Geology and Soil Mechanics
Prof. P. Ghosh
Department of Civil Engineering
Indian Institute of Technology Kanpur
Lecture – 41
Shear Strength of Soils

Welcome back to the course Geology and Soil Mechanics. So, in the last lecture we just started the discussion on triaxial shear strength which is another laboratory test by which you can determine the shear strength parameters for a particular soil right.

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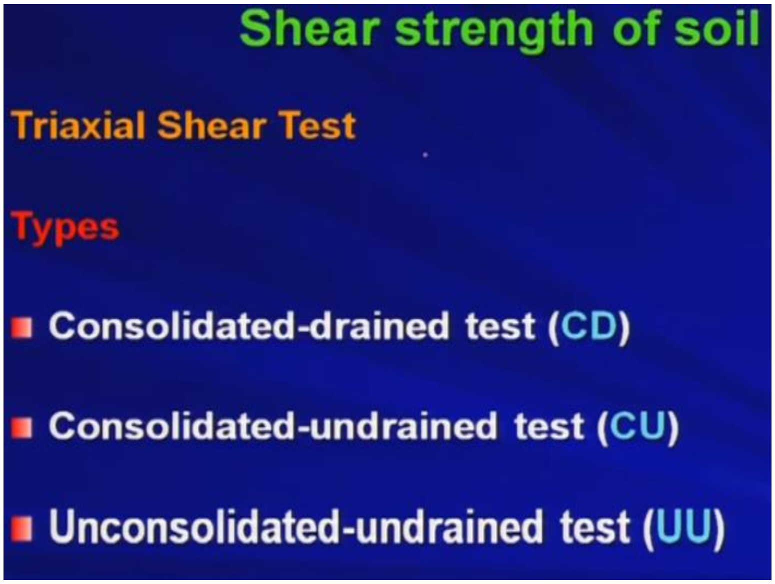

And there we have seen that you have 3 different kinds of say triaxial test one is the consolidated-drained test that is CD test. One is consolidated-undrained test that is CU test and another one is the consolidated unconsolidated-undrained test that is UU test okay.

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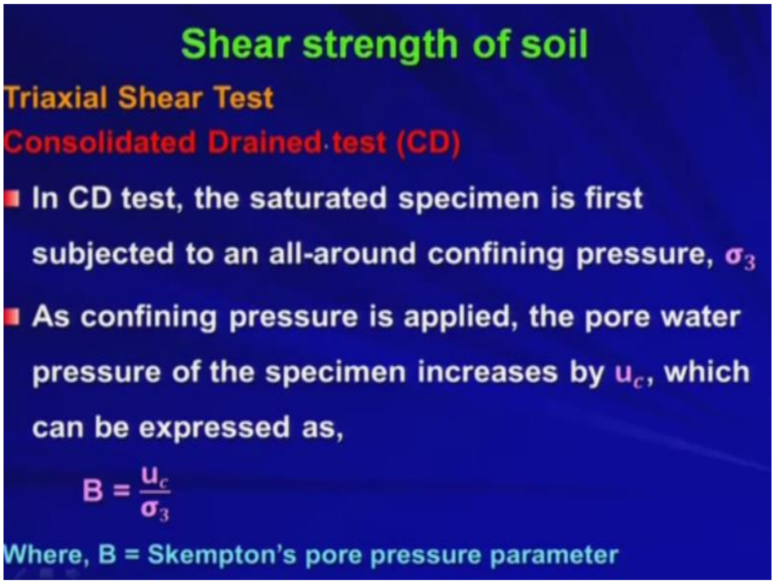

Now first we will discuss what is consolidated drained test so that is CD test right. In CD test the saturated specimen is first subjected to an all-round confining pressure say sigma 3 okay. So, basically that sigma 3 is I mean we are putting sigma 3 that is nothing but your minor principle stress and once you apply the all-round confining pressure basically that means your sigma I mean 3 is becoming the minor principle stress because along the specimen side you do not have any shear stress applied through the cell pressure right.

So, cell water will be applying the pressure in the radial direction and that is known as your that is that will be basically eventually will be becoming one principle stress. Now we will see that so will be that will be becoming the minor principle stress. So, mean first what we do we take the saturated soil specimen and then that saturated soil specimen is subjected to an all-round confining pressure say sigma 3 right.

So, at that condition so as confining pressure is applied the pore water pressure of the specimen increases by u c agreed. So, as you I mean from your consolidation chapter if you recall immediately you apply some extra pressure right so I mean soil specimen was there. Now you are applying some all-round say cell pressure that is sigma 3. Once you apply sigma 3 basically immediately you will be getting some increase in the pore water pressure right because water is incompressible.

So, in the soil specimen you will be getting some increase or enhancement in the pore water pressure that is nothing but your excess pore water pressure now which can be expressed as say

B capital B is equal to u c by sigma 3 where B is nothing but the Skempton's pore pressure parameter right. So, I mean we will come to that point.

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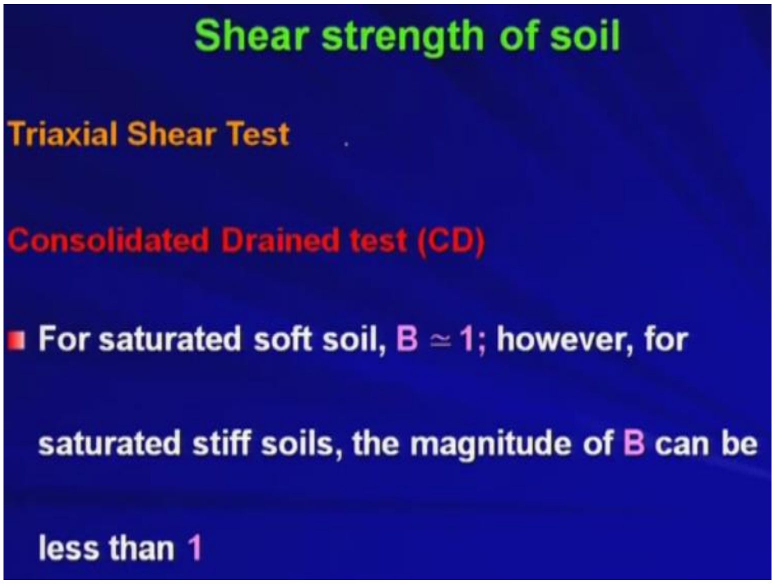

So, basically for saturated soft soil B is approximately equal to 1. Why B is approximately equal to 1? So, because you are not allowing the drainage right so you are stopping the drainage. If you recall that spring loading spring analogy so if you apply the load I mean the pressure okay on the soil specimen immediately water will try to drain out right but the because of the valve is closed immediately the whatever extra pressure is coming on the soil specimen that will be taken care of by the pore fluid that is water right.

So, therefore for saturated soil B is approximately equal to 1 that means u c that is the excess pore water pressure must be equal to sigma 3 that means there is no enhancement in the effective stress so whatever sigma 3 you are applying that is completely taken care of by the water right which is present inside the soil specimen. So, therefore B is approximately equal to 1. However, for saturated stiff clay the magnitude of B can be less than 1 okay.

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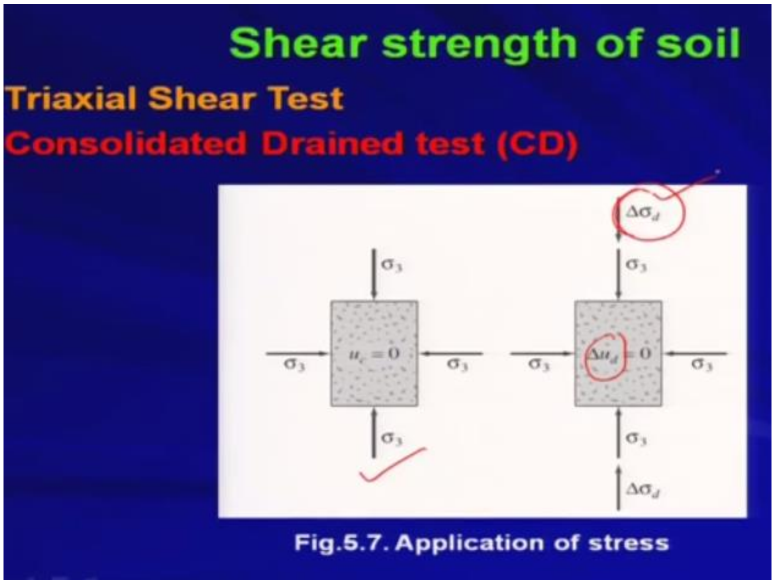

Now basically this is happening we will come to this figure this is happening that you are applying so there are 2 steps basically happening in this consolidated drained test. In the first step, you are applying sigma 3 all-round okay from top from the radial direction all-round sigma 3 that means you are increasing the cell pressure and that cell pressure will be giving you some sigma 3 all-round right and due to that you will be getting enhancement in the u c that is excess pore water pressure will be building up and at that time you just open the drain drainage valve right.

So, once you open the drainage valve basically water whatever water will be there under excess pore water pressure inside the soil specimen that water will be coming out or will be draining out from the drainage path right or the drainage pipe. Now once the excess pore water pressure is getting dissipated basically u c that is nothing but the excess pore water pressure due to the application of sigma 3 already we have seen that u c will be becoming zero after complete consolidation under sigma 3 right and then you are applying the deviator stress right through the axial loading ram whatever we have seen in the test setup right.

Through this you are applying sigma d delta sigma d and this when you are applying delta sigma d basically at that time you are closing the drainage valve so whatever load you are applying immediately it will be taken care of by the soil specimen right and then basically if you open the valve then basically this sigma d whatever excess pore water pressure will be building up that excess pore water pressure will be draining out.

So, eventually so your due to this application of sigma delta sigma d you have got the excess pore water pressure delta u d which will be becoming zero at the final state or the final (()) (5:47) when the consolidation will be happening right that soil water will be draining out. So, that is why it is known as consolidated drained test because at the first instance when you are applying sigma 3 all-round at that time you consolidate the sample by allowing the drainage and then during the test basically when you are applying sigma d at that time also you are allowing the drainage that is why it is known as consolidated drained test okay.

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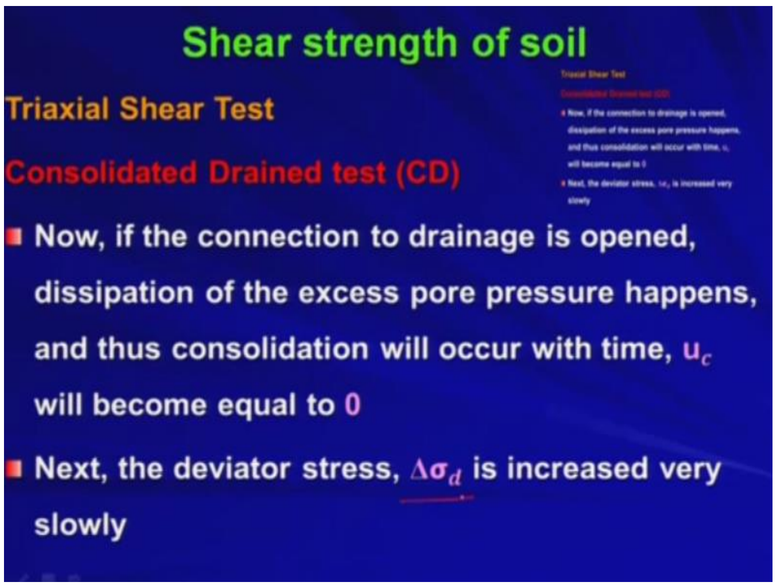

Now if the connection to drainage is opened dissipation of the excess pore water pressure happens and thus consolidation will occur with time so u c will be becoming equal to 0 as I told you right. So, once you apply the sigma 3 at that time you are you have the valve closed, drainage valve is closed and due to that you will be getting the building up of u c and then if you allow the drainage that means if you open the drainage valve right so at that time your u c will be dissipating out.

That means excess pore water pressure will be dissipating out and ultimately or the eventually u c will be becoming zero. Next the deviator stress that is sigma delta sigma d is increased very slowly very gradually now you are increasing delta sigma d and you are allowing the drainage. Now you are not closing the valve so you are allowing the drainage.

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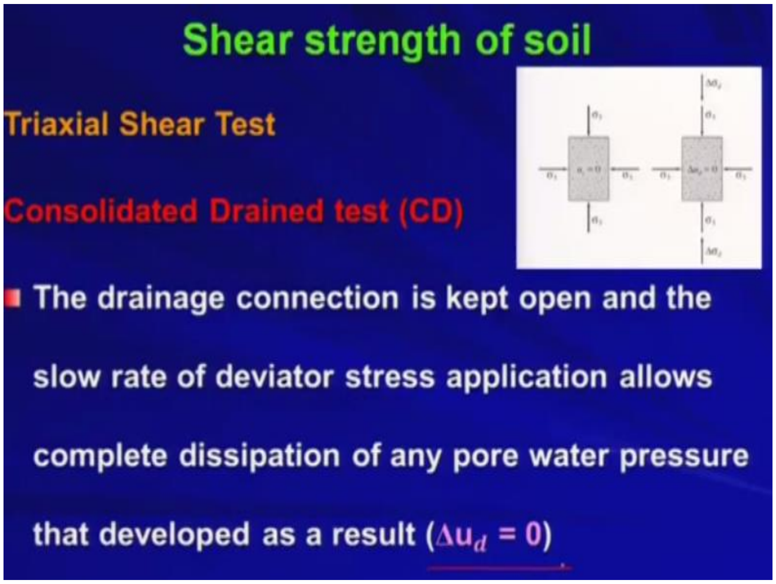

And therefore, the drainage connection is kept open and the slow rate of deviator stress application allows complete dissipation of any pore water pressure that developed as a result that is delta u d is equal to 0. Now as I told you that if you keep the valve closed and if you apply delta sigma d what will happen? So, some delta u d that is some excess pore water pressure will be building up inside the soil specimen due to the application of delta sigma d the same amount of I mean whatever delta sigma d we will be applying the same amount of excess pore water pressure will be building up.

However, you do not do that in the test actually. You keep the valve open drainage valve open so as you apply delta sigma d and this application is very slow that means slowly you are applying delta sigma d and slowly your water is draining out. So, there is no change of building up of excess pore water pressure inside the soil specimen.

So, therefore the whatever I mean may have happened actually if you keep the valve closed that is delta sigma I mean building up of delta u d that will be becoming zero because there is no excess pore water pressure getting built up in inside the soil specimen due to the application of delta sigma d okay. So, as we have seen so basically u c will be becoming 0 because you are allowing the consolidation u c will be becoming 0 eventually and then you are applying delta sigma d gradually and also your delta u d will be becoming 0. So, that means there is no excess pore water pressure getting built up in the soil specimen due to the drainage valve is open.

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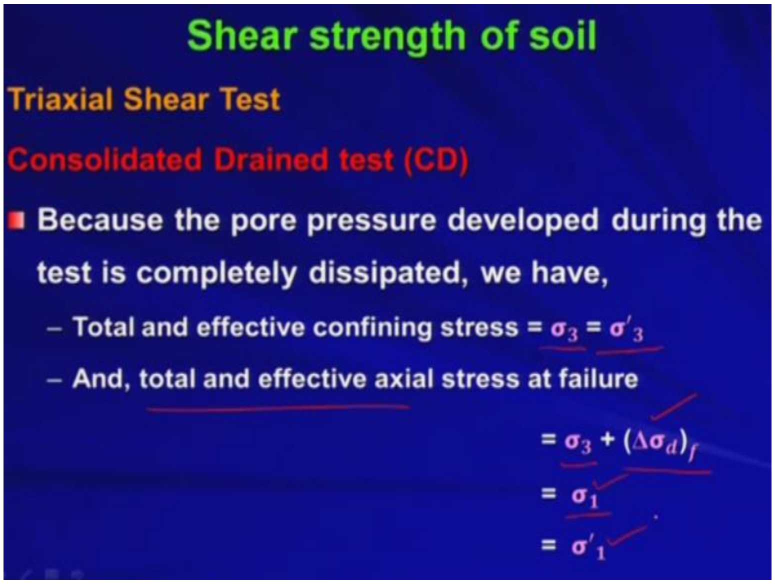

Now because the pore pressure developed during the test is completely dissipated right so there is no excess pore water pressure. So, the pore pressure developed whatever pore pressure was getting developed inside the soil specimen due to the application of sigma 3 alone and then sigma 3 plus delta sigma d along the axial direction so whatever is the situation whatever is the condition you have allowed the drainage so therefore no pore pressure is getting built up right.

So, therefore we can say total and effective confining stress that is sigma 3 is nothing but sigma 3 prime. So, total must be equal to effective because there is no excess pore water pressure agreed okay. Similarly, total and effective axial stress at failure it will be equal to sigma 3 plus because sigma 3 alone is not causing the failure as I told you right. So, as you are applying the deviatoric stress delta sigma d and then basically you are initiating the failure you are initiating the shear failure.

So, as you increase delta sigma d and once you reach the failure at that time the delta sigma d is expressed is delta sigma d f. So, sigma 3 plus delta sigma d will be the axial stress and that is nothing but sigma 1 because on the top plane you do not have any shear stress getting developed right.

So, that plane is another principle plane and on that plane whatever stress will be normal stress will be acting that is nothing but the principle stress and from the I mean mechanism you have you have understood now that along the radial direction whatever stress whatever principle stress was there so that was the minor principle stress and now you are applying sigma 3 plus delta sigma d f for at the failure and that will be your sigma 1 that will be your major principle stress and the total major principle stress must be equal to effective major principle stress because you have allowed the drainage. Is that clear okay.

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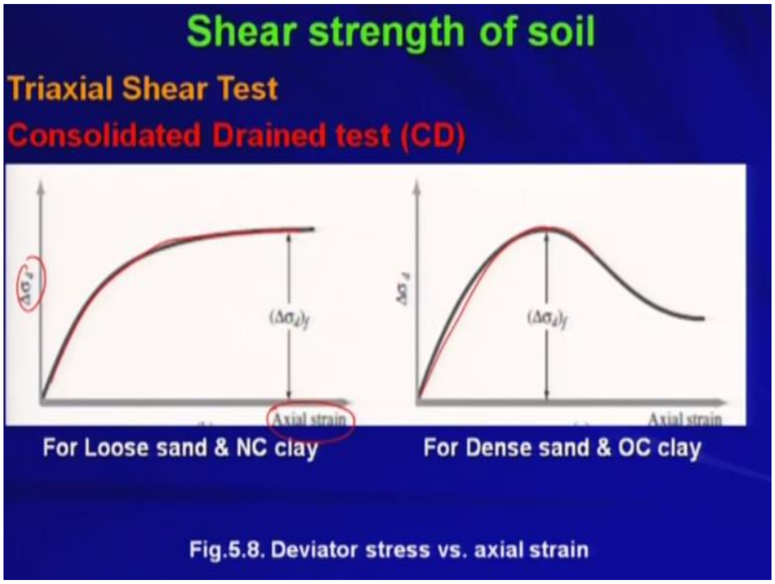

So, now basically we will see that deviatoric stress versus axial strain this plot for loose sand and normally consolidated soil and dense sand and over consolidated soil. It has been seen from the experience and from the test that loose sand and normally consolidated clay will be behaving in a very similar fashion whereas dense sand and over consolidated clay will be behaving in a very similar fashion.

So, what is that what kind of plot you will be getting in case of loose sand and normally consolidated clay if you perform this CD test. Basically, you will be getting so as you increase delta sigma d so gradually you are increasing delta sigma d and you will be obtaining or you will be measuring right axial strength right you can measure that we will come to that point later on.

So, basically you are applying that load and because of that you will be getting the shortening or the squeeze or the strain in the soil specimen right in the vertical direction right. So, slowly you increase delta sigma d your axial strain is also increasing and then it is becoming almost constant right. Whereas in case of dense sand and over consolidated clay you get initial increase and then it reach it reaches the peak which will be giving you the failure say stress okay the failure point and after that it will be decreasing okay. This is the falling part.

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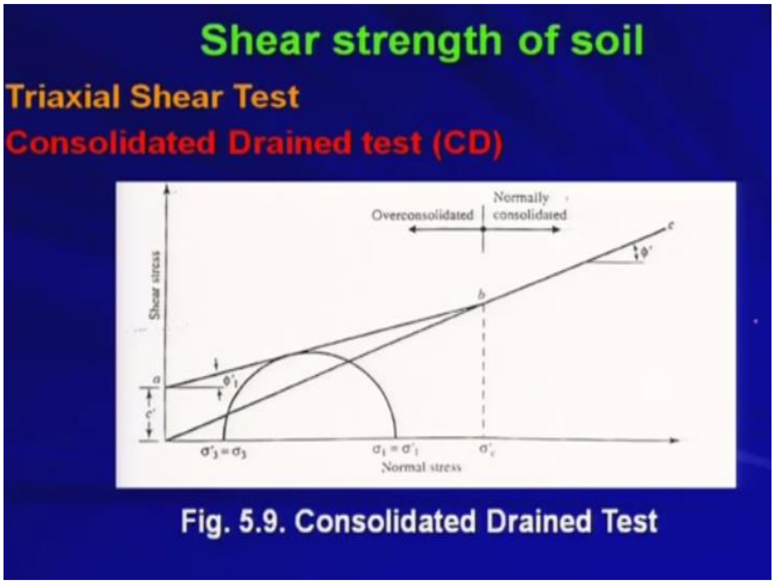

Now basically this is a this is the typical say Mohr-Coulomb failure envelope obtained from the consolidated drained test. So, basically you will be getting 2 different regions one region you will be telling about the over consolidated region another region will be telling about the normally consolidated region. We will come to that point.

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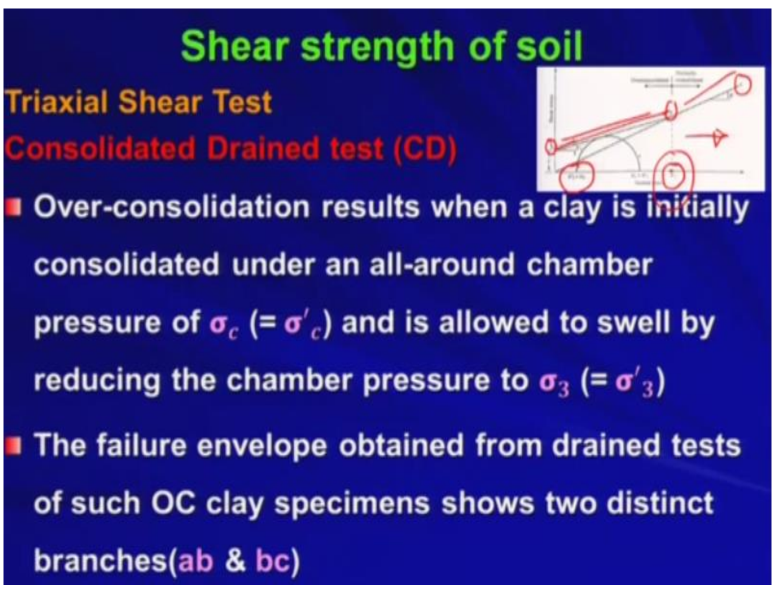

So, over consolidation results when a clay is initially consolidated under an all-round chamber pressure of sigma c and which is eventually equal to sigma c prime because the total stress and the effective stress both are equal or both are same in case of CD test right because you are allowing the drainage so there is no excess pore water pressure getting built up. So, the pore water pressure is zero.

So, sigma c or sigma must be equal to sigma prime in every situation okay. So, over consolidation results when a clay is initially consolidated under all round chamber pressure of sigma c and is allowed to swell by reducing the chamber pressure sigma 3 which is again equal to sigma 3 prime. So, what we are doing here? Now initially we are consolidating the soil specimen with a with an all-round chamber pressure of sigma c.

So, we are increasing the chamber pressure that is the cell pressure by an amount say sigma c and with that pressure basically we are trying to consolidate the soil specimen and then we are reducing okay we are reducing the chamber pressure to from sigma c to sigma 3 okay and in the reduction basically if you recall the consolidation chapter if you increase the pressure and then if you allow the swelling that means if you allow the unloading then basically after reaching the sigma c okay you are allowing the unloading till sigma 3 right and due to this reduction in the cell pressure or the chamber pressure what will happen, it will swell right.

So, this I mean this swelling is allowed and I mean therefore you can say the soil is over consolidated under the pressure of sigma c so that was the soil already experienced sigma c amount of cell pressure all-round and now it is under the pressure of sigma 3 which is lesser than sigma c okay. Now the failure envelope obtained from drained test as such of such over consolidated clay specimen show 2 distinct branches ab and bc right.

So, you will be getting 2 distinct branches ab. This is a this is b so ab and bc. So, you will be getting 2 different branches. Now what you did? Basically, you consolidated the specimen. You have applied all-round cell pressure by an amount sigma c prime right. So, you had reached up to this. Now you are performing the test by reducing sigma 3 up to this point and then you are actually doing the shear failure I mean triaxial test. So, basically the soil will fail okay.

So, this failure envelope this is your failure envelope Mohr-Coulomb failure envelope. So, ab will be nothing but your failure envelope. That failure envelope will be because of your over consolidated soil. Now if you consider the normally consolidated soil. If you say the my soil is normally consolidated soil then the soil should be falling in this region because this region will be experiencing the pressure which will be higher than sigma c right. So, therefore the soil will be behaving as normally consolidated soil. So, you will be getting 2 distinct zones, one zone will be talking about the over consolidated zone, another zone will be talking about the under consolidated zone okay. So, ab and bc they will be basically talking about the failure envelope okay for over consolidated specimen.

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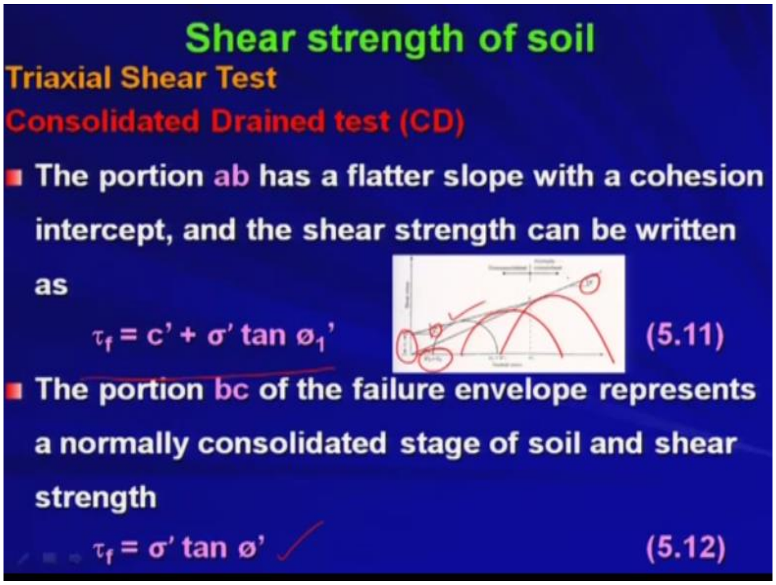

Now the portion ab has a flatter slope as you have seen portion ab has a flatter slope with a cohesion intercept with a cohesion intercept and the shear strength can be written as tau f is equal to c prime plus sigma prime tan phi 1 prime okay where phi 1 is this angle, angle of internal friction right. Now the portion bc of the failure envelope represents a normally consolidated stage of soil as I told you and shear strength is given by tau f equal to sigma prime tan phi prime where phi prime is this angle okay and this bc basically.

So, if you continuously do the test if you go on increasing sigma 3 say for example if you go on increasing sigma 3 so this is your sigma 3 first sigma 3 if you increase the sigma 3 you will be getting like that. If you further increase you will be getting like that something like that okay. So, basically you will be once you are within the over consolidated zone you will be getting the failure envelope which is defined by line ab and you will be getting the failure envelope which is define by line bc under the normally consolidated region.

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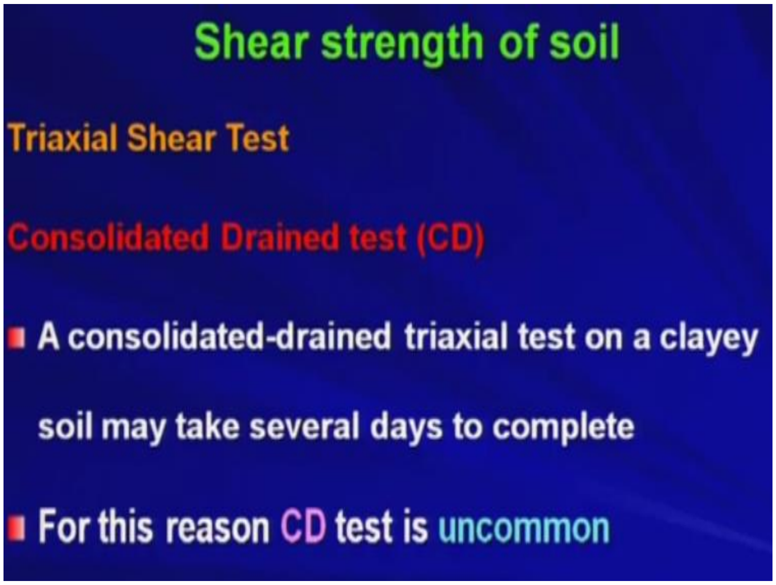

A consolidated drained triaxial test on a clayey soil may take several days to complete agreed because as you know as you have seen from our consolidation chapter that the consolidation itself is a long process, it is time dependent process right. So, consolidation consolidated drained triaxial test if you want to perform on the clayey sample it may take several days to complete because first you have to allow the consolidation okay and then you will be doing the shearing.

So, there are 2 I mean steps involved in this test. First you do the consolidation and then you shear it and you get the failure right. So, this consolidation process itself will take several days to complete. So, therefore the shearing and all those things and the total I mean if you want to I mean obtain the shear strength parameters it will take several days to complete the test. For this reason, CD test is pretty uncommon.

Uncommon means people do not I mean we will see that, that whatever you are getting from CD test we can achieve those things by other triaxial test and those tests are comparatively weaker than CD test because CD test the consolidation is I mean consolidation needs to be there I mean otherwise you will not be getting the proper behaviour. So, for this reason CD test is pretty uncommon in the geotechnical community. So, I will stop here today. Thank you very much.