Soil Mechanics
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Lecture – 45
Shear Strength of Soils
Lecture No.3

So students we meet again for the third lecture on shear strength of soil. We had 2 lectures where we have covered quite a bit of ground on certain very important concepts relating to shear strength of soil. Notably we spent a lot of time in understanding an elegant graphical procedure called the Mohr's circle procedure for determining the stresses at a point on any arbitrary plane. You may recall, the reason why we did was we need to know what is the stress acting on any given plane and to test according to some strength criterion or failure criterion whether or not shear failure will take place along that plane. And that's what shear strength of soils is all about. Given a set of stresses will the soil fail and if so along which plane and that's what we will be able to determine. Once we know the so called shear strength parameters or the strength parameters of a soil against shear. Today we will go further a head from what we saw in the last lecture.

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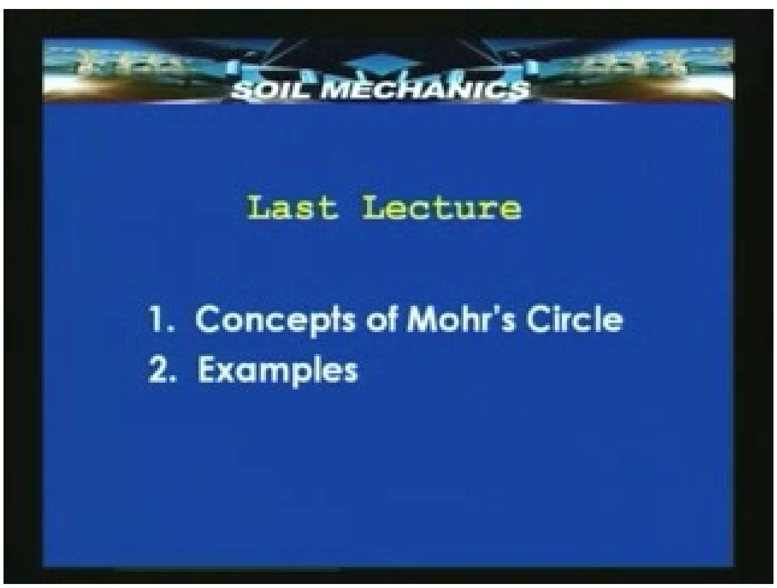

We shall go ahead and see some typical strength tests which are being usually done in order to get the strength parameters the so called cohesion and friction of the soil. There are many methods; we had in fact briefly gone through all methods as an overview in the first lecture. In today's lecture we shall be covering some of these tests in some detail. We may have to devote one more lecture to understand these tests a little more in detail. The first test that we shall be seeing at some length is the direct shear test DST.

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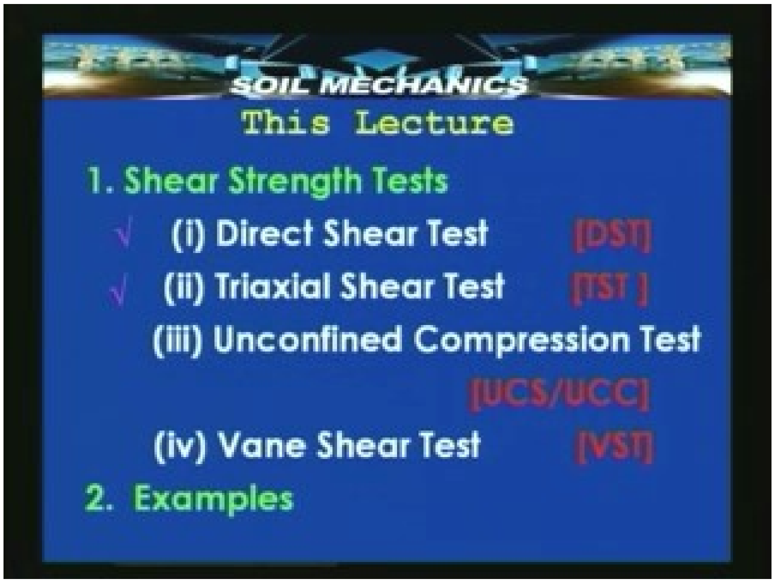

The second is the triaxial shear test TST, the third one is the unconfined compression test which is sometimes called as unconfined compressive strength test UCS or sometime it is called as the UCC unconfined compression test. The last one is the vane shear test. We shall be essentially seeing the first 2 which I have marked here with this symbol. We shall see the first 2 test in detail today. We may have to devote some more time to study them a little more in detail later and then the last two we shall take up later. Whatever we see today I will illustrate with a couple of example as well

Now there are many ways in which this topic of shear strength can be presented. After all what we need is what is the shear strength of a soil? Now the shear strength of a soil depends on many factors. So depending upon the factor that you are using a yard stick (Refer Slide Time: 4:15 min), you can study this chapter of shear strength of soils in different perspective. If you are looking at the type of test that's being conducted, the equipment that's being used then we have the classification which I showed in the previous slide. That is the direct shear test, the triaxial shear test, the vane shear test and so on. The yard stick that has been used is the way in which the shear stress is being conducted. In the direct shear test as we will be seeing, there is a predefined plane along which the soil is sheared.

In the triaxial shear test on the other hand we try to simulate the natural actual site stress state and then allow the soil to fail along the weakest plane. In the unconfined compressive strength test which is a very special case of the triaxial shear test, once again we allow the soil to fail along the weakest plane. In the vane shear test, we create a failure plane by rotating a vane inside the soil and try to study what is the resistance that has been mobilized along that known plane or surface. Another yard stick that we shall be seeing perhaps not today is the type of test conditions that we provide during testing.

Notably the condition with respect to movement of water, you know how important water is. Whenever we shear a soil which is say saturated or which has water in it, the water will try to move out. Now if you don't provide the facility for the water to move out or if the soil is not pervious enough to allow the water to move out at a reasonable rate then we have what is known as the undrained condition. Under all other circumstances when water is able to move out freely, flow free out of the sample which is being tested, we have the drained condition. So depending upon the type of condition that you use whether it is drained or undrained, the soil will mobilize and exhibits and manifest different strengths. And therefore the type of test is important and we can use that as a yard stick for dividing the different types of tests and understanding them.

There is also another yard stick that is the nature of the soil itself. Is the soil cohesive or cohensionless? Depending upon the type of soil its response will vary according to the type of test we conduct. And therefore we need to also study the type of soil and its effect on the shear strength. So these are the 3 possible yard stick. Let's see what is the importance of type of equipment that is used and what's the type of test that we conduct. So we shall be now seeing the direct shear stress. First test that we shall see in detail is the direct shear test. Now here is a diagram showing a schematic of the direct shear apparatus. See here, this is a metallic container what you see here is a metallic container.

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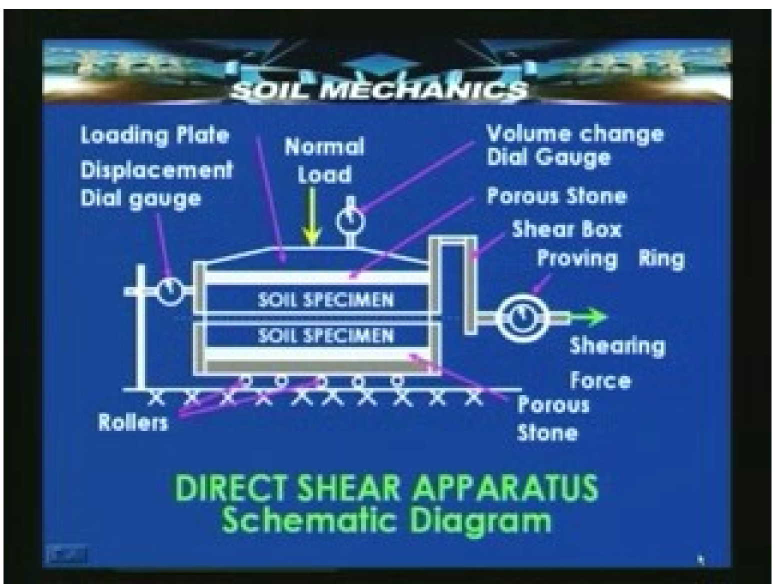

This upper portion is a part of the same container, the container is split into two halves and there is what is known as the yolk to which a proving ring can be attached, is fixed. And the soil specimen is kept in this container and the specimen again is kept in such a way that there is a small gap between the 2 parts of this container. So that the upper portion can be moved relative to the lower portion.

Then on this side you have dial gauges to measure the movement of the upper part and on the top of the specimen we have here a loading plate on which is the normal load applied. So effectively what we have tried to do here is, you have taken a sample of soil, we are trying to apply the kind of load that it is experiencing in the field and then we are applying a shear force a tangential force and make it fail and then see how it fails and what is the resistance it has mobilized at the time of failure.

So the component of this so called shear box are, there is this container. Then there is this cap which is the loading plate. There is a dial gauge to measure the displacement; there are rollers to permit the bottom portion also to move if required, there is a porous stone at the bottom of the specimen and at the top. And there is a dial gauge at top again to measure the volume change that will occur when the specimen is sheared and the upper portion tends to move outward and upward. These porous stones permit drainage of water.

Now as I said drainage is very important depending upon the condition of drainage whether we allow drainage or not or whether the drainage allowed is slow or fast depending on these conditions we will have the so called drained or undrained state and the behavior of the soil will vary and we shall be seeing shortly how this drained conditions really exists in a direct shear test do they or not. Here is where we apply the shearing force; this green arrow shows the shearing force. So in effect this describes what a shear stress direct shear tests is all about.

The specimen is typically 6 centimeter by 6 centimeters in plan area and 10 millimeters in each half, so a total of 20 millimeters. A normal load is applied first that simulates the confinement that the soil is experiencing in the field. After you apply the normal load and after you assure that the confinement and its effect have been recreated. Then we apply the tangential force until failures occurs. And the tangential force at failure divided by the area of cross section is the shear stress that the soil is subjected to. And now at the time of failure if you plot the shear stress and the normal stress for atleast 3 different tests with soils specimen molded at different moisture contents or different densities and we plot a graph which we shall be seeing later. We can evaluate and get the 2 shear stress strength parameters, cohesion and angle of internal friction.

Let's proceed. Here are 2 views of direct shear test; here is one direct shear test very old and very conventional. Here is a slightly improved and better version, the different is in the application of the normal load and shear force here. The second one, the diagram on the right hand side is a motorized device to apply the shear force. The components of these boxes are one specimen so this is where the specimen is kept; this is how the container looks. The normal load is applied here through this lever arrangement here also you can see this lever arrangement for applying the normal load. Then comes the motorized shear load application here you see the motor here and here the motor is not very visible but there is a motorized arrangement here as well.

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In earlier versions of this the application of the shear load was also manual and then we have the proving ring to measure the tangential load and then the dial gauge here to measure the vertical displacement. So this is how a direct shear apparatus looks. There are two types of test devices. We have to apply a shear force to the soil, we have to allow the drainage to take place if we want to do a drain test. All this implies that there has got to be a certain rate of shear which should be sufficiently slow considering the type of soil we have to permit water flow. Obviously the rate of shear will vary depending upon the type of soil, its porosity or its coefficient of permeability and the flow of water. Therefore we need to have the facility to have different shear strain rates.

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It’s possible to also control the application of the shear force not only by controlling the shear strain rate but also by applying the load itself in increments in such a way that the shear stress applied is in certain increment. So we can either control the strain at which the movement takes place or we can control the stress that’s applied. Accordingly we will have a strain controlled device where shear deformation is applied at a constant strain rate till failure and even beyond if we are looking for testing beyond the failure state as well. And it gives good loading control because it is very easy to have a mechanical device, reluctive mechanical device a motor to be precise by which constant strain or a constant rate of movement of the shear box can be very easily achieved.

On the other hand we also have this stress controlled equipment where the shear load is applied at uniform increments until deformation ceases. Here it’s difficult to identify the point of failure as we have done in this strain controlled equipment and therefore we keep loading in uniform adequate intervals until we find that for any given load the deformation come to a halt and then we apply the next increment. This goes on until the sample finally fails. Now let us look at the same 2 equipment once again. Both of these are conventional equipment, both are strain controlled because here there is a motor, here there is a motor which makes the upper portion of the container here to move at a uniform rate of displacement, same thing here.

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On the other hand here is an equipment which is very sophisticated and microprocessor control which is also a strain control device but it is digital, it gives you all digital display, it gives you 100% control over application of loads both normal and tangential. So this is the latest modern version of the direct shear apparatus also strain controlled.

The stress controlled apparatus doesn't look very different; it is just that in place of the motorized arrangement application of the shear force, we have a slightly different chain based arrangement by which a load is applied in increments. Let's take a look at how shear takes place.

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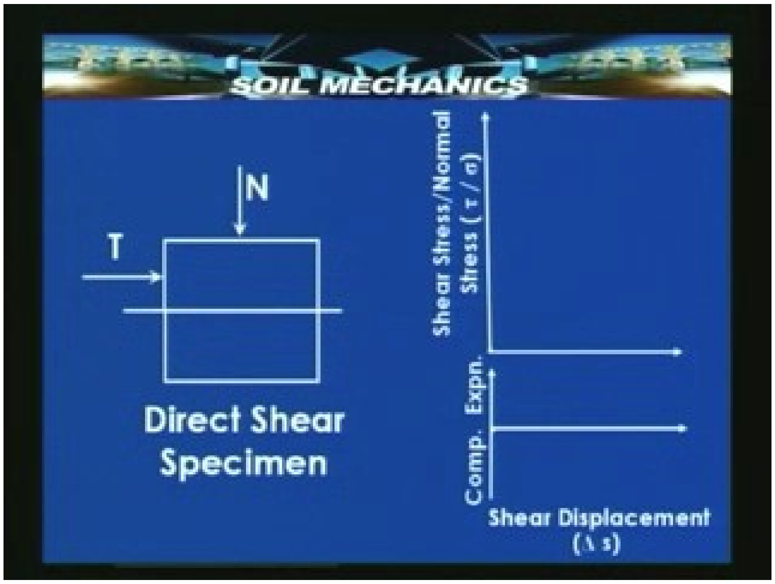

You can see here the upper portion of the specimen is moving relative to the bottom portion and simultaneously depending upon the movement, the shear stress by normal stress ratio goes on increasing and what you see here is typical of dense sand under direct shear condition and you will also find that this is upper part has moved up by a certain amount delta y.

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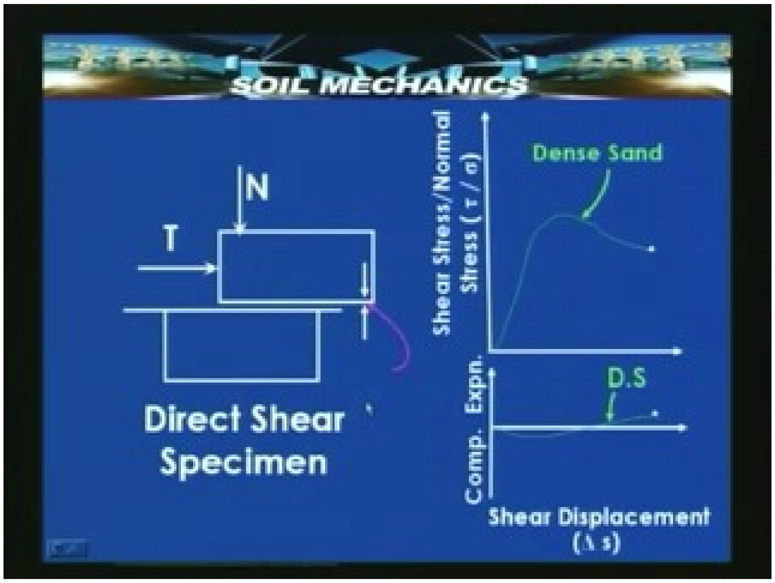

This is due to the volume change in the sand as the shear force is applied despite the existence of the normal load. There is a vertical movement upward due to volume change or dilatancy of the sand and if you plot the vertical displacement as a function of the shear displacement, you will have a graph like this. This is again for dense sand. What you see here is in the first upper plot that in case of dense sand when you induce a shear displacement that is when you conduct the direct shear test, as the shear displacement here this delta S goes on increasing the shear stress to normal stress ratio goes on increasing and it reaches a peak and after further displacement it tends to come down and it reaches an ultimate stage.

This is very typical of dense sands. One of the reasons is as you apply shear displacement, a dense sand tends to become loose and as it becomes looser and looser at some point it starts showing a downward trend in the direct shear stress to normal stress ratio. For example the shear displacement shows how the expansion takes place. Initially even in a direct shear stress there will be a small amount of compression due to seating arrangement, when you apply the normal load there will be a small amount of compression taking place and then when you apply the shear load again a little bit of compression initially takes place due to adjustments against the applied load. And then if the sand is dense then gradually it tends to become loose and loose as the shear takes place and this is how the trend is and you find from compression we have now moved to expansion and this point the stage at which expansion goes on taking place is the stage at which the shear stress at failure comes down.

Now this can be taken as a point of failure corresponding to the peak shear strength but if you continue the test further, you have a point at which a study state is reached and this may be considered as the ultimate strength. Both have their significance in practical application. Let me mention it here at this stage for completeness sake but we will see it again later. The peak shear strength obviously is the maximum shear strength that the soil can have but that is related to this shear displacement, this mount of shear displacement. Now in an actual problem in the field if the shear displacement is confined or it is within this limit then it will reach the peak stress state and it will enjoy the peak strength but if the shear displacement, expected shear displacement in an actual practical situation is much more than this displacement. Then we must understand that the dense sand in this case is undergoing a large amount of displacement and at that displacement it is not likely to have its peak strength, it will enjoy only a much lower strength.

And any design that is based on this test should make not of this and if it’s a problem in which there is going to be a long duration and a large shear displacement taking place. Then we should be careful enough to consider the ultimate strength rather than the peak strength. Suppose we have loose sand, the phenomenon is just the opposite. In the case of loose sand as we apply shear displacement, the shear stress to normal stress ratio is of course goes on increasing but it tapers off here, it doesnt reach a well defined peak nor is there a drop at large displacement.

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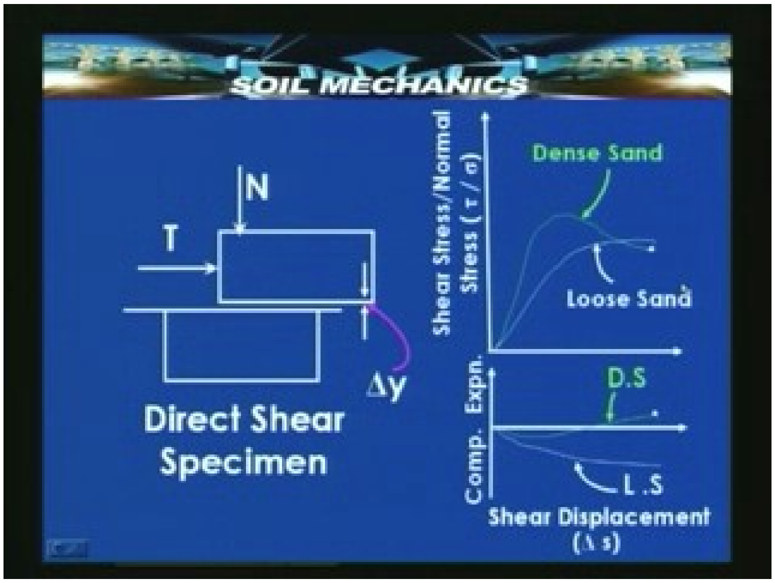

This is again because the phenomenon is exactly opposite of what takes place in the case of dense sand. In the case of loose sand there is a contraction taking place as the particle readjusts themselves under the action of normal and the tangential loads. When the particle readjusts themselves they can move up or down and then the net movement is downwards is a compression as the soil gets denser and denser. So here the shear displacement verses vertical displacement graph for loose sand is this bottom one here which is a continuous compression. This is a very simple illustration of what happens during direct shear in a typical coarse grained material. There can be variation is of course minor variation can be there and this is only typical of coarse grained soils like sand but when you go to clays or silks the behavior is not the same.

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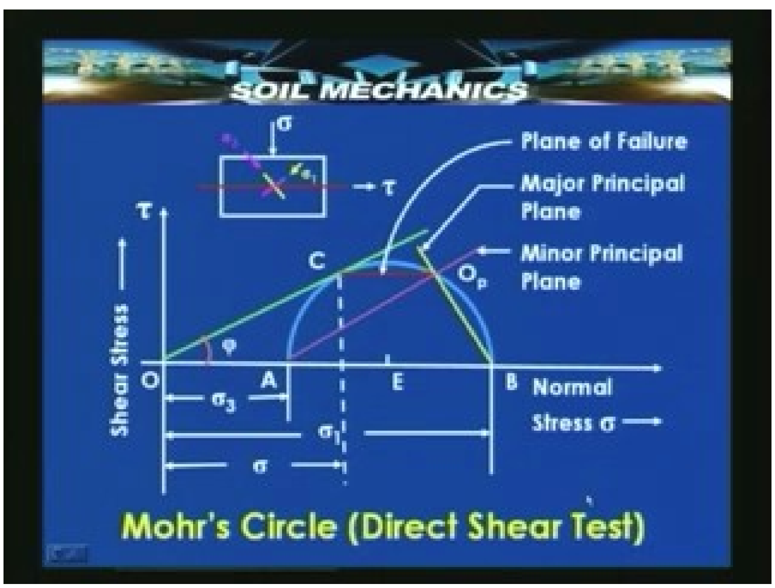

Now let’s see what is the state of stress that prevails in a direct shear test because that’s what is most important. We need to know what is the state of stress so that we can define what is the state of stress at time of failure and what is the mode of failure that takes place. After all here we are making the soil fail along a predefined plane and therefore the failure plane is already decided and correspondingly all other planes will have their appropriate stress values which if we need, we need to compute using either the Mohr’s circle or by a theoretical analytical formula.

Let us take the example of some determination of important stresses using the Mohr’s circle in a direct shear test. We have the normal stress; we have the shear stress the 2 axis typical of a Mohr’s circle. Then suppose we have the sigma and tow values at failure. Then sigma tow values at failure will belong to a point C typically as shown here. So this point C has coordinates sigma and tow and that should corresponds to the normal stress and shear stress on this failure plane because thats the point at which the Mohr envelop touches the circle. And therefore this point C corresponds to failure and therefore the Mohr envelop should pass through that and that should be tangential to the Mohr circle.

So now we can draw a Mohr’s circle which will be tangential to this envelop at this point. Now this being a drained test, direct shear test or usually drained test, cohesion is not mobilized and therefore this intercept on the y axis C due to cohesion is zero. Now if this is the envelop and if this is the Mohr’s circle, obviously the major principle stress will be OB and minor principle stress will be OA. It is of interest to know what are their orientations. Magnitudes are available now from the Mohr’s circle plot. Now what are their orientations? For example if you take $sigma_1$ to get its orientation we will use the so called pole method which we saw in detail in the last lecture. Take this point C, that’s the point whose stresses corresponds to that or rather those on the failure plane.

Therefore this point C is a point on a plane which should be parallel to this failure plane and must intersect the Mohr’s circle at the pole. So point C if you take and draw a line parallel to the failure plane at C then it intersect the Mohr’s circle at a point Op which now becomes the pole. The property of the pole is that from the pole if you draw a line parallel to any plane where it intersect the Mohr’s circle gives you the stresses on those planes. So for example if I draw a line up from Op to point B, since the coordinates of B have major principle stress and zero as the values. Op must be therefore represent the major principle plane that’s this yellow line because it passes through a point B whose stresses correspond to the stresses on the major principle plane that is sigma one zero.

So the major principle plane is very easily obtained once you know Op while connecting it to point B. Identically by the same method you can get OpA which will be minor principle plane. So we know the orientation of the major and the minor principle plane if I transfer them to this index sketch which I have here then this yellow line represents the direction of the minor principle plane, this pink line represents the orientation of the major principle plane.

And this means that although before failure the major principle plane is horizontal and the minor principle plane is vertical. At the time of failure the horizontal plane become failure plane and therefore automatically the major and the minor principle planes take up new orientations as given by these 2 lines and this angle which the envelop makes with the horizontal will be the angle of internal friction and if I join A C that will make an angle of 45 degrees plus phi by 2 as it should. Now this is how we determine the stress state in a direct shear test at failure.

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Now let us see a couple of examples to illustrate the direct shear test. This is a simple example, it read like this. Direct shear test is done on a dry sandy soil. Now I think at this point I should also elaborate. I am giving the example of dry sandy soil, the reason is I want to simplify the problem and illustrate for a very elementary case. Direct shear test are usually conducted as drained test, the reason is its very difficult to prevent drainage in them as you will see a little later. And we therefore usually conduct direct shear test on sandy soils or cohesion less soils. The reason is these soils are rapidly draining and therefore the drainage condition becomes irrelevant as long as drainage is permitted.

Now the shear strength of the specimen under such drained state in a direct shear test can be very easily determined if we know the normal stress shear stress values for at least 3 tests. So here is an example where the normal load normal stress shear load or tangential force and the shear stress are known for 4 different tests. That means test has been conducted under 4 different normal stresses and corresponding 4 different shear stresses at failure have been noted. Now from these set of $sigma_n$ and tow values it should be possible to determine C and phi. We can adopt the Mohr's circle principle; let me go back a little bit.

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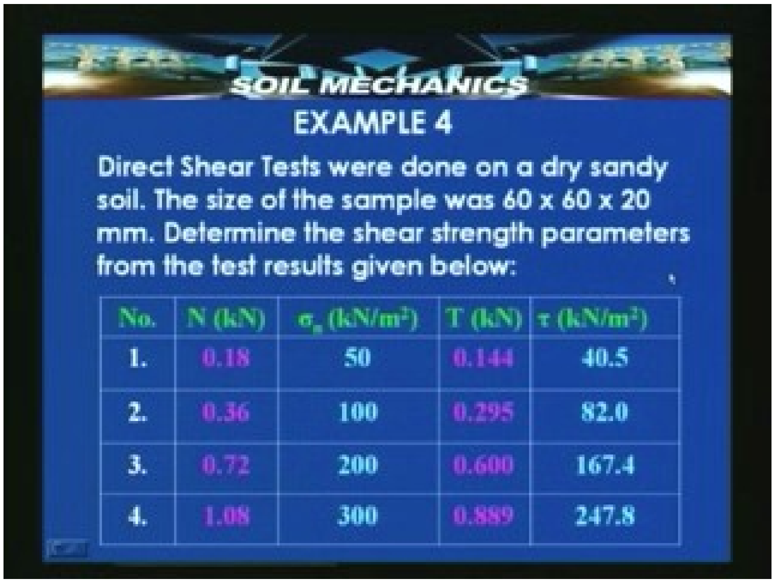

We see here that the Mohr envelop is tangential to the point C for which the coordinates are sigma and tow which means that if I take the 2 axis and test by test, if I plot sigma and tow corresponding to failure I will go on getting points C_1, C_2, C_3, C_4 one each for each one of the test conducted. So rather than drawing a complete Mohr's circle if I could just draw the x y axis shown here and plot this point C_1 C_2 C_3 C_4 of the 4 tests and join those C points, the angle that line will make with the horizontal will be the angle of internal friction. By doing 3 or 4 tests we get an average value using the best fit line through all the C points.

So we now here have normal stresses 50, 100, 200, 300 kilo Newton per meter square. These are some typical normally used values and the corresponding values of shear are 40.5, 82.0, 167.4, and 247.8. You will notice here that these values are always less than this; it's very rare that these values will go above the normal stress itself because as you will see that will indicate that the angle of friction is more than 45 degrees. There are very rare instances where angle goes beyond 45 degrees of course in the case of rocks it does go beyond 40, 45 degrees easily but it's virtually rare in the case of soils unless it's a very stiff soil.

So the sigma tow plot as it is called for this example would be like this. You take this normal stresses 50, 100, 200 and 300. They are all plotted to some convenient scale to the same scale remember to the same scale, the shear stress values are also plotted 0, 50, 100, 150 and so on and this 4 points corresponding to the 4 different test are plotted like this. You will notice that when they are plotted and joined, the line joining them will automatically pass through the origin because this is a drained test where cohesion does not get mobilized and here is the result for the first test.

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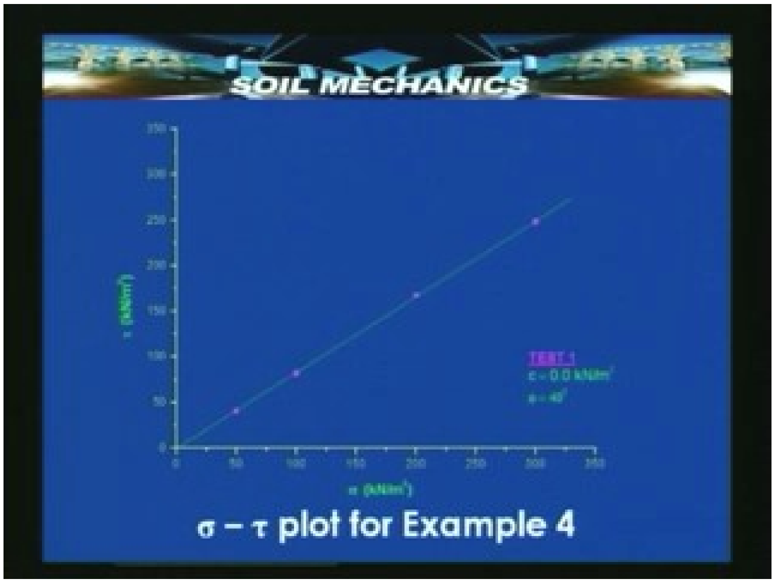

The intercept is zero therefore C is zero, since the test is a drained test the parameters that we obtained are known as the effective stress parameters. So this C this C really means C dash the effective stress parameter and this phi really means phi dash the effective stress parameter and C is zero where as phi is work out to be the slope of this line which turns out to be 40 degrees in this particular example. So now we are in a position to get the values of shear strength from a direct shear test, if we know the typical normal shear stress values of atleast 3 tests preferably more for any particular soil. Let's take another example.

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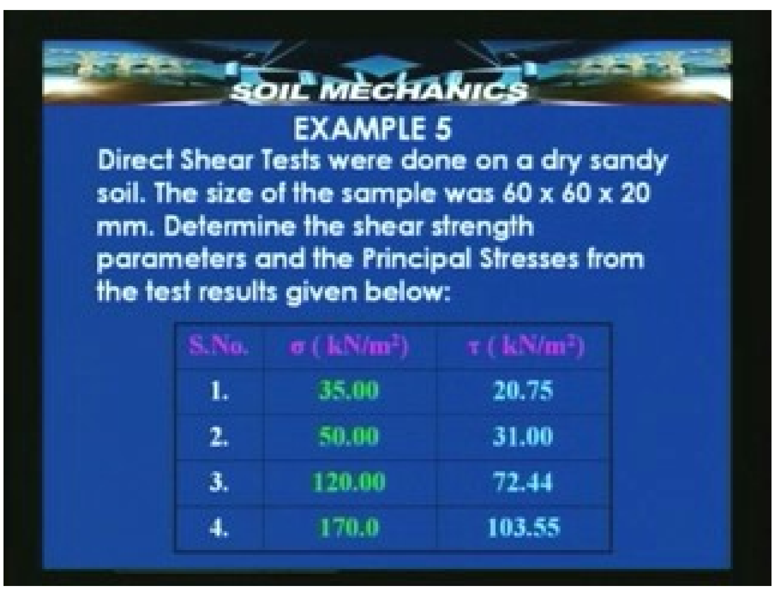

S.No.	σ (kN/m²)	τ (kN/m²)
1.	35.00	20.75
2.	50.00	31.00
3.	120.00	72.44
4.	170.0	103.55

This example is also a very simple direct shear test again on a dry sandy soil. The sample size is again 60 60 20 standard. We need to determine here also the shear strength parameter C and phi but in addition I have added here another parameter that is what are the principle stresses. From these test results can you calculate the principle stress as well? That means in the Mohr's circle which we saw earlier we want to determine $sigma_1$ and $sigma_3$ values corresponding to the extremities of the diameters of the Mohr's circle. Here the values of sigma and tow are 35, 50, 120, 170 kilo newton per meter square again somewhat typical values which are normally used and corresponding strength shear stress rather are 20, 31, 72, 103.

At one glance you will find that these values are rather small compared to the previous test. This immediately gives an indication that the value of angle of internal friction here is obviously must be lesser than what we got in the previous example that is example number 4. Let us see how this plots.

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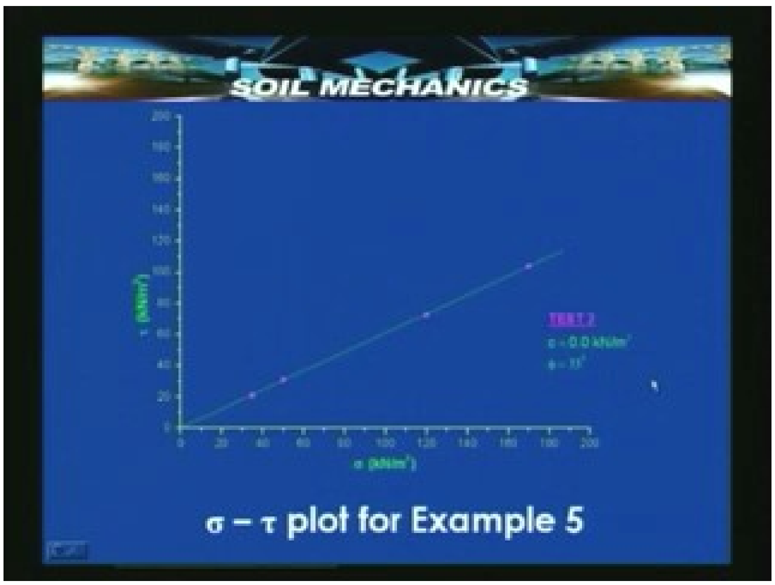

Now if you plot this, these are the 4 points corresponding to the 4 different normal stresses and the shear stresses and once again if you join these 4 points, the line joining these 4 points will pass through the origin because C is zero. Of course in a practical situation sometimes it may not actually pass through the origin but then it is fair enough to forcibly pass this line through the origin because C has to be zero under the conditions of drained testing. So here we have after plotting like this we get C equal to zero again as it should be and phi is equal to 33. This means that this has got a slightly lower angle of internal friction compared to that soil and it is therefore has having less strength. Note here one important point which I stressed here that is the scales for sigma and tow have to be the same, if they are not we cannot directly read out the angle here and take it as angle phi.

Angle phi will have to be then calculated as tan inverse of tow upon sigma because the coordinates of this are sigma tow and the angle of inclination will be tow upon sigma. And unless the scales are equal we are not justified in directly reading this angle and take it as the angle of internal friction. This is the plot for the example 5. It can also be seen that is possible to plot a complete Mohr's circle for this and if we do that what we will have is we already know sigma and tow. So take a typical value of sigma and typical value of tow and plot them you get the point C. Then you can draw a tangent to this, in the most general case there will be an intercept but in this particular problem there will be no intercept and the Mohr's envelop will pass through the origin.
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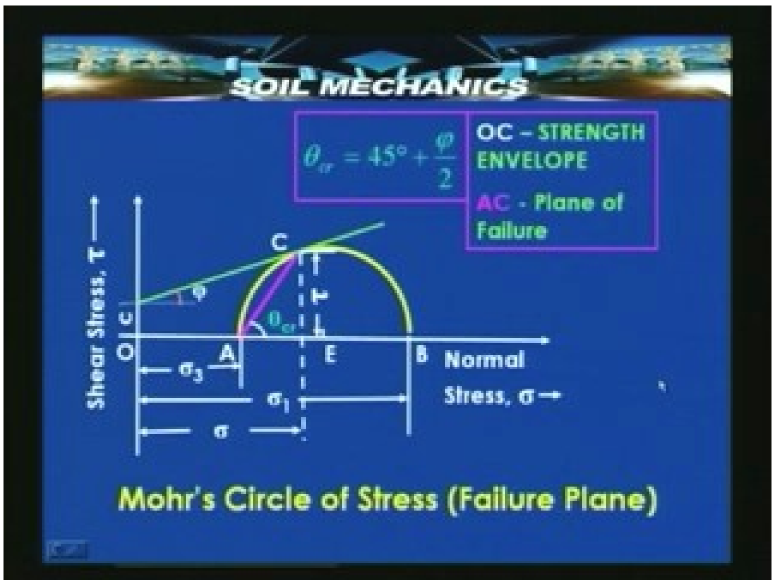

And this point C being the point representing the state of stress on the failure plane. Here a line drawn horizontally will represents the failure plane and angle as always will be the so called critical angle and it can be obtained as 45 degrees plus phi by 2. OC is the strength envelop here provided C is zero and AC is the plane of failure that's under normal conditions but in the direct shear test the plane of failure is supposed to be horizontal. So let us see a number of important points which can attributed to the direct shear test. Here I have on the first slide 4 points, number one is a direct shear test is good for relatively slow drained test, since it is open to permit drainage.

What are we doing in a direct shear test, we are moving one part of the container relative to the lower other part and in that process the specimen is continuously moving and when the specimen is continuously moving, it is going beyond the cylinder or the container. See here suppose this is the lower container, this is the upper container.

Now if the upper container moved and if it takes a position like this, in this position this part of the specimen is exposed and when this specimen is exposed you will find that there is a passage available for water and obviously therefore drainage is very difficult to restrain or prevent in a direct shear test so when we conduct the direct shear test as the upper part of the container moves there is a small path in the soil which is getting exposed which means that drainage has to take place and it is very difficult to prevent drainage and therefore a direct shear test is good for a very slow drained test on a soil which is not so easily draining if it is sand drainage takes place fast.

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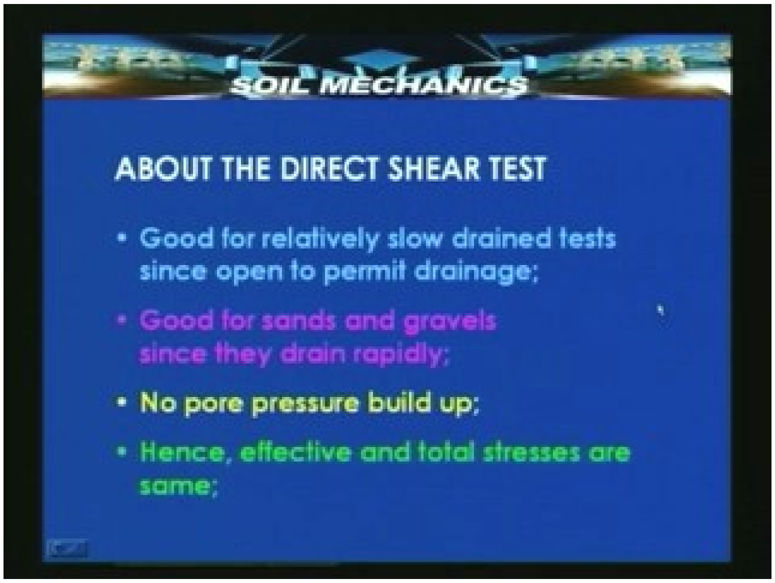

And therefore you can adopt a reasonably fast strain rate but if the soil is a slow draining soil then we should have a choice of strain rate which will permit us to move it very slowly so that drainage can be permitted sufficiently and we will get a proper drained test even on that soil which is not draining freely that is clay or silt for example. But since drainage cannot be theoretically and practically prevented whatever test we do in a direct shear apparatus is always a drained test and in drained test cohesion doesn't get mobilized and therefore a drained test always gives you an effective angle of internal friction.

Since drainage has to be permitted this kind of test is good for sands and gravels because they drain rapidly. It's very important that when we do the test we should not permit pore pressure build up because excess pore pressure build up would mean that the entire load that is applied by us is not getting transmitted to the soil instantly, it will wait until the drainage takes place to be passed on as intergranular test to the solid particles. Therefore in this test the strain rate is important it should be such, not to permit buildup of pore pressure. And since there is no pore pressure build up it also means that the total stress and effective stress are the same. There is no neutral pressure at all because the water pressure is not allowed to become mobilized at all.

So effective and total stresses are same in this test so whether you plot total stress parameters or you plot the effective stress parameters, the strength that you get will always be the effective strength and which will be incidentally also equal to the total strength. There are additional points, for clays the rate of shearing is so chosen to allow drainage because we can't do the test without permitting drainage and since we have to allow drainage and since clay is a slow draining material it is imperative that we choose an appropriate strain rate which will allow the clay sample to drain out.

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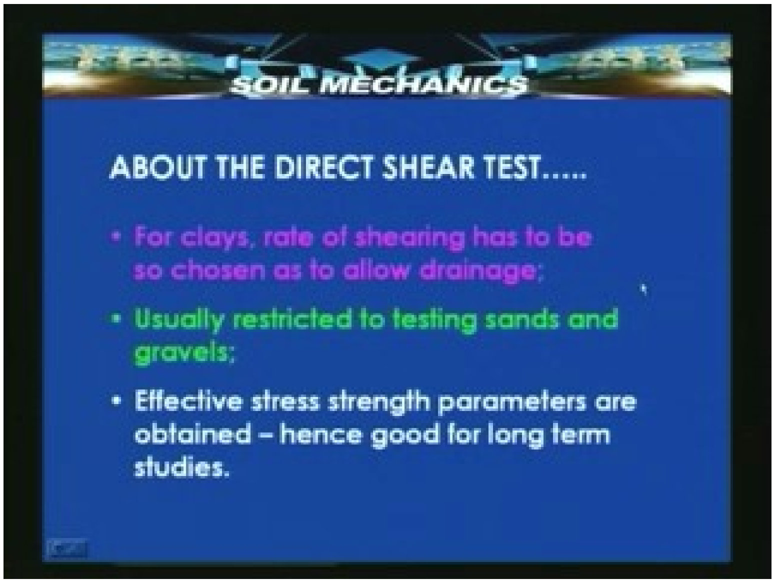

Now the testing is usually restricted to sands and gravels as we have already seen for this obvious reason and the effective strength parameters which are obtained from this test are good for long term studies. What's the importance of total stress and effective stress parameter? You might of course had a brief idea about this from some earlier lecture but let me repeat. The total strength parameters generally indicate a situation corresponding to the short term period or behavior of let us say an embankment. In the short term after the embankment has been constructed where the pore pressure in the water have still not got fully dissipated.

Total stresses still remain and we do not know the amount of pore pressure that exists and therefore the strength that we get should preferably be computed from the total stresses sigma$_1$ and sigma$_3$ or whatever or sigma and tow that we get. And the parameter of strength that we get from such a test will be known as the total stress strength parameters. On the other hand if we have a situation where an embankment has been constructed and several years already have passed and now we are having a situation where it is performing its long term function or let us say we want to design an embankment and it has got a certain life. Then we want to know what will be the performance of the embankment at the end of its life that is known as the long term behavior.

What is special about this long term is unlike the short term, the pore pressure that might have got build up in the embankment would have by now got dissipated because sufficiently long time

has elapsed and once the pore pressures which have been developed have got dissipated, the parameter of strength which we get from this are all effective strength parameters. And therefore the effective strength parameters are good for long term studies, long term behavior. Like this we have a few more important points.
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A specimen fails along a predetermined plane and not the weakest plane but in certain instances this is very useful. For example in rocks where there are predetermined joint planes which are already existing along which failure is likely to take place.
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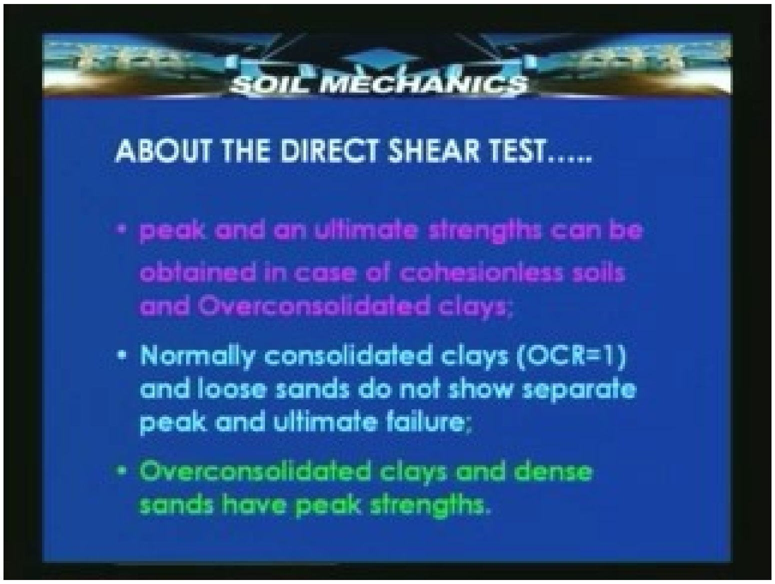

Then the next one is shear stress distribution along the plane is not uniform. It is obvious as the area over which the shear stress acts goes on decreasing, the stress distribution is no longer

uniform and this means progressive failure will takes place. And it is not possible to perform undrained test and therefore this is not preferable for clays.
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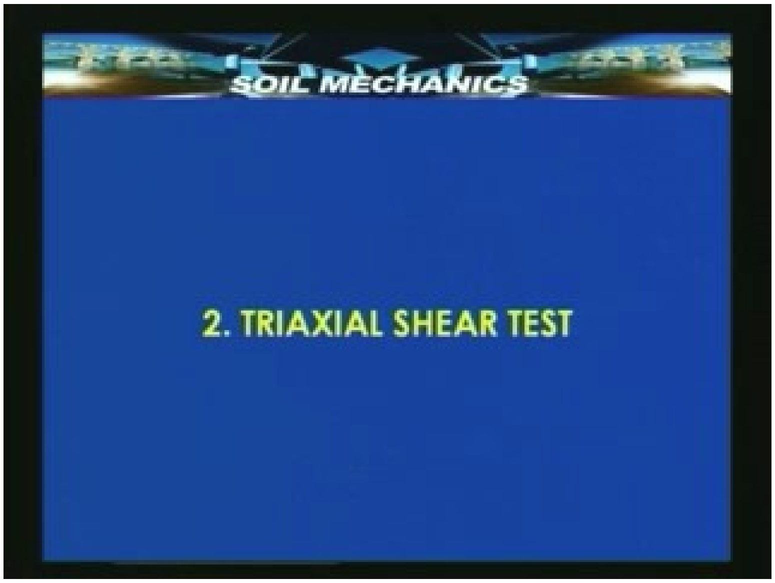

The peak and ultimate strengths can both be obtained both for cohensionless soils as well as for stiff over consolidated clays. Normally consolidated clays and loose sands do not shows separate peak or ultimate failure as we saw in one of the earlier slide. Over consolidated clays and dense sands do show peak strengths. Now let us take a look at the triaxial shear stress, this is how a triaxial apparatus looks.
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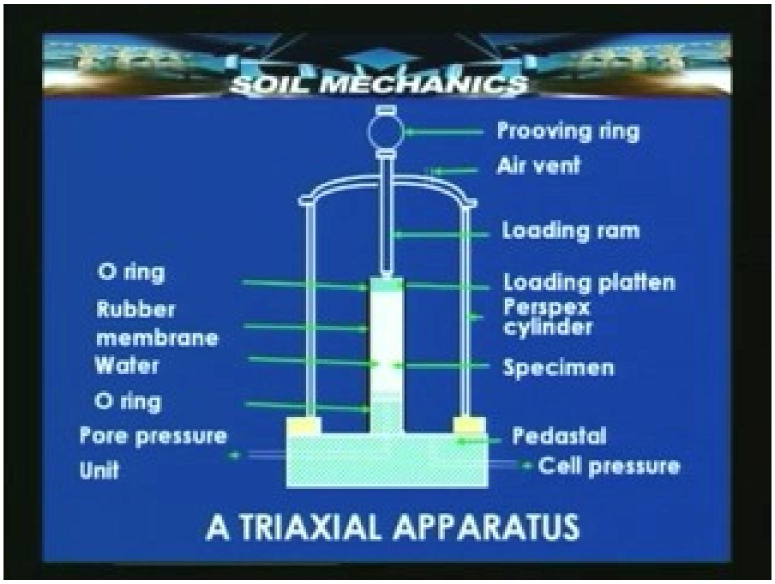

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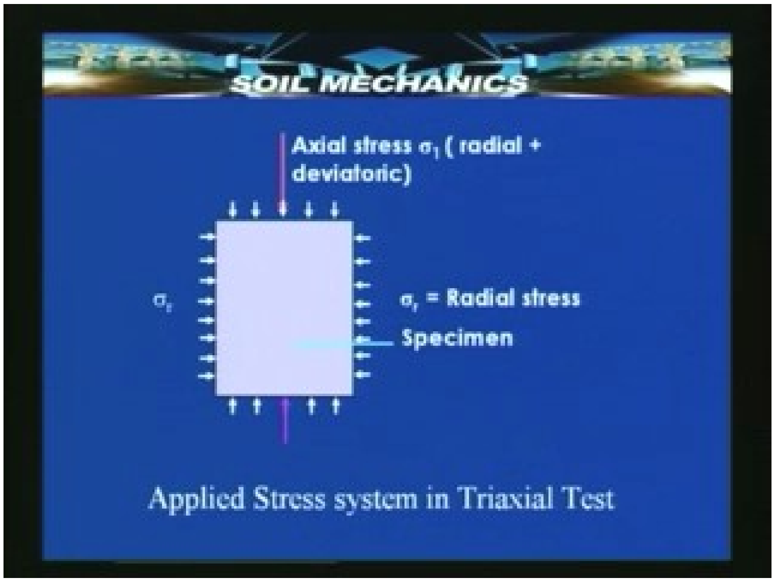

Let me show you a few slides briefly giving an overview of the remaining test, the triaxial test and the other test and then in the next lecture we will take up more details. So this is a schematic of triaxial test. Here the specimen is in the middle, it's a cylindrical specimen it is subjected to all round radial pressure and then an additional pressure at the axial direction known as the deviatoric pressure. So the axial stress applied is radial plus deviatoric that's the net axial stress and under this stress state the specimen will fail along the weakest plane inside it. Now why we go for this test is this simulates typical field situation where there is no predefined plane of failure as in the case of direct shear test.

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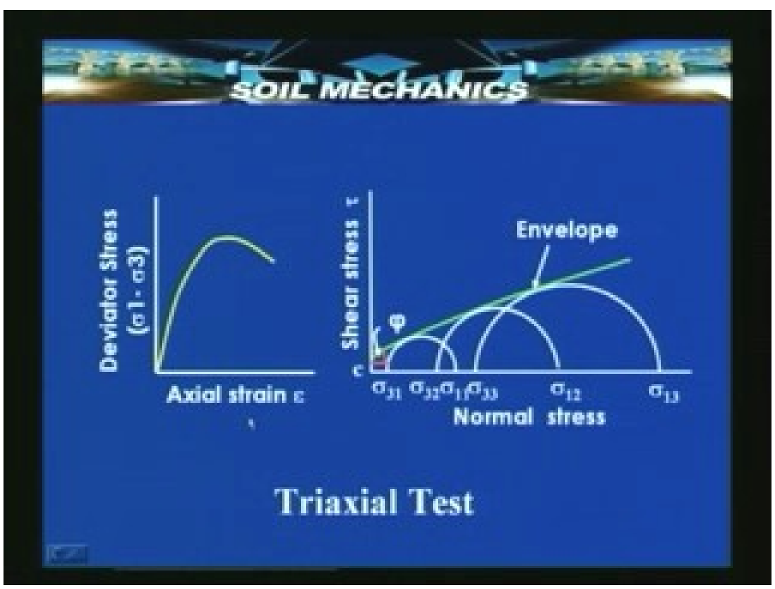

This is how the Mohr's diagram will look, if you do 2 or 3 test under the triaxial test and plot the $sigma_1$ $sigma_3$ plots and the Mohr's plot and as you apply the normal load the axial strain take place, the deviatoric stress will go on changing and it will reach its peak value corresponding to the failure strain and then it will drop down. We will under the importance of this when we go to the next lecture.

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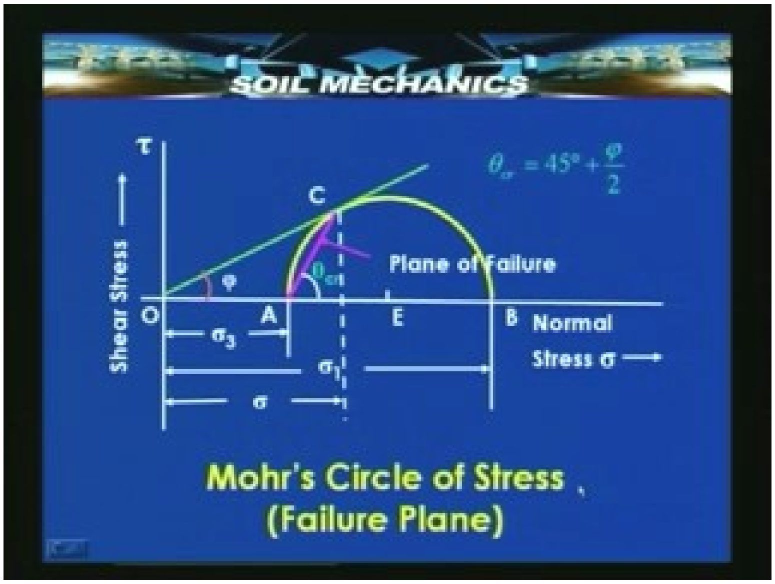

Here is a typical Mohr's circle for a triaxial test here is sigma_1 and sigma_3 we can plot the Mohr's circle, plot the envelop and get the angle of internal friction, shear friction.

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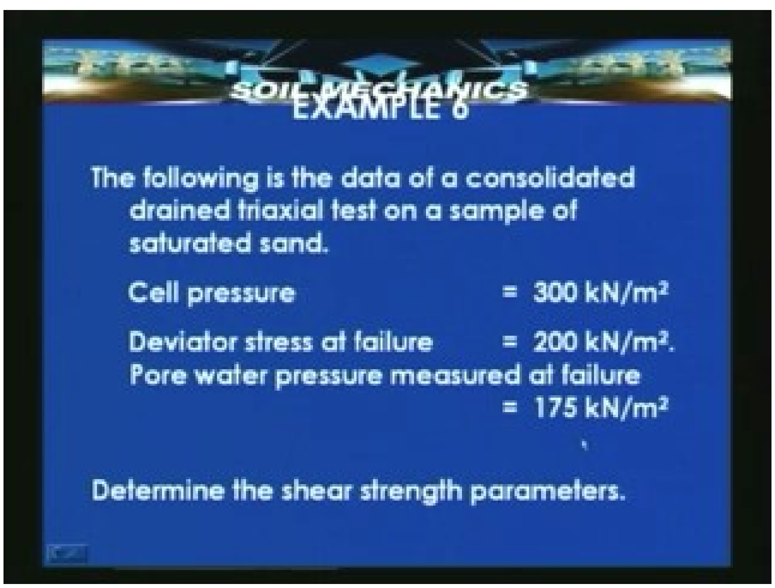

Here is an example we have the cell pressure, the deviatoric stress and we also have the pore water pressure that's the difference between a triaxial stress and a direct shear stress. The pore water pressure can be measured in this test and from this we can determine the shear strength parameter very easily.

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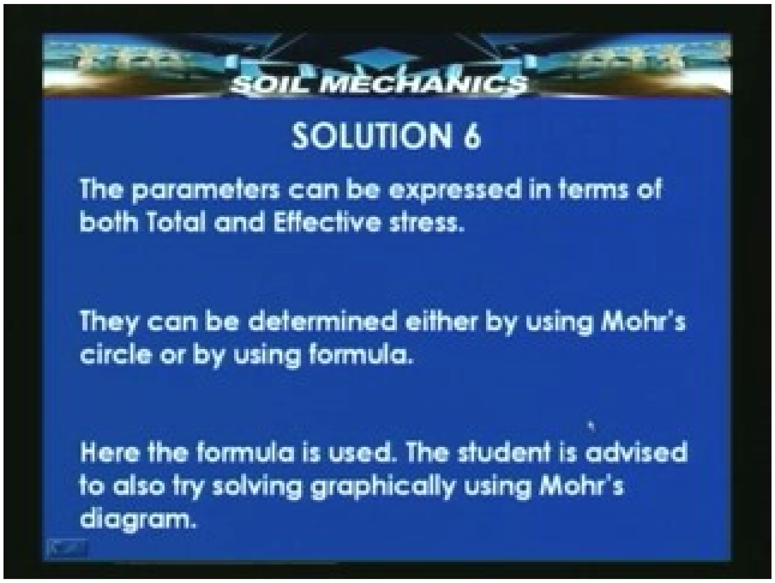

They can be expressed either in terms of total stress or effective stress, they can be determined by Mohr circle or by using formula. Here we have used the formula although you may try it out with a Mohr's circle as well.

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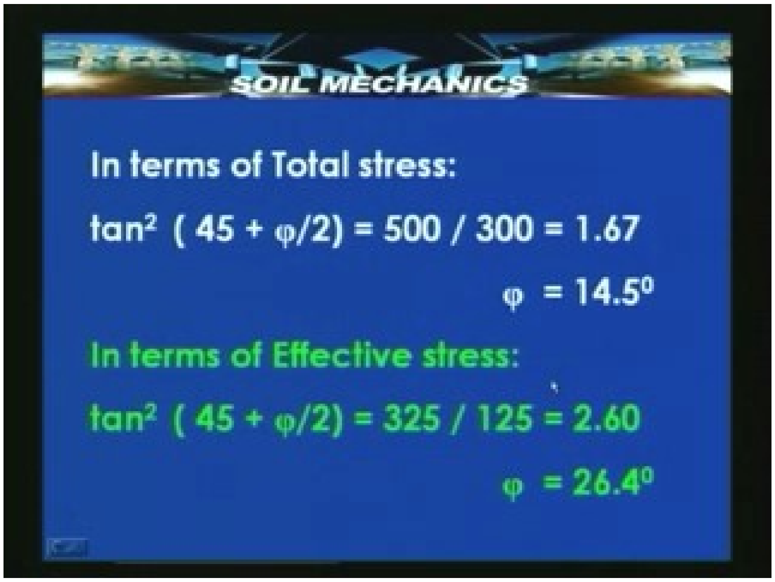

Using the formula is very simple tan square 45 plus phi by 2 which is the tangent of critical circle will be equal to $sigma_1$ by $sigma_3$ is in terms of total stresses and $sigma_1$ dash by $sigma_3$

dash in terms of the effective stresses and from there we can calculate the angles of internal friction.

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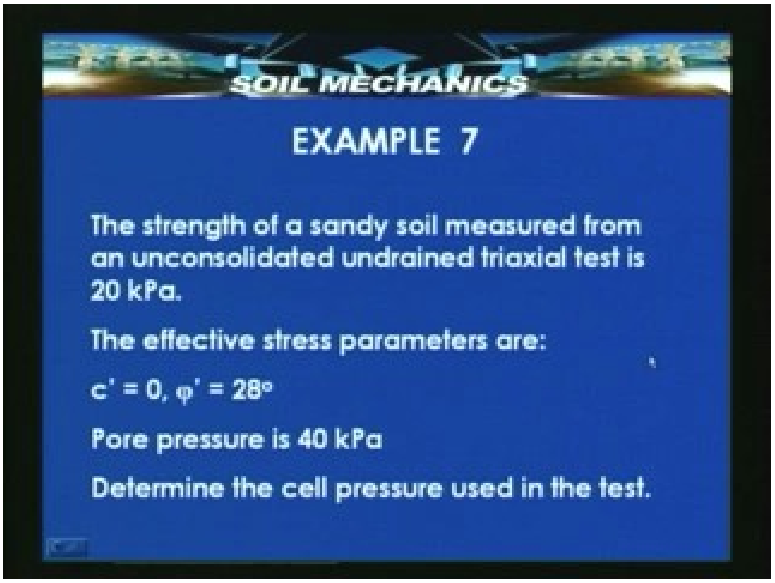

There is another example in which now we have the unconsolidated undrained triaxial strength, we have the c and phi dash values. This is nothing but the deviatoric stress these are the c dash and phi dash value, pore pressure is measured and we have to determine the cell pressure.

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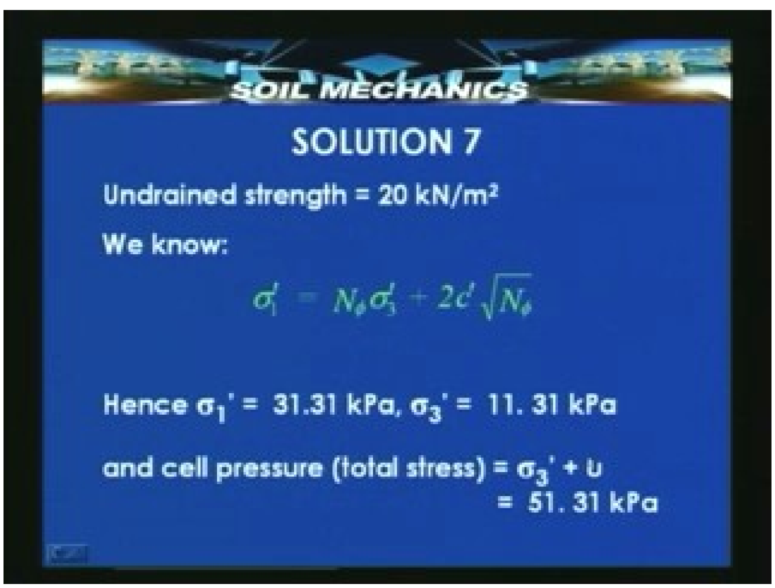

At failure this condition is valid, c dash is zero because is a drained test, $sigma_3$ dash is known $sigma_1$ dash is known or rather $sigma_3$ dash and $sigma_1$ dash have to be computed, their difference in terms of deviatoric stresses is known. So from this we can compute using this formula the $sigma_1$ dash and $sigma_3$ dash and hence $sigma_1$ or rather $sigma_3$. Here $sigma_3$ is asked and that will be $sigma_3$ dash plus u.

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Like this we can take up the unconfined compression strength test and the vane shear test in the subsequent lecture and we can see some details of those.

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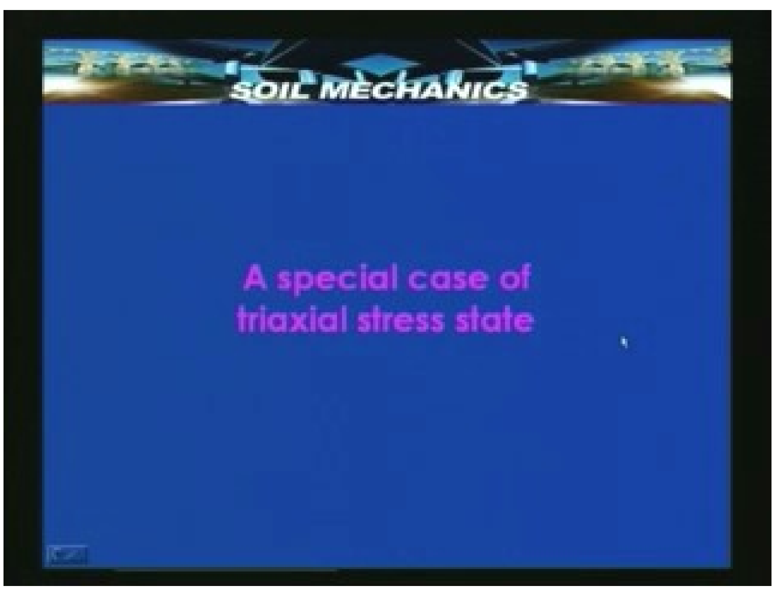

Thank you.