Rock Engineering
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Lecture-17
Shear Tests-2

Hello everyone. In the previous class we started our discussion on shear tests. And we discussed about oblique shear test and we started our discussion on direct shear test. We saw that there can be 2 types of shear tests. One was to be conducted on intact rock specimen. Another was along any joint. As far as intact rock specimen testing is concerned, we saw it in the previous class. today we will see the shear test along the joint.

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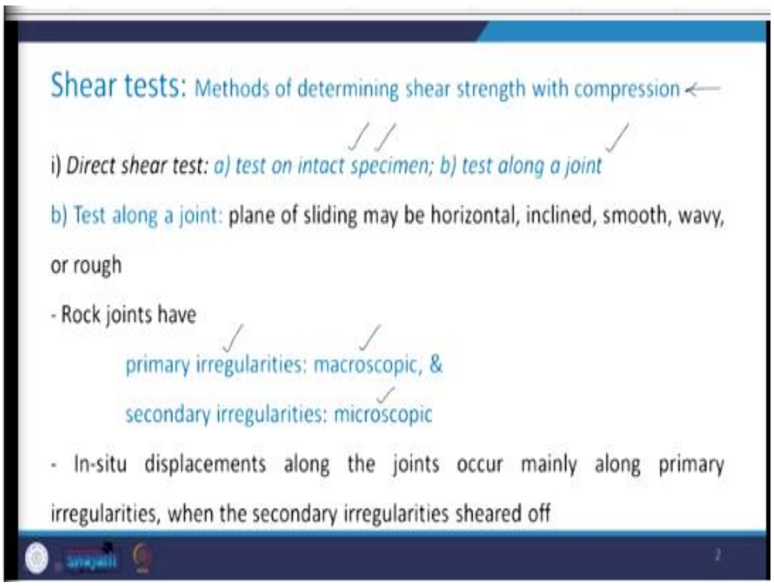

So, direct shear test, 2 categories- test on intact the specimen and test along a joint. This we have already done in the previous class. Let us see, how to conduct the test along a joint and how to carry out the analysis to obtain the shear strength? Remember, that this category of the test lying with the shear strength having compression on the shear plane. So, when we conduct the test along a joint, that plane of sliding maybe horizontal, it may be inclined, it may be smooth, wavy or rough. Why so?

Because rock joints they have irregularity. Now those irregularities can be categorized under 2 classes. First one deals with the primary irregularity which is macroscopic in nature, that means you can see them. Secondary irregularities, they are microscopic in nature. In situ displacements, they occur along the joint mainly along the primary irregularities, while these secondary irregularities, they get sheared off during the process of testing.

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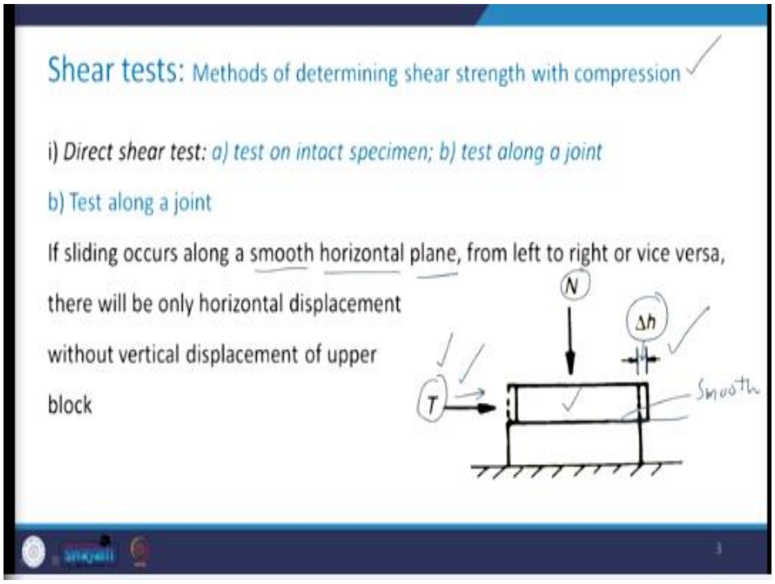

Now this, as I mentioned that the joint surface can be smooth, it can be wavy, it can be rough. So, let us say that if the sliding occurs along a smooth surface or also it is horizontal. That means the sliding is occurring along smooth horizontal plane. And look at this figure that the shearing is occurring from the left to the right, that means shear force has been applied from the left to right, which is T.

And you see, as per this category, there is a presence of this compressive load which is M. Now what will happen? Upon the application of this T, there is going to be the sliding along this horizontal plane which is also smooth. And because of this sliding there is going to be the displacement in the direction of the application of this load, say that displacement is Δh which is shown here, that is, this portion, this portion is Δh.

The sliding plane is smooth and horizontal plane, so therefore there is going to be only the horizontal displacement. There will not be any vertical displacement of the upper block.

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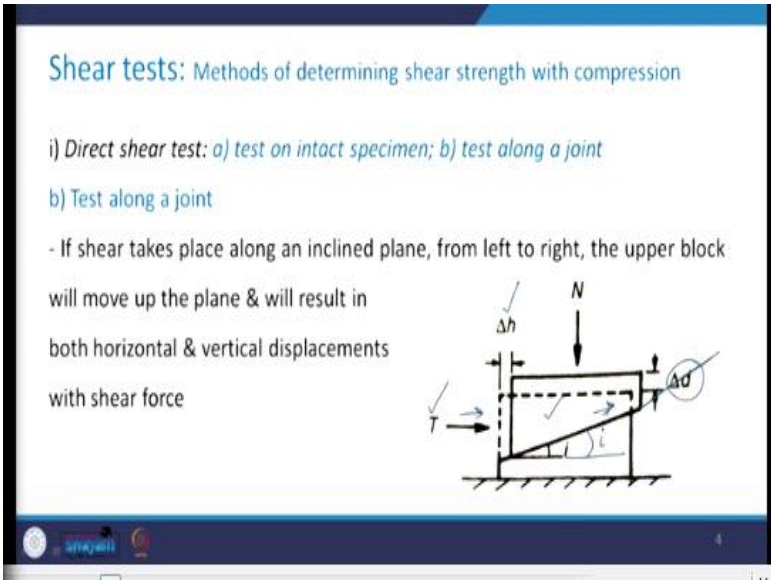

Now what will happen? If this plane of sliding is smooth but it is inclined. So, you see here in this figure that the inclination of this sliding plane is this angle is *i*, that is the sliding plane is not horizontal but inclined. Now if the load is applied, that is, T is applied from left to right, what will happen? This upper block will try to move upward. That is in this direction along this plane. So, because this plane is sliding, so this will have horizontal as well as vertical deformation.

So, as against the sliding along the horizontal plane, when the sliding takes place along the inclined plane, there is going to be the presence of horizontal as well as vertical displacements, when you increase the shear force.

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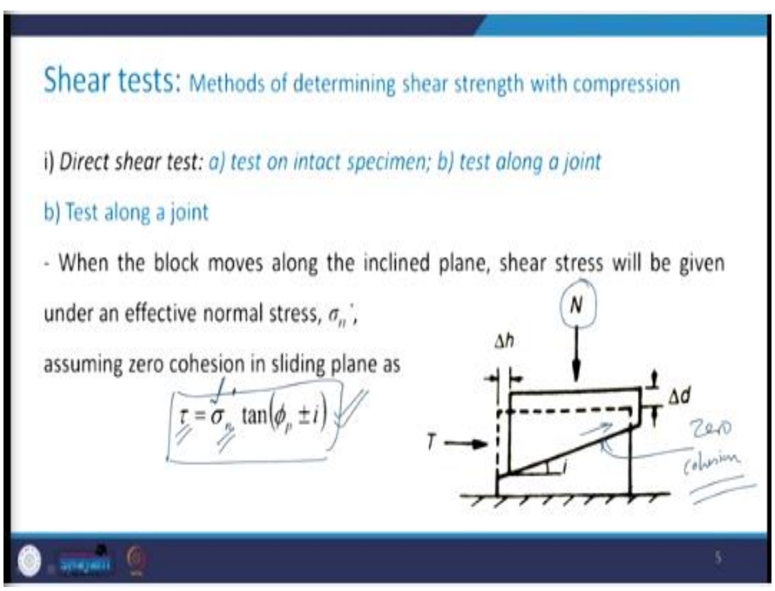

Now if the shear force is in this direction and therefore the block is moving upwards in this case. So, see, it is moving upwards along the plane of sliding. So, therefore the shear stress will be given by this expression where it is assumed that there is zero cohesion in this sliding plane, that means, here it is zero cohesion. So, you will have only the frictional component or you have a component where the shear stress is related to or a function of the normal stress σ.

And how we will obtain this normal stress? We know this normal load. We know the area along which the shearing is taking place. When you divide this N by that area, you will get this normal stress. So, if the plane is inclined along which the sliding is taking place, this is the expression that will give you the shear stress along the inclined plane.

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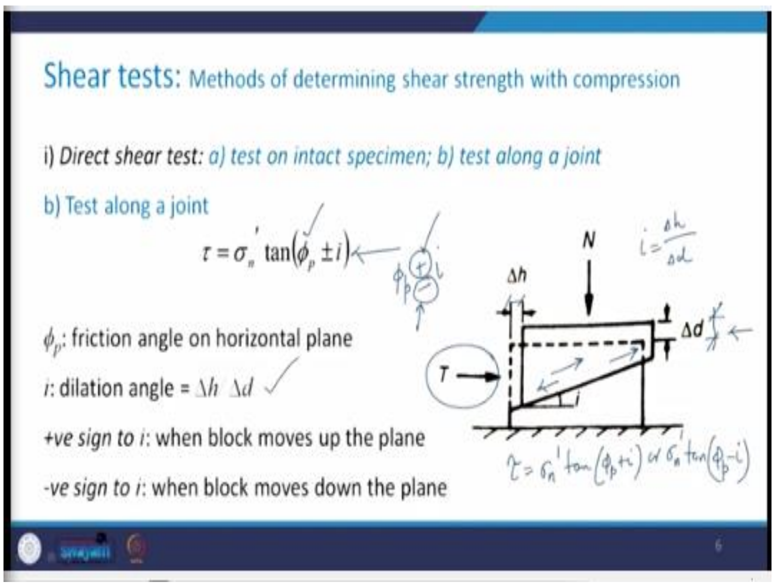

Now you see what is your ϕ_p that is the friction angle along the plane, i is the dilation angle which is given as the ratio of horizontal displacement to the vertical displacement. That means, $i = \Delta h / \Delta d$ as mentioned here. Now here in this expression if you see,

$$\tau = \sigma_n' \tan(\phi_p \pm i)$$

we have $\phi_p \pm i$ now the question is when to choose + and when to choose -? So, when the block that is this block which is sliding, moves up the plane that means it is moving up the plane in this case.

So, then we need to assign positive sign to i and let us say instead of this direction of T from left to right, now let us say this is from right to left, then what will happen? This block will start moving in this direction. So, in that case when block moves down the plane, you have to take negative sign to i. So, based upon the direction in which the block is moving or in which the shear force is being applied. Accordingly, $\tau = \sigma_n' \tan(\phi_p + i)$ or $\tau = \sigma_n' \tan(\phi_p - i)$.

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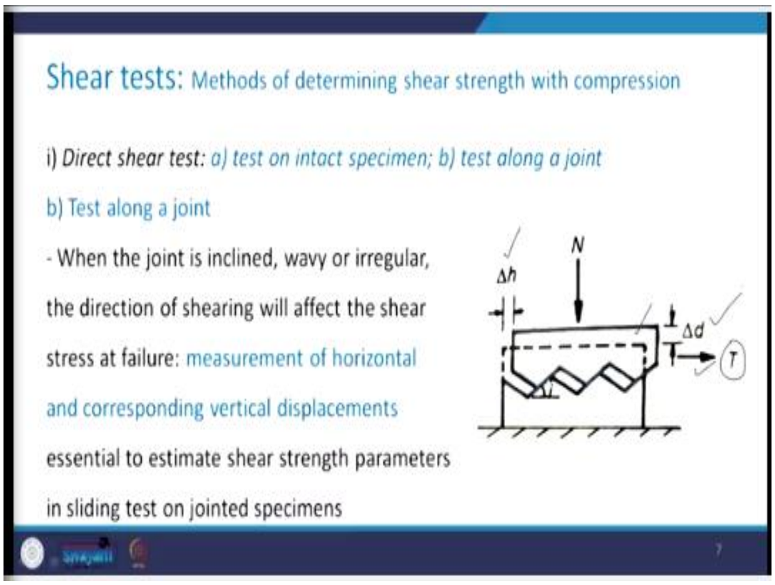

Till now, we discussed about the smooth plane first it was horizontal, then we made that smooth plane as an inclined plane. Now if the joint is inclined, wavy or irregular, the direction of the shearing will affect the shear stress at failure. So, in this case you see that it is wavy kind of a joint surface, that means that the joint surface it has teeth. So, in that case it is important for us to measure the horizontal and the corresponding vertical displacements.

So, you see here, again the shear force is being applied from left to right direction and because wavy nature of this jointed surface, when this force is applied, what will happen? It will try to slide, like this. So, this is going to be the new position of this upper block and if you just compare the original position to the new position, which is the solid line and the dotted line is the old position, you will see that this gives rise to horizontal as well as vertical displacement.

So, therefore both horizontal and the corresponding vertical displacements, they are essential to estimate shear strength parameters in sliding when the test is conducted on jointed specimen.

Because most of the time the joint surfaces they are going to be wavy or irregular. Now with increase in number of these primary irregularities and the increase in their average slope.

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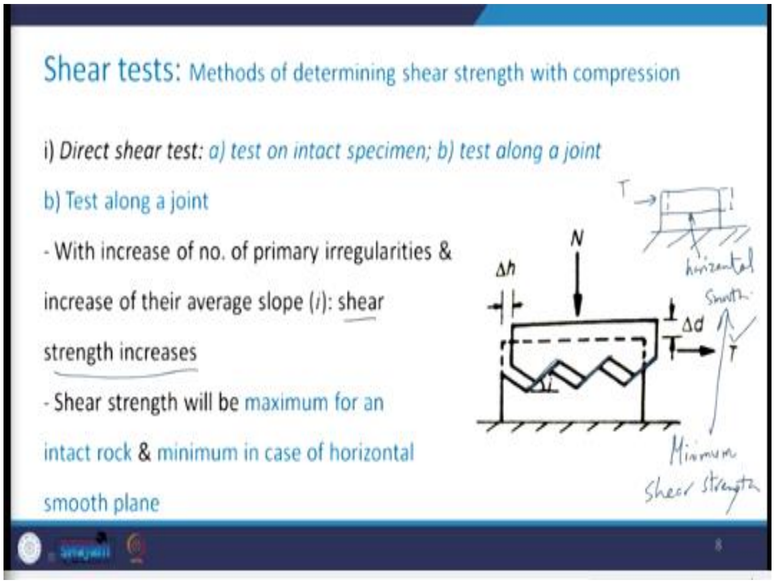

So, let us say that as I mentioned that these primary irregularities, they are macroscopic. So, you see that the sliding is taking place along these primary irregularities. So, when these number of primary irregularities, they increase along with their average slope. So, average slope, see here in this particular figure, you see that all these are parallel to each other but it may not be the case in the field, you may have irregular teeth.

So, in that case the inclination of each of this surface will not be same, so we need to find out the average slope. So, when we increase the number of primary irregularities or there is increase in their average slope *i*, the shear strength increases. Say, there are 2 specimens in one case, the number of primary irregularities let us say, they are 10 in another it is 20. So, whose strength will be more? The one which has a greater number of primary irregularities.

Similarly, when there is an increase in the average slope again that would cause the increase in the shear strength. Now you see when we have the intact rock, then this shear strength is going to be maximum obviously because there is no joint surface and for the specimen to shear, one needs to apply very large value of this T in case of the intact rock. And therefore, the shear strength will be maximum in case of the intact rock.

However, when you have the horizontal smooth plane that is, let us say, it will look like the first case as we discussed. See this is there and this is the horizontal plane and you have this *T*, so this is how it is going to be displaced. So, in this case where this plane is horizontal and it is smooth, then in that case you have the minimum shear strength. So, remember this, shear restraint will be maximum in case of the intact rock and it will be minimum when you have horizontal smooth plane as a sliding plane.

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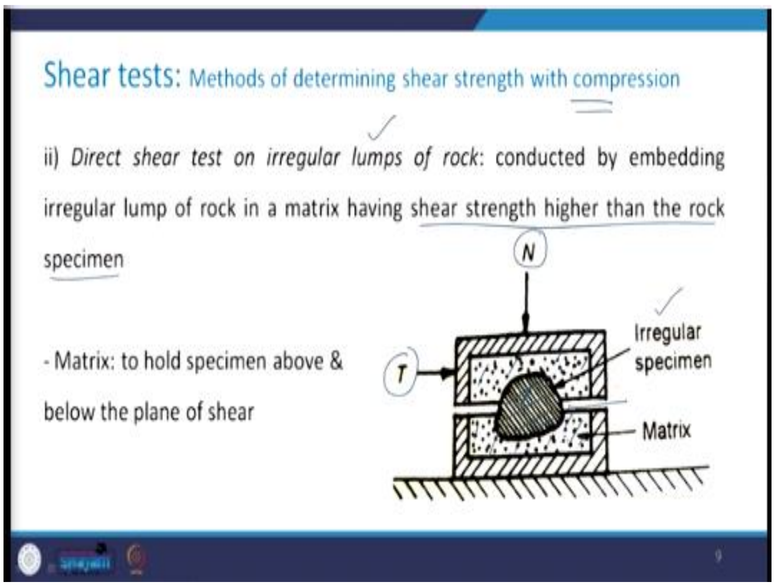

This was all about the direct shear test on the jointed specimen. In case if it is not possible to get to extract the regular shaped specimen, then direct shear test can also be conducted on the irregular lumps of rock. These are conducted by embedding the irregular lump of rock in a matrix having the shear strength higher than that of the rock specimen. Look at this figure, see this is the matrix material, and the irregular rock specimen that is, this one is held there in this matrix.

The normal load is applied, because it belongs to this category and then you apply the shear force and try to shear this irregular specimen. Now why this condition should be true? Reason being that if the shear strength of this matrix material is less than that of this rock specimen, what will happen? When the shear force is applied this matrix material will fail first rather than the specimen.

Therefore, the strength characteristic that we will obtain from the test will be of the matrix and not of the specimen that we want to test. So, the matrix is used to hold the specimen above and below the plane of the shear. You see, this is the plane of the shear. And it should have the shear strength higher than that of the rock specimen.

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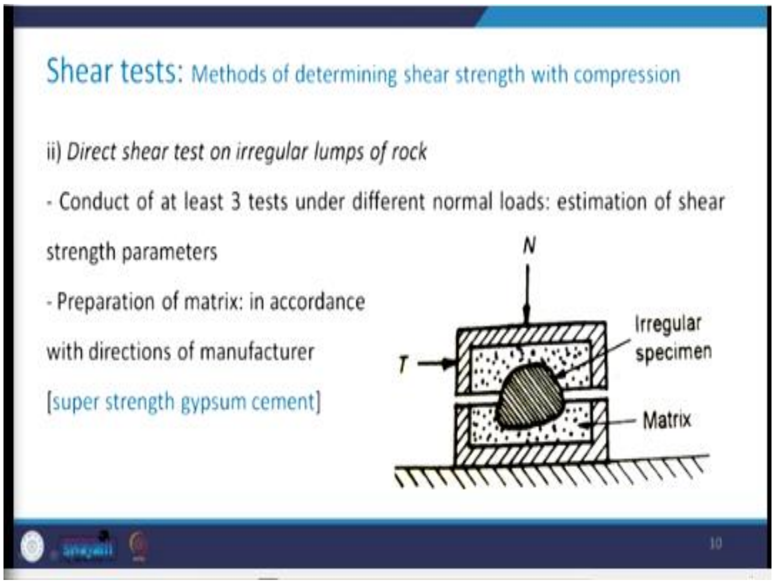

We need to conduct at least 3 tests under different normal loads. It is exactly as you conduct direct shear test in case of the soils. And then we estimate the shear strength parameters. How to prepare this matrix? This should be done in accordance with directions of the manufacturer. For example, super strength gypsum cement can be used as the matrix material.

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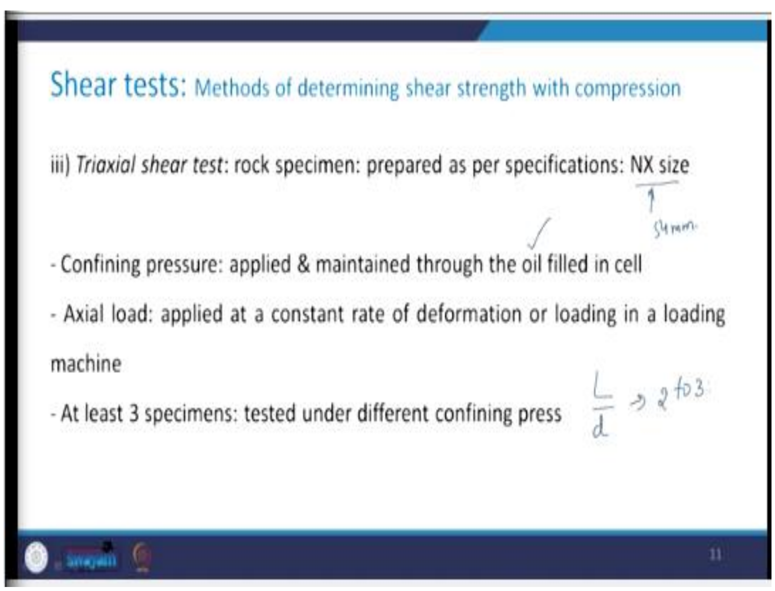

So, this is how the direct shear test on irregular lumps of specimen can be conducted. Now coming to the next category of the shear test which is the triaxial shear test. I mentioned to you that more or less, the philosophy of the triaxial shear test in case of the rock specimen is same as that of the soil. But in case of the soil, you had different types of triaxial test based upon the drainage conditions.

There were 2 stages of the triaxial tests in case of soils. In first stage, when you apply the confining pressure and you put the specimen and whether the drainage valve is open or not, depending upon that, you will have consolidated or unconsolidated test. And when you increase the actual load to shear the soil specimen, then whether the valve is open for drainage or not, then accordingly, you will have drained or undrained test.

So, basically these combinations of consolidated, unconsolidated and drained and undrained, it gives rise to 3 types of the triaxial test in case of the soils. In case of rocks, it is little bit different because drainage conditions are not there in the picture as far as the testing is concerned, there is nothing like consolidated or unconsolidated in case of rock. So, therefore basic philosophy will remain the same, that is in the first stage we apply the all-around pressure.

And then in the second stage, we increase the axial stress in order to shear the rock specimen. Now the rock specimen in this case is prepared as per the specification, which I discussed with you in some of the previous classes. The diameter of the rock specimen should be of NX size, which is what, 54 mm, as per ISRM. Then in the case of soils, we apply the confining pressure with the help of water.

But here in case of the rock specimen, we will be mobilizing confining pressure through the oil which is filled in the cell. Reason being, that rock has much larger shear strength characteristic as compared to the soil. And it is really not possible to mobilize that order of confining pressure with the help of water, and therefore oil is used for this purpose. The axial load is applied at a constant rate of deformation or loading in the loading machine.

As we do in case of the soil, here also we will test at least 3 specimens. And these will be tested under different confining pressure. Ideally, we should do as much as possible, but you have seen that there are difficulties associated with the extraction of rock cores and preparation of a specimen. At some site it may happen that you will get very few specimens such that their *L/d* ratio is lying between 2 to 3.

So, in that case we do not have much choice, that if you want to decide that we want to test let us say 10 specimens but then we are not able to get those 10 specimens as per the specifications. Then at least 3 specimens, they are required which should be tested under different confining pressure.

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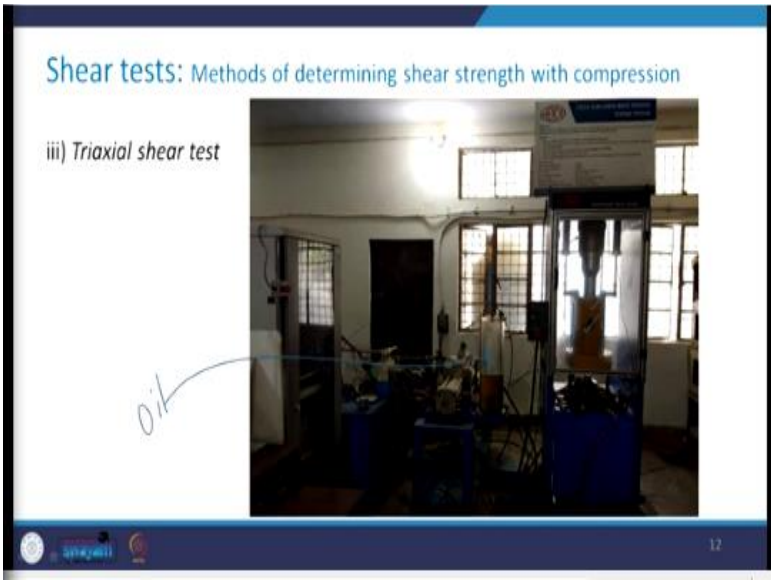

This is a picture of the triaxial shear test. So, you can see that here there is a cell although it is really not visible that what is there inside. But you can see here there is a cell, then here in this portion, you can see that the oil, oil is filled. So, with the help of the arrangement, this oil is passed to this cell where the rock specimen has been mounted. And this oil is used to maintain the confining pressure, which is required to conduct the test.

And then this whole assembly although it is not visible here, the whole assembly is connected with a computer system here, because this machine is the servo-controlled machine, where you just apply the confining pressure. And then you start increasing the axial load and directly it is going to give you the stress versus strain response. And from there you will be able to obtain or you will be able to analyze those test results to get the shear strength characteristic of the rock specimen, see how?

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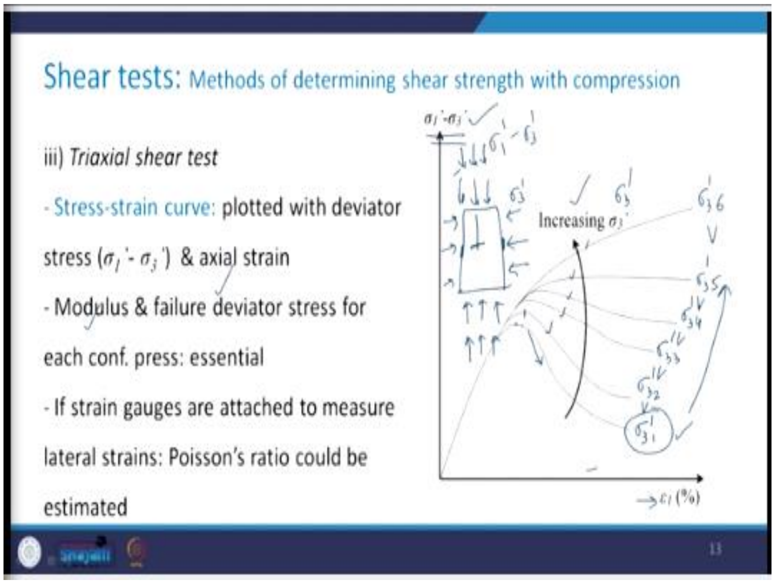

See here, this is as I mentioned that stress strain curve here it is plotted with the deviatoric stress which is σ_1'- σ_3' and on the X axis you have the axial strain which is ε_1(%). And when we keep on increasing the value of σ_3, so you can see that how the stress strain response of the same rock specimen changes when we increase the value of σ_3'.

So, therefore, the conclusion here is that the confining pressure significantly influences the shear strength characteristic of the rock specimen. So, you see in this direction this is increasing, σ_3' is increasing that means the confining pressure is increasing. So, this curve corresponds to let us say σ_{31}', this is σ_{32}', σ_{33}', then σ_{34}', σ_{35}' and σ_{36}' let us say.

So, what is the relationship between these? $\sigma_{36}' > \sigma_{35}'$, this is greater than this and it goes like this, so what do we mean? That when we have smaller value of this confining pressure, you see that slowly at the low values of the strain it just goes straight and then it achieves a peak and there is a sudden drop here in the strength characteristic, that σ_1- σ_3.

Then as the value of this σ_3 increases, what happens? You see that post peak whatever is the drop, there is the reduction in the slope of this drop. You see that when the σ_3 is smaller, that drop was sharper as compared to this, this, this and this and so on. So, this is really very interesting that on increase of σ_3, the behavior of the specimen it changes. We will discuss about these things in detailed manner in subsequent classes.

But for the time being just focus here that with the increase in σ_3, there is a change in the stress strain response for the same rock. From these stress strain responses, we can find out the modulus, we have discussed about this, you have 3 kinds of modulus, E_{t50}, E_t and E_0 which is the initial tangent modulus and you know how to determine that. So, for each confining pressure we can get modulus and failure deviatoric stress.

Now in case if the strain gauges are also attached in the lateral direction, so you see that this is what is the specimen. You have the all-around confining pressure first. So, this is what is your σ_3, and then we increase the axial stress which is σ_1'- σ_3'. So, in that case, now because we are increasing this, so obviously with increase in this what will happen? There is going to be the deformation in the axial direction.

And depending upon the level of the confinement you will have the lateral deformation as well. So, if we have mounted some device here to measure these lateral strains, then in that case from the triaxial shear test data, we can also determine the Poisson’s ratio for the rock. So, not only the axial strain, but the lateral strain can also be measured, it is just that we have to mount the strain gauges in that direction in order to measure the strains in the lateral direction.

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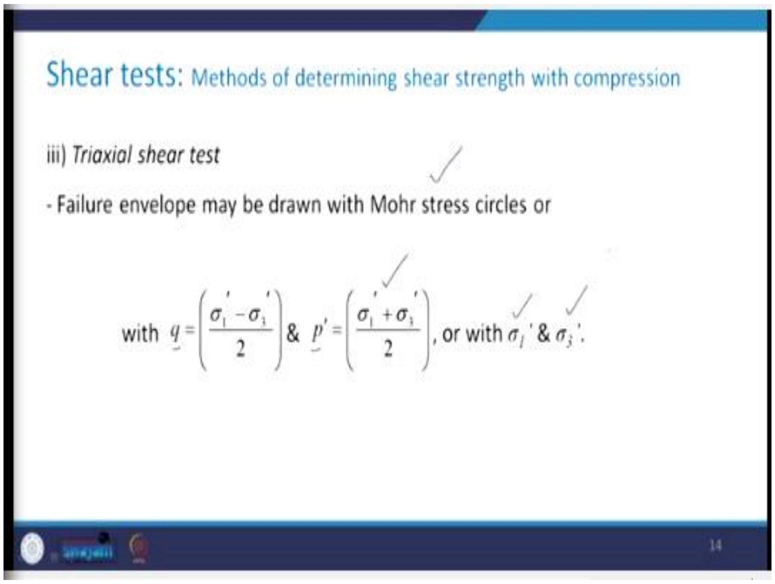

Then the failure envelope maybe drawn either by more stress circle or the plot can be done in with q and p'.

$$q = \left(\frac{\sigma_1' - \sigma_3'}{2}\right)$$

$$p' = \left(\frac{\sigma_1' + \sigma_3'}{2}\right)$$

Or we can have the plot with σ_1 versus σ_3' from there also we can get the failure envelope.

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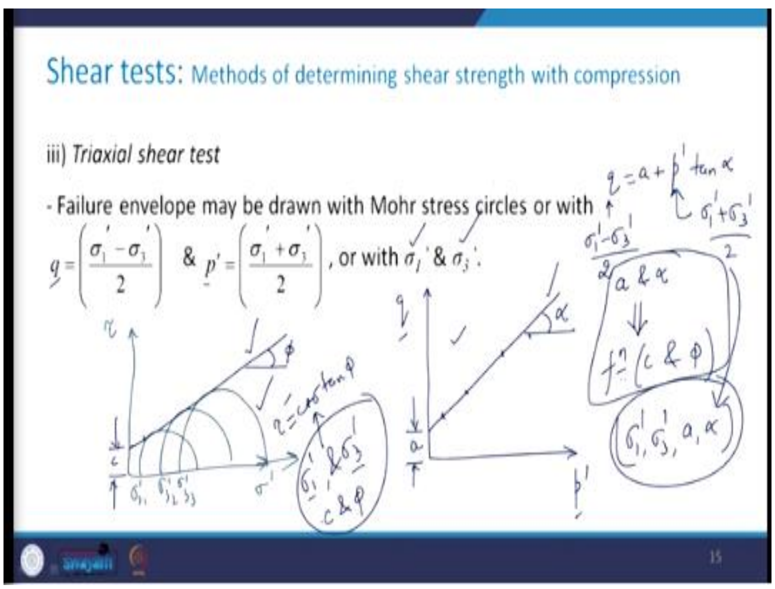

Now let us see, that if I have the more stress circle, then how can we get? You see that you have here on the x axis you have the τ and here you have your σ and then you can have or maybe you can have the maybe more circles like this for the different confining pressures. So, here in this case say it is σ_{31}', this is σ_{32}' and this is σ_{33}' and then you can draw the common envelop to these 3.

And this intercept is given as c and this is going to give you the value of ϕ, right, this is the usual procedure that way that you will be able to find. Now in case if you plot it with q and p', so what is done in that case? See here, we have p' and here you have q, so instead of representing the state of a stress with the help of a circle, which is the case when you have the more stress circle.

In this case, you represent the state of stress by a point in q and p' space. So, corresponding to each of these you will be getting say these points, then you try to fit a straight line here. Now say that this intercept is a, this angle is α. So, if you compare these 2 both are the same data representation, it is just that the space in which we are representing that data it is different.

So, therefore this a and α they can be determined as a function of c and ϕ. I mean you need to write the equation of this Mohr coulomb envelop, that is

$$\tau = c + \sigma \tan\ \phi$$

And likewise, here this can be written in terms of σ_1' and σ_3', and you can write here also this equation of this straight line will be what? q will be equal to a + p prime tan of alpha.

$$q = a + p' \tan\ \alpha$$

So, substitute this

$$q = \left(\frac{\sigma_1' - \sigma_3'}{2}\right)$$

$$p' = \left(\frac{\sigma_1' + \sigma_3'}{2}\right)$$

You will get an expression in σ_1', σ_3', a and α from this, and here you will get an expression σ_1', σ_3', c and ϕ. If you compare these 2 expressions, you will be able to establish the relationship between a, α and c and ϕ.

So, this is how the shear strength characteristic can be found out using the data which you obtain from the triaxial shear test. Similarly, when you plot between σ_1' and σ_3', you can do the similar kind of exercise and find out the shear strength parameters.

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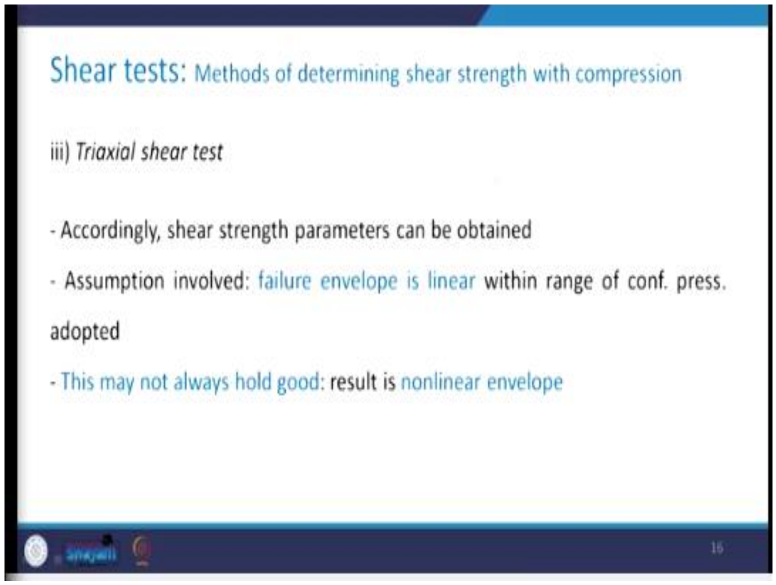

The assumption which is involved here is the failure envelope is linear within the range of the confining pressure that we have adopted, which may not hold good always. And therefore, it may result into the nonlinear envelope, which is we will see whether we will be able to cover this nonlinear envelope because it falls under some of the advanced topics. So, we will see I will try to give you a little bit idea about it.

So, this is how the analysis from the triaxial shear tests can be done, if we assume this to be linear, this is how we can find out the shear strength parameters c and ϕ. So, this was all about that I wanted to discuss with you as far as laboratory testing of the rocks are concerned. So, just to have the conclusion of this chapter, we discussed different tests starting from the determination of the physical properties.

Then we had the discussion that how we can get the unconfined compressive strength? How we can get the tensile strength? There were indirect and direct methods and one of the indirect methods was Brazilian test which we discussed in detail. Then we discussed Schmidt hammer test, we discussed the sound velocity test, then we discussed slake durability test, we also discussed free swell test and the swelling pressure test followed by how to determine the void index.

And then finally we discussed the shear test, in that we discussed about the oblique shear test and direct shear tests on the intact rock specimen as well as on the jointed specimen. And finally, we had some discussion on the triaxial shear test. So, you got the overall idea that how to prepare the specimen, how to conduct the test in order to obtain the engineering properties of the rocks? So, in the next class, we will start our discussion on a new chapter related to engineering classification of rocks and rock masses. Thank you very much.