we do? We plot the variation of resilient modulus with the stress invariant. So, this is just a typical example for a given type of soil.

Now, for any other given type of soil or any other given type of granular material, there can be other factors and that is why we see that lot many models have been proposed in the literature but this is one of the common models we are talking about where the resilient modulus is related to the stress invariant.

And you see in this example, which is shown a very good correlation, linear correlation is seen between the value of resilient modulus and the value of theta. And that is why we get the k theta model, where resilient modulus is actually $M_r = K1 \times \theta^{K2}$, something like that.

And again as I said depending on the parameters which we are considering to develop this correlation, we can use σ_3 as one of the parameter, we can use σ_d as one of the parameter, we can use theta as one of the parameter and so on. So, these are some and I mean this is just an example of how the resilient modulus of granular material is related to the triaxial test parameters.

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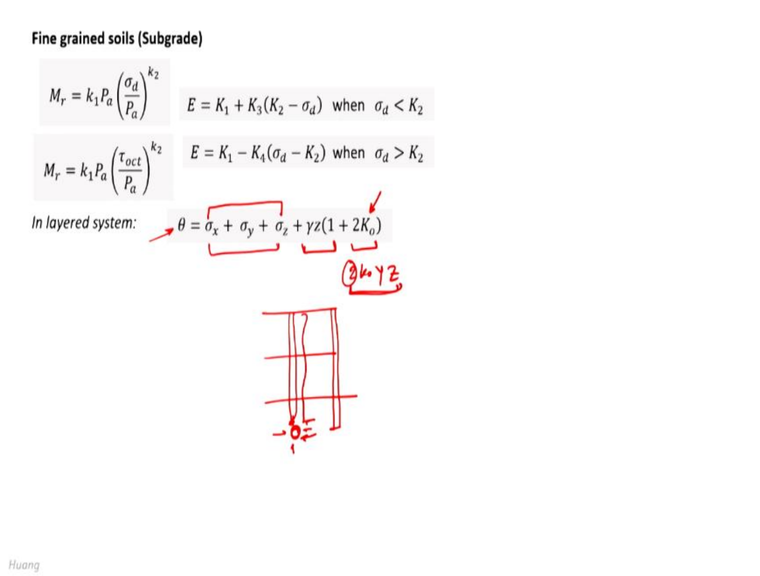

When we talk about θ, for example, we are taking the stress invariant is one of the parameters, so, as I said that this is usually the summation of all these stresses but if you see the layered system, let us say you are talking about this point, then in addition to the stresses in the vertical and lateral directions.

There is also some load which is above it and we have to consider this value of load also this amount of stress which is accumulating in this material because of the weight of the other layers over it. And that is why typically the value of γz is used and 2kγz is used. So, this k_0 is the coefficient of earth pressure at rest and if you have some background on soil mechanics, you will understand that this basically indicates.

So, k_0γz will indicate the lateral stresses which are coming in and it is 2 because σ_2+ σ_3, so, we are taking both the directions we are assuming it to be same. So, it is 2 k_0γz. And this γz is because of what is happening at the top this mass. And this is because of the load which is coming in. So, I hope that this value of stress invariant is clear to you that from where this equation has come in.

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Fine grained soils (Subgrade)

$$M_r = k_1 P_a \left(\frac{\sigma_d}{P_a}\right)^{k_2} \qquad E = K_1 + K_3(K_2 - \sigma_d) \text{ when } \sigma_d < K_2$$

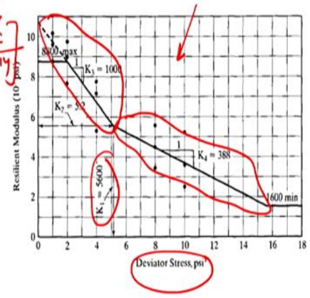
$$M_r = k_1 P_a \left(\frac{\tau_{oct}}{P_a}\right)^{k_2} \qquad E = K_1 - K_4(\sigma_d - K_2) \text{ when } \sigma_d > K_2$$

Granular: At each decreasing confining pressure apply increasing deviatoric stress.

Fine grained: At each increasing constant deviatoric stress apply decreasing confining pressure.

In layered system: $\theta = \sigma_x + \sigma_y + \sigma_z + \gamma z(1 + 2K_o)$

Deviator stress σ_d (psi)	Confining pressure σ_3 (psi)	Recoverable deformation (0.001 in.)	Recoverable strain ϵ_r (10^{-3})	Resilient modulus M_R (10^3 psi)
1	6	0.392	0.098	10.2
	3	0.416	0.104	9.6
	0	0.456	0.114	8.8
2	6	0.816	0.204	9.8
	3	0.868	0.271	9.2
	0	1.040	0.260	7.7
4	6	2.052	0.513	7.8
	3	2.224	0.556	7.2
	0	3.020	0.755	5.3
8	6	5.712	1.428	5.6
	3	7.112	1.778	4.5
	0	9.412	2.353	3.4
10	6	7.692	1.923	5.2
	3	11.112	2.778	3.6
	0	16.000	4.000	2.5



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Resilient Modulus is directly used in **Pavement design** for calculation of **stresses, strains and deflections**

Base and Sub-base materials

$$M_r = k_1 P_a \left(\frac{\sigma_3}{P_a}\right)^{k_2} \qquad M_r = k_1 P_a \left(\frac{\theta}{P_a}\right)^{k_2}$$

$$M_r = k_1 P_a \left(\frac{\theta}{P_a}\right)^{k_2} \left(\frac{\sigma_d}{P_a}\right)^{k_3}$$

$$M_r = k_1 P_a \left(\frac{\theta}{P_a}\right)^{k_2} \left(\frac{\tau_{oct}}{P_a}\right)^{k_3} \qquad \tau_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_2)^2}$$

P_a is the atmospheric pressure; σ_3 is the confining stress, θ is the bulk stress: $\sigma_1 + 2\sigma_3$; τ_{oct} is the octahedral stress when σ_2 is not equal to σ_3

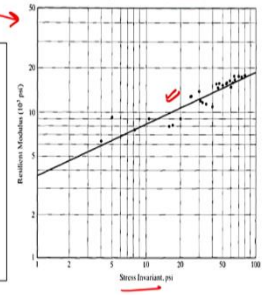
k_2 (positive) and k_3 (negative) are regression coefficients

Confining pressure σ_3 (psi)	Deviator stress σ_d (psi)	Recoverable deformation (0.001 in.)	Recoverable strain ϵ_r ($\times 10^{-3}$)	Resilient modulus M_R ($\times 10^3$ psi)	Stress invariant θ (psi)
20	1	0.264	0.066	15.2	61
	2	0.496	0.124	16.1	[illegible]
	5	1.184	0.296	16.9	65
	10	2.284	0.571	17.5	70
	15	3.428	0.857	17.5	75
	20	4.420	1.105	18.1	80
15	1	0.260	0.065	15.4	46
	2	0.512	0.128	15.6	47
	5	1.300	0.325	15.4	50
	10	2.500	0.625	16.0	55
	15	3.636	0.909	16.5	60
	20	4.572	1.143	17.5	65
10	1	0.324	0.081	12.3	31
	2	0.672	0.168	11.9	32
	5	1.740	0.435	11.5	35
	10	3.636	0.909	11.0	40
	15	3.872	0.968	15.5	45

Recoverable deformation recorded at the end of 200th repetition

Recoverable strain: recoverable deformation/sample thickness

RM= Deviator stress/recoverable strain



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So, in place of stress invariant, in addition to $\sigma_x + \sigma_\pi + \sigma_z$, the effect of the soil mass or the amount of different materials over that point is also considered. Well, for testing a cohesive soil or fine grained soil, in the first case that is granular soil which we discussed in the last slide, we saw that the value of σ_3 is held constant and σ_d changes. But here, what we do?

We consider σ_d as constant and at each σ_d we change the value of σ_3. At each σ_d we change the value of σ_3. So, this value of σ_3 is gradually decreased from one particular value to 0 and then the response of the material is seen. Here also we do the same thing which see the changes in dimension of the sample and we can calculate the recoverable deformation. And how do the machine is actually calculating?

Because we have strain gauges installed, we have albitites installed which continuously monitors that how the change in the dimension of the sample is taking place. And accordingly we can calculate the recoverable strain and so the resilient modulus. And here what is typically observed that for the same given soil, depending on the value of the deviatoric stress, there can be two separate equation based on the value of deviatoric stress.

For example, if you see this particular picture here as an example, so, this graph it shows that there are two zones. One zone of linearity is here. So, there is a particular way, the resilient modulus is varying with increase in the deviatoric stress. And after a particular value of k1, I mean which is a model parameter, the value of reseller modulus changes. So, the same curve we have two equations depending on the value of the debuted stress.

So, again this is how the equations has been developed. So, depending on σ_d is less than k2 or sigma d is greater than k2 which means two different parts. So, as I mentioned that in typically for testing the granular material at each decreasing confining pressure, we apply increasing deviatoric stress.

If I go back to this slide, so you see here that the confining pressure is decreasing and at each confining pressure you are applying increasing value of the deviatoric stress. Whereas in case of fine-grained soil, what we do that at each increasing constant deviatoric stress, so the deviatoric stress increases but the value of confining pressure at that particular deviatoric stress decreases. And this is how we do the test.

But you see this test method that is the repeated triaxial test, it involves on one hand a costly equipment and on the second hand a lot of quality control has to be monitored during the testing process in the laboratory. So, instead of using the complicated process of testing these materials in the laboratory, what researchers have done, they have tried to develop the correlation of resilient modulus with some of the parameters that can be easily defined or determined in the lab.

So, usually CBR is one such test which will be discussing very shortly with which most of the correlation of this soil parameters have been already developed and they are being very successfully used even in the pavement design process. So, for example, one of the correlation is that the value of resilient modulus of soil is equal to or this is also the stiffness modulus is equal to $M_r = 17.6 \times (CBR)^{0.64}$.

In fact, this equation is a very old equation; you can say it was proposed around 1984 and that too based on a study that was carried out in 1958. So, you can see that long back the researchers have already worked upon these aspects for developing the correlation. And this equation is valid for, I mean the the original equation which you see here, is valid for a CBR of 2 to 12 percent and in fact this equation is also used in India but we use this equation when the CBR value is more than 5 percent.

So, for 2 to 12 percent which the equation as I showed you is also used in the UK pavement design. Then there are other equations also, for example, one equation proposed by the Asphalt Institute is that E is equal to 10.3 into CBR and this is valid for soil. So, CBR is less than equal to 5 percent and the same equation we also use it in India but we just say that $E = 10 \times CBR$ and not $E = 10.3 \times CBR$. So, in India, what we do?

We use this equation when the value of CBR is less than equal to 5 percent and this equation when the value of CBR is more than 5 percent. In the AASHTO pavement design, they have also developed correlation with layer coefficients I am just writing down this equation though we are not going to discuss it because maybe we most of the participants do not have a background on the AASHTO pavement design.

So, this is just one equation which is available in the literature where A_i is the structural layer coefficients we typically use in the AASHTO pavement design. So, I hope that this is clear. Now, we will proceed further to see the other laboratory test methods which are more conventional in nature, which are more easier to perform and then as I mentioned that those, the parameters of those test methods are usually used to calculate or to estimate other parameters that are typically used in pavement analysis or design. So, now, let us talk about the CBR test. So, CBR stands for California Bearing Ratio.

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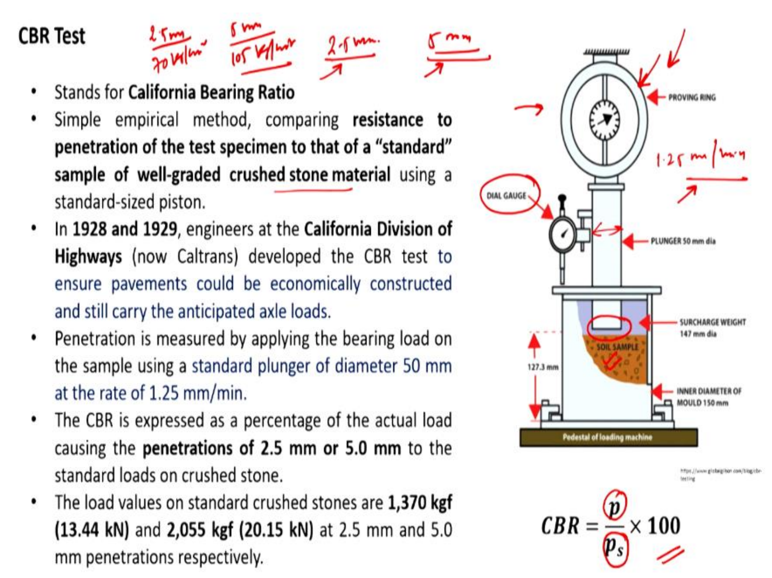

You can see that how the machine looks like. So, this is just a pictorial view of the CBR testing machine here. The value which we get using this test method that is the California bearing ratio is empirical in nature and it is used for comparing the resistance of penetration to the test specimen with a standard sample of well-graded crush stone material.

So, this is a relative strength test, we can say that we are seeing the strength of a particular material in comparison to the strength of a standard material that has already been tested and whose standard values are usually known. So, around 1928 and 29 basically, the engineers at the California Division of Highways which is now called as the Caltrans, they developed this particular test that is the CBR test.

So, as to ensure that pavements could be economically constructed and will still carry the anticipated axial load. So, in this test what we do? We measure the penetration by applying a bearing load to the sample using a standard plunger, the diameter of the plunger. So, this plunger you see here, this is the plunger, the diameter of the plunger is 50 mm which is again a fixed value.

And the penetration which has to take place is basically, given at the rate of 1.25 mm per minute. So, some of the aspects related to the testing can be seen from this particular picture. So, you see you have the soil sample here. The soil sample is loaded using a standard plunger at a particular rate that is what we have talked about. The change in the dimension of the sample can be monitored using a dial gauge which is placed here.

So, it will continuously give us readings that how the height of the sample is changing with the increase in the penetration. And the load is basically applied using a load cell here and the value of which can be monitored again using a dial gauge on this particular proving ring. So, more details about the test method we are going to talk about in this particular presentation.

Now, to define the CBR as the name suggests it is a ratio. So, CBR is expressed as a percentage of the actual load causing the penetration of 2.5 mm and 5 mm to the standard loads on which on crushed stone. So, the California division, they already tested some standard crushed stone, for those stones they have noted down that what is that particular load or you can say what is that particular pressure to attain the penetration of, I mean at the penetration of 2.5 mm and 5 mm. So, these are standard values.

And then in our soil sample which we are going to test, we will see that what is that particular load or pressure corresponding to 2.5 mm penetration and 5 mm penetration and then we will compare these values with the standard values. And the ratio of these values is basically the value of the CBR. So, $CBR = \frac{P}{P_S} \times 100$, in percentage.

Now, talking about the standard load on the crushed stone, so, when you talk about 2.5 mm penetration, the standard load for the crushed stone is approximately 13.44 kilo Newton. And the standard load on the crushed stone at 5 mm penetration is 20.15 kilo Newton. In terms of pressure at 2.5 mm, the value is 70 kg per centimeter square whereas for 5 mm it is 105 kg per centimeter square. So, both we can use either of the values like we can use the ratio of the load, but usually the ratio of the pressure is taken to calculate the value of CBR.

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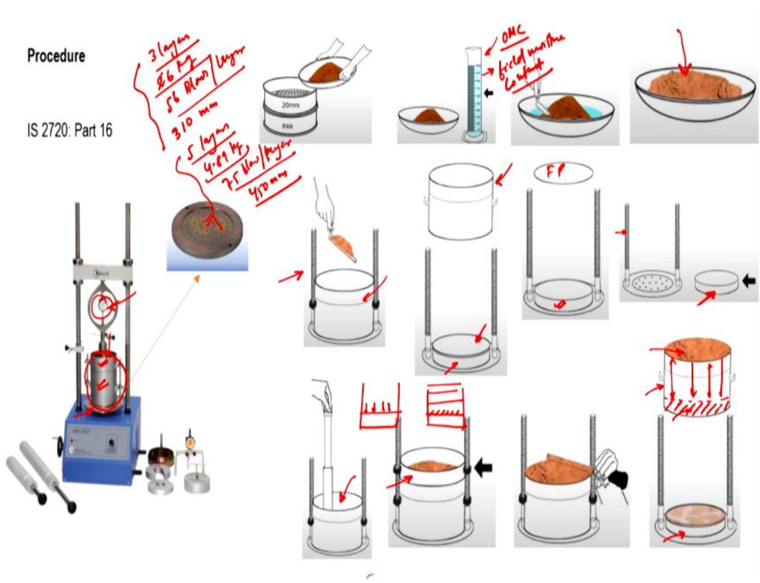

Now, let us look at the test method we will talk about the test method. Now, so, the Indian Standard code for this test method is IS2720 Part 16. This picture shows an example of the CBR testing machine which you can see that this is the proving ring here as I showed you in the last slide.

We have a dial gauge reading here, we also put one dial gauge here to record the change in the dimension of this specimen. Then this is the base plate over which the mold will rest and this is the collar, the top part and here the sample is kept on the lower part. And then we have for the preparation of this specimen inside the cylindrical mold, we have some standard process just like what we did in the Proctor test. And then we also have some standard surcharge weights which has to be kept on the sample while performing the test.

So, let us very quickly go through the steps of doing this test to understand it in a more appropriate manner. So, this is how the base plate looks like. So, you see we have a base plate with some pores in it as you see. So, in this test what we do? We will first sieve the soil corresponding to a 20 mm sieve and we will take materials that are passing 20 mm sieve. Then what we do?

We will take a specific amount of water. Now, the choice of this water depends on what we are trying to do. If we are trying to do a let us say new construction and then which means the soil will be compacted at the site at the optimum moisture content which we have determined from the modified Proctor test.

In that case, we will take this water as the optimum moisture content. In case we are evaluating an NC2 soil and we want to find that at the existing moisture content, what is the value of CBR. So, for that particular soil, we will use the field moisture content. So, depending on what is our anticipated, I mean, what is our objective, we will choose the appropriate amount of water and then we will mix, add this water to the soil sample gradually and we will mix it. And will mix it so that a soil paste will be formed. Then what we do?

Then we will prepare the sample inside the cylindrical mold. So, we will take the base plate here which you see and over this will put a spacer disc. So, this spacer disc there is a specific objective, I will tell you that why this spacer disc is basically put in the base plate to prepare the sample.

So, we will put this spacer disc on the base plate. Over this we will place a filter paper. So, we will keep the filter paper over it. So, you see you have the base plate here and then you have the filter paper. This filter paper is kept to avoid the contact between the spacer disc and the soil specimen which will keep inside the cylindrical mold.

So, after the filter paper is kept, we will keep the our mold on it and we will take the soil and we will fill the soil in different layers. So, just like Proctor test, the CBR test can also be done in two modes. One is the light compaction, and one is the heavy compaction. In case of light compaction, the soil will be filled in three layers.

The weight of the hammer will be 2.6 kg and the number of blows which will be giving to each layer will be 56 blows. And the height of the fall will be 310 mm. In case of the heavy compaction, we will fill the soil in five layers. We will use a 4.89 kg hammer for compaction. In each layer we will apply 75 blows. And the height of the fall here is 450 mm.

So, this is just what we have to remember depending on the type of test we are choosing. And then we will fill the soil in this particular mold in let us say three to five layers, let us say we are talking about the heavy compaction. So, which means we have to fill in five different layers. So, if this is the mold will first fill in one layer give 75 blows here. Then what we will do?

When this layer is compacted we will scratch this layer using a knife, so that the next layer can be well bonded with this particular layer, then we will again fill the second layer. And similarly, we will keep going till the fifth layer has been compacted. So, after we have compacted, then you see we have a collar here.

So, this collar is an additional mold which is kept on the top of the standard mold. So, we will remove this collar and we will remove this collar and then we will make the surface plane using a knife. So, extra material will be struck off and then we will get a plane surface here as you see. Then what we will do? We will remove this sample.

Now, you remember. Now, you try to imagine that before compaction there was a spacer disc here, this particular spacer disc. Which means that the compacted specimen is only up to this height and this height is empty now. So, this was the purpose of using the spacer disc to create a space here. Now, what we will do? We will just reverse the sample.

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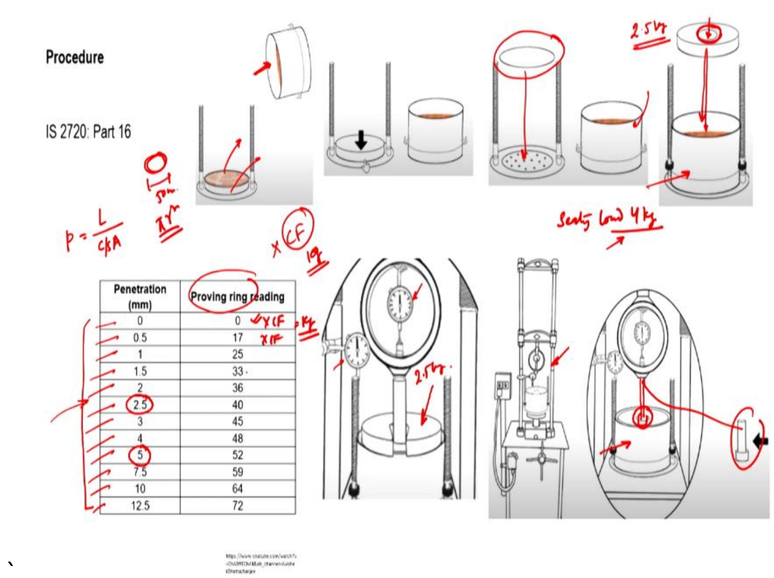

Penetration (mm)	Proving ring reading
0	0
0.5	17
1	25
1.5	33
2	36
2.5	40
3	45
4	48
5	52
7.5	59
10	64
12.5	72

So, in the next step we are you see we are reversing the sample. So, you can see you have a gap here, empty space here because of the spacer disk. So, you remove the sample and then what you do? You remove this particular filter paper and you remove the spacer disk also. So, you remove the filter paper, you remove the spacer disc and you put a new filter paper over the base plate.

You will put a new filter paper over the base plate. And then you will put this particular inverted mold over the base plate. So, this is what has been done here. After that we will use a surcharge weight of 2.5 kg and we will place it over the sample. We will take the surcharge bit and we will put it over the sample.

Now, you see this surcharge weight has a hole here. This hole is given, so that we can put plunger inside it and we can make the contact with which can make the contact with the soil. So, we will place this particular mold with the surcharge weight on the CBR testing machine. Then we will put the plunger in the place. So, this is the plunger which I will put here. So, this plunger will be put here.

And once I put the plunger, I will apply a seating load of 4 kg by turning on the CBR machine. So, I will put a seating load of 4 kg by turning on the CBR machine. Now, this sitting load is given to achieve good contact between the plunger and the soil sample before we start the test.

So, we will first give a seating load of 4 kg and then in the next step we will keep another annular weight of 2.5 kgs on the sample. So, this is again an additional load of 2.5 kg which means the total load is 5 kgs. And then we will ensure that the dial gauge reading is made 0 before we are starting the test and then we will start the CBR test. We will turn on the machine and we will penetrate this sample at a rate of 1 point 25 mm per minute. And then what we will do?

We will record the proving ring reading at different values of penetration. So, at different values of penetration, remember we are interested only in 2.5 mm penetration and 5 mm penetration, but still we have to see that how the load is varying at different penetration depths.

So, we have to plot this particular graph to find out the appropriate CBR value or to perform the actual calculation. So, these are the standard penetration which you can see here at which we are recording the proving reading. Now, the proving ring reading has to be multiplied with the calibration factor of that particular equipment which will be given by the manufacturer, which will convert the proving ring reading into kgs or any other unit depending on how the equipment has been calibrated.

So, let us say you have the calibration factor. You multiply it with all the values and you get the values in kg. And then if I want to convert this value into the pressure then what I will do? I have this load I will divide by the cross sectional area. I already know the dia of the plunger which is 50 mm. So, I will just do pi R square to get the cross sectional area and I will divide it by this load value to get the value of the pressure.

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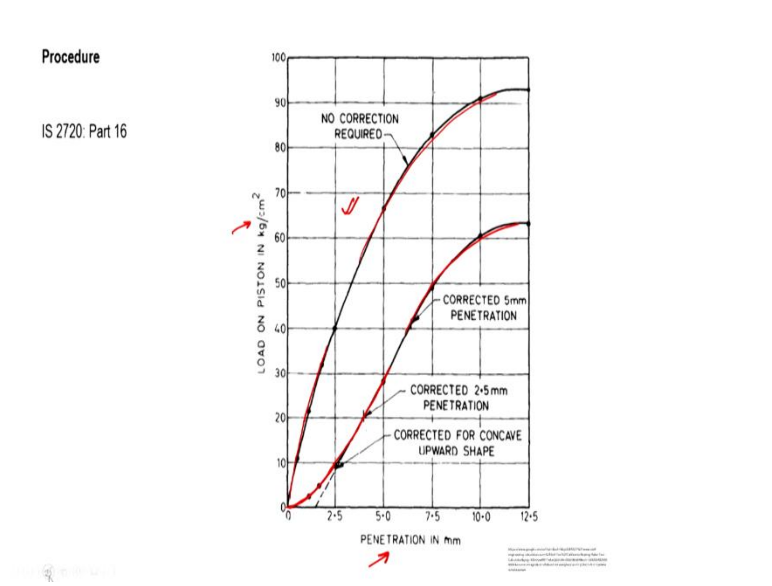

And then the load in term in kg per centimeter square will be plotted with respect to the penetration. So, you can get two types of graph after performing the penetration test. So, if you get a graph something like this which is more of convex in nature, then you do not have to perform any correction. But if you see a concavity at the beginning of the graph as you are seeing in the second graph here which means it will be more of a S type curve then you have to apply some correction. So, how you will apply the correction here? What I will do?

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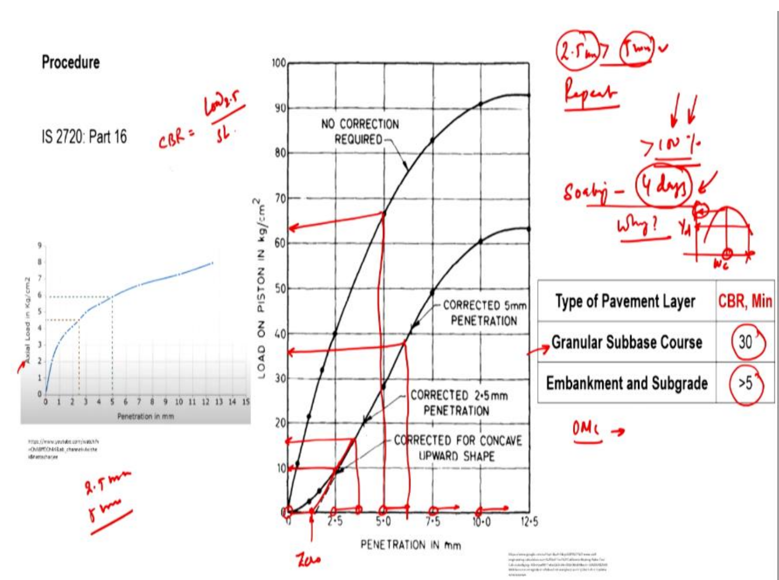

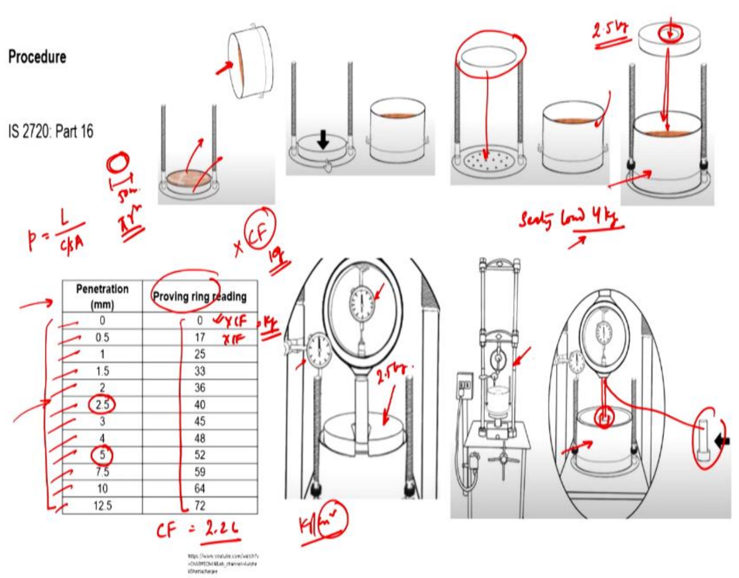

Penetration (mm)	Proving ring reading
0	0
0.5	17
1	25
1.5	33
2	36
2.5	40
3	45
4	48
5	52
7.5	59
10	64
12.5	72

I will first locate the point from where this straight part starts and I will make a tangent. So, I will make a tangent here and I will mark this point. So, this will be the New (0, 0) point which means I have to shift the axis from here to here, likewise all the values will be shifted to equal amount, I mean to equal distance. I am interested in let us say 2.5 mm penetration.

The actual reading is this one. But when I shift it, the reading which I will note down is this particular value. But in the first graph if let us say 5 mm penetration I am interested in then this is the reading which I will note. While in the second graft after doing the appropriate shifting, this is the value which I will note. So, I have to do the correction accordingly.

And then I will just note down the value of the axial load at 2.5 mm penetration and 5 mm penetration. And I will just perform a simple calculation that is CBR is equal to load at 2.5 mm penetration divided by the standard load in kg per centimeter square. Usually, the value of CBR at 2 point 5 is greater than what you get at 5 mm. If this is the case, then it is correct.

In case you are getting the value of CBR at 5 mm more than what you get at 2.5 mm, you have to repeat the test. Even after repeating the test, if you get the same trend that the CBR at 5 mm is greater than the CBR at 2.5 mm then we will take the CBR corresponding to 5 mm penetration as the final CBR value.

Talking about the specification well in terms of pavement engineering, then our codal provision, our specification tells us that the soil to be used in different layers what should be the minimum CBR value. For example, as per Ministry of Road Transport and Highways, if you are doing a construction of granular sub-base, granular sub-base then the aggregates there, the material, the soil there should have a CBR of minimum 30 percent. For embankment and subgrade the minimum CBR should be more than 5 percent.

Now, again like one important point here that it is very much possible that the CBR value for a particular soil can be greater than 100 percent also. So, this means that the soil which we are testing is even stronger than the standard crushed rock which was being tested at California. So, this is just one point that this is just a relative value and it need not be always less than 100 percent.

One more important point here, from again the perspective of pavement engineering is that we also perform this test after soaking the sample for four days typically. Now, this is done at locations where the rainfall is typically higher. And why this is done? The question is why this is done?

Because you see when we do the construction, we compact the soil at the OMC. So, at the OMC, the specimen is at its highest density and the strength will be higher. But after the construction, the moisture content in the soil can change, and I will just for reference I will draw the OMC curve here.

So, this is the dry density this is the water content and this is at the moisture content at which we have compacted the soil. So, at this moisture content we get the highest density but as I mentioned that after the construction it may happen that the moisture content in the subgrade soil can change, typically, after monsoons at some of the location if the water table is very high, then the moisture content in the soil can be very high. Which means at that particular moisture content the actual density will be less.

So, if we do the design considering the strongest state, this design may not be very conservative considering that the soil has to be constructed at those locations where we are anticipating more change in the moisture content in the subgrade soil. So, that is why the codal provision recommends that to do the design conservative, we have to see that in the worst state of moisture content, what will be the CBR of the soil.

And we will use that particular CBR in the design process to calculate the thickness of different layers of in the pavement. So, the soaking is done by keeping the sample immersed in water for four days and after four days we will do the CBR test. So, this will give me the value of CBR which will be much lower than what we will get at the optimum moisture content. And this will ensure that the design which we are doing the thickness of different layers we which we are providing, will help in reducing the stresses in the soil, typically, when the soil will have very high moisture content maybe after the monsoons.

Again just if I move to the last slide, if you want to practice to how to calculate the CBR value, you can take this particular table, you can use these values here. So, let me tell you that a calibration factor of, you can use a calibration factor of 2.26 on these readings. So, you can just use an excel sheet to plot the graph between penetration and the load. A load can be in terms of kg per centimeter square also.

In that case, you will have to use the dia of the plunger to do the appropriate calculation and then you can try calculating the CBR for this particular example. So, let us stop here today. Today we have talked about the repeated triaxial test in this lecture. And we have also discussed that how a CBR test has to be performed, what is the importance of CBR test, what are the different parameters to be considered while conducting the CBR test.

For example, when to do soak test, when should we do an unsoaked test. And in the next lecture, we will try to complete discussing about the strength properties of soil and we will discuss about two test methods. The first method will be the Dynamic Concentration Test or DCP test and the second method will be the Plate Load Test. Thank you.