Geology and Soil Mechanics
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Lecture - 42
Shear Strength of Soils

Welcome back. So, in the last lecture we were discussing about the consolidated drained triaxial test and there we have seen that what are the different issues associated with consolidated drained test and at the end we concluded that consolidated drained test is a time-consuming matter and therefore it is not very popular in the community of geotechnical engineering right.

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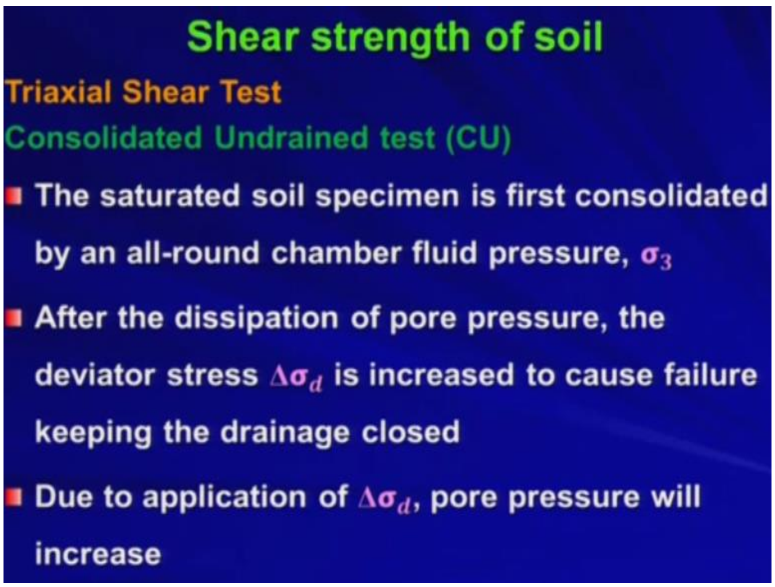

Therefore, the second type of triaxial test so basically in the last lecture we talked about 3 different types of triaxial test if you recall. The first one was consolidated drained test then consolidated undrained test and unconsolidated undrained test that is CD, CU, and UU right. So, already we have covered CD test and now today we will be talking about the consolidated undrained test.

So, what are the different issues associated with this kind of test. Let us look at those things first and then we will try to establish the mathematical equations. Now in consolidated undrained test basically the saturated soil specimen is first consolidated by an all-round chamber fluid pressure sigma 3. So, it is very similar to your consolidated drained test in that situation also you tried with the initial consolidation with the cell pressure right.

The same thing is done in case of consolidated undrained test. That is why the name is consolidated. That means you are consolidating the sample whatever soil sample you are putting inside the triaxial test apparatus. So, you are consolidating that sample with a chamber pressure or with a cell pressure of sigma 3 and then basically after the dissipation of pore pressure because once you are applying sigma 3 right all-round cell pressure you are applying and then you are allowing the soil sample to consolidate.

So, therefore the water will be draining out from the soil specimen under that pressure that incremental pressure that means sigma 3 and whatever excess pore water will be getting generated that will be getting dissipated from the soil specimen and the soil will be ultimately consolidated right. So, after the dissipation of pore pressure so that means whatever pore pressure was built up for the application of sigma 3 so after that dissipation of pore pressure the deviator stress that means the axial stress now you are applying that is delta sigma d.

So, delta sigma d is increased to cause failure keeping the drainage closed. Now here actually you are getting the difference between your consolidated drained and consolidated undrained test. In case of the initial part is quite similar that means both the cases you are consolidating the soil sample with the help of your cell pressure sigma 3 but when you are shearing that means when you are trying to cause the failure or initiate the failure in the soil specimen with the help of deviator stress say delta sigma d at that time you are keeping the valve closed in case of consolidated undrained test which was not the case in case of consolidated drained test.

At that time, also you are keeping the valve open. That means the drainage valve was open for the consolidated drained test throughout the test. However, in case of consolidated undrained test the initial part when you are allowing the consolidation with the application of sigma 3 at that time you allowed the drainage. At that time, you kept the drainage valve open but when you are actually shearing the specimen shearing the soil to the failure at that time you are not allowing the drainage.

That means you are closing the drainage valve and you are not allowing any type of consolidation. So, basically due to the application of delta sigma d your pore pressure will be getting built up right. So, that basically can be measured by some pore pressure measurement arrangement. That we will see later on. So, due to application of delta sigma d pore pressure will increase as I told you because you are not allowing any drainage so whatever water specimen water I mean fluid particle or the water particle or water substance is present in the soil specimen so that will be experiencing some increased stress in the axial direction and due to that application of stress basically your pore pressure will be building up right

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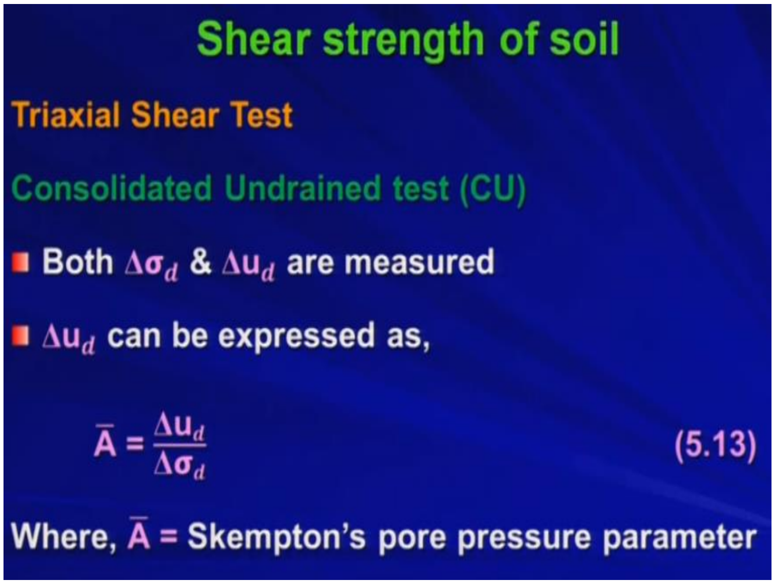

So, now both delta sigma d and delta u d are measured. So, delta sigma d you can measure anyway by the measurement by the loading ram application right. So, you are putting some loading ram and through the loading ram you are applying delta sigma. So, you can measure delta sigma how much delta sigma you are applying and also delta u d which is getting developed that is nothing but the pore pressure which is getting built up okay inside the soil specimen due to the application of delta sigma that also you can measure by some pore pressure measurement arrangement and so both the things basically delta sigma d and delta u d you are continuously measuring okay with some devices.

Now once delta u d can be measured so delta u d can be expressed as A bar okay is equal to delta u d by delta sigma d okay. So, that is the ratio between delta u d and delta sigma d. So, that is delta u d is nothing but the pore pressure enhancement or the increase of pore pressure inside the specimen due to the application of delta sigma d and of course delta sigma d you are gradually applying in the specimen right where A bar is known as Skempton's pore pressure parameter.

So, another Skempton pore pressure parameter you covered or you discussed when we were discussing about the CD test. At that time, this pore pressure parameter was basically associated with the initial part of the test that was happened during CD test discussion right. So, you have seen. At that time, we introduced one pore pressure parameter that is B right. So, there are 2 different Skempton pore pressure parameter. One is associated with the initial part that is when you are applying the cell pressure and another part another Skempton pore pressure parameter that is A bar is associated with the second part that is when you are shearing the material actually okay.

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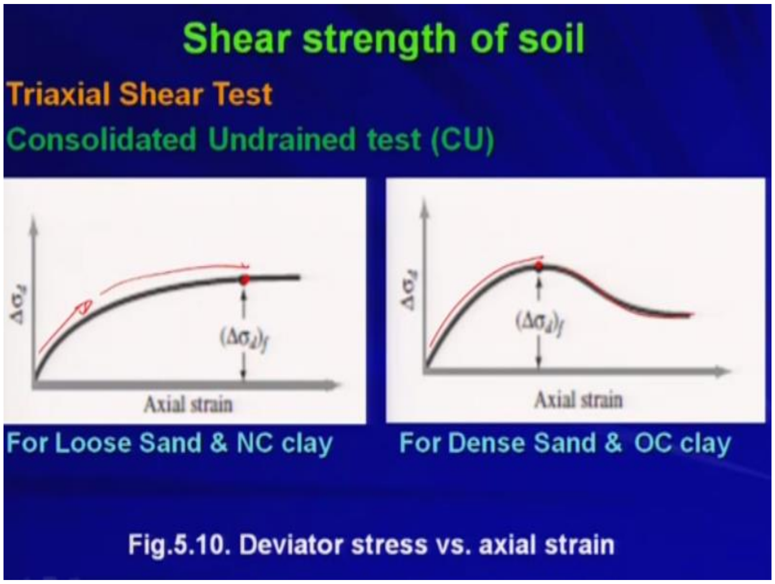

So, now basically in this figure you can see the variation of deviator stress versus axial strain. So, as you increase delta sigma d gradually your axial strain also will increase, axial strain means in the longitudinal direction because you are applying the deviatoric stress from the top right. So, basically in this direction your axial strain will be happening.

So, as you gradually increase delta sigma d that means as you are shearing the material or the specimen your axial strain will also increase and in case of loose sand and normally as already we have discussed that loose sand and normally consolidated clay both the I mean soil will be in a very similar fashion whereas dense sand and over consolidated clay they will be behaving in a very similar fashion right.

So, in case of loose sand and normally consolidated clay basically you will be getting as you increase your deviator stress gradually your axial strain will also increase and ultimately you will be getting a point here which will be defining the failure right. After that you will be getting almost constant deviator stress that means I mean the strain will go on increasing but there will be no increase in stress deviator stress right.

So, this kind of say variation you will be getting between deviator stress and axial strength for loose sand and normally consolidated clay whereas in case of dense sand and over consolidated clay you will be getting initial increase it will it will reach some peak and then it will fall down and finally it will be becoming or eventually it will be becoming constant right. So, this is this point will be denoting the failure right. So, in case of dense sand and over consolidated clay you will get the initial increase reaching the peak and then further with further increase of axial strength you will be getting the fall in the deviatory stress okay.

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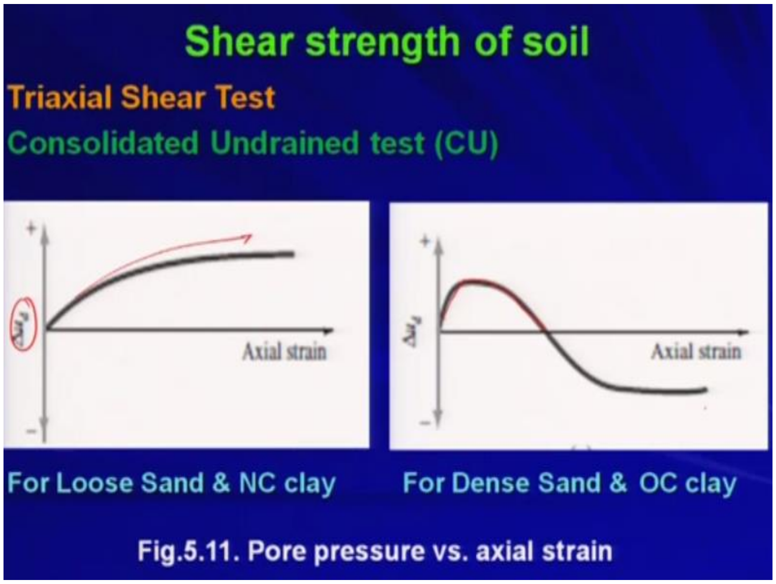

Fig.5.11. Pore pressure vs. axial strain

Now similarly because now actually in case of CD test basically this you can measure right delta sigma d versus axial strain but in case of consolidated undrained test you can also measure the how the pore pressure is getting built up right how the pore pressure is getting enhanced in the soil specimen.

So, in case of loose sand and normally consolidated clay as you go on increasing the axial strength so as your axial strength increases your pore pressure that is delta u d okay it is also going on increasing right and once it is reaching the failure and once it is become I mean that that curve that is stress strain curve whatever we have seen just now delta sigma d versus axial strength so once it becomes constant then your pore pressure will also become constant because there will be no increase or no enhancement in the deviator stress so that will not cause any enhancement in the pore pressure.

However, if you look at the dense sand and over consolidated it is very important to note it I mean it is really worth noting here so in case of dense sand and over consolidated clay you will be getting initial increase in pore pressure and then further decrease in pore pressure and it will be going to the negative side. So, negative pore pressure means something like your suction right.

So, the negative pore pressure basically with the axial strength you will be getting some dilation in the soil specimen and which will cause the suction in the pore pressure so that means instead of giving your compression it will give some it will give you some suction nature in the pore pressure distribution right. So, that will give you the negative pore pressure. So, this is very important observation and important thing to note okay.

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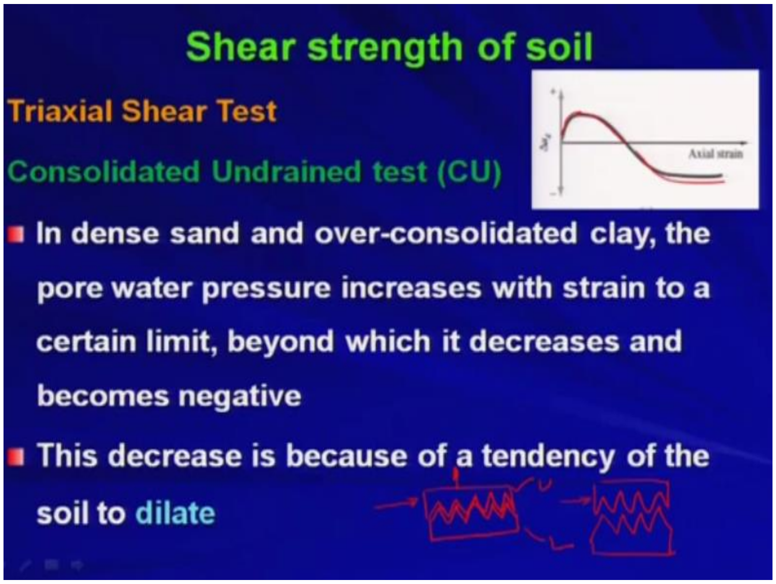

Now in case of dense sand and over consolidated clay the pore water pressure increases with strain to a certain limit as I told you it will increase to a certain limit and beyond which it decreases beyond which it decreases and becomes negative right. So, already we have discussed this thing. Now why this kind of negative pore pressure you are getting. So, this decrease is because of a tendency of soil to dilate.

So, in case of dense sand okay in case of dense sand or over consolidated clay basically if you try to shear it okay so basically it will cause some volume expansion right it will cause some dilation in the soil specimen and due to which you will be getting some suction that means when you are increasing the volume so the so suppose you have this volume and when you are increasing the volume due to shear it will try to attract or try to accumulate the water inside so that means you will be getting some suction in the pore water pressure.

Now basically I mean this thing you can I mean you can think of in this way that why the dilation is really happening right. So, it should come to your mind that in case of dense sand why you are getting this kind of dilation why not you are getting the dilation in the loose sand right. So, now this thing can be I mean explained in a very I mean say easy fashion right.

Suppose you have this kind of say you have some short teeth I mean they are 2 halves okay. So, this is your upper half and this is your lower half. So, in this 2 halves basically you are having the short teeth and at the interface basically you are having the short teeth and now you are trying to shear it okay. That means you are pushing the upper half with respect to the lower half. Now what will happen?

So, if you push it because of this interlocking in the short teeth you will not be able to push the upper half with respect to the lower half right. It will be making some rigid arrangement because of the short teeth will be having some interlocking effect right. Now once you want to shear it now what you need to do? You need to lift it up little bit right and when it will be becoming like this right then only you can push it. Now this lifting is basically is known as dilation. That means some volume expansion is happening.

So, unless until you lift the upper half with respect to the lower half you will not be able to shear it right. Now when you are allowing some expansion when you are allowing some dilation of course you are attracting the water that is how this dilation is happening and this dilation will cause will I mean attract the water particles inside the soil matrix so and therefore you will be getting some suction in the pore pressure and that pore pressure will be becoming negative. I hope that you have understood the phenomena. So, this is a very crude way as well as the easy way to understand the dilation.

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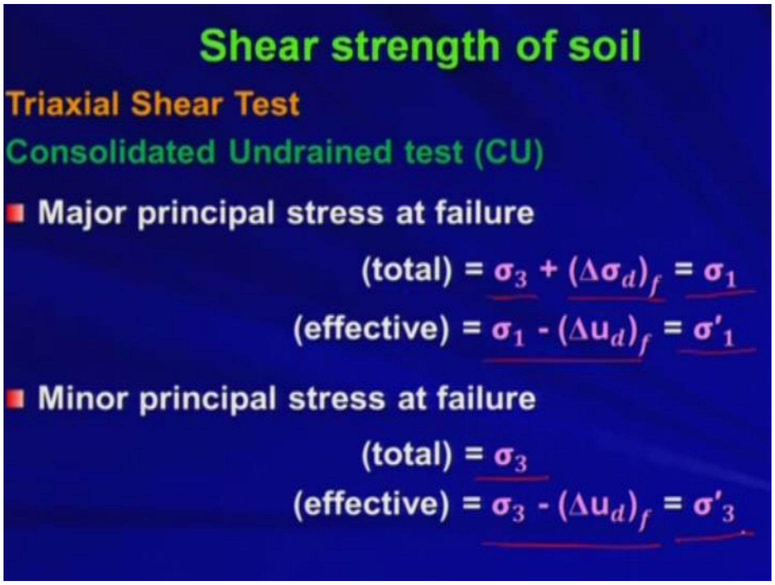

Now in case of consolidated undrained test the major principle stress at failure so if I talk about total okay so total the major principle stress at failure so that means the total stress is sigma 3 plus delta sigma d f right.

So, delta sigma d f is nothing but the failure I mean deviatoric stress at failure. So, sigma 3 will be always there because when you are applying the cell pressure at that time you are applying that is all-round cell pressure right it will be acting in the radial direction it will be acting in the vertical direction or in any direction if you consider that will be the hydrostatic state of stress hydrostatic pressure you are applying that is sigma 3 plus the deviatoric stress which you are applying and till the failure which basically the soil specimen is experiencing that is nothing but delta sigma d f so sigma 3 plus delta sigma d f is nothing but your major principle stress sigma 1 right which is acting in the axial direction in the vertical direction right.

So, effective major principle stress will be there for sigma 1 minus the pore water pressure which has been built up at the failure. So, that is nothing but delta u d f. So, sigma 1 minus delta u d f that is nothing but your sigma 1 prime right. So, in case of consolidated drained test if you recall your total stress and effective stress were both were same because in that situation that this delta u d f was zero I mean if you recall our previous discussion that delta u d f was zero for our consolidated drained test because you allowed the drainage so there was no chance no scope for this pore water pressure to build up right.

So, sigma 1 minus delta u d f was is equal to delta sigma 1 prime in case of consolidated undrained test whereas sigma 1 is equal to sigma 1 prime in case of consolidated drained test right. Similarly, if you look at minor principle stress at failure so minor principle stress total minor principle stress is sigma 3 there is no doubt because that will be acting in the radial direction or the lateral direction so that is and of course that is nothing but one of the principle stress so that is your minor principle just total minor principle stress so therefore the effective minor principle stress will be sigma 3 minus delta u d f.

So, delta u d f again that is the pore water pressure developed or the built up at the failure. So, sigma 3 minus delta u d f is equal to sigma 3 prime right. If you try to compare this thing with your consolidated drained test at that time the total minor principle stress was equal to effective minor principle stress that is sigma 3 was equal to sigma 3 prime. Here in this situation it is not like that rather you have sigma 3 minus delta u d f is equal to sigma 3 prime where you are subtracting the pore water pressure which is getting built up due to during shearing.

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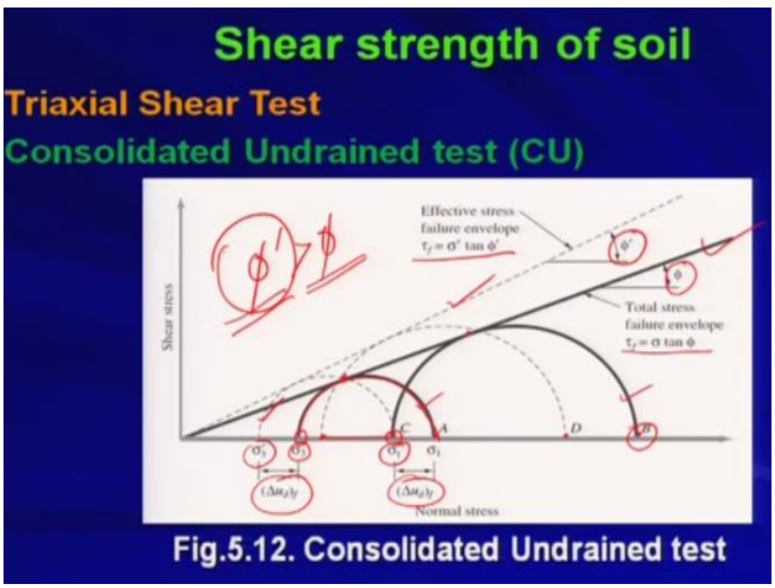

Fig.5.12. Consolidated Undrained test

So, now if you try to plot this thing that is whatever you have obtained from this consolidated undrained test, triaxial test, basically you if you want to plot the shear stress versus normal stress I mean graph basically it will look like this so basically this I mean so you will be you will be changing basically this these 2 solid Mohr circles they are talking about the total stress at different confining pressure at different cell pressure.

So, for if you consider for example if you consider this small circle basically at that time your confining stress was sigma 3 that is here right that means the minor total minor principle stress was here. Now if you do the same test okay that is consolidated undrained test for the same specimen but with increased say cell pressure and say that is nothing but at this point so this sigma 3 again you are using the same sample same test okay but you are just increasing the cell pressure.

So, of course when you are increasing the confinement of course you will be you need to apply more deviatoric stress to get the failure so that is happening at this point. So, now basically these 2 I mean these 2 Mohr circles of course will touch the failure envelope because in both the cases you are getting the failure. So, both the cases the both Mohr circles must touch the failure envelope and that is here so this is your Mohr-Coulomb failure envelope right.

This is your Mohr-Coulomb failure envelope which is touching the Mohr circle at these points right. So, now this is nothing but your total stress variation okay. So, if you plot the shear stress versus normal stress graph in with respect to the total stress phenomena then basically they will be looking like this but now I mean from the earlier discussion if we try to plot the effective stress parameters then basically everything should be subtracted by an amount sigma delta u d f right.

So, this sigma 1 earlier case you are getting sigma 1 here right in the small circle now this sigma 1 minus delta u d f is giving you sigma 1 prime. Similarly, this sigma 3 must be subtracted by delta u d f to get sigma 3 prime. So, you are getting this dotted this dotted Mohr circle which will be giving you the effective stress Mohr circle. Similarly, for the increased sigma 3 you can this sigma 3 will come to this point okay with the subtraction of delta sigma delta u d f.

Similarly, this point sigma 1 should come to this point d sigma 1 prime which will give you the effective major principle stress right. So, again if you draw the Mohr-Coulomb failure envelope for the effective stress parameters for the effective stress concept so that will be looking like this. So, basically what you are getting. So, this is this line this dotted line is effective stress failure envelope and it is given by tau f equal to sigma prime tan phi prime whereas this is your total stress failure envelope which is equal to tau f equal to sigma tan phi.

But in both the cases you are getting the failure. One is your total stress concept. So, you are drawing the Mohr circle you are drawing the failure envelope with respect to the total stress. In other situation, you are drawing the failure envelope with respect to the effective stress. Now if you see these figures in case of total stress you are getting little bit fatter failure envelope and that is defined by this angle phi right.

Phi is nothing but the angle of internal friction. Now in case of effective stress you are getting this is your inclination of the failure envelope that is phi prime. Of course, phi prime is greater than phi in this situation right whatever you (()) (21:01). Now if you basically what I mean to see mean to say that if you express or if you report the angle of internal friction of a particular soil sample based on this consolidated undrained test based on total stress concept then basically whatever phi value you will be reporting that will be always lesser than the actually developed effective stress phi prime parameter right.

So, therefore I mean if you design something based on this total stress parameter of course you will be underestimating the actual soil strength which is nothing but phi prime and which is eventually happening right I mean phi prime basically so if you allow the drainage and if you allow sufficient time the soil will be I mean ultimately the soil the effective stress will be getting developed and effective stress parameters will be coming into the picture.

So, if you design based on phi that is the total stress concept basically you are underestimating the soil strength because ultimately you must get the effective stress that is nothing but phi prime which is greater than phi right. So, here actually you need to think about that in which way you will be moving either you will be designing with respect to total stress or you will be designing with respect to effective stress.

Now however if you see this see these plots whatever plots we have seen just now whatever maybe the case sigma 1 could be different from sigma prime, sigma 3 could be different from sigma 3 prime, but sigma 1 minus sigma 3 that is the difference between the major and minor principle stress will be always equal to major and minor principle stress difference between major and minor principle stress even in the effective stress situation.

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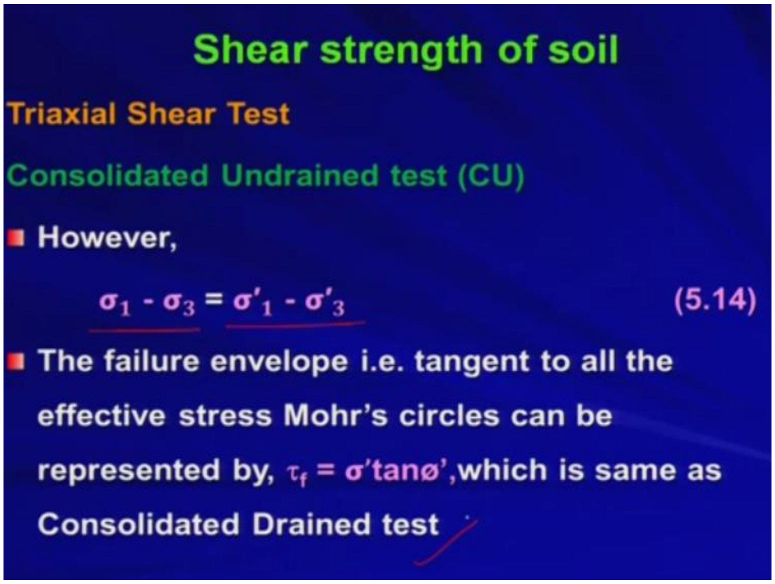

That means sigma 1 minus sigma 3 must be equal to sigma 1 prime minus sigma 3 prime right. So, that difference is not changing. Only change is happening that is sigma 1 is getting changed to sigma 1 prime from total to effective and sigma 3 is getting changed to sigma 3 prime from total to effective but however the difference between sigma 1 and sigma 3 will be remaining same, the difference between sigma 1 prime and sigma 3 prime.

So, the failure envelope that is tangent to all the effective stress Mohr circles can be represented by tau f equal to sigma prime tan phi prime which is same as consolidated drained test right. In case of consolidated drained test, you have got the same thing that means you have got because in in that situation you expressed everything with respect to the effective stress parameters.

That means your failure envelope was I mean tau f equal to sigma prime tan phi prime but the same thing you are getting you are but in case of consolidated undrained test you are getting both. You are getting the total stress failure envelope or the variation in total stress ambience as well as you are getting the variation in effective stress ambience right. So, both the things you are getting. When you are getting the effective stress parameters at that time basically that is nothing but your consolidated drained test values right. So, that is that it is this statement is saying that thing only.

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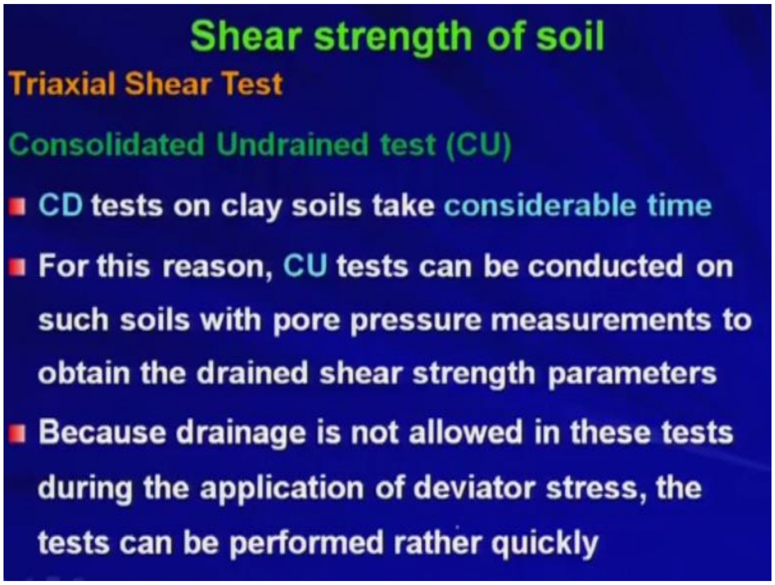

So, CD test on clay soil take considerable time already we have discussed already we have seen that is in case of clayey soil you know that permeability is very low so the consolidation will take enormous time so if you perform CD test that means consolidated drained test that means you have to allow the drainage and you have to allow the complete consolidation so it will take considerable time right.

So, therefore CD test is not very popular very not very common in practice. So, for this reason CU test can be conducted on such soils with pore pressure measurements to obtain the drained shear strength parameters. So, that is why people what people do people do CU test with some pore pressure arrangement, pore pressure measurement arrangement okay and they measure the pore pressure and once you measure the pore pressure basically you will be getting both the representation total stress representation as well as effective stress representation whereas effective stress representation is nothing but the consolidated drained test I mean result right.

So, that means if you perform consolidated that means CU test basically you will be getting the result I mean eventually getting the result for CD test also. So, therefore CU test generally people perform and because drainage is not allowed in CD, CU test because you are not allowing the drainage right when you are shearing it when you are applying the deviator stress you are not allowing the drainage am I right.

So, you are not allowing the drainage so therefore in this test during the application of deviator stress so that means because drainage is not allowed in this test in CU test during the application of deviatoric stress the test can be performed rather quickly agreed because once you allow the drainage you have to wait right as the water is expelling out water is draining out you have to wait till that period till that time.

In case of CD test, it was like that so you are allowing the drainage but in case of CU test you are not allowing the drainage and therefore you can perform the test quite fast right and therefore CU test is very popular and very common because the test is test itself is very quick very fast at the same time whatever I mean results whatever plots or whatever representation you are getting from CD test that also you can get from CU test. So, therefore CU test is basically the global set where CD is coming as a subset right something like that.

So, anyway I will stop here today. So, in the next lecture we will continue with CU test as well as UU test. Thank you very much.