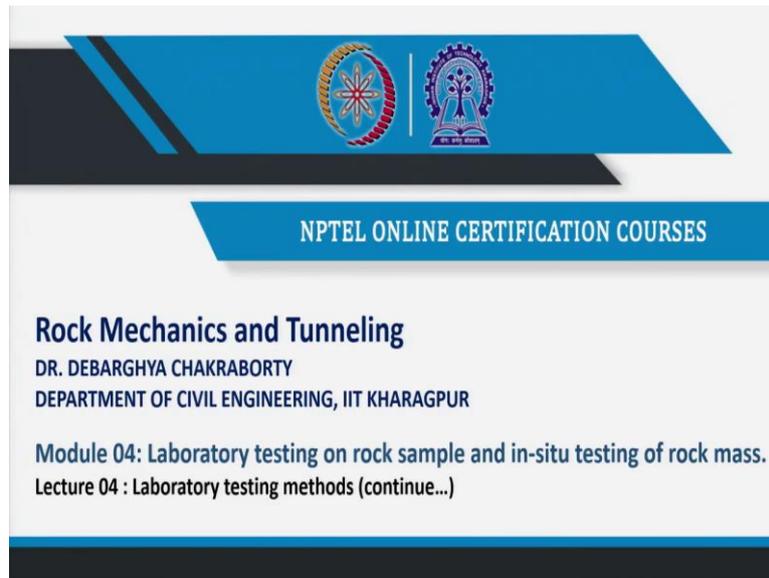**Rock Mechanics and Tunneling**
Professor Debarghya Chakraborty
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 20
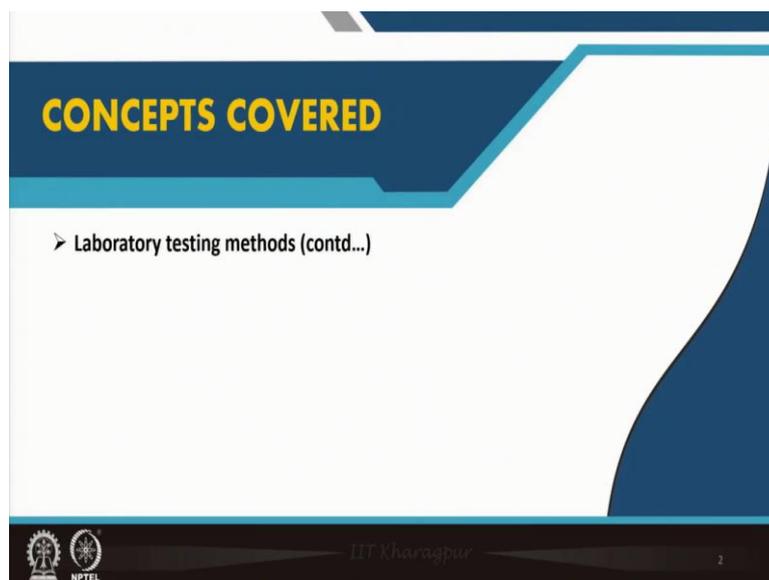**Laboratory Testing Methods (Contd.)**

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Hello everyone, I welcome all of you to the fourth lecture of our module 4. So, in our module 4, we are discussing about the laboratory testing on rock sample and in situ testing of rock mass. So, here, we will continue with our discussion related to laboratory testing methods.

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Laboratory Testing Methods (contd...)

Direct shear test
- The failure plane is assumed to be horizontal
- The test plane should be square as far as possible
- Rate of shear displacement should be less than 0.1mm/min
- Tested as per IS 12634: 1989

Direct shear test apparatus
Source: Muralha et al. (2017)*

*Muralha, J., Grasselli, G., Tatone, B., Blümel, M., Chryssanthakis, P. and Yujing, J., 2014. ISRM suggested method for laboratory determination of the shear strength of rock joints: revised version. Rock Mechanics and Rock Engineering, 47(1), pp.291-302.

So, as I have stated, we will continue with our laboratory testing methods. So, we have already discussed about different testing methods. One of the important laboratory testing method is direct shear test about that we will discuss briefly because already you know, what are the basic mechanisms of direct shear test in your undergraduate means, if you have learned about it.

So, anyway, we can see over here, how the basic mechanism of the direct shear test apparatus look like. So, the failure plane in this direct shear test is assumed to be horizontal that is one of the important thing as we know, then the test plane should be square as far as possible. So, that is one of the important thing that this plane should be square as far as possible.

Then rate of shear displacement should be less than 0.1 millimetre per minute. So, that is also it should not be too high shear displacement. So, there is a recommended rate of shear displacement, this and all these things are as per the IS code recommendation that is as per IS 12634: 1989. So, for performing the laboratory direct share test one should definitely follow this IS code.

Now, let us focus on this picture of this schematic diagram of this test apparatus. So, as we can see that the rock sample is kept over here. So, maybe as we know this test not only give us the shear strength parameters, but along with that, this test is extremely useful for finding out the joint strength.

So, that is very important as you can see over here. Now, what are the things here means, in order to retain this sample over here, you need to have some incapacitating material over there with which it is kept inside this specimen holder as you can see. Now, normal loading is

applied here like this and shear loading system is applied over here, you see the shear. And these are the main components very similar to the direct shear apparatus for conducting the direct shear test in case of soil.

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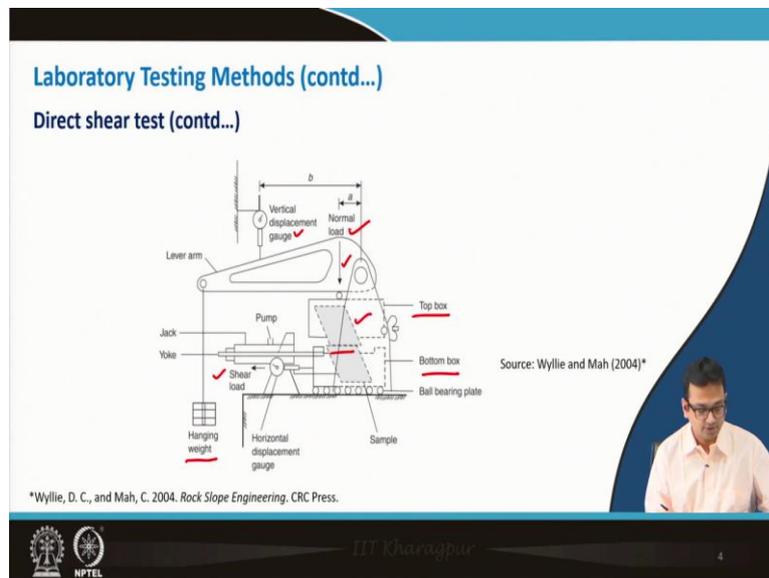
Now, another picture you can see this is the full schematic diagram as you can see over here that is the hanging weight which is ultimately applying this normal load as you can see over here, there should be a vertical displacement gauge, you should find out the vertical displacement as well as the your horizontal displacement you also need to measure, also the shear load you need to measure.

And you see here the sample is kept, and after shearing, how, what has happened to the sample, just look at over here. So, this is the bottom box and top box. Yes, these are the things what we can notice from here and by conducting this test what we get, let us try to see. At different normal loading we need to perform the test so that we know.
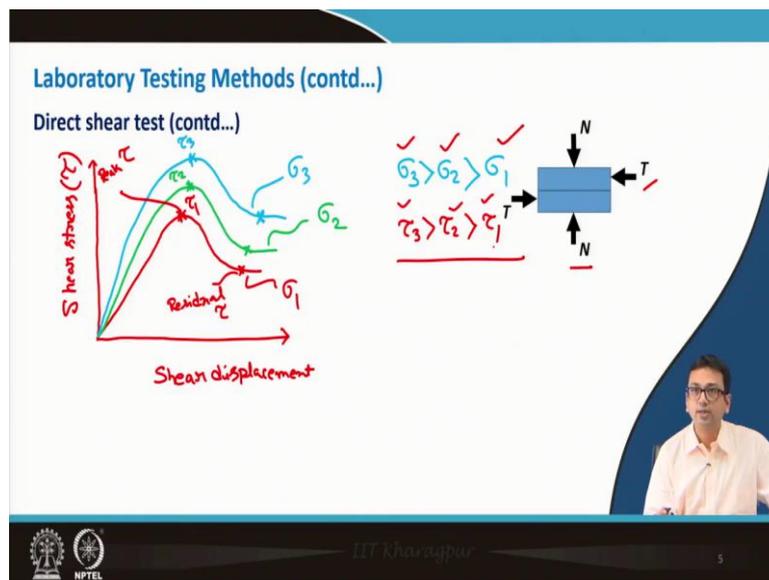
Let us draw the stress strain diagram. So, here we will be interested in drawing the shear stress versus shear strain or shear displacement diagram. So, suppose this is suppose shear stress in this axis and here your shear displacement or shear strain also we can plot over here. Now, as we know this test is conducted under different normal loading. So, at lower suppose some x normal stress is there.

So, suppose under that one it is showing this type of behaviour, like this. Now, here let us consider the corresponding normal stress is $\sigma 1$. Now, under little more normal stress, it is expected we will get something like this. So, suppose this is corresponding to $\sigma 2$. And similarly, for further higher magnitude of normal stress we will get this type of plot. So, here $\sigma 3 > \sigma 2 > \sigma 1$.

Now, what we can also get, you see this one this plot is giving us the magnitude of maximum shear stress at this peak. So, this is nothing but my shear stress, the peak shear strength for the first test, where the normal loading is suppose $\sigma 1$. So, let me write it has like one peak is this one, peak tau likewise here we get the residual shear. So, let us consider this is the residual tau.

So, similarly, for this case also we will get a peak tau and also a residual tau and subsequently we will get the peak shear strength and residual shear strength from these three diagrams. So, now, let us only focus on the peak shear strength. So, let us consider this is corresponding this value is tau 1, this one is suppose, sorry this should be tau3 sorry. So, let me, let us consider this one is tau3. This one is tau2, and this one is tau1.

And corresponding normal stresses are σ1, σ2, σ3. So, what obviously from here what we can notice that definitely sigma, your $\tau_3 > \tau_2 > \tau_1$. So, similarly, if this is what I have shown over here the peak shear stress is marked with the help of τ_1, τ_2, τ_3. Similarly, we can also obtain the residual shear stresses or shear strain rather.

So, ultimately what I mean to say is for a particular normal stress you need to obtain the corresponding shear stress that may be peak or that may be residual. So, similarly for σ1 it is τ_1 for σ2 it is τ_2 and for σ3 it is τ_3. So, generally this is the train and this type of for higher normal stress, the shear strength what we get is generally higher. So, now, using this data, so we have now, these data available.

So, now, normal stress is acting and that means normal force and shear force. So, because of the normal stress and shear stress whatever developing that we are writing. So, now, using these σ1, τ_1, σ2, τ_2, σ3, τ_3 what we can do remember this τ_1, τ_2, τ_3 may be peak or it may be residual.

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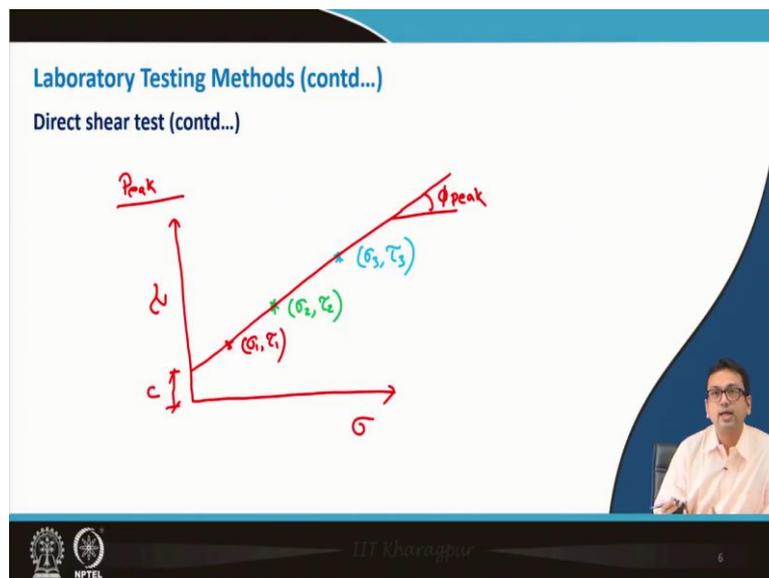
So, ultimately, so let us consider for the peak case. So, what we will do, we will now after obtaining σ1, σ2, σ3 what we will draw, we will draw the normal stress versus shear stress plot we will draw. So, now, you see from the first one it is normal stresses σ1 corresponding shear stresses τ_1. So, suppose this point is suppose somewhere here. So, this is σ1,τ_1.

Now, for the second case our σ2, τ_2. So, suppose that point is somewhere here and this is σ2, τ_2. And third one is σ3, τ_3. So, let us plot over here. So, maybe this is σ3, τ_3. So, now, final

job is we need to draw a best fit line. So, suppose that best fit line is passing like this. So, what we will get then, so if we now measure this angle, this will give us nothing what the phi peak value and this will give us the corresponding cohesion value.

So, in this way by conducting direct shear test, we can very easily obtain the shear strength properties. And similarly, it can be for your residual stress also when you perform a laboratory test on intact rock sample, we can find some of the very interesting things.

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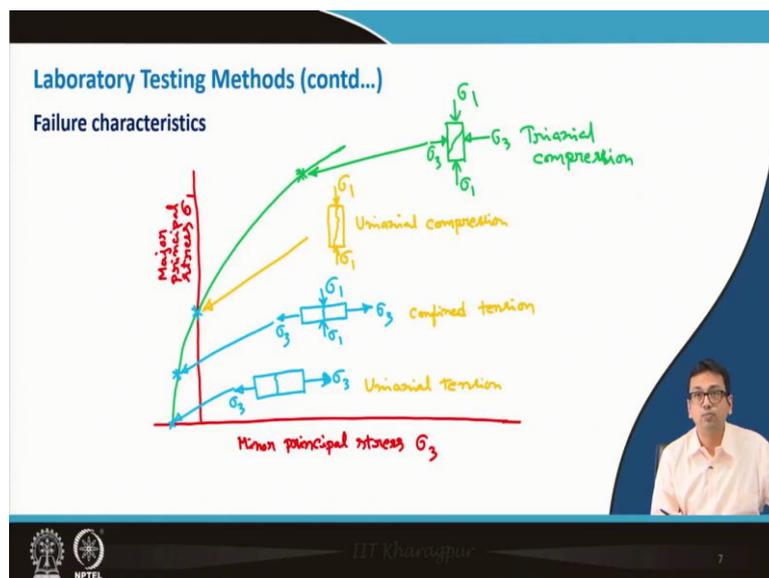
So, let us try to see what I want to show you is suppose, if I want to plot the suppose in this axis, I am plotting the minor principal stress, minor principal stress that is $\sigma 3$. And if these axes if we plot the major principal stress $\sigma 1$, then if we suppose get a some plot like these the major variation of minor principal stress and major principal stress if we see the variation is suppose like this, now that tells a lot of things, let us try to see.

So, this point, maybe let us use some another colour, suppose this point. What this one is indicating? You see here my minor principal stress is there but major principal stresses becoming 0, and if we consider that the like the compression is positive here, so that is nothing but that this is giving us the tension. So, this situation is corresponding to what, the sample which is subjected to tension and these are nothing but the $\sigma 3$ and if this type of tension we apply then this type of crack will develop.

Now, let us consider intermediate position like this, here what we can notice we can notice that the sigma 3 is negative means tensile whereas, major principal stress sigma 1 is positive that is compressive. So, corresponding similar type of diagram we can draw. So, that is if we

consider the situation is something like this. So, we have here σ3 along with that compressive sigma 1 is acting here.

So, this is the situation now, there may be here you see the tension is acting, so as we know rock mass obviously strong in compression but not that much strong in tension. So, they are also we can expect something like this type of crack may develop depending on the what is the σ1 value, what is the σ3 value obviously. If we focus over this point. Now, what we can see over here.

Just let me use maybe some other colour. So, this is the situation then what we can notice that their σ1 is present that is major principal stress is there, but σ3 is 0 because it is on this axis. So, the situation is something like this and you see σ1 is on the positive side so it is compressive, so σ1. So, here also the situation is it is under compression, so it is similar to the uniaxial compression.

So, let me write over a uniaxial compression, that situation is developing here, this one is nothing but the uniaxial tension. And this situation it is confined loading is there along with the tension is also there. So, it can be considered as confined tension. And under this situation as we know the cracks may develop like these as we know, so similar to that. Now, the last situation if we consider that is suppose a situation somewhere here where both σ1 is positive, as you can see, σ3 is also positive.

So, then what it is corresponding to which situation. So, this is nothing but corresponding to the triaxial compression. So, the situation is we have our σ1, along with that compressive σ3. So, this is nothing but triaxial compression. And as you know here this type of shear failure occurs. So, this is a nice pictorial representation of how the state of stress is changing from uniaxial tension to triaxial compression.

So, similar to this you see here I have plotted all this diagram with respect to major principal stress and minor principal stress. So, similarly, we are very much familiar with the Mohr circle. So, similarly, we by using Mohr circle also we can understand this fundamental little more deeply. So, it will clear our concept even more.
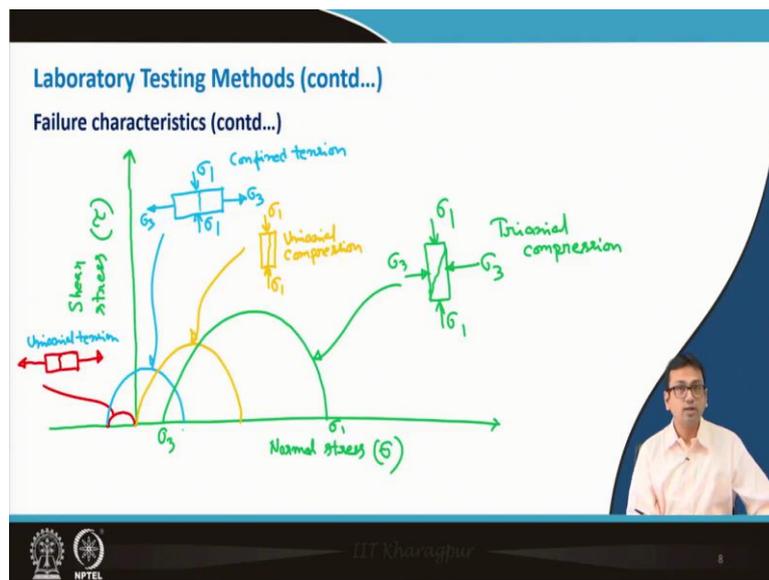
So, let us see what we know if I want to do Mohr circle what I do, I take this axis our normal stress. So, σ and this axis we plot the shear stress or strength of the material so τ. Now, I will extend it to this side little more maybe this portion, let me write the shear over here. Now, there may be a situation where just look at here you see the Mohr circle is something like this. So, what we can notice over here, you can see that your this stress is 1 and this one is sorry, yeah, this one is some finite value is there.

Now, as we can see that there is positive is in this direction and positive is compression. So, this must be some tensile loading. So, now, this situation is corresponding to then what or maybe let me use some other colour. Now, maybe let me write here, so there what we can notice that the $\sigma 1$ is, as you can see over here what was there, we had the only the $\sigma 3$ was acting over there.

So, here you see the compression is positive, so this direction this is more than this. So, we have a situation something like this. Obviously the crack will be something like this. Now, there may be a situation where we can get a Mohr circle something like maybe let me use another colour like this.

So, this situation is what as you can see, one value is this is compressive this is negative tensile. So, this is positive this is negative. So, this situation is something corresponding to just as we have seen sometimes back, it is we are having here $\sigma 3$, $\sigma 3$ here, $\sigma 1$, $\sigma 1$. So, again there may be this type of crack may develop. So, as we have seen this is uniaxial tension as we wrote earlier.

So, and this is similar to the previous one it was confined tension. So, now, third one was what you can see here the uniaxial compression. So, under uniaxial compression what happens, we do not have any $\sigma 3$. So, obviously, that means, we will have some Mohr circle something like this maybe. You see here my $\sigma 3$ is 0, but we are having some $\sigma 1$. So, this is corresponding to this situation.

As we have obtained over here, so here also it is similar to that, so it is we can get this type of crack, so uniaxial compression. And finally, as we know the first one was sorry, the first final one was the triaxial compression this situation. So, in Mohr circle, if I want to plot that, so how will it look? So, this will be something like maybe to start from here and the Mohr circle will be like this, where this is my $\sigma 3$, this is my $\sigma 1$.

So, then the situation is $\sigma 1$, $\sigma 1$, $\sigma 3$, $\sigma 3$, and the crack is expected to develop like this here. So, this is nothing but the triaxial compression. So, this is very important. So, we have tried to understand the fundamental and from both we have shown the different state of stresses with respect to the major principal stress and minor principal stress as well as by drawing the Mohr circle also we could be able to understand this situation.

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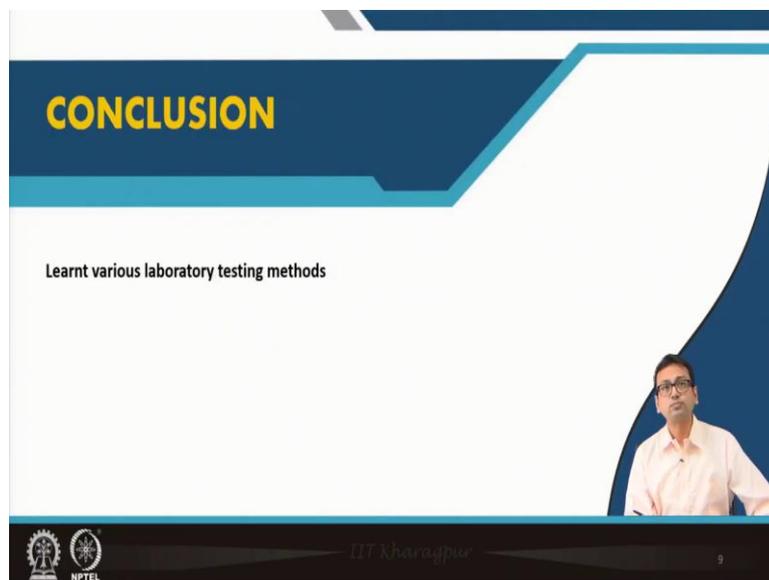
So, with this I am concluding the laboratory testing methods. So, we have learned different laboratory testing methods and how to interpret the obtained results that also we have tried to understand in detail. Thank you.