Soil Mechanics/Geotechnical Engineering I
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Lecture – 35
Shear Strength (Contd.)

Once again, let me continue the shear strength. In my previous lecture I was giving behaviour of soil under shear and various aspect. I have shown and few more things I would like to show. So, let me go the first slide; this is the one.

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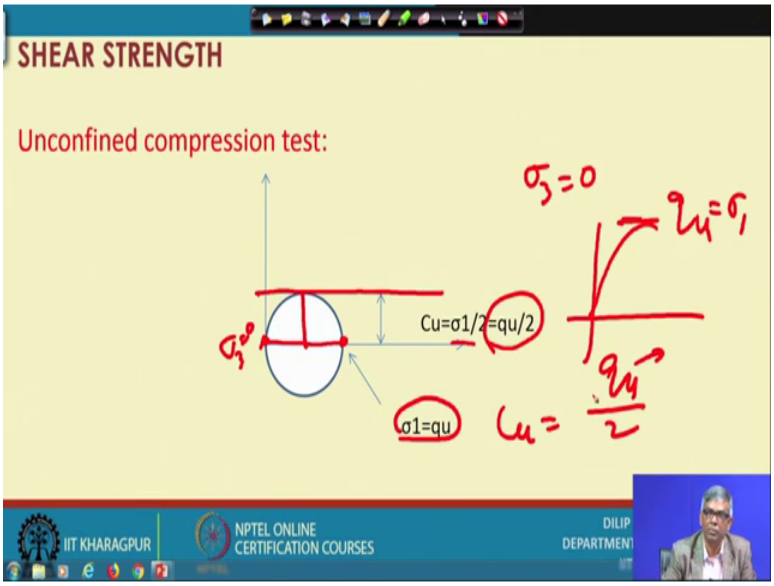

Under unconfined compression test how it will be as I have mentioned that unconfined compression test is the special form of triaxial test; that means, your sigma 3 is 0 here. And if this is sigma unconfined compression test also we suppose to do on saturated soil. And if you do that and then you will have sigma 3 is 0 and sigma 1 here is nothing, but sigma 1 is qu that is if you go to a stress strain curve and you get the value that is actually say qu ultimate shear strength and that is sigma 1 qu u nothing, but sigma 1 and sigma 3 is 0.

So, based on this sigma 3 equal to 0 and sigma 1 equal to qu if you plot the circle if you make the Mohr circle, and then Mohr circle you know this will be suppose to be unique circle if you because all the one circle we can get and there will not be any phi and so your; that means, your shear strength will be constant and then your envelope will horizontal like this. And if it is so then your Cu undrained strength from the unconfined compression test suppose whatever you get Cu which will be nothing, but this diameter half of the dia, this is radius and so this is diameter. So, diameter is itself here is sigma 1. So, radius will be sigma 1 by 2 and so; that means, Cu equal to sigma 1 by 2 and this is nothing, but qu by 2.

So that means, from shear strength result sorry undrained strength test if unconfined compression strength is given some in some problem, many competitive exam some problem will be given instead of giving the shear strength parameter they may give unconfined compressive strength is given some value. Then what you have to do? You have to take the shear strength parameter from there which will be nothing, but Cu equal to qu by 2. So, many time students take whatever is given that itself is Cu and then everything will be wrong. So, that is also another important point you should remember.

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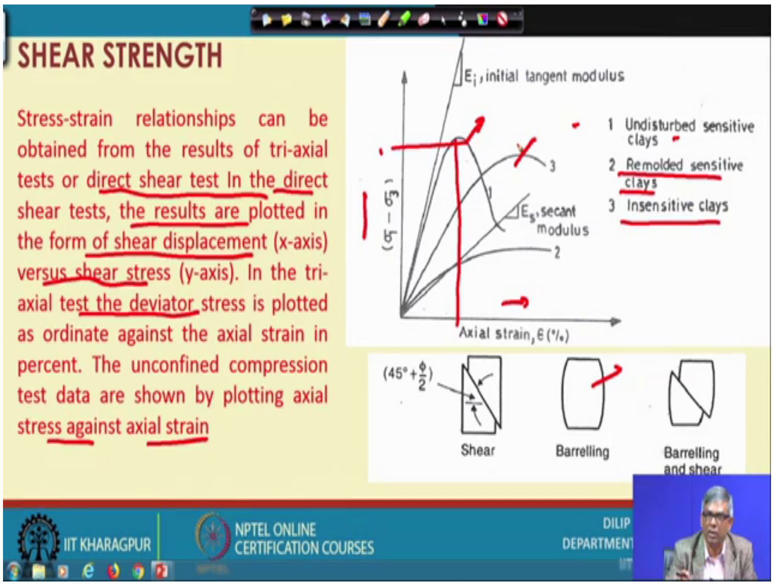

Now, shear strength relationship for different soil and you can see here generally we have different convention for plotting different test results and shear strength relationship can be of from the results of triaxial test or direct shear test or uncompression compression test any test you do. And results are plotted in the form of shear displacement direct shear test actually in the direct shear test it is plotted shear displacement x axis and shear stress is y axis and in the triaxial test one axis is deviator stress other axis is axial strain.

And for unconfined compression test it will be axial stress and other is axis. So, this instead of sigma 1 minus sigma 3 it will be axial stress. So, it will be nothing, but sigma 3 is 0 is nothing, but sigma 1. So, that is why.

So, now this is a figure represented here with shear strength behaviour of 3 different soil and you can see first one this is the one. This one is undisturbed sensitive clays sensitive clays when is undisturbed condition if you test you will have a prominent peak with a at a very low strain if prominent peak stress which at a lower strain and this one typically can have some failure like this suddenly.

And second sample is remolded sensitive clays. So, in the sensitive clay it remolded and sample is prepared and tested then it will be stress will be increasing the stress here actually stress will be increasing gradually much more gradually with a increase of shear strain compared to this, this here actually shear strength with the shear strength verses increase of shear strength is quite rapid.

Whereas here with the increase of shear strain shear stress increases quite slow and it you can see it will be continuously extend and it may not show any prominent failure and; that means, how to decide that whether test is completed or not. So, that when this behaviour occurs that time sample say take like this barrelling that mean it will shortened and it will laterally expanded. So, that is called barrelling happens and how much we allow. Generally to terminate the test we generally 15 to 20 percent strain, if it is exceeds the 15 to 20 percent strain then we terminate the test and we consider that as the failure. So, if barrelling occurs; that means, we allow maximum up to 15 to 20 percent strain and then you terminate the test.

And similarly there is a another sample that is third one that is insensitive clays and it will be, it will have a comparatively increase of stress with increase of strain greater than this one, but lower than this one and it will be reaching to a peak then it will be sometime decrease in value or it will may continue constant. So, that is another type of soil that is insensitive. So that means, if this type of some time in a competitive exam this type of graph will be given and 1 2 3 is marked and then there will be several combination will be given what is what actually you have to identify. So, if until unless you know the behaviour of the soil a stress strain behaviour of the soil for a different condition you will not be able to identify. So, that you have to understand properly. This is actually for undisturbed sensitive clay, this is a remolded sensitive clay and this is a insensitive the normal soil.

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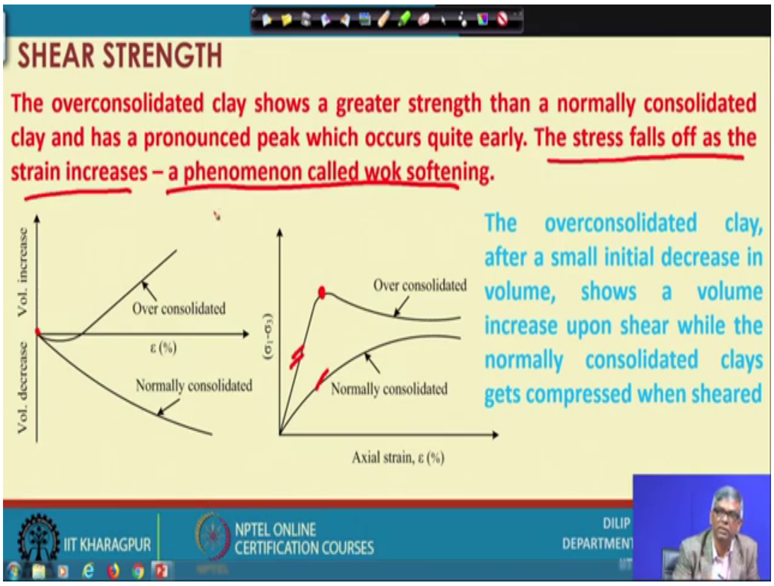

And now as I have mentioned at beginning normally consolidated and over consolidated you can see here when normally consolidated soil you test axial strain, verses shear strain that will be continuous increase and deviator stress with the increase of strain and it will be reached to a peak, and then it may continue keep constant or decrease little where as for over consolidated clay it will be increase the stress with the increase of strain sharply reached to a peak value and then it will be going down.

So, this is over consolidated clay shows a greater strain than a normally consolidated that; obviously, strength and strain this is a greater strain than this and has a pronounced peak it has a peak, but it does not have any peak and the stress falls of as strain increases; that means, beyond this if you increase further strain then the stress strain value reduced and that phenomena is called work softening.

And this is one thing and then while shearing also normally consolidated soil generally continuously decrease in volume, as a result, so volume decrease will be there. So, if this is the 0 change, 0 reference then if you axial strain verses volume change if you observe for normally consolidated it will continuously decrease in volume. Whereas, if it is over consolidated clay it initially it will show some decrease in volume, but after sometime it will be continuously increase in volume like a behaviour dilation in sand similar type of things is happened here.

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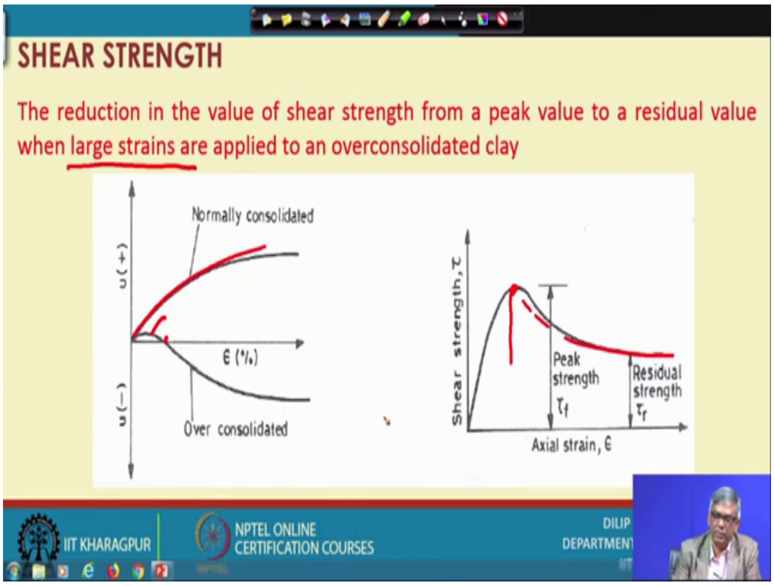

And the deduction in the value of shear strength from peak value to a residual value when large strains are applied to over consolidated, over consolidated typically whatever we have shown there. So, it will reach peak after reaching the peak and if you apply a large strain then it will fall and reach to a value that is called residual strength. And since during the shearing there is a volume change is taking place and you have seen for normally consolidated it is continuously volume decrease if it volume decrease then what will happen pore pressure will be positive.

So, that is what it is happening if a pore pressure measurement you do normally consolidated test during shear then your pore pressure will be continuously like this whereas, if you observe for a normally over consolidated clay their actually you have seen that initial strain few strain level sorry due to initial straining up to some percentage the volume will be decreasing. So, there also pore pressure is positive, but after reaching to a certain value of axial strain the volume increases.

So, that volume increase actually volume is increases volume increases your pore pressure will be negative. So, that is if it is a over constituted clay this is the pore pressure measurement during the shear if you do then initial increase positive pore pressure and then at some time it there will be continuously negative pore pressure will be observing during shearing.

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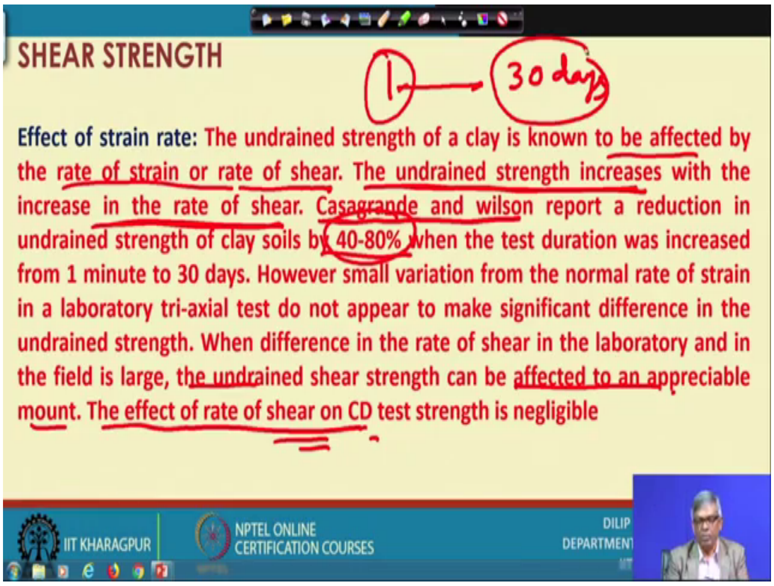

Effect of strain rate, that is also another when we to talk about the shear strength. So, triaxial test or unconfined compression test or direct shear test anywhere you do always we maintain a particular value of the state rate and what is the what is the effect of strain rate change of change of strain rate these are the several things and this is undrained strain of a clay is known to be affected by the rate of strain or strain or rate of shear. The undrained strength increases with the increase in rate of shear that is the observation. Undrained strength increases with the increase in the rate of shear.

And what rate, some before some scientist actually are they have any structure they observe this Casagrande and Wilson they have reported that this increase can be up to 40 to 80 percent when a soil sample is drained a shear suppose 1 minute and 30 minutes. If one sample is shear at within 1 minute, another sample is sheared by 30 days it is so slow, then because of this change of rate that increase in shear strain can be up to in the order of 40 to 80 percent, but different soil will have different increase.

How about the small variation from the normal laboratory test actually we recommend some value of a standard, but if there is a small change minor change that actually it will not may not affect the test. However, the difference in rate of shear; that means, whatever shear rate is in the field and actual field and what about shears rate or a strain you apply during the test if they are significantly different than your undrained strength will be appreciably different value will observe.

So that means, you need to maintain the strain rate expected during the failure during the failure in the field same strain rate if you maintain in the lab then only that value will be useful for the calculation. So, that is the thing you have to keep in mind. Whereas you can see when whereas CD test that mean consolidated drain test if you do in that case generally that there is hardly there is any effect on rate of strength subtended does not have much effect on CD test.

So, these are the few observation; that means, with the change of strain rate there is a increase of undrained strength we observe and whereas, in CD test generally there is no change. And in between qualitative information how much change; that means, 1 day to 30 days; that means, if you same sample if you shear by 1 day another sample will be shear over a period of 30 days then increase in strength can be in the order of 40 to 80 percent depending on the soil. So, these are the important point which can be noted for effect of stain on shear test.

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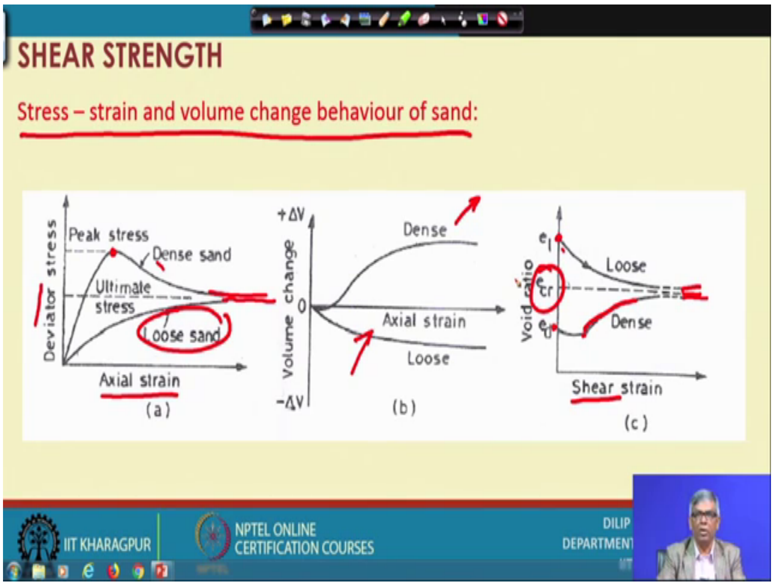

Similarly, stress strain and volume change behaviour of sand. Whatever we have discussed for clay at that to be, that to normally consolidated over consolidated different clays will behaving differently that we have seen. Now, here actually for sand also you can see that sand again like clay we have we have differentiated or divided into two group one is normally consolidated other is other one is over consolidated whereas, here sand actually classified dense and loose.

There can be in between also, but if is extreme dense sand if you test and extreme loose sand if you test and then we will whatever stress strain deviator stress verses this is a deviator stress and this is the axial strain if you plot, then this test actually for sand it will reach to a peak or a certain value of strength and then finally, it will be decreasing and reach to a constant value after high value of strain this shear stress or deviator stress reach to a constant value and that is called ultimate stress for that sand.

And if you test to a loose sand similar condition loose sand we apply deviator stress and we apply same confining pressure and stir it. Then you can see that the increase of deviator stress or deviator stress required to strain with the increase of axial strain deviator stress increases very quite slow, and it is a flat and finally, at a large value of strain it will be also meeting to the value for a fix ultimate stress of the dense sand. So, we can see it was peaking reaching to peck and then dropping to constant value and it is continuously increasing and it finally, reaching to the same value. So, this is the behaviour of shear strain, shear strains behaviour of the loose and dense sand.

And now another observation is we have seen already that your loose sand when is subjected to a sharing a load then what will happen; it will be continuously volume change will take place and that will be you can see volume decrease for loose sand for continuously volume decrease. And for whereas, in the for dense sand it will be initially up to certain strain value this volume decrease will be there, but up when it exceed that strain value then it will have volume increase that is dilation dense and will have dilation effect. So, this will be increase in volume. At this behaviour is, that mean dense sand behaviour is almost like almost similar to over consolidated clay and loose sand behaviour is similar to normally consolidated clay behaviour.

Now, another observation is that we have mentioned that critical density where if you during shearing neither it goes undergo volume change or increase or decrease and neither increase nor decrease. So, that is called critical density and corresponding to critical density you get the critical void ratio.

So, here actually if you consider a loose soil the initial void ratio may be here that is e lowest or loose and when you shear continuously at different stages is void ratio will be decreasing that because its volume is changing means voids is reducing. So, void ratio automatically becoming smaller. So, it will be with shear strain value void ratio will be decreasing, but the decreasing and at a large strain value the value become that will be void ratio will become constant.

Similarly, for dense sand it will have a very low value of void ratio dense sand mean void is less and as we see that at initial portion of the shearing it volume change volume increase happens. So, because of that void ratio will also decrease up to some point and then further increase of strain the volume will be increasing. When volume increasing will be there then your void ratio again will be increasing.

So, that because of that from here there is a upward direction, upward movement of the void ratio plot and finally, it will reach to a constant value where it will be reaching loose sand when is a last end whatever value it reached dense sand also and a last end will reach to it will value will be reducing, but finally, it will reach to a stable value and that value is a nothing, but the critical void ratio. So, this critical void ratio also can be obtained from the laboratory by some mechanism and that you can see in the next slide.

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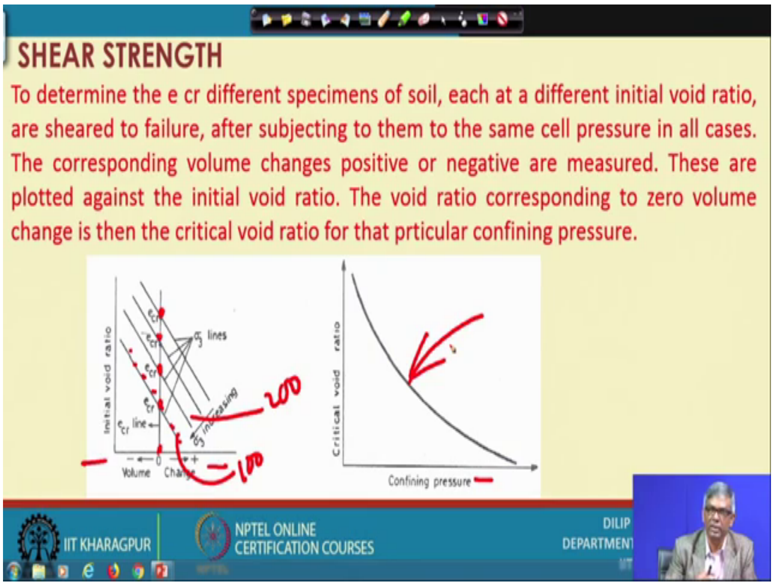

You can see here that we can see at this point, this point actually no volume change and if it is a positive volume increase this side and volume decrease this side if I plot and this side is initial void ratio. Suppose I choose a initial void ratio very small and then I apply confining pressure certain value of confining pressure and then I will see the volume change and if I see the volume decrease then I will get some point this side and if I see the volume increase then I will get a point this side.

So, like that for a particular value of confining pressure I will choose several initial void ratio and then I will get several volume change either increase or decrease. And then finally, those points if the confining pressure is constant. So, for different initial values the initial void ratio values if I test volume change or measure the volume change those point if I plot here those points will be in the same line and if I join all those lines it will pass through this line 0 line. So, when this line is intersecting the 0 line that is actually critical void ratio.

Similarly, now suppose I have conducted this test to the sigma 3 equals to some values of ten k p a or 20 k p a or 100 k p a, now I will do another set of test with another confining pressures of 200 k p a. Now, again with 200 k p a I will choose at one initial void ratio and then I will go up to shear and see what is the volume change if it is decrease I will put this side if it is increase I will put this side. Then I will take another initial void ratio then same confining pressure and go up to the shear and see what is the volume change if it is again decrease this side decrease this side like that I can get a number of points and finally, those points if I see that they will be coming in a straight line and that straight line when will join it will intersect the 0 point at this point.

Then; that means, the second suppose it is 100 k p a confining pressure this is about 200 k p a confining pressure. So, for different confining pressure we are getting deferent critical void ratio. So that means, by changing confining pressure and changing the initial void ratio we can get those lines and those lines will be intersecting with the 0 volume change line and from there we can get the sigma corresponding to each sigma 3 values I can get the one critical void ratio.

And finally, if I plot them critical void ratio verses confining pressure I will get a curve like this. So, this can be so critical void ratio is a very important term for sand where we will not get any volume change. If it is, if the void ratio is lower than the critical void ratio then it will dilation will be there; that means, volume increase and if the void ratio is greater than the critical void ratio then on shearing the volume decrease will be there. So, that is the important observation can be noted.

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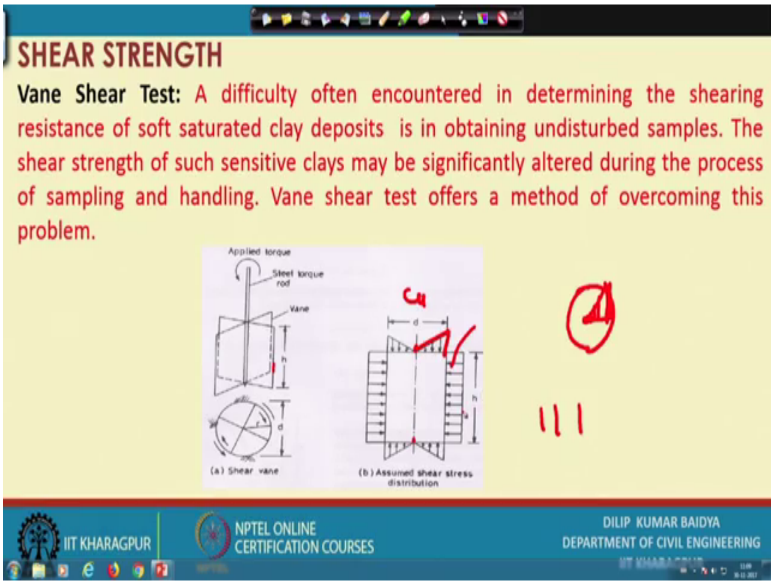

Now, another last I have listed several test I have mentioned direct shear test, I have mentioned triaxial test, I have mentioned unconfined compression test and I have mentioned also vane shear test.

So, vane shear test is a very import test is a field test basically why and where we apply this field test actually generally when there is a very soft and sensitive clay there actually obtaining a undisturbed sample is very very difficult and while if you try to do that then actually it is actually strength behaviour will change significantly and because of that instead of sampling to that soil we can directly go to the field and test and that is the test actually vane shear test which is suitable for soft sensitive clays.

So, this is the vane shear test it will be have four wanes and it will be welded to a rod and between two wanes actually there will be ninety degrees angle; that means, you can imagine one rectangle here this side one and other side one as these two together when we join one rectangle the length width of a rectangle can be considered as a diameter of the wane.

And whereas the wane in this direction depth wise that is the considered as a height of the wane and these wane actually with this connected to a rod with 4 wanes it can be lowered or you have pushed inside the soil and after pushing to the soil then of the desired depth and we can through the road we can apply a torque. And when we apply the torque then the different places shearing resistance will be developed so that shearing resistance can be developed below the wane one the soil this, like this, and shear strain resistance also can develop above the vane they if it is inside the soil deep enough then before failing that above the surface of the at the top of the wane also there will be shear and also cylindrical surface. Suppose this is the wane is rotating while rotating the soil around will give a resistance like this so that mean resistance around this cylinder.

So, that is what. If I imagine those our stress actually and you can see there is a whatever cylinder vertical surface whatever resistance that you can say Cu here and similarly at the bottom this is actually like a circular shaft to you are applying a torque. And you know that from solid mechanics the shear stress distribution along the, it will be something like this, 0 will be here and at the periphery it will be maximum shear stress. So, that is what at the base or at the top shear stress or shear strain distribution is like this here is a maximum here and minimum here.

We can use this, but instead of using this we are considering a average, average shear strength whatever is here we are considering shear soil shear strain same value here that is Cu here, that is uniform I will consider at this place I will consider Cu also here and if I consider that based on that I can whatever external torque I have applied and whatever resistance develop and that can be converted into torque and that to be equated from there I can find out the shear strength of the soil. So, I will show those in the next one or two slides.

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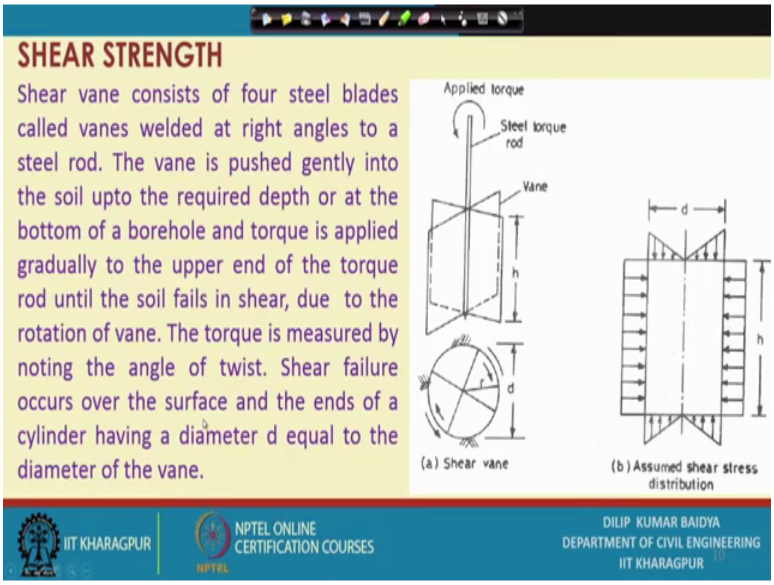

So, this is the thing once again I have explained here this is the wane and we to apply whatever already all I have told in this one I do not want to spend much time on this.

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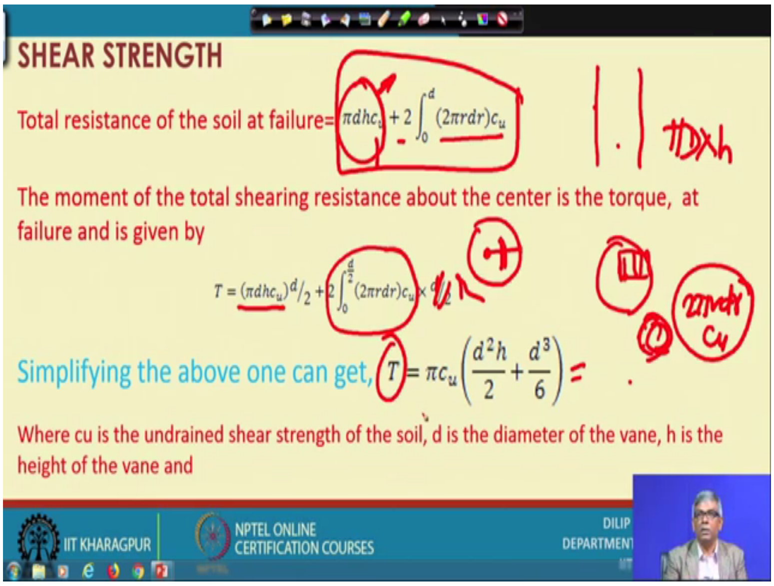

And this one this is a, see as I have mentioned that from the cylindrical surface, this is the cylindrical surface and when it is when is rotated, so along this surface the shear will be there, perpendicular to this the shear will be there like this. So, if I consider shear is Cu undrained shear strength then what will be the force will be there is perimeter is pi times d and then if I multiplies by h then it will be total surface area of the cylindrical surface. And if you have undrained shear strength is Cu, Cu multiplied by surface area will become the shear force similarly in the circular area if I consider uniform pressure here throughout and then at a radial distance r, if I take if I consider a annular area.

So, it will be its area is 2 pi r into dr the area is 2 pi r into dr and if I multiply by Cu then it become force. So, that 2 pi r dr into Cu this become force and r is varying from 0 to d suppose if the circle is this one, this is 0 and this is d. So, varying, I will have to integrate 0 to d and since resistance come from top and bottom and I if I assume resistance from the top and bottom same I would can after doing this I can multiply by 2. So, this will be the total shear force developed by the vane.

Now, but we have applied moment. So, we have to equate with moment only. So, if I want to take the moment then whatever I have got this one this is acting at a distance r from the centre. So, I will multiply this force multiplied by d by to then I will get a torque all of your shaft. Similarly, this is the force and again it is acting at a this is not d by 2 this will be r actually this will be r actually. So, at this force was at a r distance then I will multiply by r. So, I had taken annular being here. So, this force in r I will multiply and then this become torque now. This when I am this was force I am multiplied by r this become torque this was force I have multiplied by these then become torque.

So, this torque suppose is (Refer Time: 30:19) we applied torque and this one if I integrate and simplify equate with this torque then I get this expression pi Cu d square h by 2 plus d cube by 6 when I have considered resistance from both the surfaces and where Cu is the undrained shear strength.

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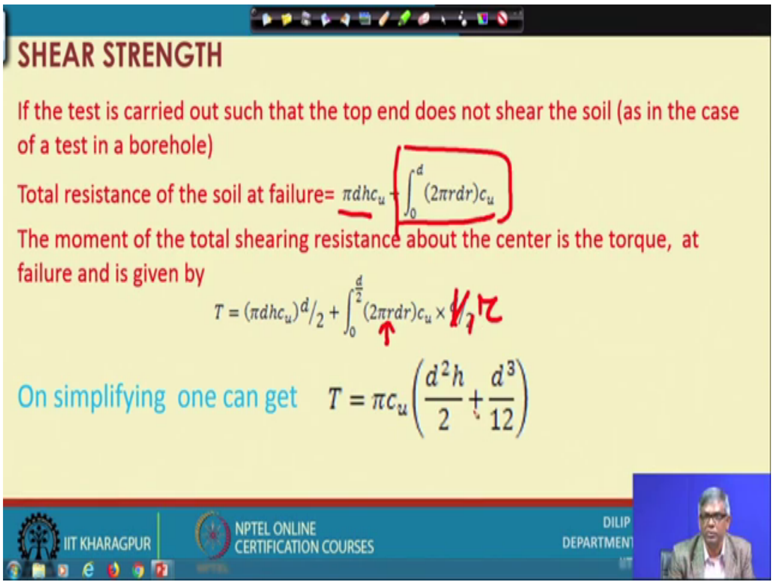

And now if I consider the, if I ignore the resistance from the top then your total shear force will be this much total this much and this will be one this not multiplied by 2 and this will not be d by 2 it will be r actually this r distance we have taken.

And so again this one if I equate and simplify then T equal to I will get another expression slightly different from that because we have ignored the resistance from the top. So, this is the another expression.

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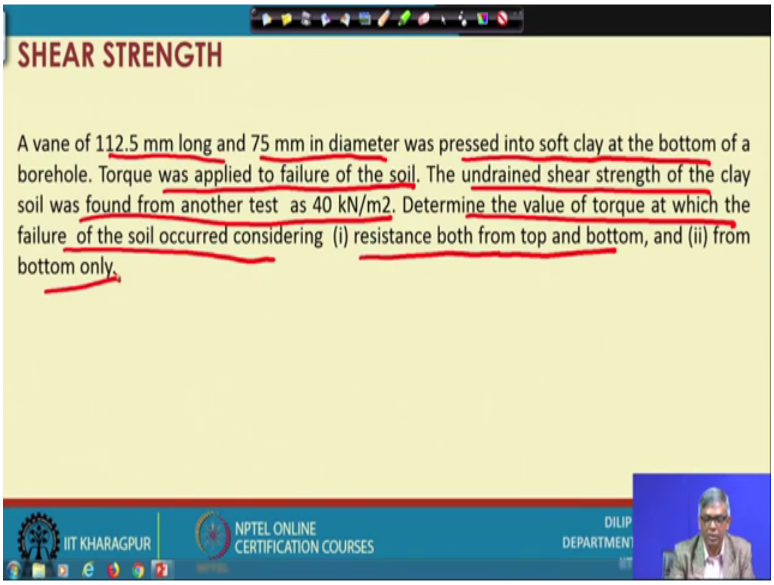

Next I can give you one example of this the problem is a vane of 112 millimetre long and seventy millimetre diameter was pressed in soft clay at the bottom of a borehole. Torque was applied to failure of the soil. The undrained shear strength of the clay was found from another test 40 kilo Newton per metre square. Determine the value of torque at which the failure of the soil occurred considering, resistance both from top and bottom and (Refer Time: 31:43) from bottom only.

See if I do this problem it will be very simple problem just application of if I consider the first one.

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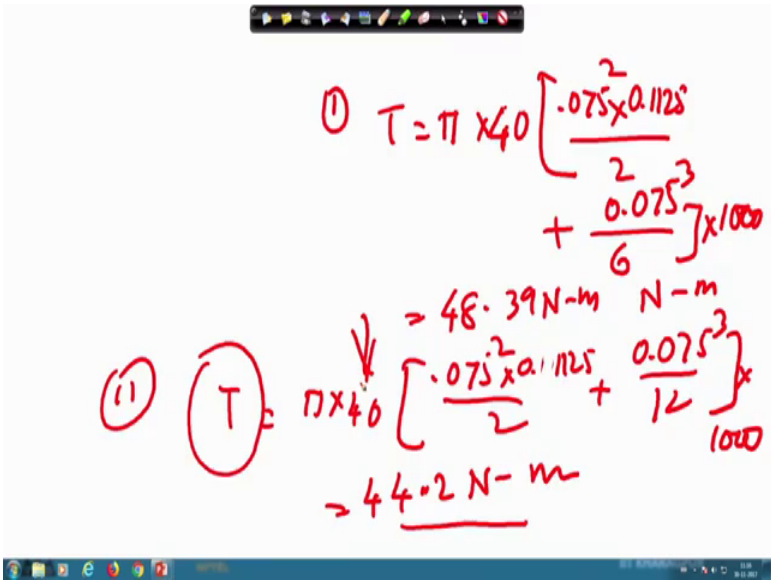

First one expression will be T will be equal to pi Cu actually forty and your it will be 0.075 square into 0.1125 divided by 2 plus 0.075 cube divide by 6 into 1000 Newton metre. So, it gives you the value equal to 48.39 Newton metre. And for second case actually it will be T equal to pi into 40 into 0.075 square into 0.0 not 0; it will be 0.1125 by 2 plus 0.075 cube by 12 here, into 1000, that gives you 44.2 Newton metre.

So obviously, when resistance at the top is not there lesser torque will be required. So, that is what when you have considered only one side resistance you have got the lesser value of torque. So, this is the problem. We have since suppose from some test we have got the undrained strength and we can verify by torque. Generally we measure the torque generally we measure the torque and get the value of Cu. Here actually for the verification purpose suppose Cu is known what value of torque is required that is suppose we can be want to find out this problem is given in the reverse way.

Thank you. So, I will stop here. This is the one, I just want to almost clear. Almost shear strength is covered. Now, since it is a very important topic I will take one more module where I will just highlight the important point and summarise the shear strength topic.

Thank you.