Rock Engineering

Prof. Priti Maheshwari
Department of Civil Engineering
Indian Institute of Technology-Roorkee

Lecture-14
Indirect Method for UCS, Brazilian Test, Schmidt Rebound Hardness Test

Hello everyone. In the previous class we had the discussion on indirect methods for determination of the compressive strength of rocks. And we also discussed about the failure mechanism, complete stress strain curve for the rock under compression. So, as far as indirect methods for determination of the compressive rock are concerned, I mentioned to you that we will be discussing 2 methods.

And we already discussed one method which was given by ISRM in 1961. So, there we took one egg shaped specimen and we conducted that test and then the correlation was given in order to convert the compressive strength of the irregular specimen to the regular specimen. Now, the next method which is more commonly adopted, it is being used to determine the compressive strength is called as the point load strength index test. So, in this case we take roughly chiseled spherical mass with the diameter ranging between 30 to 50 mm.

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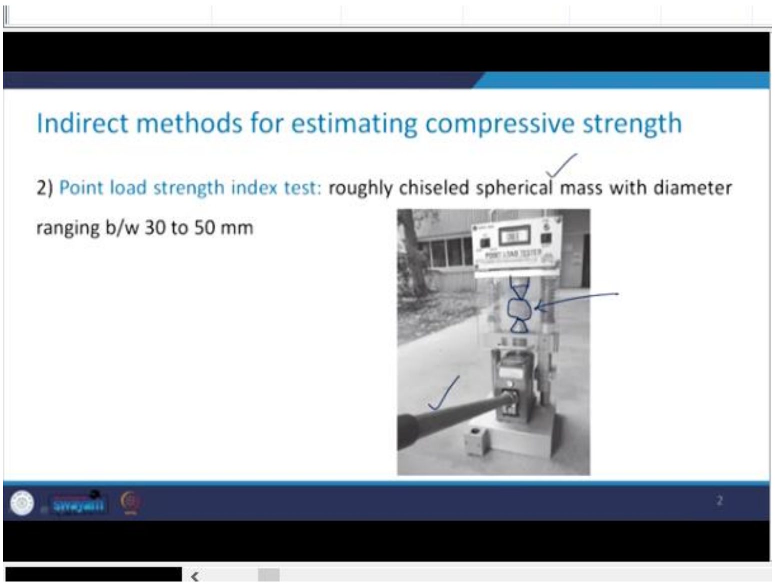

Please do not get confused that on one hand I say that it is the irregular specimen and right now, I am saying it to be spherical mass. I already mentioned to you that whenever you have these sharp edges, which you can have in irregular specimen, I have shown you also when I showed you one of the irregular specimens in earlier classes. We need to give the light blows of hammer and simply smoothens that out and roughly we need to get in this case point load strength index test this spherical mass.

And the diameter can range between 50 to 30. So, that is a machine which has been shown here in this figure. So, you can see that, here the specimen has been placed between these spherical loading platens, you can see. I have outlined it. And then with the help of this lever, you just apply the load and whenever this specimen breaks, you note down that particular load. Using that load, we will be finding out the point load strength index and that would be correlated to the compressive strength of the rock.

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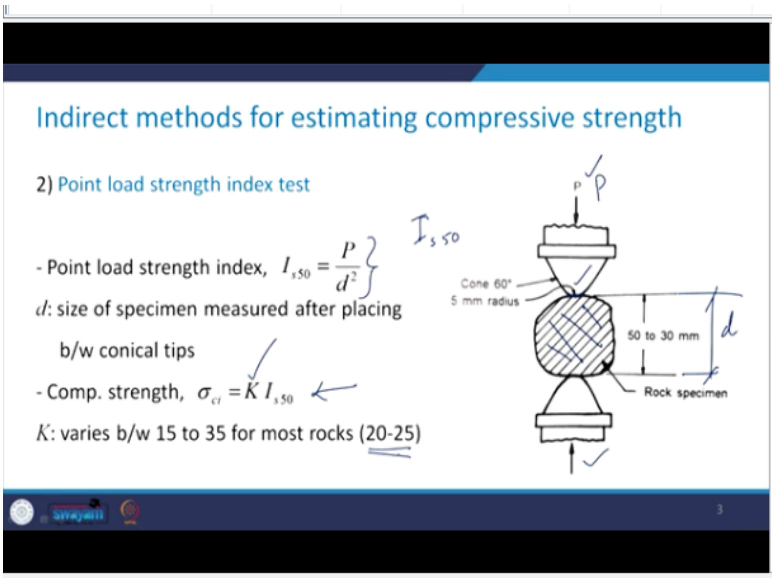

As I mentioned, this is the line sketch. Here is the rock specimen, this one which may have the dimension from 30 mm to 50 mm and you have the loading platen as the cones which are having 60° apex angle and then here it is, this is 5 mm radius. You apply this point load here, which is capital P. So, the point load index is defined as

$$I_{s50} = \frac{P}{d^2}$$

This expression, where this d is the size of the specimen which is measured after placing between the conical tips that is this dimension is dimension d. Then, the compressive strength is correlated with this point load strength index in this form that is you need to multiply it with a constant K that varies between 15 to 35 for most of the rocks and in general, we take it to be between 20 to 25. If nothing is given, you just take the one value in this particular range.

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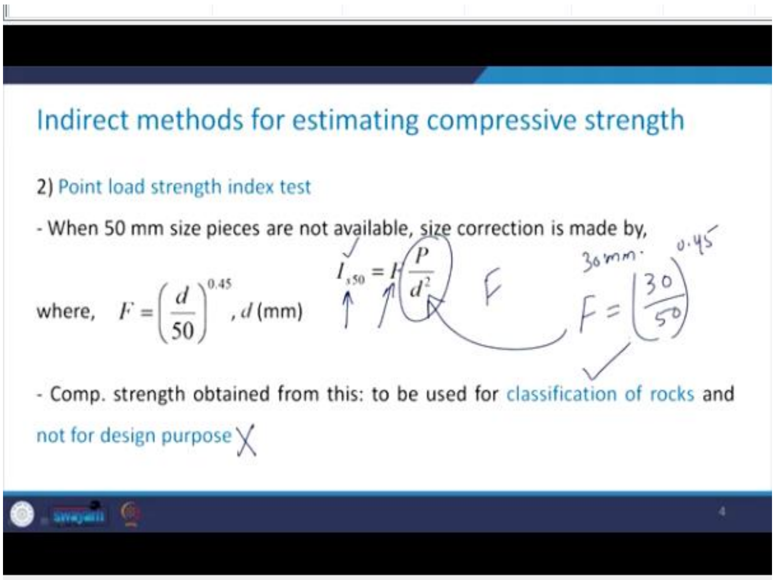

Now, the question is if 50mm size pieces are not available, then one needs to go for the size correction. If you recall, we discussed about this size correction in case we did not get L/d ratio 2 or more than 2 in case of the regular cylindrical specimen, they are also we had corrected the value which we got from the lab in order to get the compressive strength of the rock.

So, likewise here also this index is modified or corrected for the size of the specimen when it is not 50 mm. So, let us say if it is 30 mm size, then you have to apply this correction. So, corrected index *F* is defined as:

$$I_{s50} = F\frac{P}{d^2}$$

$$F = \left(\frac{d}{50}\right)^{0.45}, d\ (mm)$$

So, let us say that, that I have made that test or I have conducted the test at 30 mm diameter of the specimen. So, what this is F is going to be in that case 30 upon 50 to the power 0.45. So, whatever is this value of F that you get, you just substitute it here and you will get the correct value of this I_{s50}. Please keep in mind that the compressive strength that we obtained from point load is strength index test should not be used for the design purpose.

However, one can use it for the classification purpose; This is a very, very important aspect. It is not to be used for design purpose, but only for the classification of rocks.

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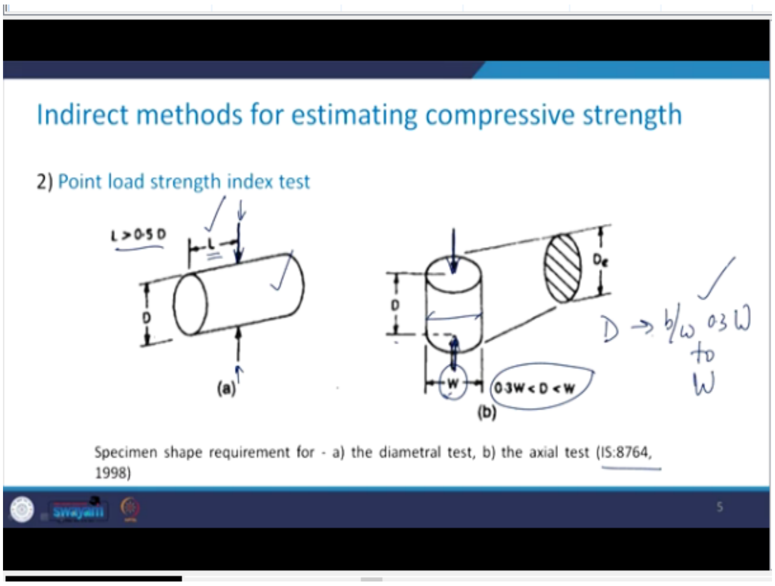

Now, in case if we have any other shape of the specimen, then the code that is IS:8764 gives us some of the shape requirement for the specimen for different shapes of the specimen. So, let us say that, for the diametral test, when I say diametral test means the loading is applied along this diameter and the length of the specimen or the loading point should be more than 0.5 times its diameter from one end as has been shown here.

So, you see that this dimension should be more than 0.5 times D. So, that is the shape requirement if you want to conduct point load a strength index test in case of such shaped specimen. In case if you have the axial test, that is, here you see the loading is applied in this direction and the dimension is W in this direction that is this one and D is its height. So, you see that the equivalent diameter, you can find out there is a relationship between D and w and it should follow this.

That is this dimension D should be in between 0.3 W to W. So, if this is not satisfied, then the value that you will get from the point load in a strength index test, it cannot be used for the determination of the compressive strength.

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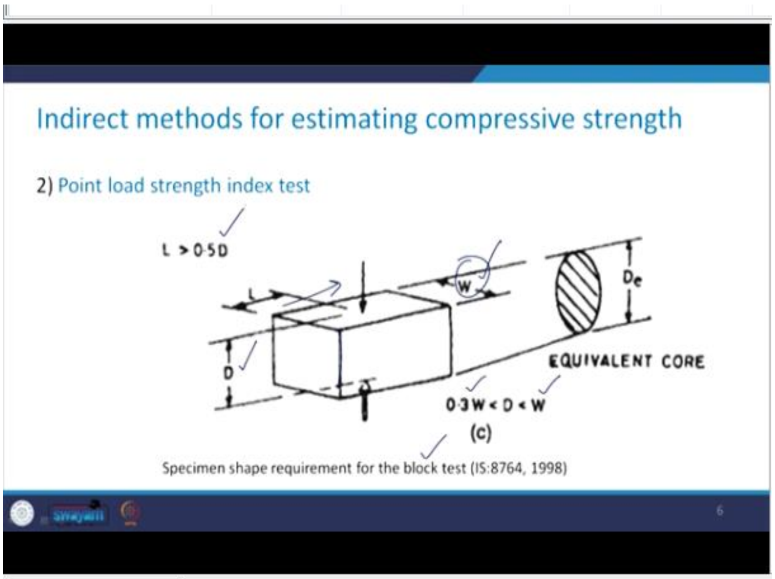

Similarly, in case if you have a block kind of specimen, so, this is the block test. So, in that case, you see that, this figure gives us the idea that what should be the shape requirement. So, again in this case, this dimension that is *D* should lie between 0.3 *W* to *W* where *W* is it is this dimension here and again the length that is in this direction, wherever the loading is applied, that distance from this phase should be greater than *0.5 D*. So, until unless we get have this, we cannot use this method to determine the compressive strength.

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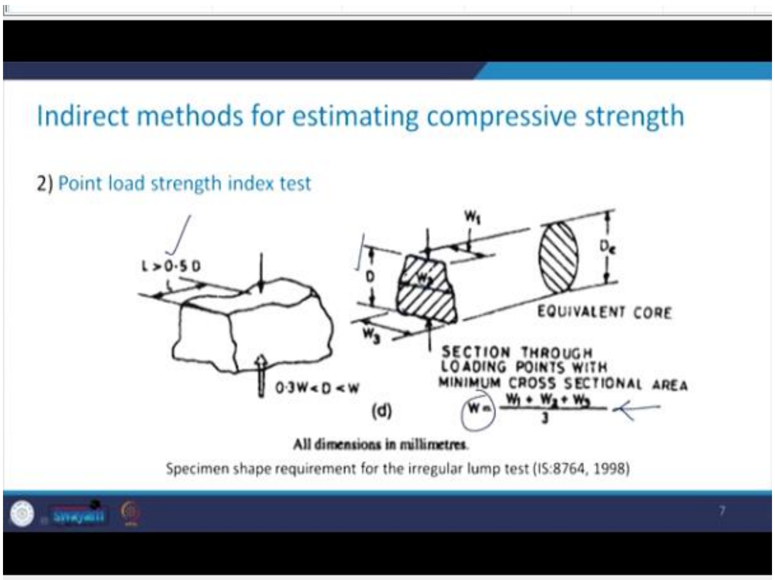

Similarly, if you have the irregular lump test, so, in that case again this length requirement remains the same and its cross section if you see, it is not constant along this dimension *D*. So, what you need to do is you take the average dimension in this direction, so, that you can obtain as *W 1 + W 2 + W 3*. That means, you measure it at the top at the bottom and at the middle, you measure the width of the specimen and then take the average of these and you will be able to get the value of *W* in this case.

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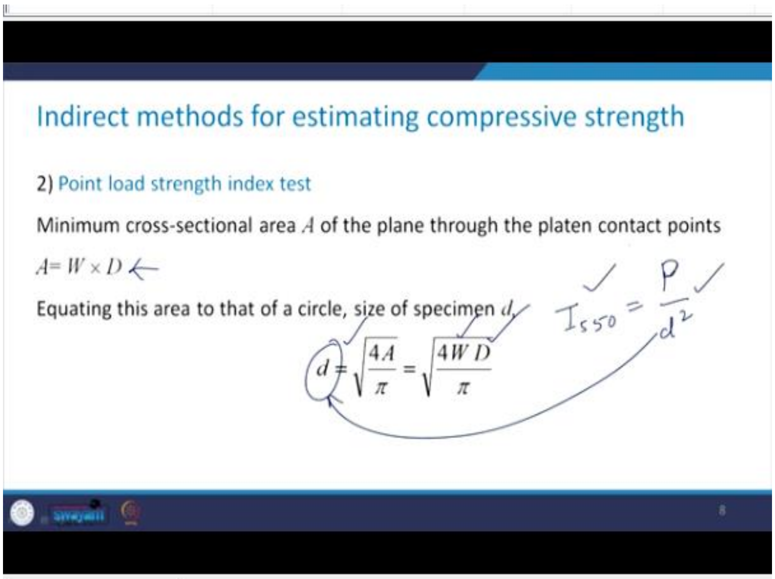

The minimum cross sectional area *A* of the plane through the platen contact point is defined for any shape as *A*=*W* * *D*. What are the requirements on *D* and *W*? I have already explained that to you as per the codal provision. Now, if we equate this area to the equivalence circle, so, the diameter of the circle we will get it in this particular manner. So, if we have *W*, if we have *D*, we should be able to find out the equivalent diameter *d*.

And then we can use the expression, that is,

$$I_{s50} = \frac{P}{d^2}$$

Then instead of that, you have to use this *d*, $d = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4WD}{\pi}}$ for these special shaped specimens, use this, find out I_{s50} and then you can get the compressive strength. So, this is all about the compressive strength of the rocks. So, the next we will discuss about the tensile strength of the rock and we will see that how to determine the tensile strength in the lab. So, I have already explained you that as against soil, rock possess some tensile strength.

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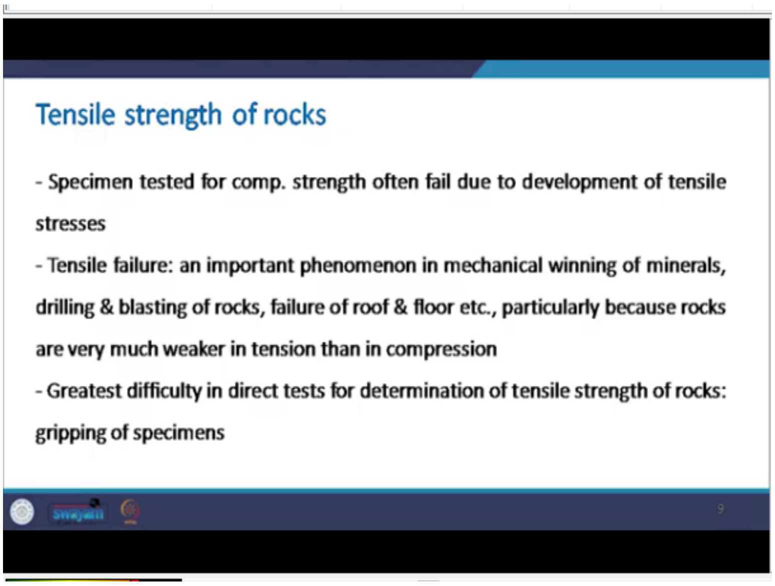

And especially in case of the tunnels or some kind of mining activities, drilling and blasting of the rocks. In case of the tunnels, it is the failure of roof and floor, tensile stresses develop. Until and unless we know the tensile strength of the rock, I will not be able to design that structure properly. So, therefore, not only the compressive strength, but also the tensile strength of the rock is equally important. Because many times the specimens which are tested for compressive strength, they often fail due to the development of tensile stresses.

Because the rocks have lesser tensile strength as compared to compression, we need to be even more careful wherever there is an occurrence of the tensile stresses and take care of that, for that we need to know the tensile strength of the rocks, how to determine it? In case of the compressive strength determination, what we did? We had the specimen, we subjected it to the compressive load directly and we obtained that at what level of the compressive load the failure took place.

Now, what happens in case if we want to find out the tensile strength. I have to subject the specimen to tension or let me just draw it here. See if this is the specimen, I need to subject it to the tension because then only there is going to be the development of the tensile stresses in the rock and at whatever value of this tensile load, this specimen fails, that is going to give us the tensile strength of the rock.

Now, the question is, if I have to subject any specimen to the tensile stresses, what should be done? We should have a proper grip and then apply the pull. So, regular specimen will not be able to give us this kind of an arrangement. So, that we can hold it and subject it to the tensile stresses. So, therefore, the gripping of the specimen becomes one of the greatest difficulties in order to obtain the tensile strength of the rock from the direct methods. When I say direct methods means, I am applying these tensile stresses to the specimen directly.

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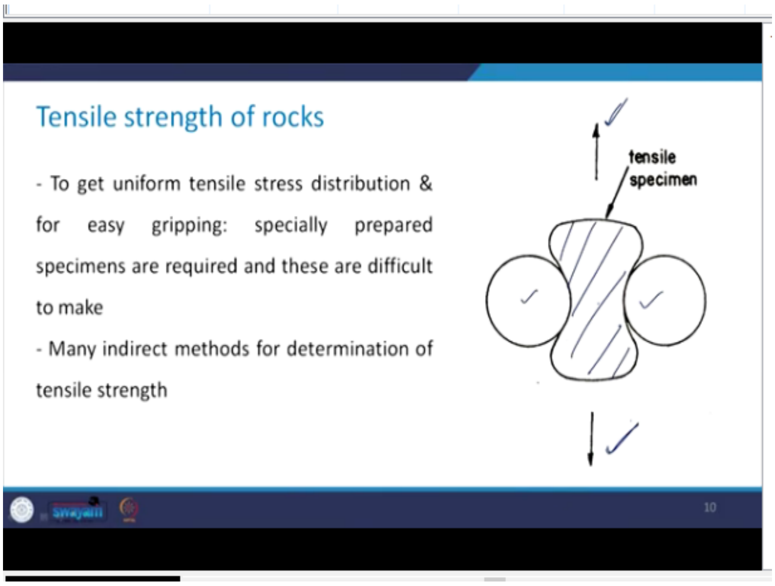

Take a look here at this and then you will realize that what I mean to say that it is difficult to make that a special shaped specimen. So, you see in order to get uniform tensile stress distribution throughout the specimen and for easy gripping. We need to prepare these specimens especially, and these are so difficult to make. For example, here I have given with the help of this picture, this is bracket shaped specimen.

You see, this is the specimen. How will you make it? This is very difficult and the rock is not a material which can be moulded in any shape. So, it is not that easy to make these specimens. Now, let us see, if I am able to make this shape of the specimen, then I have to provide some kind of arrangement for the gripping of this specimen onto the machine, where these direct tensile loads can be applied.

So, you see here that I have designed these gripping mechanisms in such a manner that it is holding this specimen in the position when we apply this load here at its end. Now, what will happen? First of all, it is very difficult to make this specimen. Second thing is, think about what will happen at these interfaces in these zones? There is going to be huge stress concentration in these zones.

That is contact zones between these gripping arrangements and the specimen. And what will happen because of that stress concentration? There will not be uniform stress distribution all along the specimen and the moment there is non-uniform stress distribution whatever is the strength that you will get from the test, that will not be giving you the correct picture of the strength.

Therefore, in order to overcome these difficulties, there are many direct methods which have been devised for the determination of tensile strength. Let us take a look at them as in a comprehensive manner. So, there are various indirect methods. So, they include bending test.

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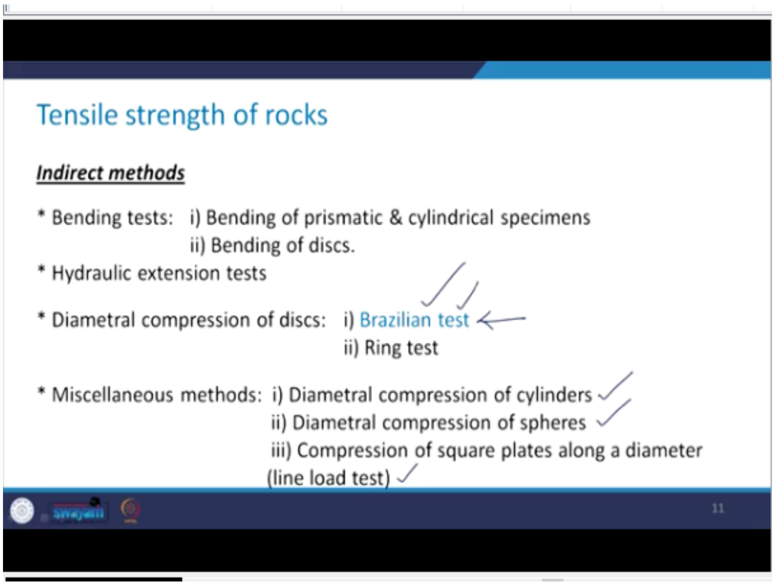

In this bending of prismatic and cylindrical specimens is carried out and then the second one is bending of discs. So, in this case the specimen is of shape of a disc and then the bending takes place, then the second one is the hydraulic extension test, in this one you have kind of a hollow cylinder having thick wall and then at its inner diameter, you apply the internal pressure. So, what will happen because of that pressure that specimen will be subjected to tensile stresses.

And accordingly using the theories of thick cylinder, the tensile strength of the rock can be obtained. Next category is diametral compression of disc in which you have Brazilian tests and ring tests. So, here I have highlighted Brazilian tests, because we are going to discuss this in detail. And most of the time, it is this Brazilian test, which is adopted to determine the tensile strength of rocks in the lab.

What are the specimen preparation requirement? How this is conducted? We will discuss. But then before that we have other category of these indirect methods, which are miscellaneous methods, in this one you have different type of tests. So, one is the diametral compression of cylinders, then diametral compression of spheres and then compression of square plates along diameter. So, this is kind of a line load test.

So, we will be focusing as far as this course is concerned, we will be focusing only on this Brazilian test for the determination of tensile strength of rocks.

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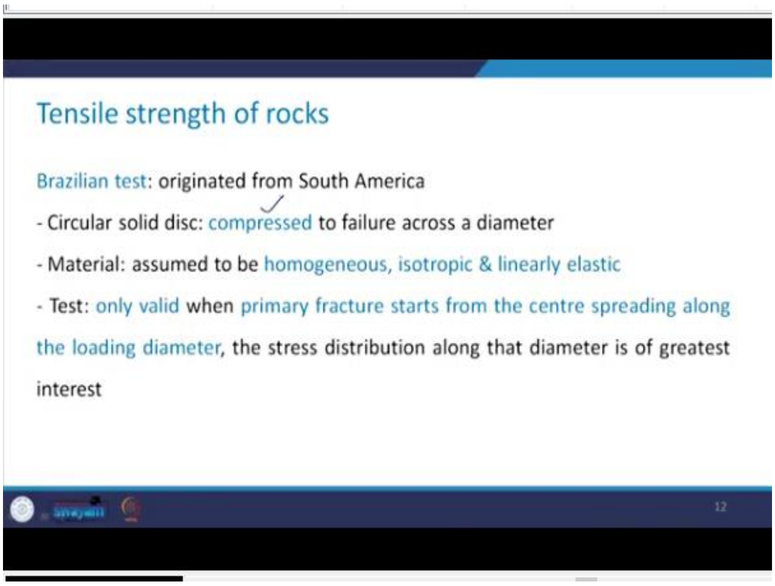

So, basically as the name suggests Brazil originated from South America. In this we have to take the circular solid disc. This is compressed to the failure across diameter. So, you see, although I have to find out the tensile strength, the specimen is compressed, that means that the specimen will be subjected to compressive stresses, but not the tensile stresses and that is why we are calling these tests as indirect tests because we are not subjecting the specimen here directly to the tensile stresses.

In this case, material is assumed to be homogeneous, isotropic and linearly elastic. Now, there are few limitations of this test. However, in spite of all those limitations, this test gives us reasonably accurate values of the tensile strength of rocks. So, this test is only valid when the primary fracture starts from the centre spreading along the loading diameter. In this test, the stress distribution along that diameter is of the greatest interest. Let us see how it is done?

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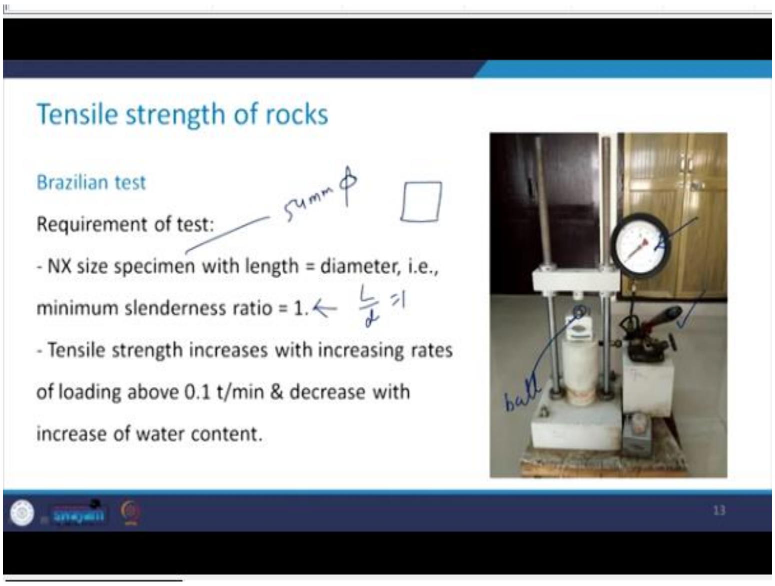

So, the test requirement for the specimen it should be the NX size specimen. Now, what is the typical characteristic of NX size specimen? That it has 54 mm diameter, now with *L/d* ratio to be equal to 1. So, minimum slenderness ratio *L/d* we will take us 1 in this case again. So, it will be something like this, this tensile strength increases with increasing rates of loading above 0.1 tonne per minute.

And it reduced with increase in the water content in the specimen, all these things we have discussed with respect to the compressive strength and I have given you the idea that what is the reason behind such type of failure? So, the same thing is applicable here in this case. Here, this is the Brazilian test setup that is the machine which is there in our lab. So, you can see that here you have an assembly this one where we will fix these specimens.

And then on top of that, you can see there is a spherical ball here and then here is a lever through which the load is applied that is a compressive load is applied to the specimen which is mounted here and this is the dial gauge there you can measure, you can see that at what load the specimen failed? Let us see how it looks?

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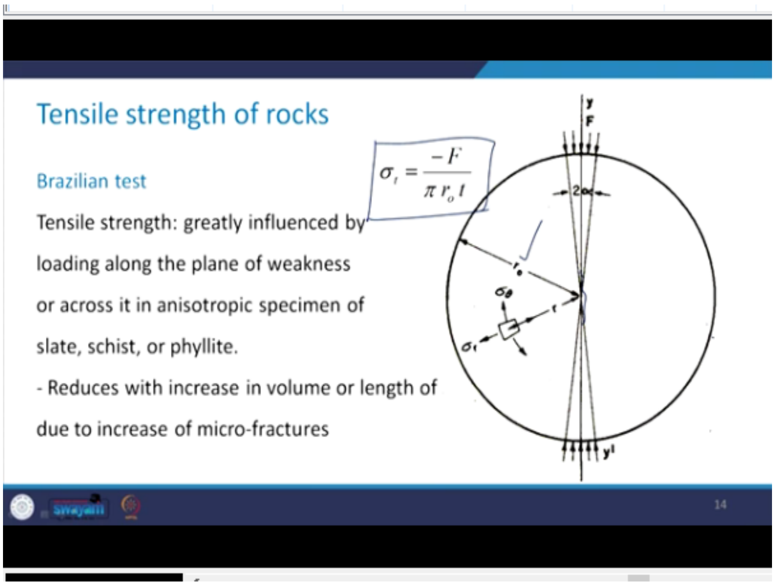

As a schematic diagram, as I mentioned that the specimen should be loaded along the diameter and this is valid when the crack starts propagating from the centre only along this diameter. So, this is the philosophy. So, this tensile strength can be determined by this expression,

$$\sigma_t = \frac{-F}{\pi r_o t}$$

there this r_0 = radius of the specimen,

t = thickness of the specimen in the plane perpendicular to this plane.

So, the tensile strength is greatly influenced by the loading along the plane of weakness or across it, especially in anisotropic specimen and rocks like slate, schist or phyllites, they are highly anisotropic. So, in that case, the tensile strength would be greatly depending upon that how you are doing the test along which diameter you are loading the specimen? Again, if you increase the volume of the specimen or the length of the specimen, the tensile strength is going to reduce.

The reason is same as it was there for the case of the compressive strength, when we have the large volume or the large length, what happens? The number of micro fractures, they are more and therefore, they have weakening effect on these specimens. So, whatever that, strength that we will get for the larger specimen it will be small as compared to the one which is required that is at minimum slenderness ratio of one. That is the reduction in strength will take place with increase in volume or the length of the specimen.

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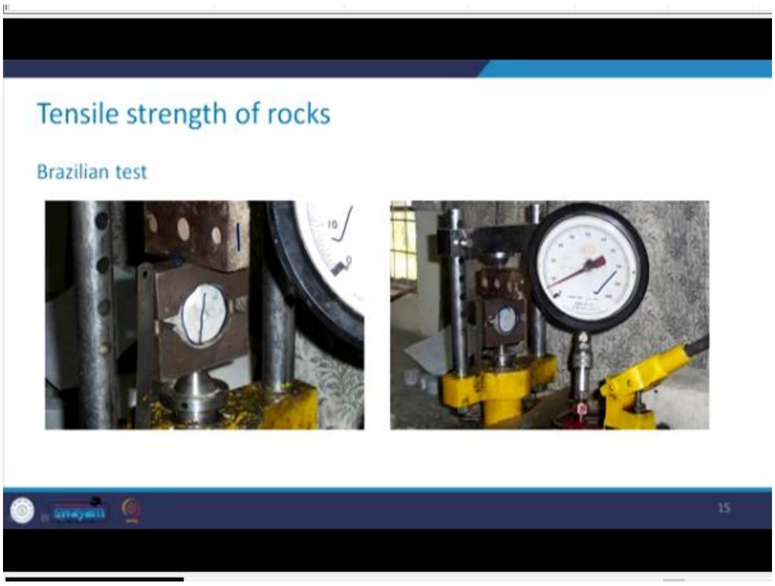

Again, this is some testing which is going on in the lab and some pictures have been taken. So, you see that this is how the specimen is mounted, can you see this here? And see the crack is being developed like this in this case, how the loading is being applied through this loading platen? There is a spherical ball in between this and how we can measure from this dial gauge that at what load this has failed?

So, another total complete view of this, this was the close up and see this is the total view. So, here you can read the load which is in *kN*, that at what load this specimen which has been mounted here it failed. So, we are applying the compressive load, but we are trying to find out the tensile strength of the rock.

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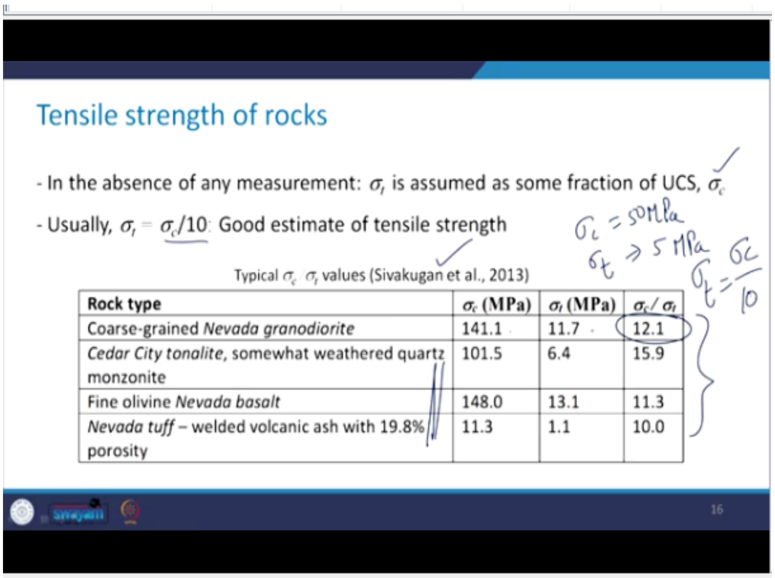

Now, in case if we do not have any measurement related to this tensile strength, then this tensile strength can be assumed with some percentage of the UCS that is σ_c. That means, we have conducted let us say, UCS in the lab and we do not have any data or any means to carry out this Brazilian test. Then usually it can be taken as a good estimate of the tensile strength that is $\sigma_t = \sigma_c / 10$ can be taken as the tensile strength that is the good estimate of the tensile strength.

So, if you are not able to carry out let us say, the tensile strength test in the lab and you have the data for UCS, that is the kind of thumb rule that we adopt in the field that if the compressive strength let us say, is 50 MPa, then σ_t can be taken as 5 MPa of this order. Now, some of the literature they show typical σ_c / σ_t values for different rock types.

So, here we have mentioned again this has been taken from this reference. So, the coarse-grained Nevada granodiorite. So, this is the granodiorite, we have discussed that what kind of rocket it is, what is the mineral composition of this? Nevada is a place. So, σ_c, σ_t and then you can see that it is of the order of say 12.1. Similarly, for these different types of rocks here is the σ_c / σ_t values.

So, in general it has been seen that, if you take $\sigma_t = \sigma_c / 10$ that gives reasonably good estimate of the tensile strength.

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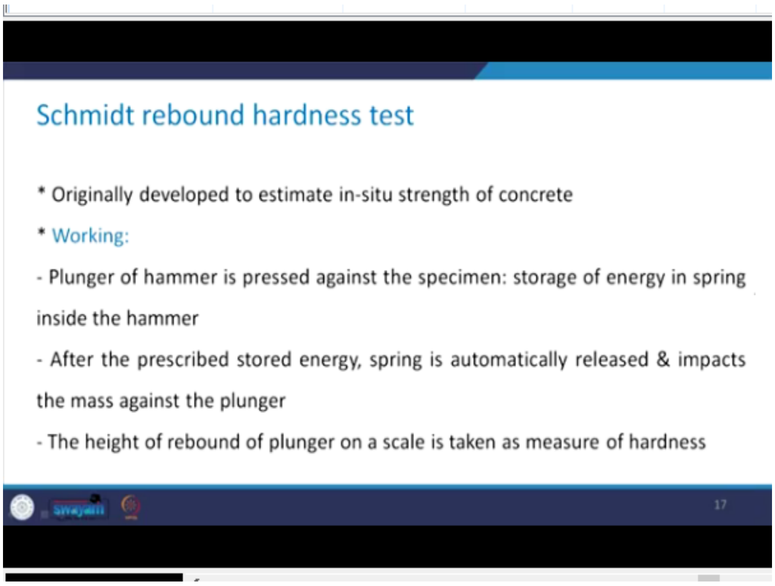

Now, coming to the next test, which is useful in order to obtain the compressive strength of the rock and it is very simple. That is called as Schmitt rebound hardness test. This was originally developed to estimate the in-situ strength of concrete. What exactly is its working? So, there is a hammer in the body of this Schmidt hammer. So, that we call as Schmidt hammer and there is a plunger.

So, what is done is, that plunger of the hammer is first pressed against the specimen. So, what happens is that spring gets compressed and therefore there is storage of energy in the spring which is inside the hammer and when you have the prescribed stored energy. So, how to know that how much energy is prescribed? So, there are different types of hammer. So, usually for rocks, we use L type hammer, which has some prescribed stored energy that is again given by the manufacturer.

Once this energy is stored, the spring is automatically released. And the moment this spring is released, what happens is that the hammer impacts the mass against the plunger and what happens? The moment it hits there is a rebound. So, whatever is the height of the rebound of the plunger on a scale that we take as a measure of the hardness of that rock? See, I will show you it with the help of the schematic figure.

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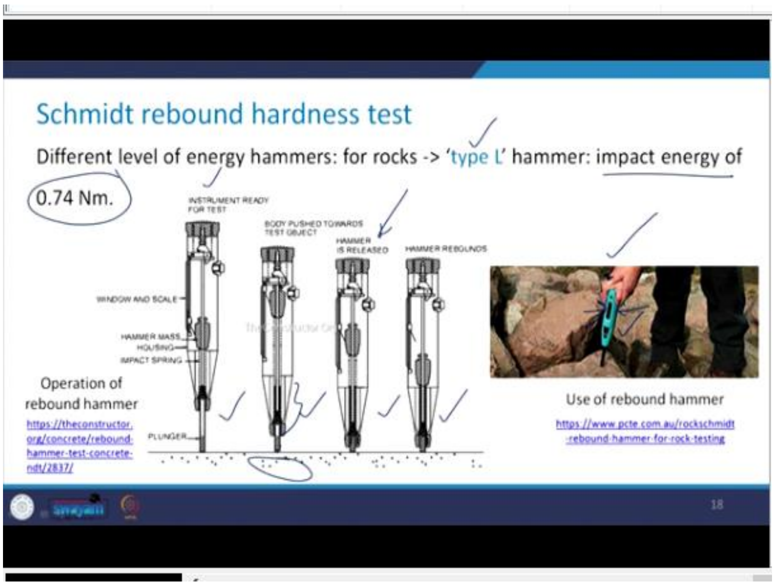

First of all, take a look at this figure. This is the rebound hammer that a person is holding and you see it is very easy to carry this in the field and you just put it vertically at the rock surface, like this person is holding here. Just press it and release it and you will get a rebound here which will be recorded and just note that down. So, as I was mentioning that different levels of energy hammers are there for rocks.

So, for rocks, we have a type L type of hammer which has the impact energy of 0.74 Nm and these 4 stages show the stage wise working of this Schmidt hammer. You see that, see original position where it is ready for the test. Then we push the body towards the test object. So, here it is the test object. So, this you see that the plunger is pushed, there is the energy which is stored here in this spring and now the hammer is released.

So, what will happen? This plunger will bounce back. So, that rebound is being noted here on this scale. Now, how to make use of this rebound?

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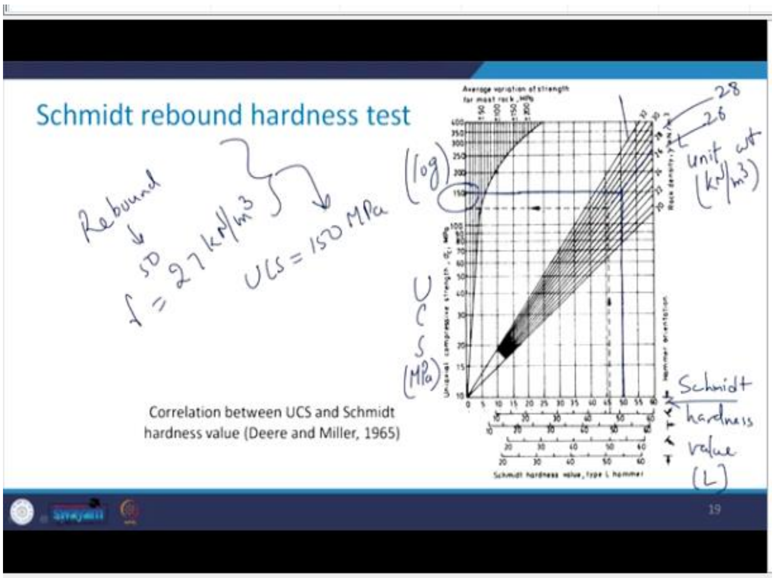

See here that you have the correlation between UCS and Schmitt hardness value. So, this is given for the L type hammer. So, on this axis here you have UCS in MPa. And these radial lines, these are giving the unit weight of the rock in kN/m^3 and this axis gives us the Schmidt hardness value and this is for L type hammer. Now, how to read this?

Let us say, that here you have the numbers 0, 5, 10, 15, 20 and so on and on this axis, which is the log scale. Here you have 10, 15, 20, 30, 40, 50, 60, 70 and so on. Now, how to determine the unit weight? That we have seen. So, when we were learning about the physical properties determination of the rock, so there we have learned or otherwise let us say, you have a cylindrical specimen just take the weight of it and you know its volume you can measure its dimension. You can find out its volume and you can find out the unit rate of that.

Now, let us say for example, how to read this chart. For example, say that the rebound value comes out to be 50 in this case, say the rebound value is say 50 and the unit weight of the rock is, say, 27 kN/m^3, read 50 on this scale. So, you follow the 10 see here I will take it to this. Now, this is 26 and this is 28 kN/m^3 and in between this line is for 27.

So, we take it here and wherever this vertical line intersects that is at this point. So, you will just draw a horizontal line here from this point and see in this case, this is working out to be that is, UCS is coming out to be 150 MPa, corresponding to this reading. So, like this, we can find out from this Schmitt rebound value, we can also find out that what is the UCS of that rock surface.

So, this is useful especially when we want to find out the strength characteristic for the expose surfaces there in the field because it is very easy to carry this hammer in the field, conduct this study and get this value using this correlation. Now, you need to be careful that the surface that you are testing, that should be perpendicular to the hammer. That means the hammer should be held perpendicular to that surface.

Although there are, I mean you can hold it at any orientation, but then you have to apply the corrections which are given here. But since this is right now, beyond the scope of this course, we are not going to discuss that. You should understand the philosophy behind this Schmitt rebound hardness test and how this is used to obtain the UCS. So, today what we discussed was that point load strength index test and then how it is conducted, how the index can be used to determine the UCS of the rock.

Then, we discussed about different types of tensile strength tests, all direct as well as indirect test. We saw what is the difficulty and why we should go for the indirect tests for the tensile strength determination of the rock. And then we saw the Schmitt rebound hardness test. So, in the next class, we will continue our discussion and we will have some discussion on sound velocity test. How it is used to determine the dynamic properties of the rocks?

And then we will discuss about the slake durability test that would be followed by the free swell test. And then we will discuss about the various type of shear test, so that we can find out the shear strength of the rocks. Thank you very much.