Geotechnical Measurements and Explorations

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Lecture No. # 23

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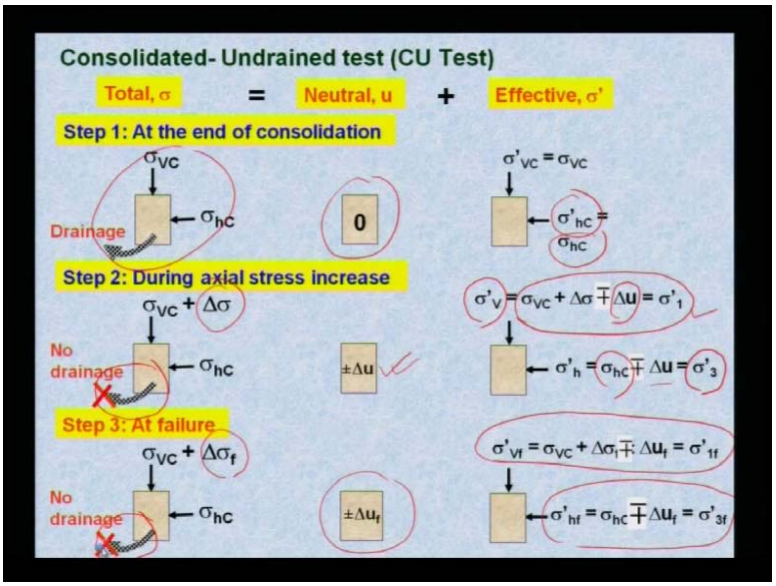

Last class, we have finished this CD test, consolidated-drained test, now we will start this consolidated-undrained test or CU test. In this case, total stress is equal to u plus effective, and if you look at this stage 1 and stage 2, at the end of consolidation, that means, in the case of stage 1 the drainage valve is open and this u is equal to zero, this pore water pressure is equal to zero because of drainage valve is open. And effective stress, sigma v prime is equal to sigma vc; sigma vc is nothing, but your confining pressure. Sigma hc, lateral stress is equal to sigma hc, sigma hc prime is equal to sigma hc. During axial stress, in stage 2, during axial stress, the increase will be delta sigma and at this stage this is undrained conditions. One is your consolidated, that means, stage 1, this is your consolidation condition; stage 2, it is undrained condition, in this condition there is no drainage, that means, drainage valve is going to be closed.

So, definitely, once drainage valve is going to be closed, there will be increase in pore water pressure. So, either negative or positive pore water pressure will be measured. So,

in that case, now this total effective stress, in vertical effective stress is equal to self pressure or confining pressure plus delta sigma plus minus delta u. Delta u is your increase in, increase or decrease in pore water pressure. This is your sigma one, sigma one prime and sigma h is sigma h c plus minus delta u, this is your sigma three prime.

So, at failure, that means, this is the condition second stage. During axial stress increase what will happen? Axial stress will go, goes on increasing, increasing at failure, so there is no drainage. So, it will be sigma hc, sigma h vc plus delta sigma f plus change in pore water pressure at failure. So, this is your vertical and lateral stress.

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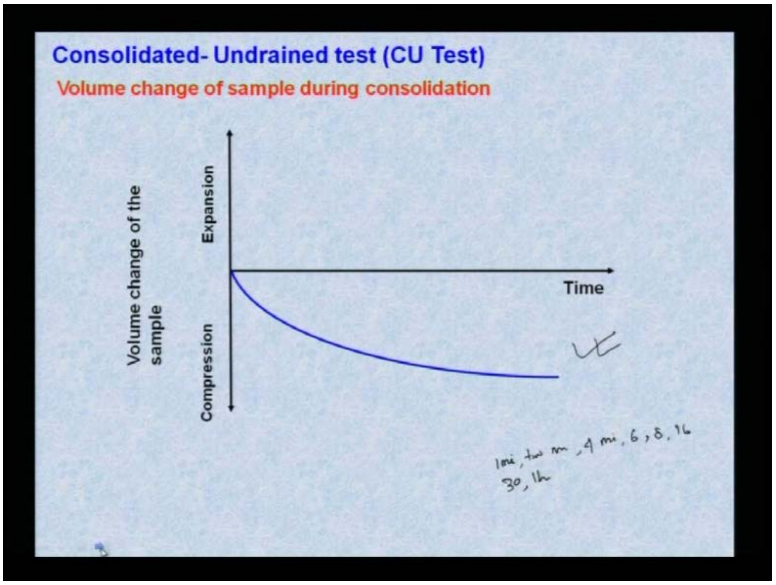

Now, how this volume change will look? You can measure volume change sample during the consolidation, that means, during consolidation compression, with this compression with time means, with time you can, 1 minute, 2 minute, 4 minute, 6, 8, 16, 30, 1 hour, these are all equal, means double the time interval you can measure this. How much is your compressor and volume change of the sample, you can plot it, that this is called your compress, means consolidation graph.

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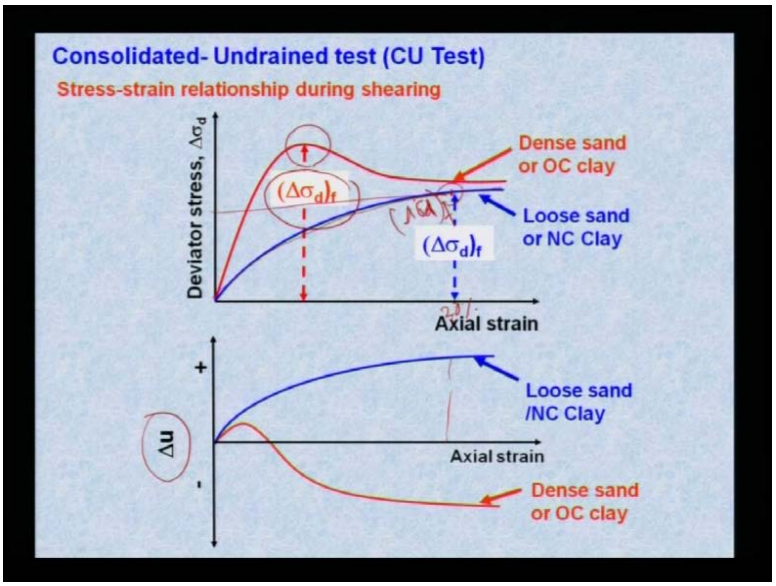

Now, stress-strain relationship during shearing, so deviatoric stress delta sigma d, it will increase with (( )), means stress will increase with axial strain. So, you will get at the peak, you will get deviatoric stress at failure f and similarly, axial strain also change in pore water pressure, with respect to volume change versus axial strain. This is nothing, but your volume change versus axial strain and this will be your for dense sand or over consolidated clay.

Now, what will happen? Loose sand, 20 percent of strain, corresponding to that 20 percent of strain, you will get the failure, that is your delta sigma d f because in, in CU test, particularly loose or normally consolidated clay, you might not get a peak failure. This stress-strain curve will increase, increase, it will continue, that you will have to wait up to 20 percent of, means, you will take the 20 percent of axial strain as the failure criteria. The strain of the, 20 percent axial strain, where it got these, with respect to that, what is that stress, that is, your failure point?

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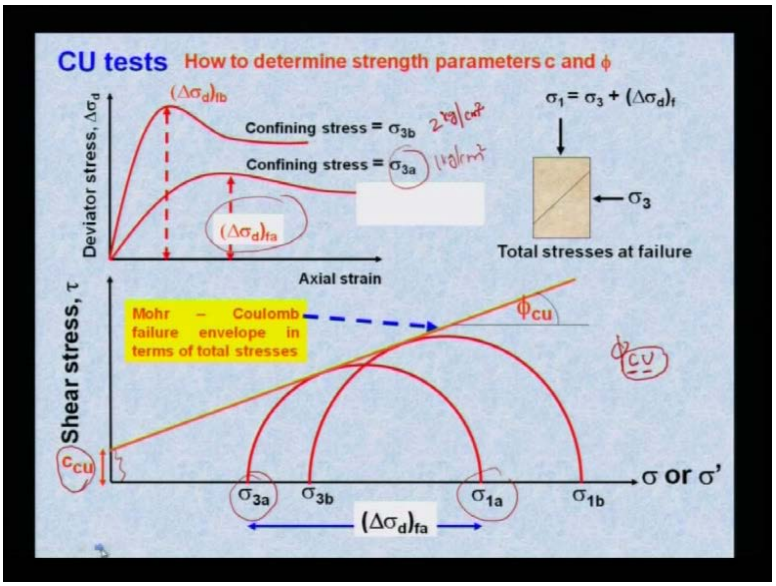

Now, how to determine this strength parameter in case of CU test, that is, means C and phi. In this case, you have to do at least because there are two unknowns, as I say, there are two unknowns, one is C other is your phi, at least two test required, but it is preferred if you can do three test. Suppose, let us say, one confining pressure, say delta sigma 3 for one confining pressure, suppose say 1 kg per cm square, you do this test and find it out what is it? It is deviator stress and axial strain. From there, you can find it out delta sigma d at failure. Then, consider 2nd one with respect to, once you get delta sigma at failure, that means, you are getting sigma 1 and sigma 3, delta sigma 3, you know, delta sigma 1, you can find it out from here, then draw the, this is your delta sigma d at failure. So, you draw the Mohr circle for confining pressure sigma 3a is equal to 1 kg per cm square.

Let us say, now for next step take one more, one more soil sample with this confining pressure, let us say 2 kg per cm square. With that you can get your failure and you can draw the 2nd Mohr circle. Similarly, go for 3rd one also. If possible, you can go, but as I said, there are two parameters, C and phi, only two Mohr circles will be enough to draw this to get your Mohr–Coulomb failure envelope. So, once you draw the Mohr circle, draw a common tangent, which touches both these Mohr circles, then extend it, where it intersects, that is your C and this angle with respect to your angle, that is your phi. Once you say, this is consolidated-undrained test or CU test, you can name it as phi CU, C for consolidated, u for undrained. That means, it will mean, it will, it will mean, that this test

has been done from consolidated-undrained test and C, C, U is your cohesion in consolidated and undrained test, so you get C and phi.

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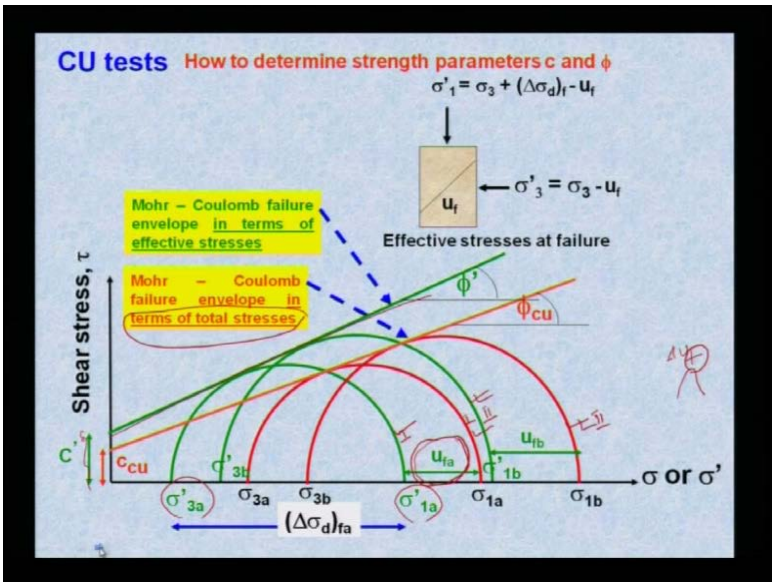

Now, look at this effective stress failure. If you go back to earlier one, this is in terms of total stress, this is in terms of total stress, there is no measurement in case of total stress, there is no measurement of pore water pressure, change in pore water pressure or change in volume delta u. So, this will be in terms of total stress. Now, you can plot it for effective stress with this same graph this Mohr-coulomb failure envelope. Once you draw in terms of total stress, now you go for effective stress, now it will shift towards left, equal amount of pore water pressure change in volume at failure. That means, pore water pressure built up until failure. How much is your pore water pressure? That is your delta u f; f is nothing, but is your failure. Now, it has been shifted, now this will be your new sigma 1 prime, effective principle stress sigma 1, 3 prime. This is for your 1st one, 1st Mohr circle, 1st Mohr circle in terms of a effective stress it has been plotted.

Now, go to the 2nd Mohr circle, that means, this is in terms of, in terms of pore water pressure, it will shift towards left, this will be my 2nd Mohr circle. If this is your 1st, this is your 1st, this is your 2nd and this is your 2nd. Now, draw a tangent, which will touch both, both the Mohr circle, means, a common tangent if I, if I draw, it will pass somewhere else here from there, you will it find out C prime as well as phi prime. Now,

next step, look at here, so this is Mohr-Coulomb failure envelope in terms of effective stress that means, this is C prime and phi prime.

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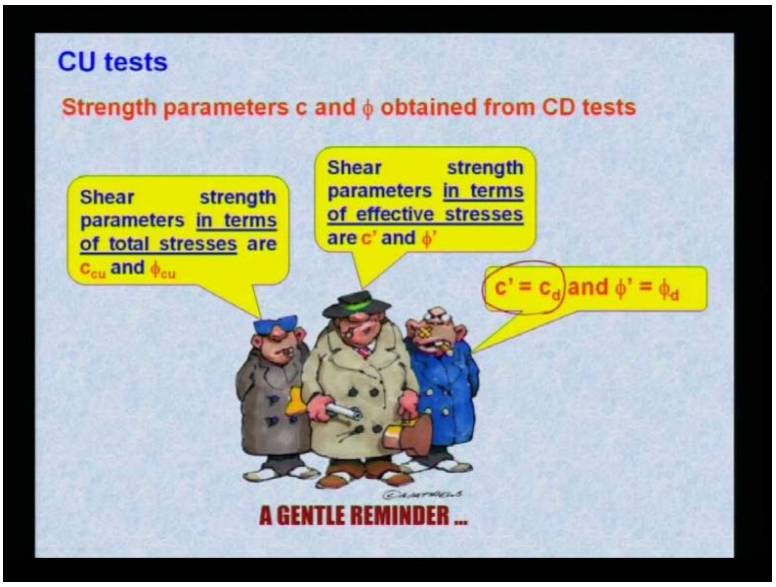

CU tests strength parameters, c and phi obtained from CD tests. Shear strength parameters, in terms of total stresses, it is said C cu and phi cu. Now, shear strength parameter, in terms of effective stress, it is effective means prime, once prime is their C prime or phi prime, it means, it, it denotes to effective stress.

Now, similarly, if, if, if it is strength parameter, in case of effective stress, that means C prime, that means, C prime will be equal to C d, that means, C prime equal to C d, it will be undrained test and phi prime is equal to phi d.

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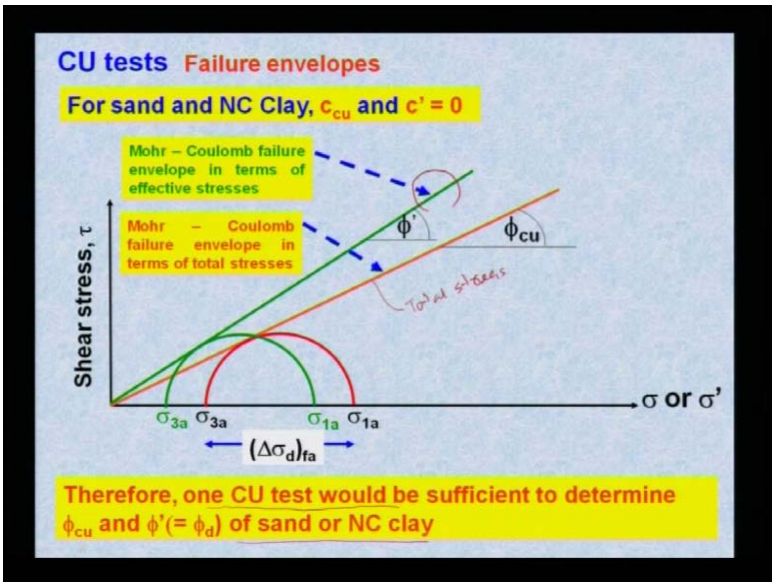

CU test failure envelope for sand and normally consolidated clay, C cu and C prime is equal to 0. For sand and for normally consolidated clay, if you look at here, Mohr-Coulomb failure envelope in terms of total stress, this is in terms of, in terms of total stress, in terms of total stress and this will be in terms of effective stress. In this case, it will start from origin, so C prime will be zero only. Once you test, if you look at here, I am not doing, means only one Mohr circle, that means, only one test, one Mohr circle means one test, therefore only one CU test would be sufficient to determine this phi cu and phi prime for sand or normally consolidated clay.

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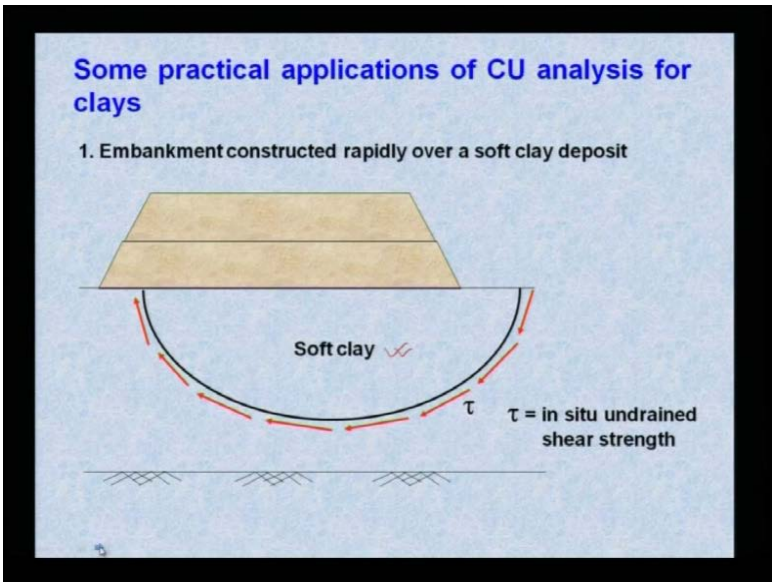

Some practical applications of CU analysis for clay let us say for example, embankment construction rapidly over a soft clay deposit. This is a soft clay deposit, it is there a layer in this case. In soft clay deposit, embankment has to be constructed, means this construction will be very rapid. So, in that case, what will happen? Because there is a construction is rapid in stages, definitely there will be consolidation will occur in 1st stage and stage two during shearing, it will be a first shearing. That means, there will not be any time or you will not get any change in pore water pressure. So, this is case one embankment construction rapidly over a soft clay deposit.

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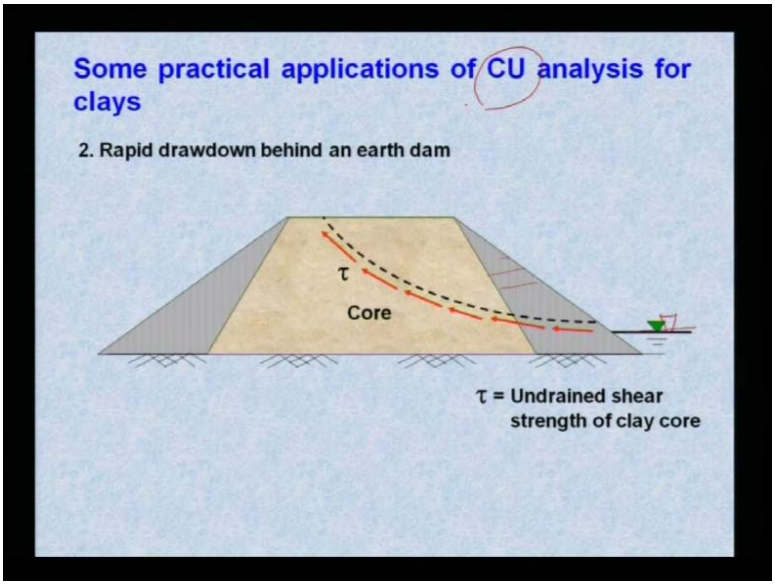

Case two, rapid drawdown behind an earth dam. Now, what is rapid drawdown? Suppose, there is a water table here, over the period of time, maybe summer season, the water table fluctuates, that means, it will come down very rapidly during summer season. So, in that case, once it will come down very rapidly, still pore water pressure, there will not be any change. The pore water pressure, it is inside, it will be their because of rapid drawdown, there is no change in pore water pressure. So, this will be again another example of consolidated undrained analysis.

As I said, as I said, during summer there is a chance, that sudden drawdown will occur because of change in water table, if I change in water table sudden drawdown, so now the failure envelope will change. It will go to the core, then this analysis will be taken as from the test of consolidated undrained test.

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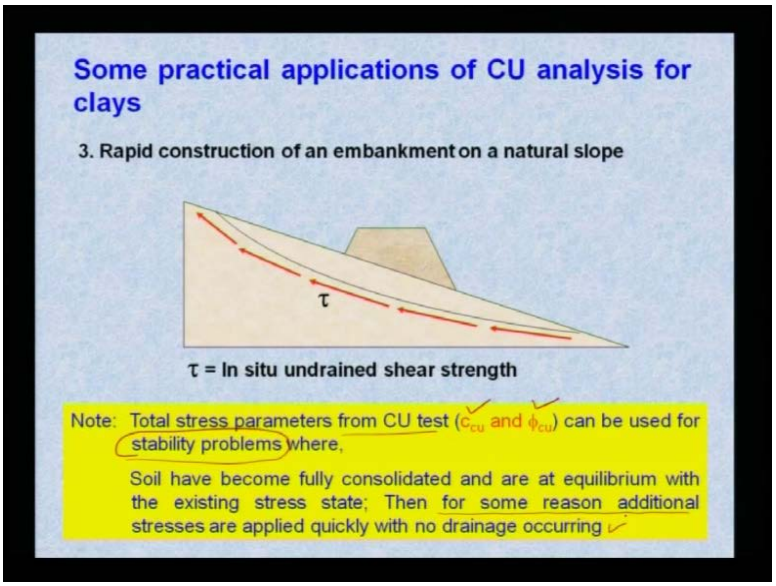

Third example, rapid construction of an embankment on a natural slope, this is an embankment, the construction will be rapid, that means, this construction is not slow enough, so that development of pore water pressure or change in volume due to water, it will, it will occur. So, because of rapid, this generation of our development of pore water pressure will not occur. So, this will be example, 3rd example, for practical application of CU analysis.

Total stress parameters from CU can be used for stability problem, remember, as I said, total stress parameter can be used for stability problem, means, the question is, why this CU, CD or UU test is required? What for, where it is applicable? Suppose, this soil is, as I said, this, suppose you want to take soil from here and if you test it in the laboratory, what kind of test you are supposed to do? And what parameter you have to give the design engineer, so that they can use for analysis, they can use for analysis? So, this is the example, case by case we are seeing. Once, any stability analysis, any stability analysis, this has been, means, particularly total stress parameter of CU test is required or maybe, used in terms of C cu and phi cu soils or soil have become fully consolidated and are at equilibrium with the existing stress state. Then, then for some reason additional stresses are applied quickly with no drainage occurring, with no drainage occurring.

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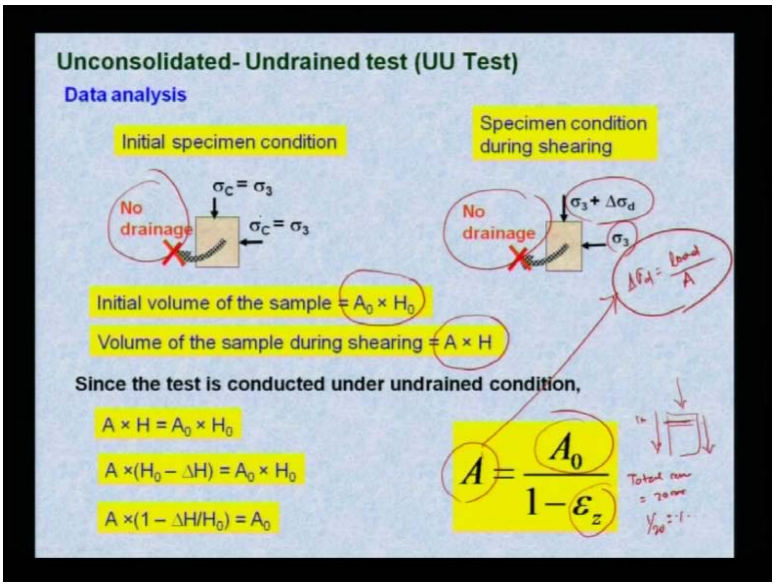

Now, 3rd part is your unconsolidated-undrained test or UU test. So, there are two conditions, initial specimen condition, in this case no drainage, drainage valve will be closed. So, initial volume of the sample will A 0 into H 0, so no drainage, that means, in this case, sigma c is equal to sigma 3. So, specimen during shearing, in stage 2 during shearing also no drainage, so that means, confining pressure sigma 3 is equal to sigma c and sigma 1 is equal to sigma 3 plus increase in stress delta sigma d, volume of the sample during shearing, A into H.

Since this test is conducted under undrained conditions, so A into H is equal to A 0 into H 0. So, HA 0 and H 0 is your initial volume of the sample. Then, A into H or AH is the volume of the sample during shearing. Then, from this you can find it out corrected area. After this shearing, it will be A 0, initial area minus 1 minus e z 1 minus e z is strain, e z is your change in z direction, change in height during shearing. Definitely, it will, compression will occur. So, change in height during shearing, so strain in z direction. If this is my z direction, total compression, say, total compression, total compression is equal to, say 20 mm, say, at initial stage, say, 1 mm. So, it will be, percentage will be 1 by 20, this is your percentage. So, 1 minus e z, from there you can find it out corrected area and you can utilize to find it out. Once you get the corrected area, then you can find it out, sigma 3 delta sigma d. You can find it out, deviatoric stress, deviatoric stress is nothing, but your deviatoric load divided by area and this will come here. Delta sigma d is equal to load, deviatoric load by this area. Then, once you get, then sigma 3, this sigma

3 plus this, it is nothing, but your sigma 1 and this is your sigma 3 all round. Confining pressure sigma 3 is nothing, but sigma c, this is your confining pressure.

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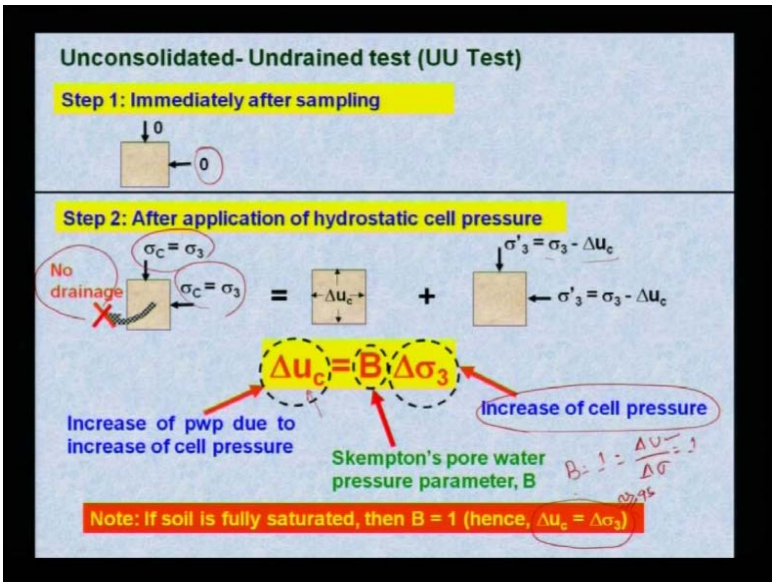

Unconsolidated-undrained UU test - step one, immediately after sampling means, before placing in the triaxial immediately after the sampling has been done, that means, it lost, it lost your confining, that means, sigma c is equal to 0, so there is no overburden or no confining pressure, so this is 0.

Step 2, after application of hydrostatic cell pressure, sigma c is equal to sigma 3 because all round confining pressure has been applied in triaxial, so it will be sigma c is equal to sigma 3; sigma c is equal to sigma 3, no drainage. Now, which is equal to nothing, but as there is no drainage, which is equal to nothing, but delta U c. So, it is, is, if, if I write it in terms of effective, so sigma 3 prime is sigma 3 minus delta u c and sigma 3 prime here, sigma 3 minus delta u c. So, delta u c is nothing, but your b parameter, b into delta sigma 3.

Now, increase in pore water pressure due to increase in cell pressure, this is nothing, but increase in pore water pressure due to increase in cell, cell pressure and this is your increase in cell pressure. This is your skempton pore water pressure parameter b. It has been checked, whether this has, this sample has been saturated 100 percent or not. If the sample is saturated 100 percent, then b parameter is supposed to be 1, which is equal to delta u by delta sigma. That means, with increase in self pressure, suppose say, initially

the sample is there, self pressure is 1. If I increase in 1 to 1.5, this is supposed to be expected to increase. Also, change in pore water pressure also 0.5, so it should be 1, but we assume it 90 percent more than 90 or 95 percent. We assume, that if you are getting b is equal to more than 90 or 95 percent, at that stage we can say, it will be 100 percent saturation.

If soil is, that this is the case, I said, if soil is fully saturated, then b is equal to 1. Hence, delta u c is equal to delta sigma 3.

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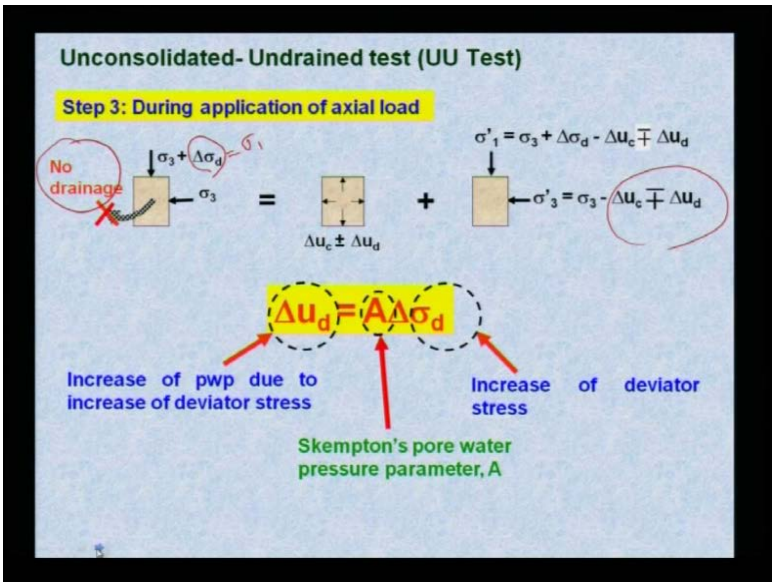

Now, stage 3 or step 3, during application of axial load what will happen? There is no drainage, so sigma 3 plus sigma delta sigma d. Delta sigma d is nothing, but your sigma 1. If I write in terms of change in pore water pressure, so it will be delta sigma 1 sigma 3 plus delta sigma d minus delta U c plus minus U d U c plus minus U d.

So, again, delta U d is equal to A into delta sigma d u delta U d is your increase in pore water pressure due to increase in deviatoric stress. This is because of increase in deviatoric stress, means this is particularly unconsolidated-undrained test. In this case, there is no drainage; there is absolutely no drainage. That means, once you increase the cell pressure, you can get also increase in pore water pressure. If you increase your deviatoric stress also, this increase in pore water pressure.

Now, increase of deviatoric stress delta sigma d is your increase of deviatoric stress. This is your skempton pore water pressure parameter A.

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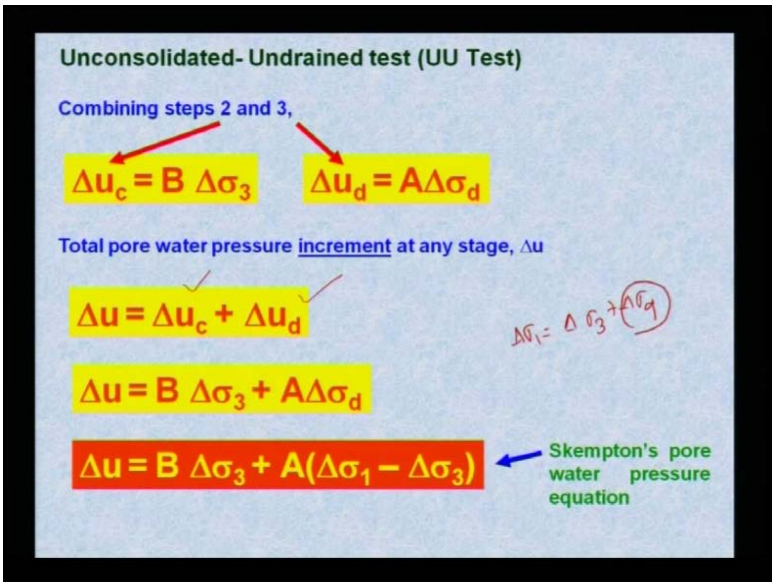

Now, combining step 2 and step 3, delta u c because of confining pressure, delta u d because of your deviatoric stress, total pore water pressure increment at any stage, delta u is equal to delta u c because of your confining and because of your deviatoric; because of confining, because of your deviatory. And this, I can write in terms of b into delta sigma 3 plus A into delta sigma d. So, this is nothing, but it has been derived skempton's pore water pressure equation delta u is equal to b into delta sigma 3 plus A delta sigma 1 minus delta sigma 3. Because if you say, delta sigma 1 is equal to delta sigma 3 plus delta sigma d, once you say that, what is your deviatoric stress? This will be delta sigma 1 minus delta sigma 3.

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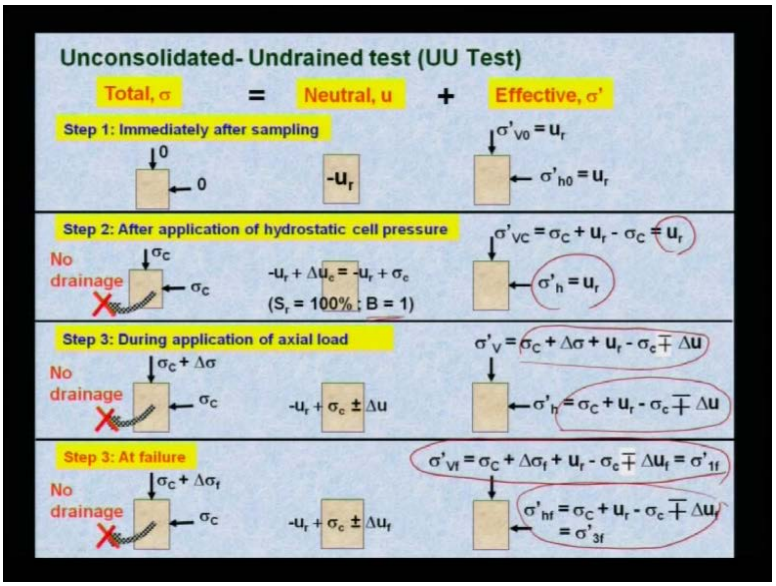

So, total stress is equal to effective stress plus pore water pressure u. So, immediately after sampling what will happen? This is the test procedure, earlier I say what will happen here immediately? Sampling, so it will be sigma v prime is equal to u r sigma h 0 is equal to u r. Whatever they are inside, this negative pore water pressure, it will be, become sigma v prime sigma h prime, after application of cell pressure no drainage. So, suppose, s r is equal to, after application of cell pressure I can say, that it is 100 percent saturation if b parameter is equal to 1. Then, in this case, sigma v prime is equal to sigma c plus u r minus 2 sigma minus sigma c. This is nothing, but u r sigma h prime is equal to u r.

Now, during application of axial load, this is in case of no drainage, that means, again in case of, in the, in application of axial load there is no drainage. So, in this case it will be, this is your sigma v prime, this is your sigma h prime, now at failure, this is at failure you are getting sigma 1 and sigma 3, at failure, at failure in terms of cell pressure I have written sigma c plus delta sigma f plus u r minus sigma c minus plus delta u sigma 1 prime. Here, sigma c plus u r minus sigma c minus plus delta u f is equal to sigma 3 prime.

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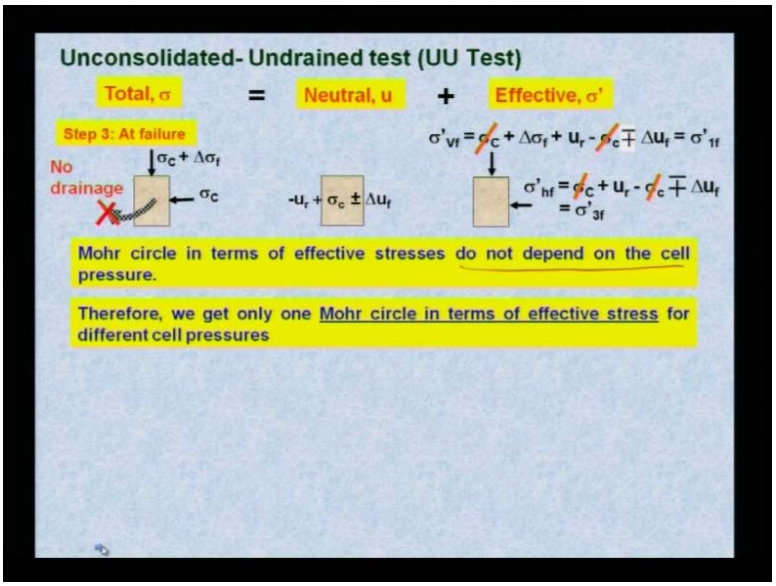

Now, unconsolidated-undrained test, so this is at your failure, if I write, if I plot it sigma c prime, sigma c prime has been, you can cancel it. Similarly, here you can cancel it. What is your conclusion in this case? In this case, this conclusion is Mohr circle, in terms of effective stress do not depend on cell pressure. Mohr circle, in terms of effective stresses do not depend on cell pressure. Therefore, we get only Mohr circle in terms of effective stress.

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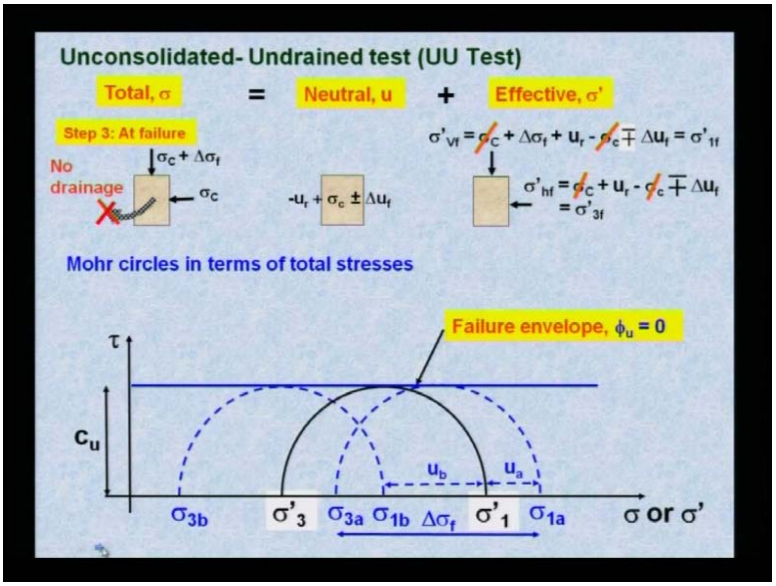

For different cell pressures, Mohr circle in terms of total stresses, you see.

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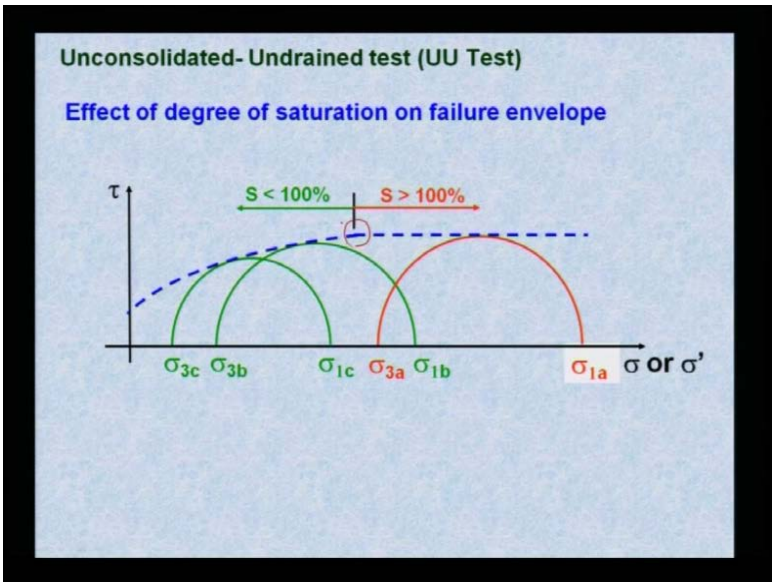

Now, this failure envelope will come out, it will be phi u equal to 0. For degree of saturation on failure envelope, effect of degree of saturation on failure envelope, if you look at, here if the degree of saturation is less than 100 percent, then it will be, there you will be, see that you can mark it at distinguish intersection for this degree of saturation. This is, at the case of degree of saturation, 100 percent. If it is less than 100 percent how it behaves? If it is more than 100 percent how it behaves?

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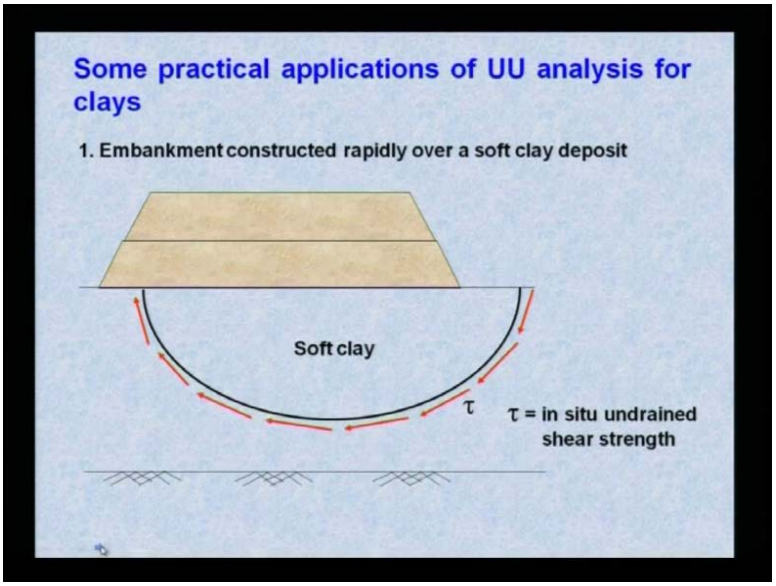

Now, you come back to some practical applications of UU analysis. That means, in field conditions what are the conditions where you will prefer for this test, unconsolidated-undrained test, first is your case one.

Let us say, example one, embankment constructed rapidly over a soft clay deposit. That means, suppose this is a soft clay deposit, you construct embankment very rapidly, that means, once you construct it very rapidly you will not get any time for your consolidation, as well as, any during shearing. No, there will be not be any drainage, in both the steps there will be no drainage. So, this is your in situ undrained shear strength, this is called in situ undrained shear strength.

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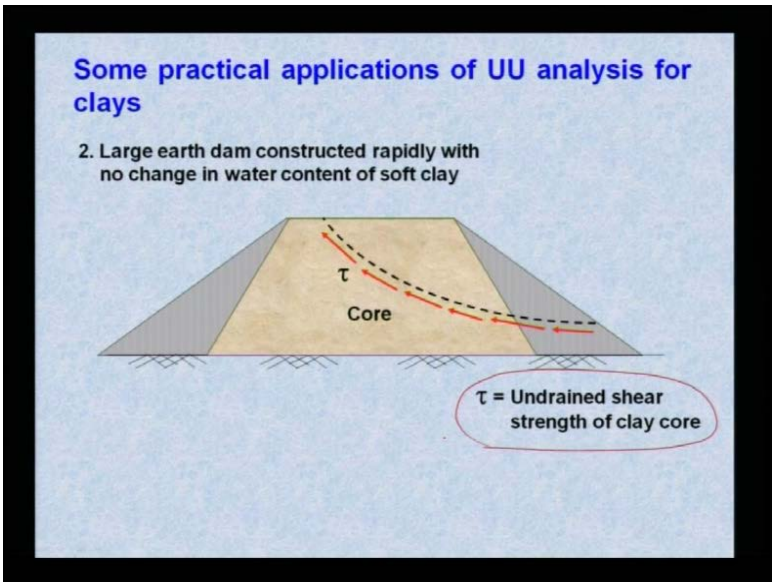

Now, example two, large earth dam constructed rapidly with no change in water content of soft clay. There is no change in water content in the soft clay means, in that soft clay this water content will be remain same. In that case, you will be getting undrained shear strength of clay. That means, in this case, you will go for UU test in the laboratory.

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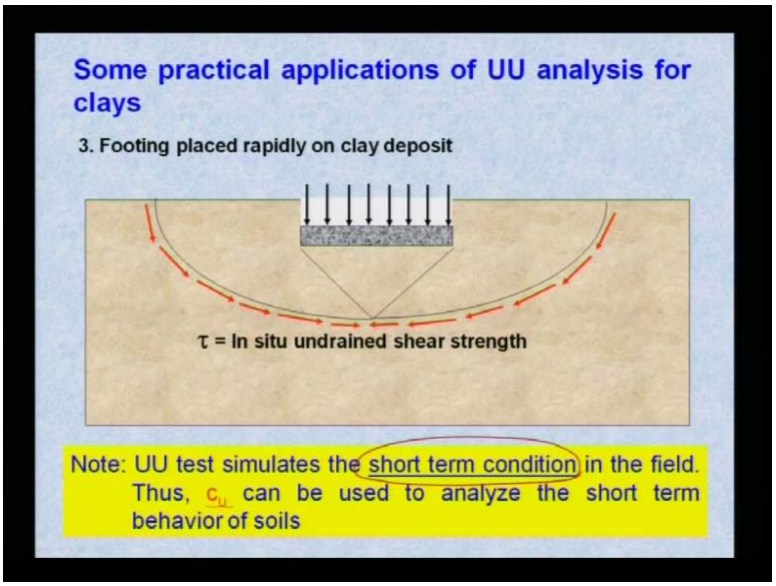

Footing placed rapidly on clay deposit, in that case also the test, what kind of test? Suppose, footing placed rapidly, that means, for immediate means for, long, short term conditions what you want to go for? You will go for UU, undrained and undrained in both, consolidation as well as shearing, means, there is no change in, no change in pore water pressure, no volume change because of your change in water. So, in this case, you will get for footing placed in rapidly on a clay deposit, the test preferred to be UU analysis. As I say, UU test simulates the short term conditions; for short term conditions you will go for UU test.

Any construction or stability analysis, any or embankment, where you go for a short term analysis, in that case you will go for UU test. So, c u can be used, means undrained shear strength c u can be used as analysis of short term behavior of soil.

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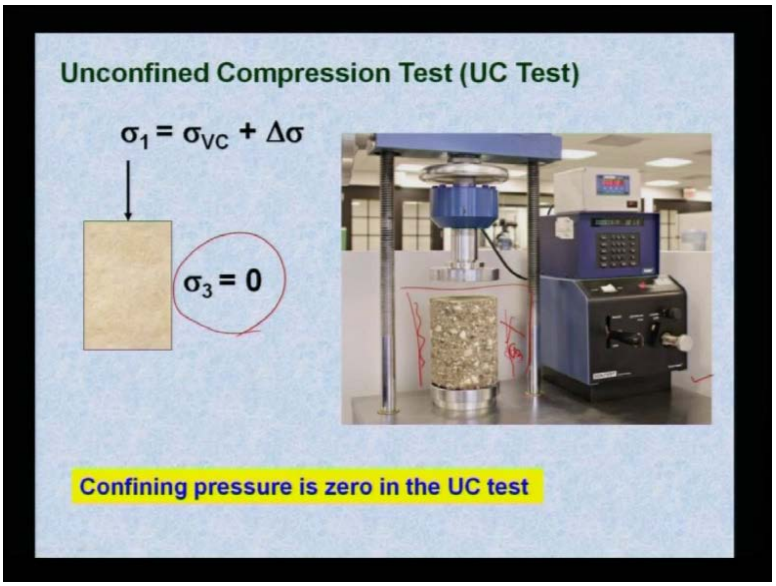

Last one is your, I, I explained also unconfined compression test, I have already shown in this lectures, previous lectures in the blackboard, this unconfined compression test. If you look at this, how the machine looks like? Unconfined compression test here, there is nothing, no confinement, no self, self pressure, nothing, only you can place the sample in the base of the pedestal where you can apply, apply from the vertical, you can apply deviatoric stress. That means, the confinement sigma 3 is equal to 0.

So, there is no confinement, no shear is there, no water pressure has been applied, only this vertical load or deviatoric stress will be applied, so that you can measure only sigma 1, sigma 3 is equal to, in this case it will be 0. This is the test equipment for unconfined compression test.

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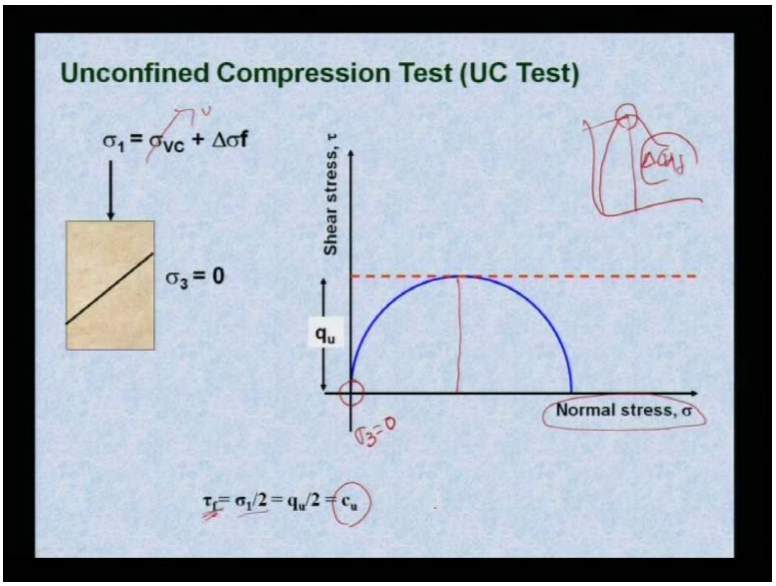

What you are supposed to get? You will get if, if I go for unconfined compression test, you will get, this is your normal stress del sigma. If I come back here, look at here, sigma 3 is equal to 0. That means, there is no confinement; that means, sigma 3 is equal to 0. If I want to plot this Mohr circle, that means, sigma 3 is equal to 0, means it will start at origin. In this case, it will be sigma 3 is equal to 0; that means, if I draw the Mohr circle, this is my sigma 3 and sigma 1.

Whatever you will get it from stress, deviatoric stress versus strain, this is related to your failure, from there you will get it delta sigma f. From where you will get it? Sigma 1 is nothing, but your delta sigma F. So, this is also, again 0, so it will be delta sigma f. You will get normal stress of sigma 1 and if I plot a Mohr circle, it will touch this origin, it will pass through the origin. Now, draw a common tangent, which is touching this, your Mohr circle. So, once you will, it will touch, you will get it to u; that means, undrained means, unconfined compression strength q u.

So, tau f is equal to, tau f is equal to sigma 1 by 2, sigma 1 by 2, which is equal to q u by 2 or which is equal to c u. So, this is all about your c u, c d and u u and u c test. Now, the difference of, if I look at here, in u c, unconfined compression test, there is no confinement.

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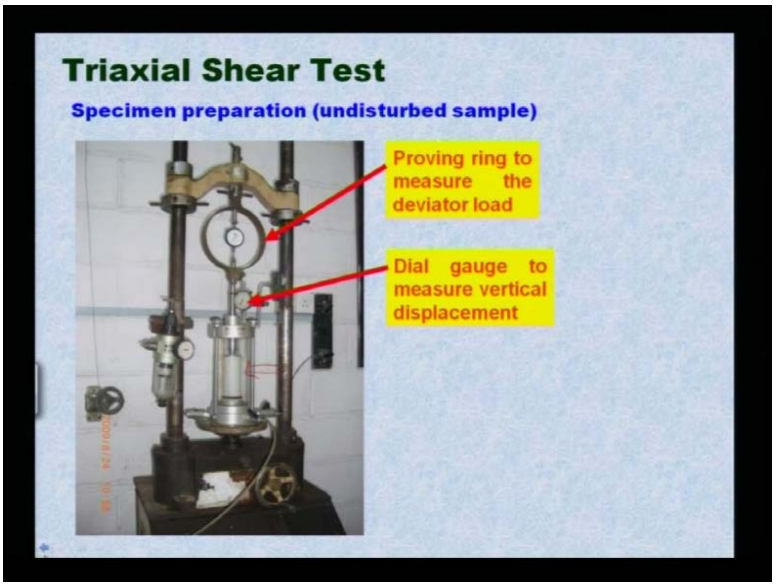

If I go my earlier of this triaxial test equipments, look at here, this confinement comes from here in the cell. In the cell, the confinement sigma 3.

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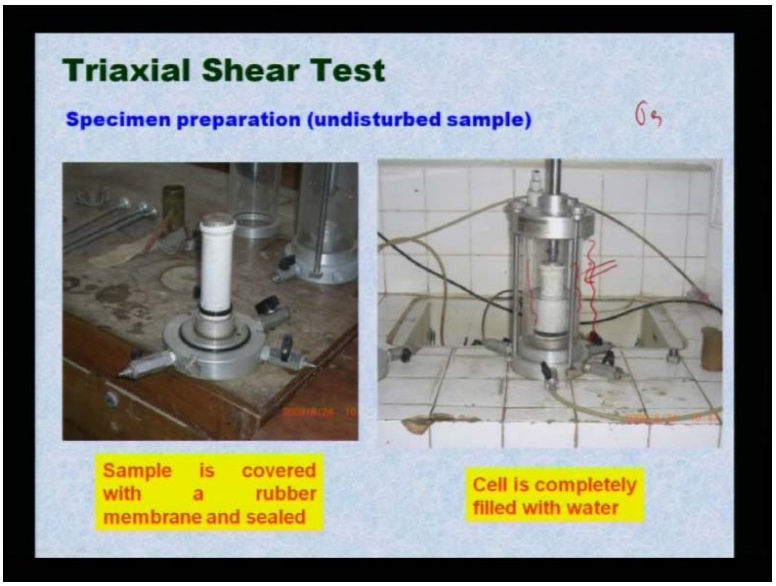

Once again I am repeating this, once you place this sample in the base and place inside the cell, this is your triaxial cell, place inside the cell, that means, this confinement means, confinement, you apply confining pressure by means of water filling inside.

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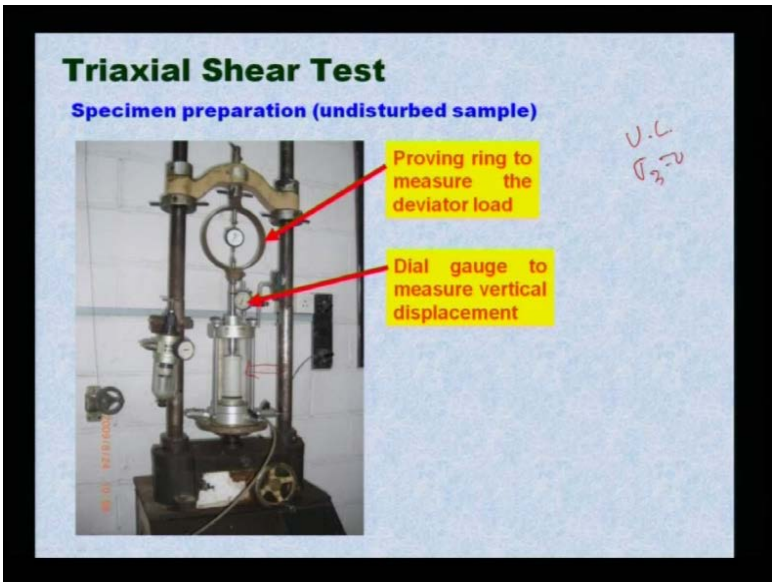

But in case of u c test, this confinement is not completely there, this is the difference. Here, you are applying sigma 3, but in u c test no sigma 3, sigma 3 is equal to 0 in case of u c test. So, this is all about your triaxial shear test, about the equipment and what are the, tests is, test we are going to do and where it is applicable, in what actual field condition the test should be applicable? All about triaxial, then we will go next class, more about your field test, other field tests, which are related to dynamic property of soil, we will discuss in next class.