Soil Mechanics/Geotechnical Engineering I
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Lecture – 31
Shear Strength (Contd.)

Let us continue with shear strength, in the last lecture I have taken some aspect of shear strength that is I have explained that soil can have two shear parameter C cohesion and phi angle of internal friction.

There can be different types of soil, one particular soil only can have phi, the angle of internal friction, that is called cohesion less soil and that is suppose the sand is example, similarly some soil can have only cohesion and that is called cohesive soil and the example is pure clay, but most soil is combination of both C and phi; that means, it may be a mix of sealed, clay and sand. So, if you test then you will get both C and phi; that means, this type of soil will offer resistance by both cohesion and friction.

So, and then the cohesion parameter is, we are universally denote by C and frictional parameter we generally denote by phi, angle of internal friction phi, and then if I know C and phi and if I explain that there are different normal stresses, that is sigma 1, sigma 3 and then how relate sigma 1 and sigma 3 relate to C and phi, we have shown in the last lecture, now we will see how what are the and also I have mentioned that by conducting the test, we can determine the C and phi parameter because I can on a identical soil sample, if I carry out two test.

Since C and phi is not changing, only change is we are applying different normal stress and then we are getting different failure shear strength and based on that I can say it any number of, I can conduct any number of test and I can say at any number of equation and only by taking two equation, necessary two equation only necessary to solve two unknown parameters C and phi. So, I can pick, I can take two combination and then we can find two set, two equation and then solve them to find out C and phi. So, that much I have just mentioned in my previous lecture.

Now, I will try to show, what are the different test available for determining the shear strength of the soil. So, those things are, these are a different test.

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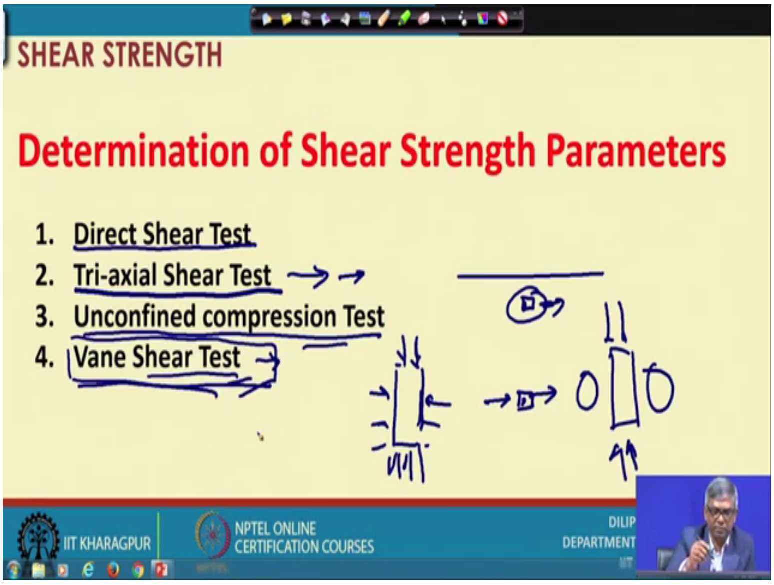

Actually, soil mechanics popularly we use 1 is direct shear test and the name direct shear test actually is a very clear. We prepare a soil sample and we give a pre-defined shear plane, there will be soil will be there and in two halves and in a box and the middle part of the box actually is not connected, before preparation of the sample we connect it and compact it and when till, while doing the test we remove the connection and then we try to slide one lower half with a suit other half, then the shearing only can take place only that in the between the box, that where we have that is the predefined or predetermined shear plane.

So, directly we are trying to force the soil plane on that plane. So, because of that it is called actually direct shear test and then there is a direct shear test will be suitable for some test, some soil type, all soil can be tested, but popularly or commonly, we use for a we use for cohesion less soil that is sand and; obviously, we can do for other soil, but it is not. So, simple.

Whereas next one is a Tri-axial shear test. This Tri-axial shear test is a unique one, an universal one, this one actually Tri-axial that with three types of test is a stress we can apply and in fact, as I have mentioned before that if this is a ground mark and if I take a sample from here and if I take a sample here the stress condition here and here is totally different. So, if I collect sample here and test and get the shear strength parameter you will get some value and if I collect sample from here and test, then I may get a different shear parameter. So, what is the reason because the stress level stress condition is different.

So, in the Tri-axial test is a test where we can simulate this condition; that means, whatever stress condition at there under that stress condition I can test conduct the test similarly at this point whatever stress condition is there similar stress condition I can simulate in the Tri-axial sand and get the value. So, that is the one exact condition we can simulate through Tri-axial test by applying different stresses in different direction and this is three direction actually and two direction will be identical since we use a cylindrical sample. So, sigma 2 and 3 will be same and are equal and sigma 1 will be another measure principal stress.

So, Tri-axial system is a universal test, where we can vary different parameter and we can simulate different field condition. So, the because of that, this is a very universal test and any type of soil can be tested by Tri-axial shear test and next is Unconfined compression test, this is also a test similar to Tri-axial, but only thing it is unconfined; that means, there is a no all around pressure only in all direction pressure will be there. So, the special form of Tri-axial test is the uncontained compression test when there is a Tri-axial test the sample will be given compression from this to all direction from all direction it is confined from all direction and then we are shearing.

Whereas, in Unconfined compression test only load will be here from this direction and there will be nothing confinement no confinement. So, if I remove the confinement from Tri-axial test it become the Unconfined compression test and another test is the vane shear test this is a test actually sometime very useful for very soft sensitive clay or sensitive soil mainly because this type of soil when this is a field test.

In fact, this type of soil when you make sample and try to do test in the laboratory, during this process lot of changes take place and because of that we do not get the correct representation of the field. So, because of that for soft sensitive clay, this is the test field test directly in carry out in the field, itself to get the strength parameter of the soil. So, this is applicable only for very soft and sensitive clay soil not other than that, sometime we carry out in the laboratory to explain or to demonstrate, but it is actually a field test.

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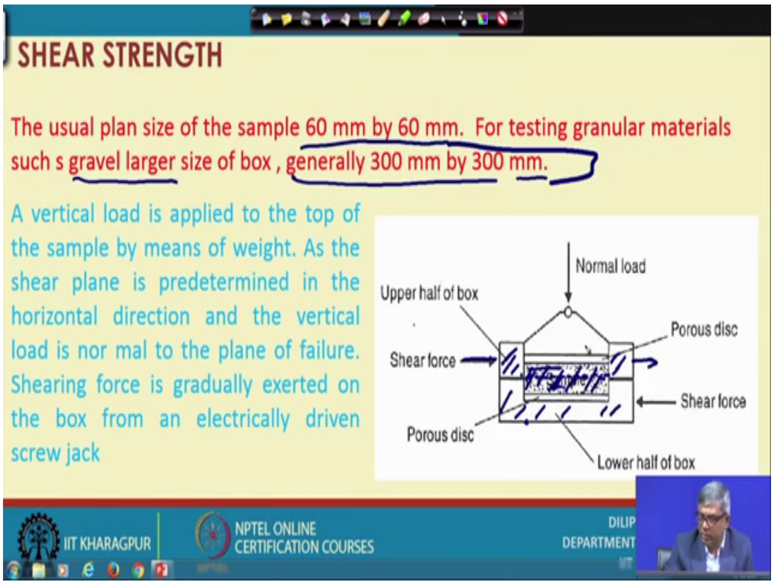

Now, the as I have mentioned the first one is the direct shear test. So, Direct shear test is a typical box is this one, this is a box and you can see this is the upper half and this is the lower half and this is jointed initially fixed and then in between this sample is prepared and this box will have standard dimension in the laboratory test 60 millimetre by 60 millimetre and for generally normal soil, but if the bigger particles are used the particularly your gravel and all sometime large box size can be used and 300 millimetre by 300 millimetre box size sometime big gravel test actually we use direct shear test that is sometime will be used in that in the laboratory also,

And in this setup generally you can see that after preparing the sample, I can give the normal load through this so; that means, I can imagine one plane here along this I can imagine a plane so; that means, this normal force is perpendicular to this plane, now by some mechanism the screw jack or something through that is also motorized.

I can push one half with respect to other then if try to this one, try to move this direction and this is fixed then what will happen, this when it will move this soil also will move and this is stationary suppose then between this soil and this soil there is a movement as long as long as the applied shear stress is smaller than the shear strength of the soil the more I mean there is no failure will occur and as soon as the horizontal applied force is bigger than the shear strength of this, then it will show the failure suddenly slipping will be taking place.

So, based on that we apply different values of normal load and then we shear the soil and by that way, we can get the different soil data and then from there actually using whatever equation we have got correlating shear strength, cohesion and phi we can find out the C and phi. So, this is the way this is the simple mechanism, this is box two halves and the normal load and then you are moving giving relative movement with respect to other one.

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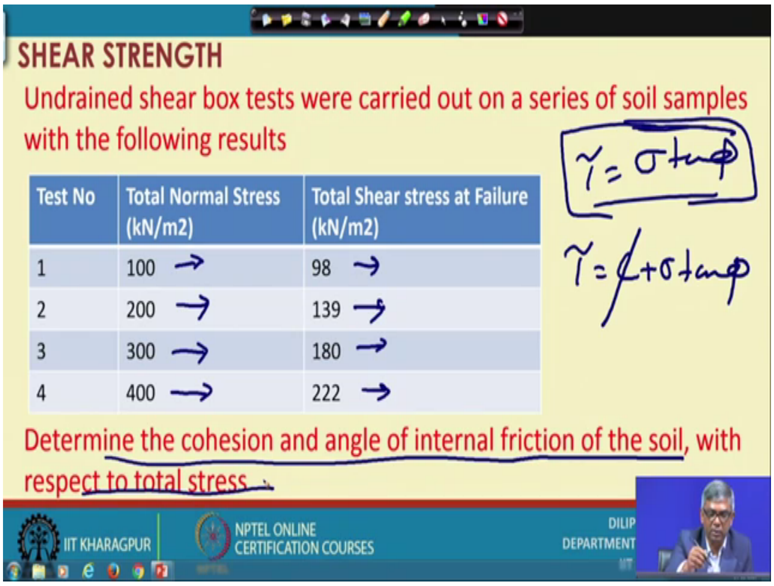

So, this one if this is the test procedure, and then suppose I will take a set of data; suppose, you have got a format test and a particular test. Suppose you have applied, as we have seen the normal shearing resistance from friction is a function of normal stress. So, because of that test is carried out for different values of normal stress and 100 200 300 and 400 and you can see when you applied 100 same it, but we are doing different test, but to find out the value of shear parameter what you need to do, we need to conduct the test on identical sample; that means, with the shear box you has to be filled up with definite amount of soil.

So that it is void ratio density and all will remain unchanged. So, suppose that is suppose ensured and then sample 1 is prepared and then 100 k p a normal stress is applied and then we have applied shear and suppose by 98 k p a shear stress it fail. So, this is one set of data suppose you have got then I have increased the shear normal load to 200 k p a and then corresponding shear is 139 and then we have increased the normal to 300, normal stress and corresponding shear stress is 180 and then we increase the normal stress to 400 and corresponding shear stress is about 222.

So, we have got this data and now we know that our equation is tau equal to C plus sigma tan phi and this is for 100 shear box test were carried out on a series of soil samples with the following results. So, series of soil sample and this sample actually not it is not mentioned the sand as I have mentioned that shear test is the Direct shear test is good for cohesion less soil. So, if cohesion is absent then directly you can do C plus tau equal to sigma tan phi. So, this is the way we can do, but since it is not specified, whether this is a cohesion less or not. So, we will see the data and see how it comes.

So, based on these data determine the cohesion and angle of internal friction of the soil with respect to total stress. So, this is the problem.

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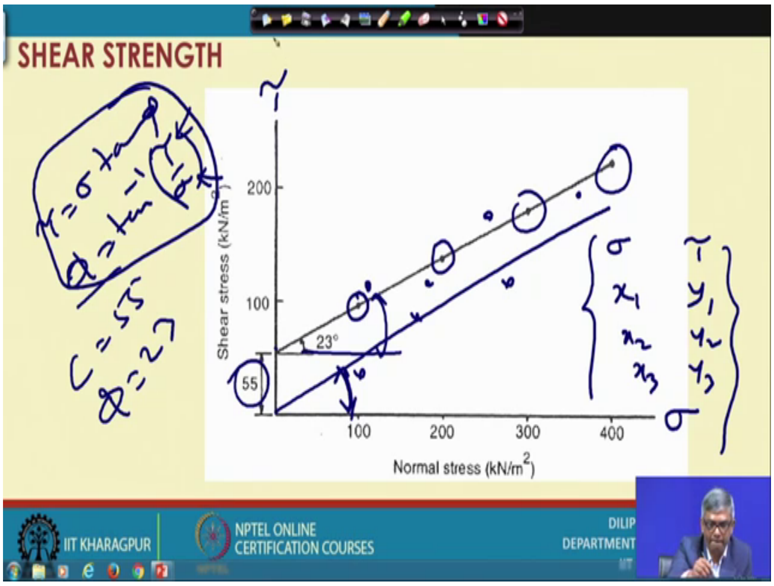

So, let us see if I take this data in a tau sigma plot, this is suppose sigma, this is sigma and this is tau and this is suppose first point 198, this is second point 200 and something, corresponding value this is about 300 and corresponding shear stress 400 shear value and corresponding as 400 normal and corresponding shear value.

So, see here actually you can see all points are perfectly on line, but most of the time while doing test in the laboratory you will not get the point may be somewhere here point, may be somewhere here, maybe somewhere here, but we know that shear strength envelope is a straight line. So, we can in that case if that is a scatter then we can draw a best fit straight line and if it is mentioned that is a cohesion less soil, then we can assume that it will pass through the origin. So, (Refer Time: 15:17) we can draw, since this soil also has some cohesion. So, we need to draw a best fit line and we will see, where it intersects here in the y axis or tau axis.

So, you can see tau axis intersected here and the value read as 55 k p a; that means, the soil has C equal to 55 and if I measure this angle that is coming 23 degrees; that means, based on the test results, whatever we have carried out we are getting the shear parameter of the soil C equal to 55 and phi equal to 23.

And as I have mentioned that most of the time here if the soil is cohesion less soil is tested in direct shear apparatus and; that means, if that is done then if you get sigma if you apply and tau you get suppose you get some value x you will get some value of y some x 1, y 1, x 2, y 2, x 3, y 3 like that we can get and those points suppose like this then we can have a best fit line like this and then directly measuring this angle we can find out the value of phi r directly when it is a cohesion less soil is a tau equal to sigma tan phi or phi equal to tan inverse tau by sigma.

So; that means, if though we carry out while conducting the test, we will do a number of test 3 4, but you can see that directly if I apply a normal stress and if I get a shear stress directly from there I can get the phi value, but still there may be some error in the test and all and. So, because of that to get the average value, we generally conduct the test on several samples and finally, plot and then finally, to plot the average straight line passing through origin and measuring the angle we get the value of phi otherwise direct shear test by conducting one test also one can find out the phi by using this.

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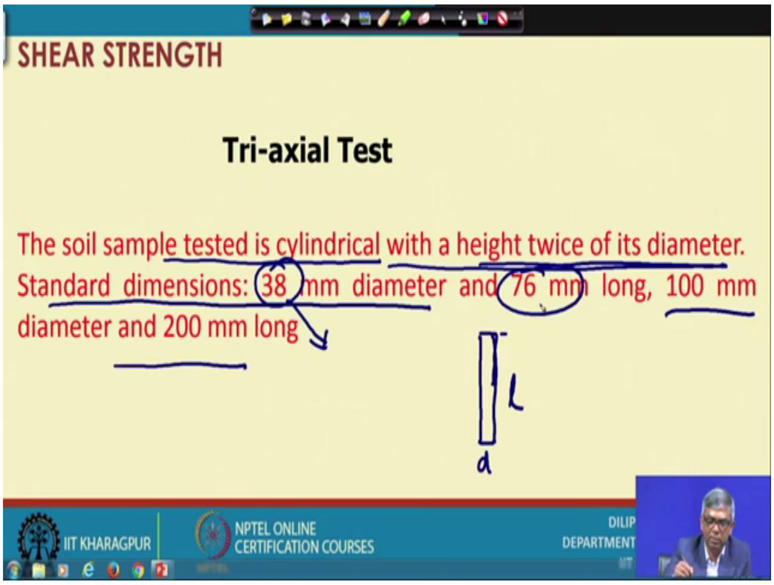

And now, Tri-axial test and Tri-axial test actually, it is the soil sample tested cylindrical samples cylindrical sample with a height twice of its diameter the soil sample tested is cylindrical; that means, cylindrical surveillance, there will be definite diameter and length if it is d and if it is l and you can see that standard, if you test on different sample will get different results.

So, best results or may be very consistent result we get when a when you maintain a particular l by d ratio. So, that twice height is twice of its diameter that is a standard everywhere we use and that standard dimension in most of the laboratory, we conduct that is actually 38 millimetre diameter and 76 millimetre long and it was originally actually one and half inch and 3 inches and so, as you converted then it becomes this.

So, all laboratory most Tri-axial apparatus if whatever is there most of them will can capable of testing the sample with diameter 38 millimetre and length 76 millimetre and some cases you can also have 100 and 200. So; that means, l by d always the two has to be maintained and to get the best result.

So, this is the sample, regarding the sample next and Tri-axial test apparatus how it looks like as I have mentioned that this is the sample actually.

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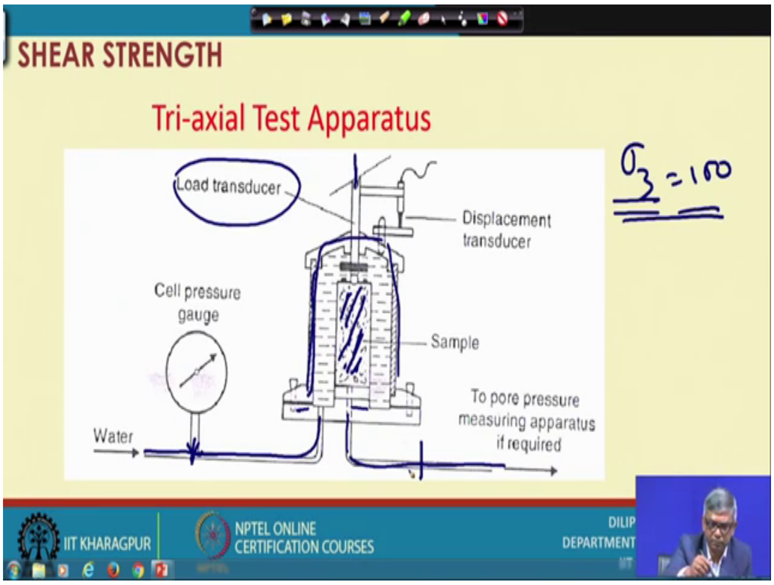

This is the sample and this sample will be first this is the suppose pedestal stand on the machine, on that first sample will be erected and then after erecting the sample, this is the chamber, this is a cell , it will be covered and all should be leak proof and after covering by the cell, we can push water inside it and fill it and we can apply definite amount of pressure, suppose I want to conduct with a self pressure of sigma 3 that is whatever we are applying that is sigma 3, all round pressure that is sigma 3, I can suppose I can conduct suppose sigma 3 equal to 100 k p a. So, I will apply and then close this one.

So, under 100 k p a pressure then everything will be closed and then through this load will be axial load will be applied and till it fails.

So, this is actually very simple one we are mentioning now, because I am applying confining pressure and automatically I have immediately after confining pressure the soil is saturated, then what will happen some pressure will develop and if you allow to pore pressure to develop dissipate then what I have to you have to allow the consolidate the sample and; that means, the inside whatever pressure developed that has to be released that by how it will be released, when some amount of water will come out.

So, there is a different definite path if I keep the path open after immediately after applying confining pressure if I keep this path open then some amount of water will come out and then finally, the soil will be consolidated, after soil consolidating the soil we can again shear,

and during shear again, we can apply draining or you can close that drained, undrained condition. There are several ways this test can be done I will discuss that one later part , right now what is the very simple way what I am telling you that is that first sample will be prepared then they will be covered by a cell and that cell will be filled up with water and we apply definite amount of pressure, which is equal to suppose sigma 3.

And now under that I will keep all valve closed and now we will be applying a normal axial load to the sample till it fails. So, when a particular sigma 3, how much sigma 1 is there at failure what is the sigma 1; that is the thing we observe and after observing that as I have shown before sigma 1, sigma 3, C and phi there is a relationship by using that relationship we can find out C and phi.

So, this is the by enlarge, the Tri-axial apparatus and you can see this is the sample this displacement (Refer Time: 22:22) there is a mechanism the how much it is displacing over time or applying load that can be recorded and this the whatever load is applied that will be also measured through load transducer, there will be water pressure can be applied through gauge we can measure and here actually when it draining is required you can keep it open, when training is not required you can close it. So, these are the universal test procedure in Tri-axial test.

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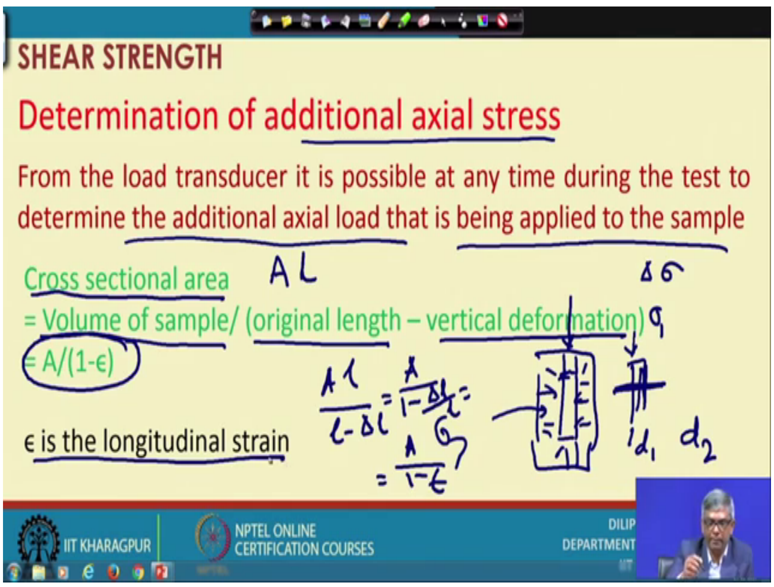

And now, determination of additional axial stress; that means, when we apply the self pressure that self pressure will be acting from all direction equally, even from the top suppose this is the sample when this is the sample and this is the chamber suppose and if I give pressure suppose sigma 3 here. So, sigma 3 will be acting all direction. So, all directions sigma 3 is there and additionally, we are giving some axial load. So, that is what is called additional axial stress.

So, from the load transducer it is possible at any time during the test to determine the additional axial load that is being applied to the sample; that means, how much you are applying at any time that we can find out that is delta sigma you can say additional axial load and another thing is, when the sample is loaded applied with axial load, then sample actually what will had will compress and it will be shortening, and because of the shortening and then there is a chance of a change in diameter, what since the compressive load is applied diameter change in what direction, it will be, it will bulge or diameter will increase.

And so, that at any time suppose I have applied some amount of stress I have applied, but if I consider with original cross section we will get some value of stress, but if I consider at a at any level of stress suppose what is the diameter it initially diameter was suppose d 1 and later on diameter change to d 2 now if I want to find a sigma 1 was some value and now sigma 2 will be load applied divided by this area at with diameter d 2. So; that means, I have to find out the cross sectional area during the test at different level of load, what is the cross sectional area that has to be obtained and for that actually, the cross sectional area at any time can be obtained volume of sample divided by original length minus vertical deformation and then if I simplify volume actually is nothing, but area into length.

And so this is original length actually; that means, your expression is A l divided by l minus delta l and if l get cancel then a by 1 minus del l by l and del l by that is actually nothing, but y 1 minus del l by l is epsilon. So; that means, cross sectional area at loading condition will be volume of sample divided by original length minus vertical deformation if I simplify this one that will be a by 1 minus epsilon. So, epsilon is the longitudinal strain.

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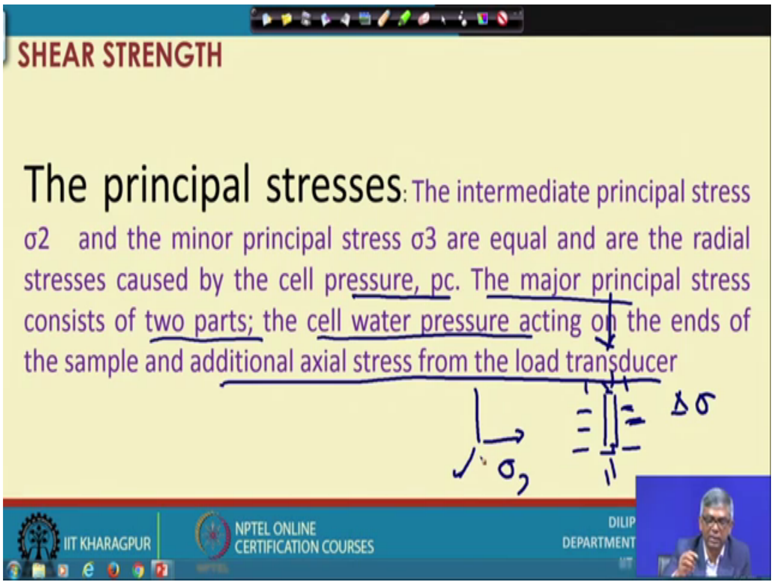

And the principal stress is you can see now I already, I have mentioned that since, we are considering cylindrical sample and then 2 though we have 3, 1, 2 and 3 direction and since it is cylindrical the 2 and 3 will be identical and they are called intermediate or minor principal stress and which is nothing, but whatever through self pressure we are applying sigma 3.

The major principal stresses consists of two parts, major principal stress consist two parts that is actually self pressure we are at; that means, when your sample is there we have given all round pressure everywhere that is sigma 3 already there and then we have applied delta sigma. So, because of that these two component will become the total sigma, additional axial stresses. So, then I can show you that how this can be related. So, what is the additional axial stress sigma 1 and sigma 3 how they are related. So, that can be seen in the next one.

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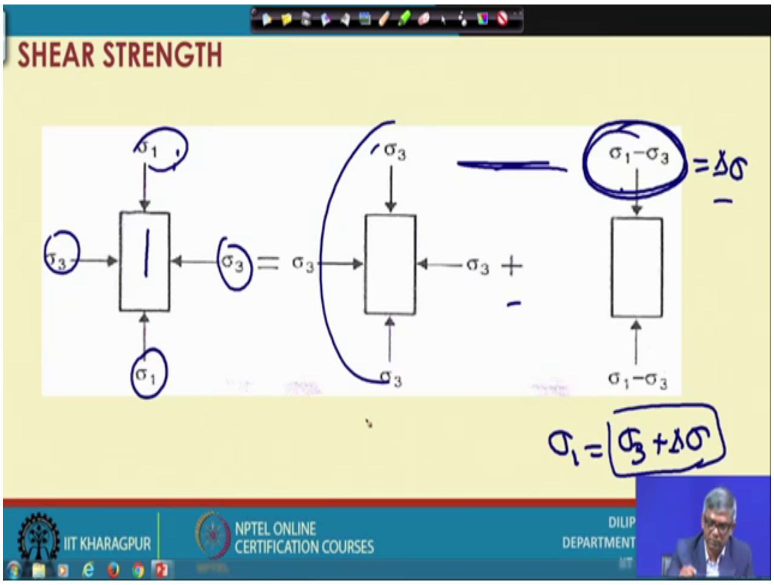

You can see that at any stage of test. So, this is the sample and I can visualize that sigma 1 is acting, sigma 3 acting and sigma 3 sigma 1 are acting. So, this is of course, all around sigma 3 and sigma 1 this is the visualization I can do for the sample.

But we have conducted or prepared the setup in two stages. Initially we have applied sigma 3 all direction this you can say plus we have applied this. So, you can see that mean whatever we have applied that is nothing, but sigma 1 minus sigma 3. So, these two if I add then we will get this so; that means, whatever additional axial stress we are applying that is nothing, but sigma 1 minus sigma 3.

So, if I put this is delta sigma then you can find out, the sigma 1 will be sigma 3 plus del sigma, the del sigma whatever we are measuring and that plus this will be sigma 1 plus sigma 3. So, that this is the relationship we can so; that means, at just before failure whatever the stresses are applied if I simulate this will be like this, but we have applied that since in two stages initial stage is this final stage is this, but I have to see now that this is final. So, this plus this should be this so; that means, if this is sigma 3, then this will be how much this will be sigma minus sigma 3 and that is actually del sigma.

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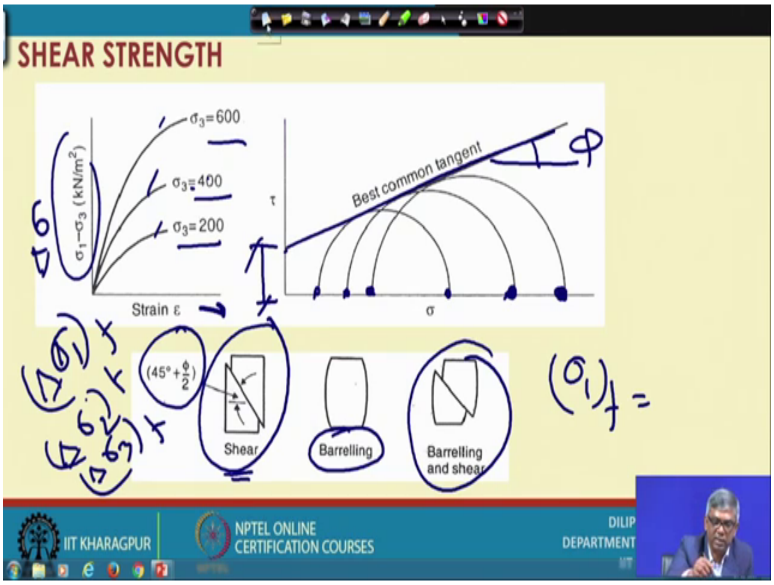

And during test actually, well different application of different normal stress, suppose sigma 3 gets 200, 400, 600, and then under different confining pressure I can apply sigma 1, minus sigma that is del sigma that is additional axial stress whatever we are applying, verses strain then we get different type of stress curve and from this I can find out what is the delta f, delta sigma at failure that mean delta sigma at failure, from there actually sigma 3 is constant.

So, sigma 1 at failure also I can find out. So, if I get that then sigma 1 at failure and sigma 3 already known at failure. So, I will get this two point and I know these are all major principal stress. So, I can get the circle.

Similarly, another set I can sigma 2. I apply value another value have this one and then correspondingly, I get delta sigma f, another two suppose this is one then I will get sigma 1 and second set and then corresponding value of sigma 3 already known, suppose this one then third stage I another value delta sigma 3 f, I get from there I will get sigma 3 another and sigma 1 here and sigma 3 here, this get the circle and joining this circle actually and I know that that your failure envelope will be tangential to the failure stress circle and, so if I get 2 3 circle sometime because of the error.

So, by single circle, if you draw, where to draw tangent we do not know. So, because of that we should do 2-3 test and finally, draw a common tangent and sometimes it may not be tangent to all, but by eye estimation best tangent to be drawn where maximum circle will be, the line will be tangent to the maximum number of circle and then finally, we get this failure envelope, from this failure envelope what we get, we get this angle as phi and this C this as c.

So, this is the way I can determine the soil parameter and during this testing soil will be failing. So, different ways soil can fail and I have mentioned that failure plane theta related to phi that is 45 degree plus phi (Refer Time: 31:43) that angle can be (Refer Time: 31:44) soil fails, if I can see that failure plane the angle if I see I can measure this angle and then equate to this equation from there I can find out the theta.

This is another type of, this is one type of failure that is when it fail by shear; otherwise sometime if the soft soil then instead of showing a prominent failure, it may continuously bulge then it can; that is called barrelling. So, if it is excessively deformed then, at after certain stage we can stop test considering that as a failure because excessive deformation and sometime combination of these two barrelling and shearing failure also called.

So, it fails it shows a definite shear plane at a same time bulging also occurs. So, that is also another type of failure, that is barrelling and shear and this is barrelling and this is pure shear. So, these are the different types of failure, during test we observed in the Tri-axial test.

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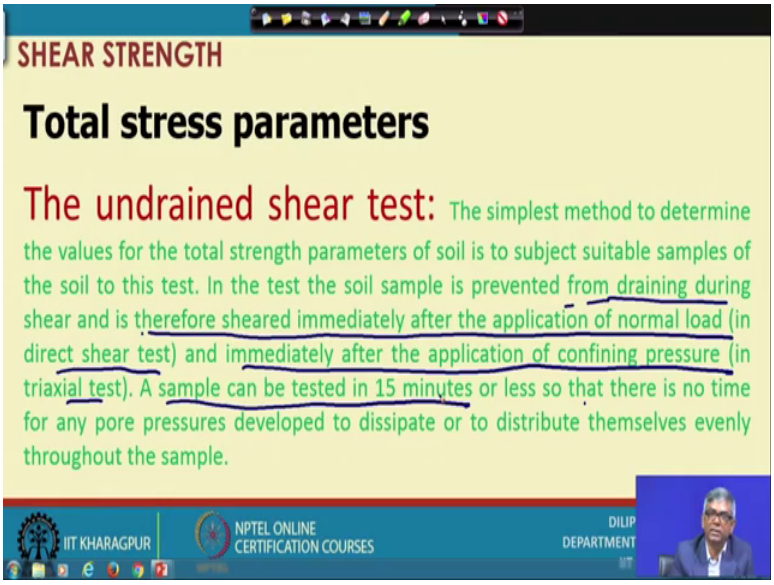

And then total stress parameters, undrained shear test parameter the undrained shear test parameter can be obtained actually by a very simple way; that means, you apply your confined pressure; that means, self pressure and immediately test and that test give you the undrained test; that means, we are not allowing any draining, that the consolidation is not allowed during draining, during the shear. So, sample is prevented from draining during shear. So, that is why it is called undrained test, the shear immediately after the application of the normal load that is shear test and immediately after the application of confining pressure in Tri-axial test.

The sample can be tested in 15 minutes the undrained test can be carried out in 15 minutes time or 15 20 minutes time, but if you want to give draining; that means, every application of load excess pore pressure will develop, we have to give time for dissipating the pore pressure and that takes actually time. So, this is the so, if you want to test that type of test it will take long time that I will discuss later on; obviously, but undrained test can be done very quickly. Some of the problems, application I will show you in the next few classes right now I just next slide.

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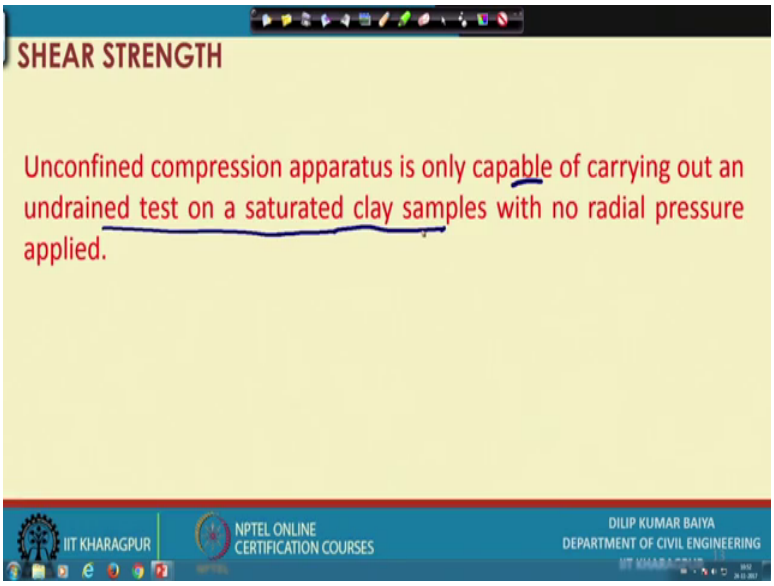

And unconfined compressive test as I have mentioned that unconfined compression apparatus that is which is a special form of Tri-axial test, where with no confinement will be there and that will be capable of carrying undrained test, the strength of the saturated clay. So, that is also very quickly can be done and quite satisfactory result we get. So, these are the different test Tri-axial test a different version is there.

So, first I will take some problem about undrained test and then later on I will discuss in detail what are the different ways of Tri-axial test can be done, and then each type, what type of data or result will get what is the implication of those I will discuss in the few next few classes

Thank you.