**Rock Mechanics and Tunneling**
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**Lecture 16**
**Mechanical Properties (Continued)**

Hello everyone, I welcome all of you to the fifth lecture of module 3. So, in Module 3 we are discussing about the physico-mechanical properties and in our previous lecture, we have started with the mechanical properties. And today also, we will continue with that, let us see what we have to do.

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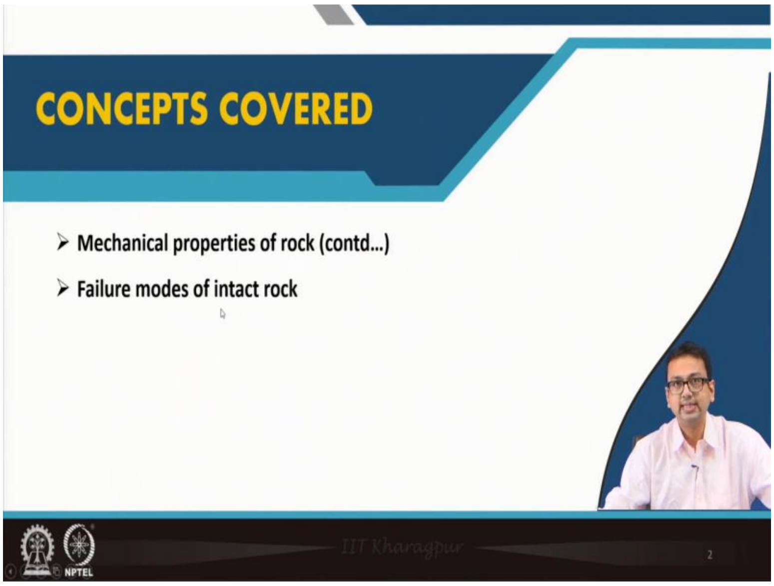


So, mainly, as I have stated, we will continue our discussion related to mechanical properties of rock. And, briefly we will discuss about the failure modes of intact rock.

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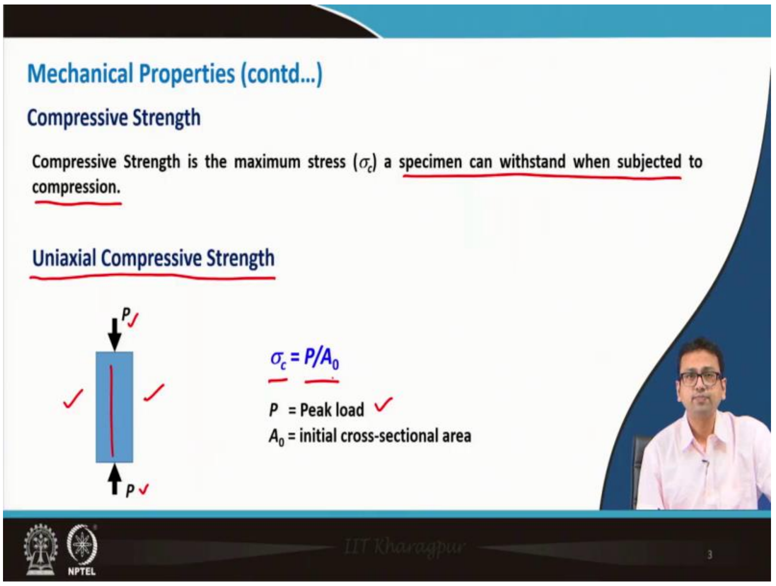


So, compressive strength, first is the compressive strength. So, what is composition, the compressive strength is the maximum stress a specimen can withstand when subjected to compression.

Now, in rock mechanics, this uniaxial compressive strength is extremely important parameter. the magnitude of uniaxial compressive strength can be obtained relatively easily and it is used its application is wide actually, we will see gradually when we will discuss about different other things in future about like about the different failure criteria, there will also see that it is very important parameter.

So, I think we should discuss about this in little detail. So, that is why it is kept here. So, basically uniaxial compressive strength means, we will apply only this kind of loading, no confinement. So, here this side this side nothing is applied. So, no confining pressure is applied or no load in the surrounding means, this sides, but at the top and what you see in this x axially occurring in this along this axis only, we have applied the load.

So, uniaxial compressive strength will obtain by testing a sample if we apply this kind of loading. We will see about that in our next module, how the test is performed, we will see some pictures also, the experimental setups picture. So, basically this sigma c which is the this uniaxial compressive strain is nothing but P by $A_0$, P is the peak load means at which it is failing and means that after that it will actually fail.

So, as it is written maximum stress a specimen can withstand when subjected to compression. So, P is nothing but my peak load and a naught is my initial cross sectional area and this is nothing but average stress in that form only we will represent it because that is practically in when we deal with big structures then, we need to consider this evidence trace only and here $A_0$ is the initial cross sectional area.

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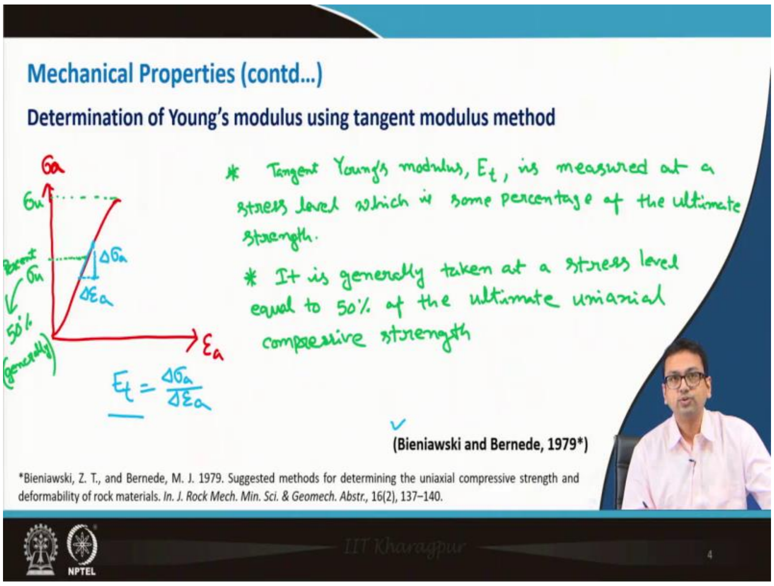


Now, from this test actually, if I apply this kind of compressive loading, some axial stress will develop as well as some axial strain and we can plot them on a graph paper.

So, if we plot them, by taking the slope of that plot, we can get the Young's modulus. So, same stress axial stress, axial strain plot what we will get from this uniaxial compressive strength test is using that depending on the requirement we can find out the tangent Young's modulus or average young one last or secant Young's modulus. So, how to get that let us quickly see that very simple thing.

So, let us consider this is my actual stress and this is my actual the stress and strain axis and suppose my stress strain diagram is something like this. Here it is suppose failing. So, basically this will give us the ultimate strength. Now, first one is the tangent modulus. So, tangent Young's modulus is what? So, basically it is measured at a particular stress level which is basically some fixed percentage of the ultimate strength of the sample.

So, just let me write down then I will draw. So, the tangent Young's modulus that is $E_t$ is measured at a stress level which is some percentage of the ultimate strength. Now, this is generally considered as the 50% of the ultimate strength. Now, it is generally taken as or the 50 or taken maybe taken at let me write down taken at a stress level equal to 50% of the ultimate uniaxial compressive strength.

So, what I mean to say, suppose this is my u so, that means my 50% is somewhere here. So, this is maybe the percent $\sigma_u$. So, generally it is as you have stated 50% generally. For now at this location if I obtain the slope, so, then what it will be let me use maybe another color. So, if I find out the flow here, then basically this is my $\Delta\sigma_a$ and this is my $\Delta\varepsilon_a$ maybe. So, then my $E_t$ is equal to $\Delta\sigma_a / \Delta\varepsilon_a$.

So, this way at 50% of ultimate strength if I find out the slope of this curve or line, so, that will if you take the tangent there and if you find out $\Delta\sigma_a$ and $\Delta\varepsilon_a$, there we can get our tangent Young's modulus. So, this is I guess this paper it is just taken or written over here. So, this is what tangent modulus.

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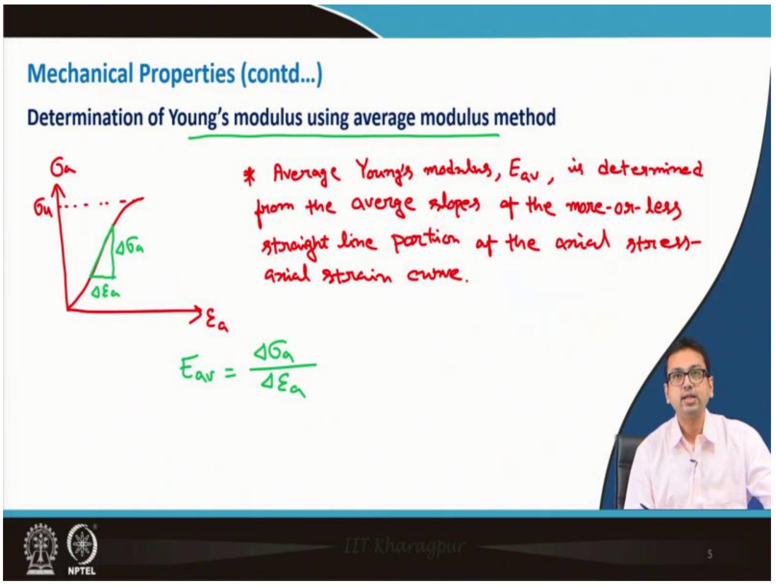


Now, similarly, we can have average modulus. So, again just quickly let me draw the string. So, average Young's modulus generally written as $E_{av}$ is determined from the average slopes of the more or less straight line portion of this axial stress axial strain curve.

So, let me write down is determined from the average slopes of the more or less straight line portion of the axial stress versus axial strain curve. So, basically if I use another color so we can see this portion is almost straight. So, from here we can obtain this. So, my $E_{av}$ is equal to $\Delta\sigma_a / \Delta\varepsilon_a$. So, this is my Young's modulus as well as average modulus.

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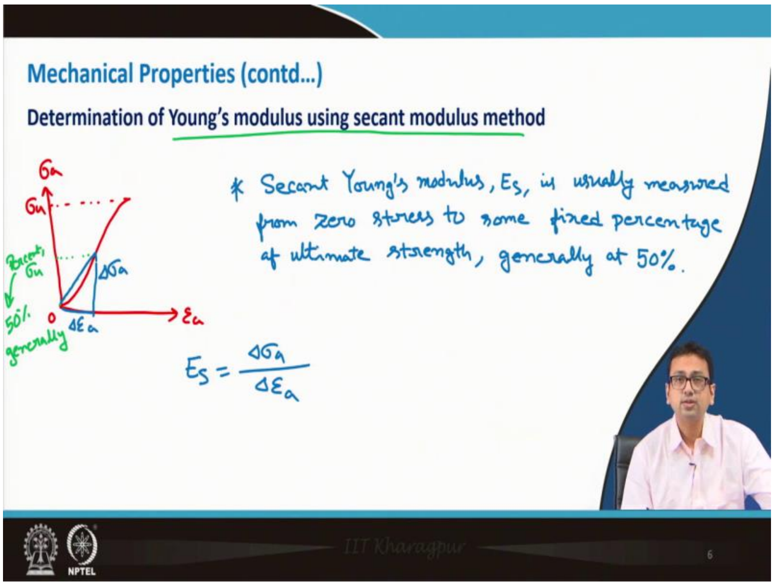


So similarly, as I have stated another one is the Young's modulus using the secant method. So, again let me draw the stress-strain plot first, so this again here my ultimate is this and this is the prop. Now, what is done in case of secant Young's modulus. So, secant Young's modulus is usually measured from the 0 stress means this one this is the 0 to some fixed percentage of the ultimate strength.

So, anyway we can write down the thing. So, secant Young's modulus $E_s$ is usually measured from 0 stress to some fixed percentage of ultimate strength and generally as they have stated generally at 50 percent it is considered. So, again these three types of Young's modulus concept we have learned now, I hope that is clear.

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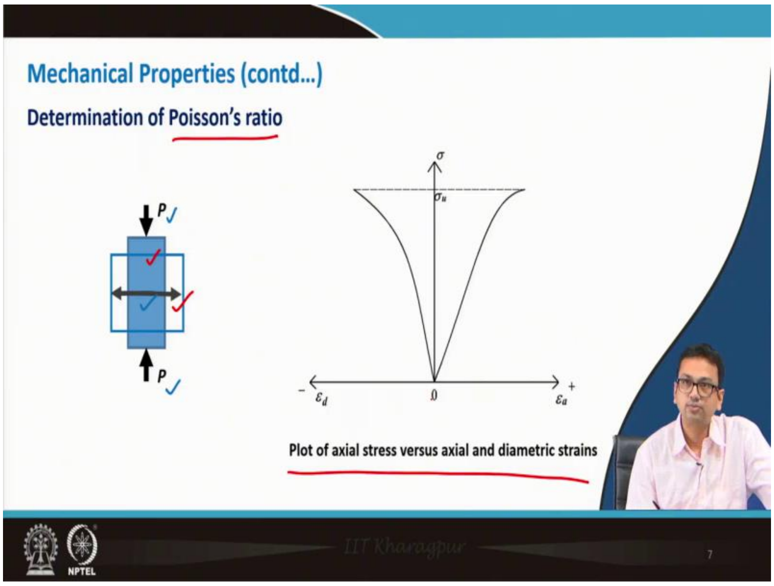

Now based on this what else we can get from this uniaxial compressive strength test? So, if we perform this test what is going to happen? So, actually it will compress and laterally it will expand as we can see from here. So, expanding and it is compressing in this direction. So, obviously, by measuring how much compression has occurred and how much in diameter increased, the average one obviously, so, you have to measure at different locations. So, from there we can very easily get my Poisson’s ratio.

So, that as we know Poisson’s ratio is nothing but minus lateral strain by axial strain, so, it is in diametric direction. So, diametrical strain, if you find out also and if you can find out the axial strain you can very easily get it and also you see this plot is also very important. So, plot of axial stress versus axial and diametric strain. So, you can plot this diagram also from your in this your uniaxial compressive strength test, you can get this diagram also which can be useful for different purpose like for means, definitely for design purpose like for getting different other parameters also it can be useful.

So, this test is very much important for optimizing these parameters. So, we will again discuss about this test how the setup is we will see in our next module.

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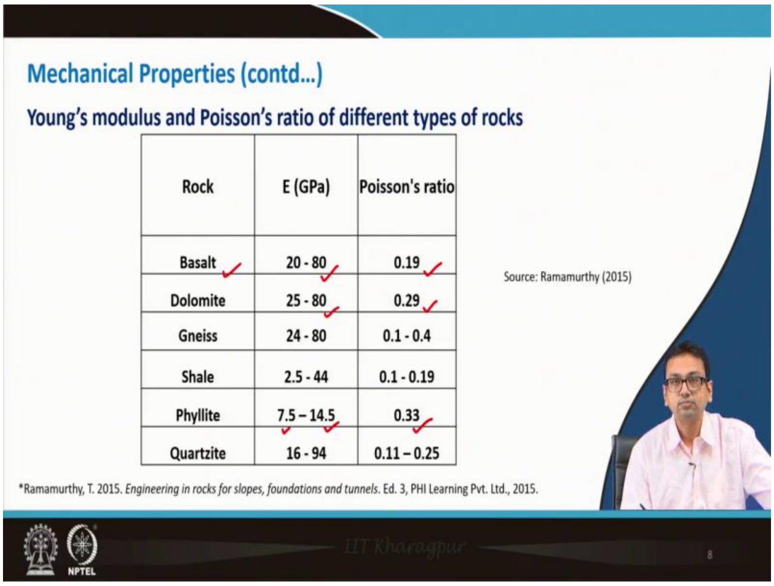


This is a just to give you some idea about the Young’s modulus and functions issue for different types of rock like basalt the questions to see is 0.19 and E is 20 to 80 GPa. So, range of variation is quite high likewise, dolomite 25 to 80 whereas Poisson’s ratio is 0.29. Now, you can even notice that the Phyllite is having portions to show 0.33, whereas its Young's modulus may vary between this 7.5 to 14.5.

So, there are different ranges provided to you just to get some idea if someone somebody asks you that can you give some idea about what is the Poisson's ratio, Young's modulus maybe basalt or maybe the phyllite or anything, some idea at least you can have means this table will give you some idea about that.

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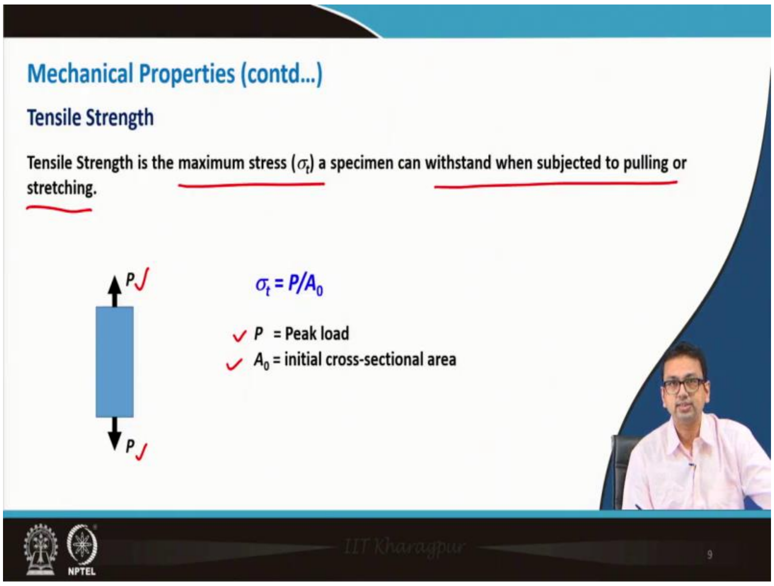


Now tensile strength. Now, as we have stated compressive strength likewise, we can state that the tensile strength is the maximum stress that $\sigma_t$ we generally use a specimen can withstand when subjected to cooling or stretching. So, cooling is happening in one actual direction only it is happening and this $A_0$ is nothing but the initial cross sectional area and P is the peak load. So, it will give us the average tensile strength of the sample.

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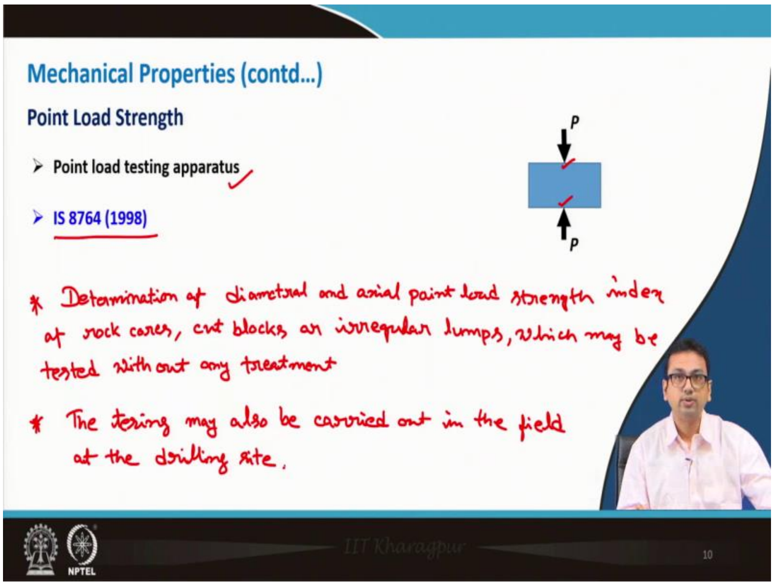

So, the regarding the source we will see discussed later about how the setup look like now, point load strength is extremely important in case of rock obtaining some of the important strength parameters. So, about this the testing process, we will spend a good amount of time in your next module, but just to tell you this is an important mechanical property, we just have written it here.

So, this is performed using point load testing operators and as per IS 8764-1998 this test can be performed. So, this load is applied in this manner on the sample will see this active points it is applied, we will see discussing about this in detail. So, what we can see here basically, the equipment is not quite big in size. So, and the procedure of performing this test is very simple.

So, that is why this test not only we can perform the laboratory, the equipment can be taken to the site, because the size of the equipment is not so big, small means moderate size. So, in site only then and there where the drilling operation is going on, there only we can obtain the point load strength of the particular rock sample.

And in the strength this, the diametral drill and axial point load strength index also find out basically using this test and IS this 8764 gives complete description about that. So, we will discuss about that in our next module. So, just we can write down something like it is used for like determination of diametral and axial point load strength, point load strength index of rock core you can do that directly or even sometimes you may not get a nice core means that sample may not be very good in shape.

So, then also like cut block if you get that also you can test, then even the irregular samples also can test, irregular sample lumps, irregular, maybe tested or which may be tested means without doing much like modifications to that or any treatment to that, we tested maybe we can write without any treatment. Also as I have stated the testing may be carried out in the field. The testing may also be carried out in the field, maybe at the drilling site itself. So, we will discuss about this in our next module as I have stated.

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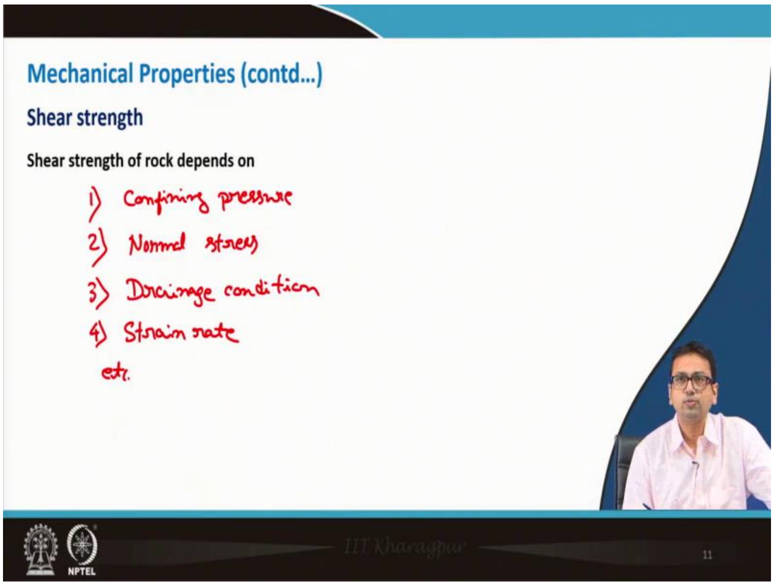


Now shear strength. Shear strength of rock means you know about shear strength of soil and for performing shear, obtaining a shear strength of soil, you must have learned about the direct shear and triaxial shear tests. Here also same these two types of tests we perform and basically you see this shear strength actually depends on several factors such as like as in case of triaxial test, it is the confining pressure that is very important. Then in case of like direct shear, the normal stress is very important.

Then also obviously, you know the drainage condition is extremely important. So, also such as the strain rate at which strain rate you are performing the test on that also it depends a lot so, etcetera. So, I hope you have some idea about this shear strength of soil. So, it is two segments quite similar to that only.

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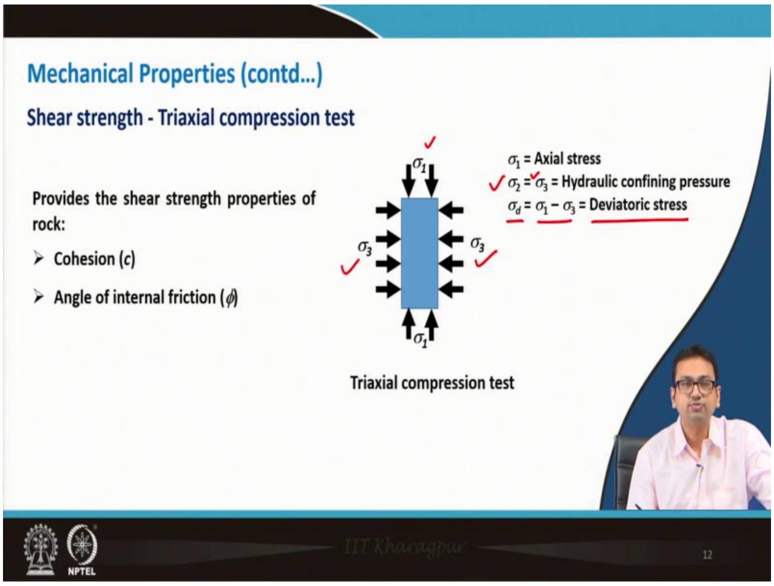

So, first if we see that just roughly see the triaxial compression test, what we do here. So, here confining pressure we apply and then $\sigma_1$ that is the normal axial stress is also applied. So, confining pressure or round same it is, so that is why $\sigma_2$ and $\sigma_3$ though that both the intermediate and minor principle stress $\sigma_2$ and $\sigma_3$ that becomes nothing the hydraulic confining pressure and $\sigma_d$ is nothing but the deviatoric stress which is $\sigma_1$-$\sigma_3$. So, here it is the major principle stress.

So, this test we perform in as you know to get the shear strength properties like cohesion, friction angle all these things. So, cohesion, friction angle.

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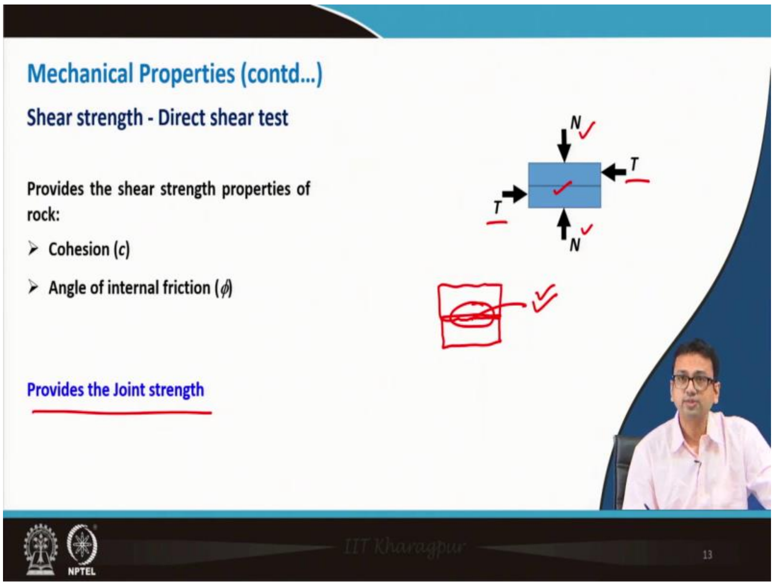


Then also we know we have another test very common test for in case of soil mineable, there is a direct shear test. So, here this normal stress is applied over there, this is performed in a box as you know. So, this type of shear force is applied and the sample is kept here if we consider this the sample, so, it is assumed that the failure occurs in this horizontal plane.

This test also is you know useful for obtaining differentiation parameters like cohesion, friction angle along with that in case of rock as you know, the joint strength properties are very important. Suppose, you have a rock sample like these and they are some joint is present like this. So, how what about this strength of this joint regarding that if you want to know, then this test can be very useful. This direct shear test.

So, otherwise basic procedure of conducting the test is same and next module we will see some of the means the pictorial representation of the experimental setup and discuss again.

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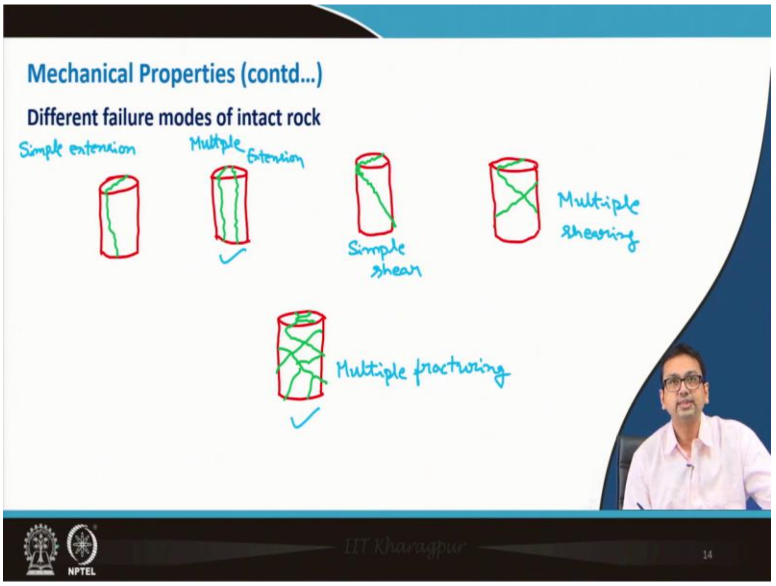


Then different failure modes in rock. So, this is quite important basically for intact rock depending on what type of test you are performing the failure modes also changes. Suppose, there may be just try to show you draw some of the diagrams, there you may find failure like this. Similarly, you may find failure like these or again, you may find failures something like this may be, then there may be like this also there may be like this.

So, there are some names we can write down the names of these different modes of failure. So, like this is the simple extension, so, simple extension. Next one is multiple. This one is multiple extension. This is you can see the shear failure is occurring means, you must have seen in case of triaxial test in case of soil this type of failure you must have noticed. So, this is kind of shear failures or simple shear failure it is happening.

And then here you can see one this is a shear failure, this is another shear failure. So, this is called as the multiple sharing and this one you see the full of fractures you see. So, this is called as the multiple fracturing. So, this is called multiple fracturing. Now, why these situations arises? So, maybe we can briefly discuss about that.

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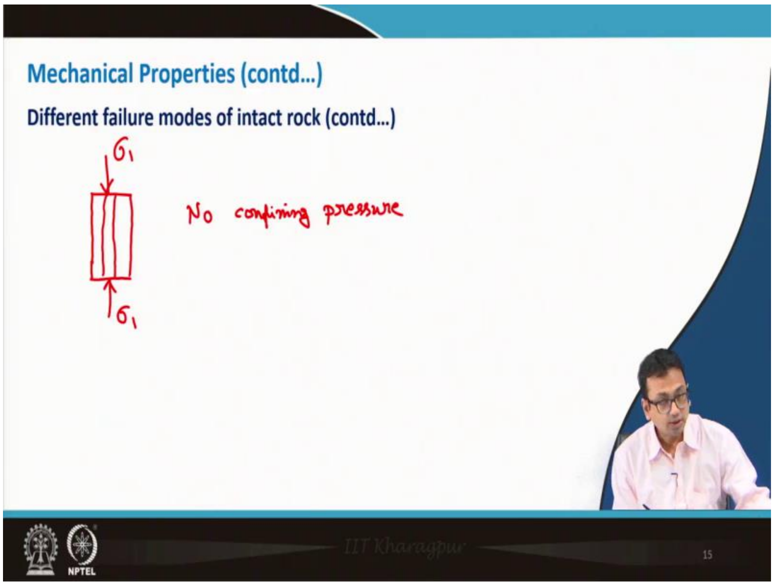


Now, let us discuss a little more about these failure modes. So, basically, if we see this type of conditions means only the axial loading if it is applied over there, then basically this kind of longitudinal cracks or fractures develop. So, this is, so for $\sigma_1$, when no confining pressure is applied, then this type of failure modes are actually developed and in this condition basically, when you perform the uniaxial compressive strength test, then the rock sample intact rock sample generally behaves like elastic material and then there is abrupt failure is observed.

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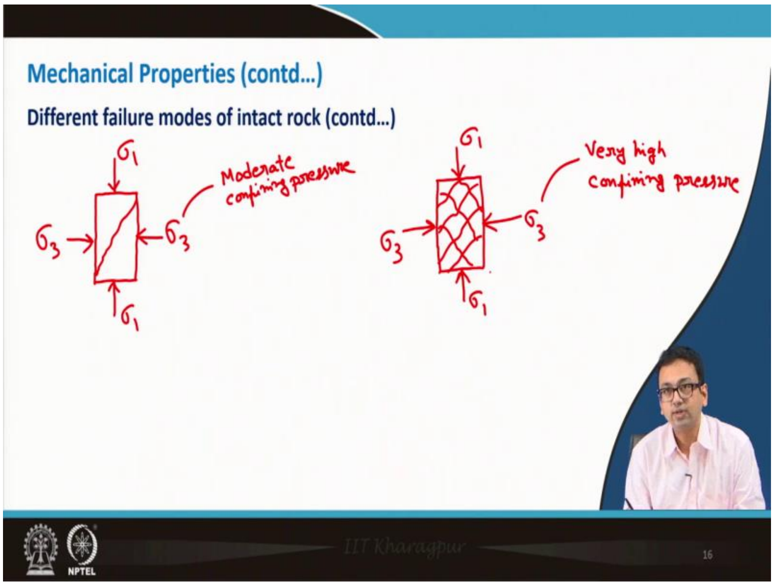


Now, what happens if we apply the confining pressure? So, let us consider again $\sigma_1$ this vertical loading and along with that let us consider some confining pressure is applied. Now this confining pressure is let us consider moderate; moderate confining pressure. If you moderate amount of confining pressure we apply, then instead of happening that longitudinal fracture, this type of clear failure plane actually develops.

Now, similar to this condition only if we increase the confining pressure to very high pressure instead of moderate confining pressure multiple fractures develop and under these situations basically rock start behaving like a ductile material.

So, you see what we can notice when this situation no confining pressure it behaves more or less like an elastic material, then gradually it's state changes and when we apply a very high confining pressure, then it start behaving like a ductile material. So, I think that is it, we have discussed about this failure modes also in to some extent in detail. So, with this I am concluding our third module and in our next module that is fourth module, we will start discussing about the different laboratory test and In-situ test. Thank you.