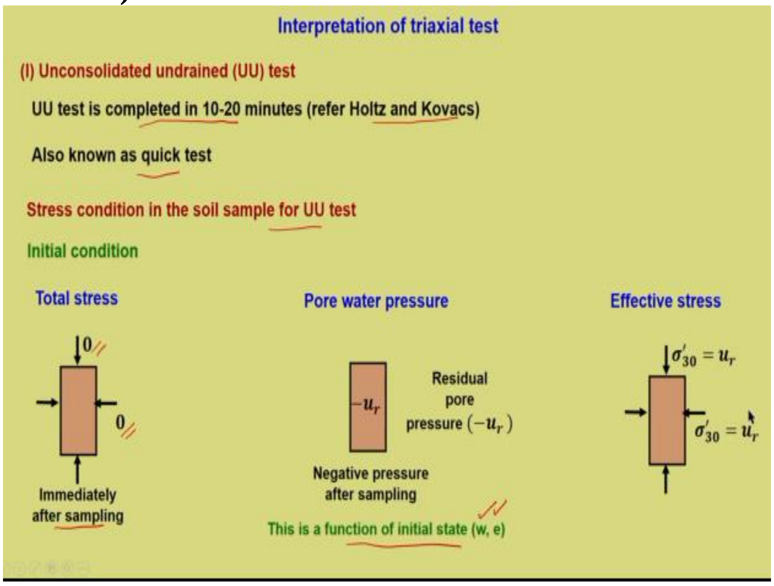
Advanced Soil Mechanics
Prof. Sreedeep Sekharan
Department of Civil Engineering
Indian Institute of Technology - Guwahati

Lecture - 28
Interpretation Triaxial Test - UU UCS

Welcome back all of you, in the last lecture, we have seen the different possibilities of triaxial testing and what are the different type of tests that we can execute in a triaxial cell. In today's lecture, we will learn how to interpret these test results. As we have seen there are 3 major type of triaxial testing, UU unconsolidated undrained, CU consolidated undrained and CD consolidated drained in today's lecture, we will see the interpretation of unconsolidated undrained test.

(Refer Slide Time: 01:10)



So, it iSuU test we have already discussed that UU test is a quick test and it is completed mostly by in 10 to 20 minutes you may refer to Holtz and Kovacs book because much of these discussions I am referring to that it is also known as quick test. Let us first see, what are the different the stress condition in the soil sample for UU test the initial condition pertains to the soil sample once it is sampled from the field.

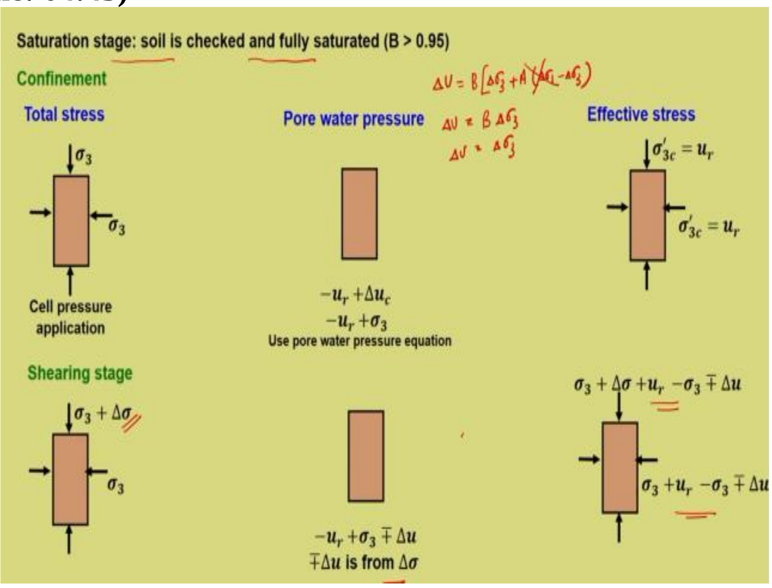
Referring the figure, let us consider the sample soil which needs to be tested for UU we have already discussed about the effect of sampling in our previous lecture. And what did we discuss there what we have told is that during sampling the confinement and the overburden stresses gets released and we have tried to compute what is the pore water pressure that would be there in the soil specimen now, that information becomes quite handy for this particular lecture.

Because, when you sample the stresses are released and hence, we have the lateral as well as actual stresses to be 0 and this is immediately after sampling. Now, what is the pore water pressure whether pore water pressure will be 0 or it will be something else? We have already seen for a typical normally consolidated case with A value of 0.5 in our previous lecture, we have seen the final pore water pressure will be always less than the pore water pressure when it was there in the field that means it tends to become negative.

So, here I am considering it to be negative because it is lesser than the initial condition due to release of the confinement the pore water pressure tends to be negative. Now, this is represented as -u_r as negative pressure after sampling and thiSu_r is known as residual pore pressure. So, thiSu_r or the - u_r is instrumental in preserving the sample or holding the sample intact this also we have discussed in the previous lecture.

Now, thiSu_r what will be its value? It will be a function of initial state and initial state when I say it also pertains to w that is the gravimetric water content and e which is the void ratio. It is also a function of a third quantity, which we have already seen, which is stress history, because A value is dependent on stress history. So, what will be the effective stress total stress minus pore water pressure. So, we have σ'_{30} that is all round stress will be equal to u_r. So, this is the initial condition of the sample.

(Refer Slide Time: 04:45)



Now, this sample need to be saturated first so, the very first stage in triaxial testing is saturation. And we use the B parameter we have seen all these things. Let us say that the sample is fully saturated now. So, the next stage is confinement so, what will be the stress changes, that happens to the sample? So, to the sample we apply the cell pressure σ_3. Now, because of this what happens?

The pore water pressure will change because in UU test it iSunder undrained condition. So, pore water pressure will be $-u_r$ was there the residual pressure pore water pressure which was already there in the sample, it was already there, so, $-u_r + u_c$ now, $+u_c$ comes from where now, this $+\Delta u_c$ is comes from because of the cell pressure application.

So, the pore water pressure after the application of confinement is $-u_r + \Delta u_c$, now, Δu_c comes from where it is because it is associated with the application of cell pressure. So, we need to use the pore water pressure equation, so, it will give the same value, what is the pore water pressure equation? That is

$$\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]$$
$$\Delta u = B\Delta\sigma_3$$
$$\Delta u = \Delta\sigma_3$$

So, I am writing this just to make you understand how handy the pore water pressure equation is now. So, that is how it comes here $-u_r + u_c$, so it becomes $-u_r + \Delta\sigma_3$ and $\Delta\sigma_3$ is the confinement applied. So, what will be the effective pressure?

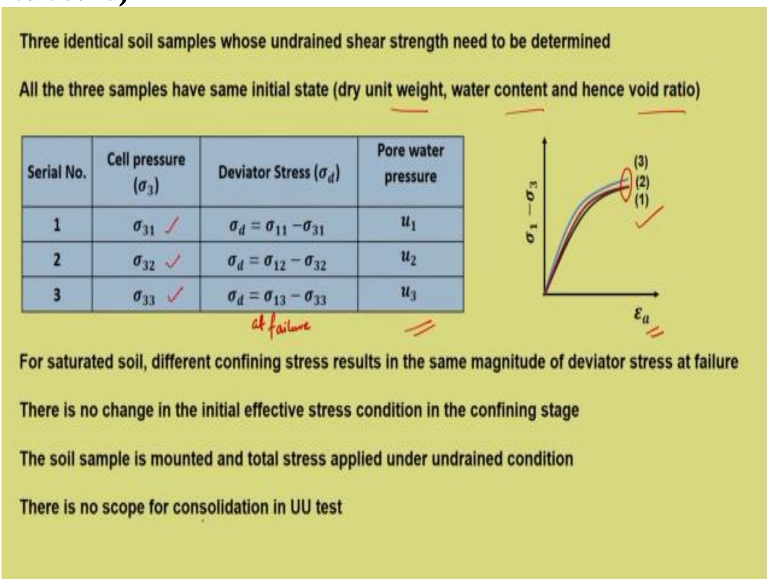
Effective pressure will be $\sigma_3 - u_r + \sigma_3 = u_r$. So, the effective stress is u_r now, so, then comes the shearing stage. So, without opening the drainage wall stress is applied or the actual load or the actual stress is applied and that is equal to $\Delta\sigma$ which is the deviatoric stress component that causes failure and what will be the pore water pressure? So, it will be $- u_r + \sigma_3 \pm \Delta u$. Now, this Δu is because of the result of $\Delta\sigma$ now, why it is $\pm\Delta u$?

Because, we have already seen that for depending upon the stress history, whether it is a normally consolidated or an over consolidated soil in terms of volume change during shearing over consolidated soil will tend to dilate and normally consolidated soil tend to compress now, it is an undrained condition. So, we have seen that accordingly the pore water pressure would change.

So, dilating soil will have negative pore water or pore water pressure will start reducing and tend towards negative whereas, compressing soil like NC that will have positive pore water pressure. So, that is the reason why we have plus minus Δu. So, it is simple then the effective stress will be this $\sigma_3 + \Delta\sigma + u_r - \sigma_3 \pm \Delta u$.

So, ultimately here it will be σ_3 gets cancelled off and the final expression will be $\Delta\sigma + u_r \pm \Delta u$. So, this is the different stages of UU test and what will be the kind of stresses in the soil sample.

(Refer Slide Time: 08:48)



Now, how do we do the UU test we need to have at least 3 identical samples, for example, we want to find out what is the undrained strength at a particular depth. Now, from that particular depth we take it we sample or during subsurface investigation we collect undisturbed samples; which corresponds to that particular point. So, at least 3 identical samples are needed so, that iSused for determining the undrained shear strength. Now, all the 3 samples are assumed to have initial state same that is dry unit weight water content and hence the void ratio.

Now, this is not really practically possible to have exactly same, but we assume that these 3 identical samples are in fact identical in terms of its initial state, because this assumption is very important for understanding the strength the moment it changes, the strength aspect also changes. Now, this is the condition let us say these are the 3 identical samples to which we are applying 3 cell pressure σ_{31} first, then σ_{32}, σ_{33}, where $\sigma_{31} < \sigma_{32} < \sigma_{33}$.

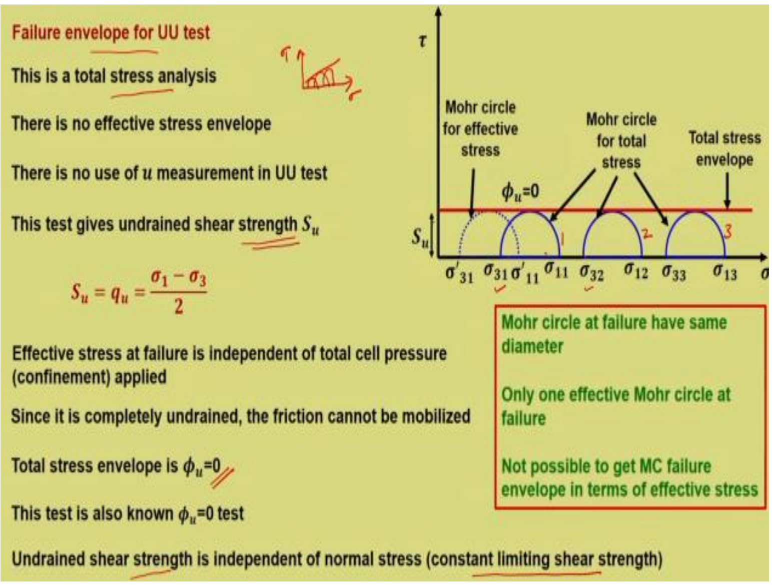
Now, at failure, I am not going to the details of it after the test is conducted, we have the failure stresses now, which is deviatoric stress, which is $\sigma_{11} - \sigma_{31}\, or\, \sigma_{13} - \sigma_{33}$ so, this is the deviatoric stress at failure. So, this is at failure condition and we have already discussed that there is no need of measuring pore water pressure, we will come to know in a few slides like why this is valid, but still I am marking that the pore water pressure is $u_1, u_2\ and\ u_3$.

So, what happens like if you plot these results like $\sigma_1 - \sigma_3$ versus axial strain ϵ_a, there is something interesting what comes out that is the final deviatoric stress at failure, it comes out to be more or less same. So, for saturated soil, even though the confining stresses are different, we have the same almost identical magnitudes of deviatoric stress at failure. Now, this has some important significance, there is no change in the initial effective stress condition in the confining stage.

Now, why this is so? Why we are having such a result? Like there is no change in deviatoric stress, even though the cell pressure is increased, we know that we are not consolidating the sample, it is an unconsolidated test. Hence, there is no change in the initial state of the sample only when you consolidate, there will be changes in void ratio or water content. And hence, the initial effective stress condition changes and we know that the strength of the sample is dependent on effective stress conditions.

So, here there is no such change and hence, the deviatoric stress at failure is more or less same. The soil sample is mounted and total stress applied under undrained condition. So, there is no scope for consolidation in UU test.

(Refer Slide Time: 12:22)



So, what is the net result of this? What do you mean by same deviatoric stress and how does it translate to failure envelope so, that is what we will see here is a failure envelope for UU test here it is τ versus σ plot. And now, we will see that sets of experimental results we have plotted in terms of Mohr circles. Now deviatoric stress strain is same means it means $\sigma_{11} - \sigma_{31}$ is same so, you have same diameter Mohr circle.

So, this is the first one, this is a second one and this is third one, all of them have same diameter. So, this means what is changing then? σ_{31} does the initial point is changing, because there is a Mohr circle. Now, σ_{32} has been increased now, it starts from here, but the deviatoric stress or the diameter of the Mohr circle remains same, same with the third case.

Now, for the first one, we have the pore water pressure measurement, if you find out the effective stress circle, how will you do just minus the pore water pressure we will get the effective stress circle what is happening there are 3 total stress small circles, but there is only 1 effective stress circle. So, that is what we see from this particular figure. So, what will be the failure envelope, the failure envelope is basically tangential to the Mohr circle. Now here the only possibility of tangential this thing is a horizontal line.

So, this horizontal line represents the Mohr failure envelope, but this is very specific to undrained condition. So, this is purely a total stress analysis, there is no effective stress envelope there is effective stress circle, but there is no effective stress envelope when will you say that you have an effective stress envelope? Only when we have τ versus σ and if there is multiple effective stress then I can draw a failure envelope but here 3 total stress circles have resulted in only 1 effective stress circle.

So, if you cannot draw a Mohr circle failure envelope, we can draw Mohr failure envelope only if we know what is the angle of internal friction? So, there is effectively no effective stress envelope possible from UU test and some of you would have understood this, concepts very well during your UG but it is normally observed that these aspects are not fully appreciated during your UG learning.

So, it is very important to understand what is the significance of UU? So, that is why I am taking time and explaining it in detail for some this may not be needed. The Mohr circle at failure have same diameter I have already explained only 1 effective the Mohr circle at failure I have explained what is the reason because there is a corresponding increase in the pore water pressure for σ_{31} there iSu_1, σ_{32} proportionally it is increasing.

So, by u_2, σ_{33} proportionally it is increasing to u_3. So, there is no scope for any sort of changes not possible to get Mohr column failure envelope in terms of effective stress. So, there is no use of u measurement in UU test now, possibly you will appreciate this point why there is no need of pore water pressure measurement, even if you measure you are not going to get any effective stress envelope.

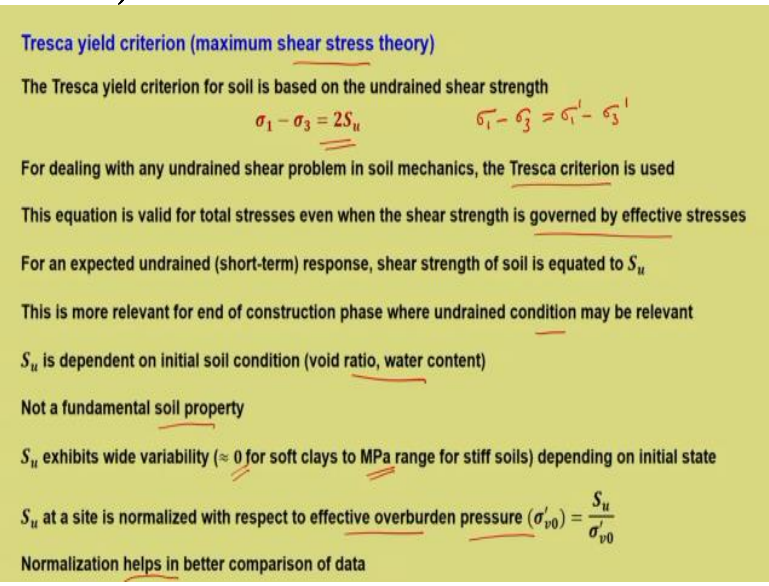
This test giveSundrained shear strength exclusively the value of S_u now, there are several textbooks in which you will find it is denoted aSundrained cohesion. In fact, if you understand this aspect, that is that from UU test what you get iSundrained shear strength, there is no harm even if you use the term untrained cohesion, because it is very difficult to comment on the kind of cohesion that exists.

So, here it is, in general, it is better to use the terminology undrained shear strength and which is represented by S_u and this S_u is what you obtain from UU test and which iSused for specific design applications. So, S_u is what? $S_u = q_u$ which is equal to $\sigma_1 - \sigma_3 / 2$. So, this we need to get the radius of the Mohr circle and that is the Mohr failure envelope.

So, $\sigma_1 - \sigma_3 / 2$ effective stress at failure is independent of total cell pressure applied we have seen there is no effect of σ_{31} σ_{32} σ_{33} these statements denotes the same thing, but why I am stressing these statements again and again is that these are different ways by which you tell the same thing so, that you need to understand it carefully. Since it is completely undrained the friction cannot be mobilized.

So, there is no concept of ϕ coming into picture so, total stress envelope is ϕ = 0. Hence, this test is also known as ϕ = 0 test. So, undrained shear strength is independent of normal stress which is constant limiting shear strength, thiSundrained shear strength S_u is known as constant limiting shear strength now, what do you mean by this statement at various normal stresses, you have the same value of S_u so, that is why it is independent of normal stress.

(Refer Slide Time: 18:40)



Now, this part many of you would have understood, but what is the significance of this ϕ = 0 failure envelope. Now, this condition iSused by Tresca failure criterion or it is known as maximum shear stress theory because you are considering the maximum shear stress point. In fact, the soil when you consider the effective stress conditions or various other triaxial test results you will see that it does not fail at maximum shear stress conditions only for undrained condition.

The failure is associated with maximum shear stress that emerges in this soil. So, Tresca yield criteria for soil is based on the undrained shear strength S_u. So, σ_1 - σ_3 = 2 S_u so, when the stress condition approaches S_u it is found that this soil would yield for dealing with any undrained shear problem in soil mechanics, the Tresca criterion iSused. This equation is valid for total stresses even when the shear strength is governed by effective stresses why? What is the importance of this statement?

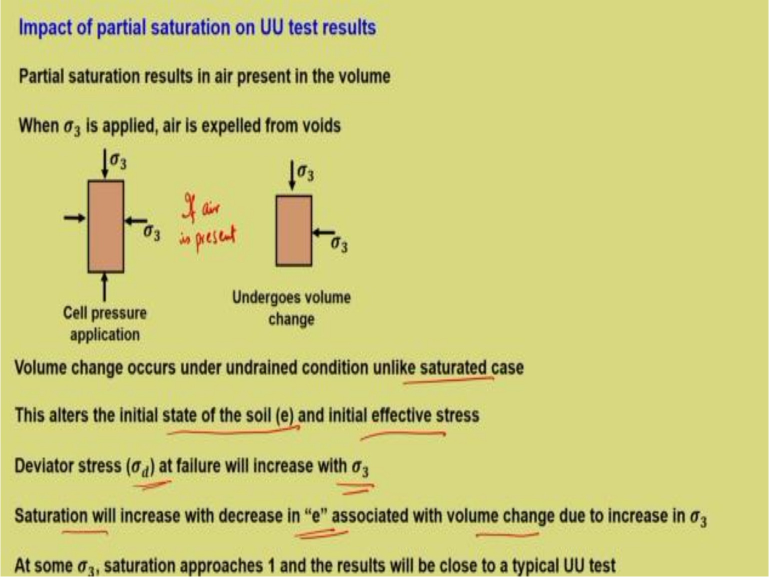
This equation means σ_1 - σ_3 we know that even though there is pore water pressure or not, whether it is effective stress condition or not $\sigma_1 - \sigma_3 = 2 S_u$ will be valid, we know that shear strength of the soil is exclusively determined by its effective stress condition. So, even if I write $\sigma_1 - \sigma_3 = \sigma_1' - \sigma_3'$ so, it is not violating in any form that when whatever our understanding is that the shear strength of the soil is exclusively dependent on effective stress conditions.

So, this does not violate this for an expected drain undrained condition that is a short term response shear strength of the soil is equated to S_u what we need to understand is that, if we know that we are doing a short term analysis and the conditions are undrained it is that we equate the strength of the soil to this undrained shear strength S_u this is more relevant for end of construction phase where undrained condition may be relevant.

S_u is dependent on initial condition we have already seen this void ratio and water content hence, it is not a fundamental soil property. It exhibits a wide variability you can see that it is approximately 0 for soft clays, to MPa range for stiff soils depending on the initial state. Now, if you considering the actual field problems, then S_u at a site is normalized with respect to effective overburden pressure, which is equal to σ_{v0}' it is effective overburden pressure why?

Because, as the overburden pressure increases, we know that the void ratio or the water content would change. Now, we get we will get multiple values of Su which was influenced by the overburden conditions. So, that is why it is normalized with respect to effective overburden pressures, so, that comparison will be easier. So, this normalization with respect to σ_{v0}' helps in better comparison of data.

(Refer Slide Time: 22:13)



Now, we have talked it is quite understood that whatever we are discussing now is with respect to saturated soil. Now, what would happen if there is improper saturation for the soil samples so, that is what we will see in this slide. Partial saturation results in air present in the volume. So, this is also known to us when σ_3 is applied now, when there is air present what will happen as you apply the σ_3 air tends to dissolve into the water and hence the void tends to close.

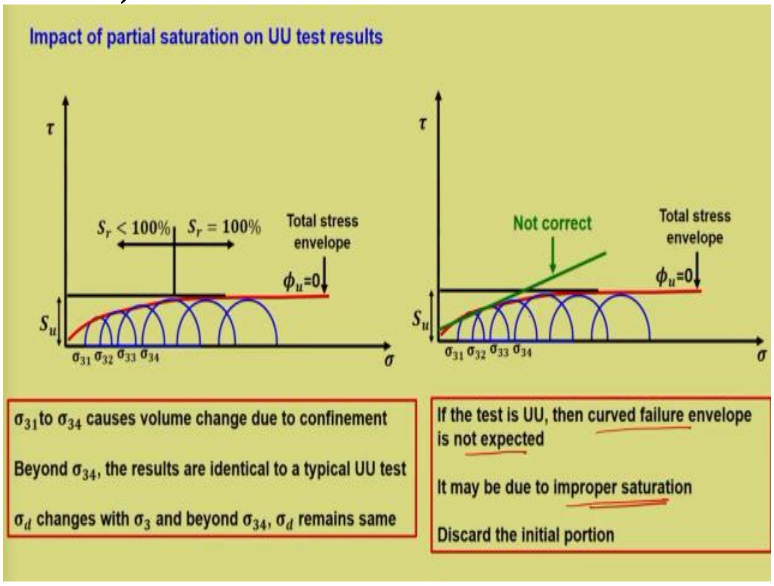
So, what we are doing for an expected undrained test there is going to be a volume change now, this is against what we want, because for a truly undrained condition, we expect that there is no volume change, but if there is presence of air then volume change is bound to happen. So, if you see that this is the cell pressure application, so, if air is present, what will happen there will be volume change.

So, there is an unexpected or hidden volume change in an undrained test where we assume that there is no volume change. So, volume change occurs under undrained conditions, unlike the saturated case, this alters the initial state of the soil. Now, once the initial state alters, then that will impact the strength of the soil and the initial effective stress condition why? Because, there has already been a volume change now, the deviatoric stress which was same at failure for a saturated system.

Now, it will increase with σ_3 because as σ_3 increases, the amount of volume closure also increases till the entire air voids is removed. So, that will influence the deviatoric stress at failure which keeps increasing. So, saturation will increase with decrease in e as the voids close when the air gets dissolved into the water or expelled out what will happen the saturation also will increase.

Now, as the volume change increases, saturation also increases and at some σ_3 saturation approaches the value of 1 and the results will be then close to a typical UU test. So, what will happen as the confinement goes on increasing the amount of wide closure also increases saturation increases at some point of time saturation approaches one. So, then the results what you will be getting will be identical to the saturated UU test.

(Refer Slide Time: 25:11)



So, that is the impact of saturation let us see what is happening now, this is σ_{31}, where some of the voids gets closed because of the expulsion of air σ_{32} again some volume closes and you can see that the deviatoric stress keeps on increasing now deviatoric stress keeps on increasing means diameter of the Mohr circle keeps on increasing now, up to σ_{34}, there is a increase in the Mohr circle now, beyond that, the Mohr circle diameter, more or less remains constant.

So, what would have happened now, this is a typical test of UU, but the soil sample was not initially saturated. So, instead of getting a horizontal failure envelope, you are getting a curved failure envelope and at some confining stress, it becomes same as $\phi_u = 0$. So, this is the value of the undrained shear strength. So, what is this initial portion, this initial portion is mainly due to the partial saturation or improper saturation.

So, here beyond this line, it is S_r less than 100 percentage and for this it is S_r = 100%. So, from here on, it is 100% saturation and hence, we get the same failure envelope $\phi_u = 0$.. So, σ_{31}

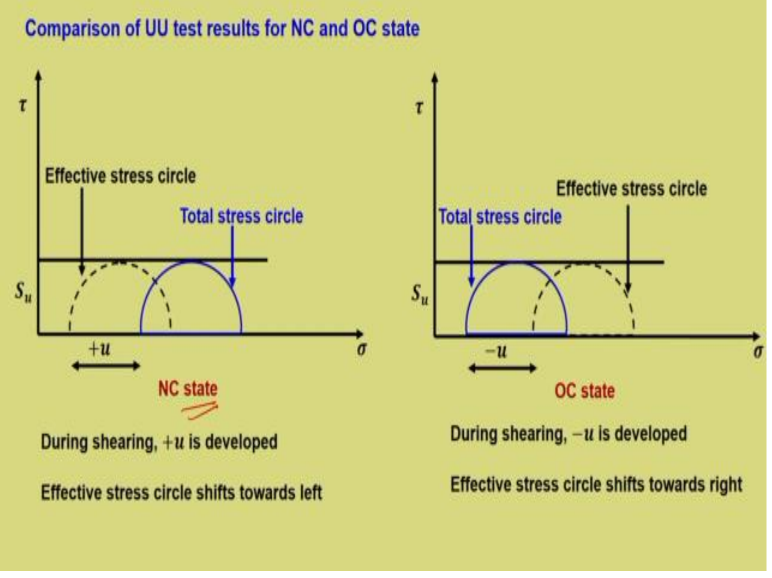
to σ_{34} causes volume change due to confinement beyond σ_{34} results are identical to typical UU test σ_d changes with σ_3 and beyond σ_{34}, σ_d remains same.

So, this is again I have redrawn it here to show you important aspect which we have to keep in mind, when we know that we are conducting UU test. So, if one gets such a pattern of Mohr circle or maybe most of the time, what we do is we have only 3 or 4 repetitions or identical samples tested. So, if it is 3 or 4, then what happens is 1, 2, 3 we will be getting a curved failure envelope, but we know that it is a UU test result.

So, if we know it is UU test, then we know that we are not expected to get a curved failure envelope it has to be a horizontal failure envelope. So, unless we appreciate this point, when you go through a test report, then it is difficult to make out this point. So, always keep in mind that if it is a UU test, then $\phi = 0$. If you find that there is a curve failure envelope which is tangential to the Mohr circle, then the problem lies with the saturation.

So, this is what I told curve failure envelope is not expected it may be due to improper saturation. So, we need to discard the initial portion, either repeat the test or discard the initial portion or take an average value of S_u and definitely if you are considering the initial portion where it is curved, this particular portion if you are averaging it out, definitely you will be having a lesser value of S_u. So, it is always better to investigate why and what has caused curved failure envelope in UU test.

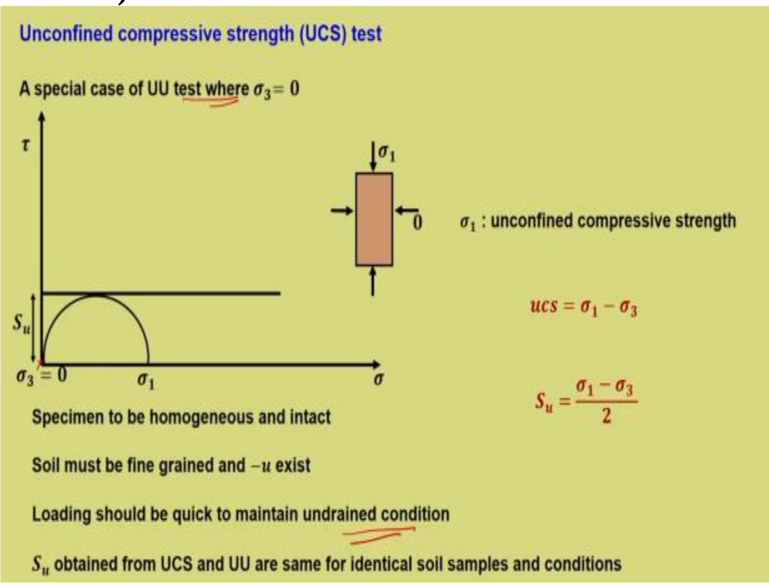
(Refer Slide Time: 28:43)



Now comparison of UU test for NC and OC state. So, you can see that τ versus σ is a total stress circle $\phi = 0$. Now, because of positive pore water pressure, you will have effectives to circle shifted towards the left and this is a typical case of NC state that is normally consolidated soil normally consolidated soil during shearing will have positive pore water pressure.

So this will shift the effective stress circle towards left and the same for over consolidated soil u will tend to be negative and hence the effective stress circle shifts rightward. So, these are the 2 comparisons how the stress history would influence the UU test results.

(Refer Slide Time: 29:33)

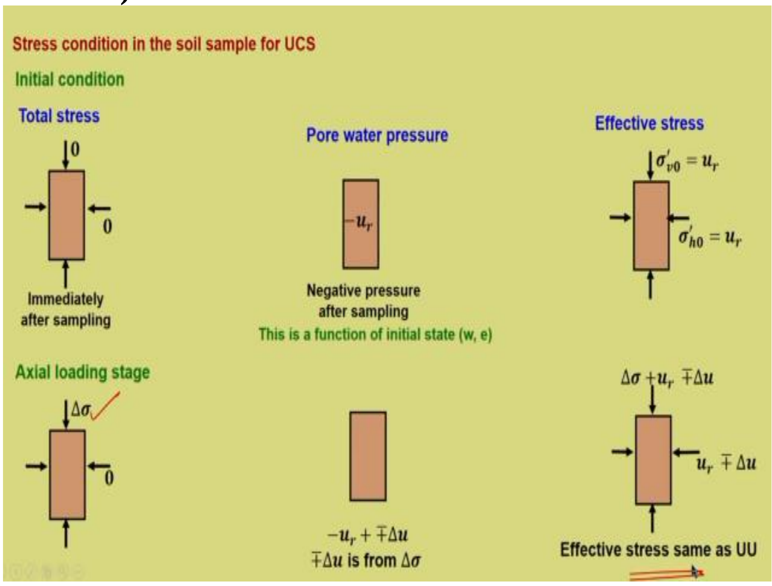


Now we have almost finished the UU test discussion and its interpretation we will see what happens in unconfined compressive strength. Now this is a special case of UU test that is why I am discussing along with UU test. So it is a special case where $\sigma_3 = 0$. So this is the condition where $\sigma_3 = 0$ and σ_1 is the unconfined compressive strength, this is what I meant.

So, instead of starting from somewhere here, the starting point is at $\sigma_3 = 0$ and this diameter is $\sigma_1 - 0$ that gives the unconfined compressive strength, but everything else remains the same, we have the same undrained shear strength. So, UCS = $\sigma_1 - \sigma_3$ and $S_u = \sigma_1 - \sigma_3 / 2$ rather $\sigma_1 / 2$ in this particular case, specimen to be homogeneous and intact soil must be fine grained and negative u exist I mean to say the negative residual pore water pressure is there otherwise this soil will not remain intact.

So, it is applicable UCS is applicable for these situations loading should be quick to maintain undrained condition because this considered to be an undrained test. So, S_u obtained from UCS and UU are same for identical soil samples and conditions. So, there are cases where you may not get identical test results of UCS and UU depending upon specific conditions, but in practice or in general, we always consider UCS test and UU test for this same initial state of the sample will be more or less identical.

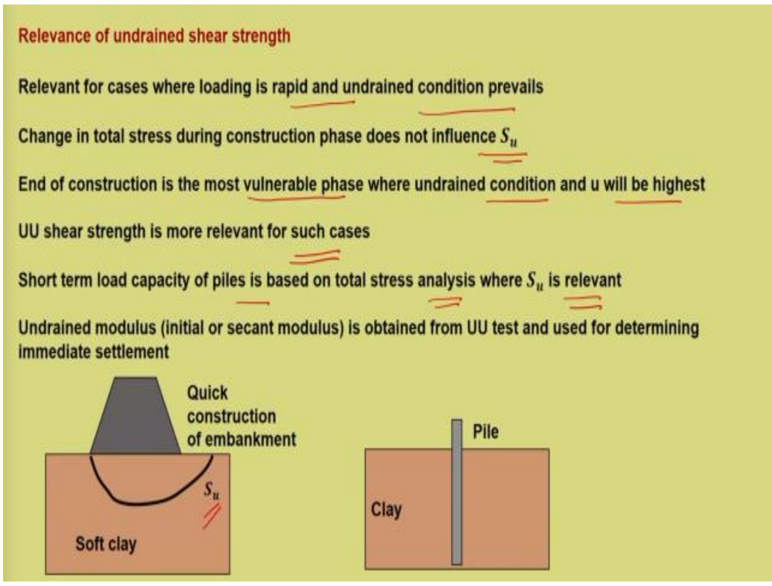
(Refer Slide Time: 31:26)



Stress condition in UCS same as that of UU test let us see that this is the initial condition u_r the same as that of whatever we have discussed. Now, axial loading state there is no confinement. So, it is directly axial loading stage we apply $\Delta\sigma$ and that is nothing but σ_1. So, what will be $-u_r \pm \Delta u$ which is coming from delta σ why this is considered to be an untrained test?

So, please do not forget that particular aspect, you will be wondering where is the pore water pressure coming from, but it is there because it is a quick loading test. So, what is the effective stress condition it is $-u_r \pm \Delta u$, you can see that if you compare this effective stress with that of UU you will see that this is same. So, that means that we are going to get the same strength.

(Refer Slide Time: 32:20)



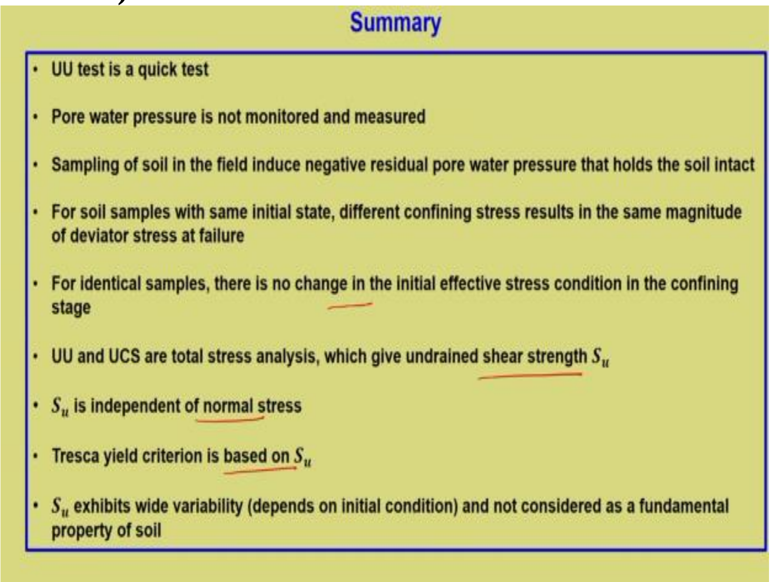
Now, what is the relevance of undrained shear strength is relevant for cases where loading is rapid and undrained condition prevails S_u which is the undrained shear strength to change in total stress during construction, it is not going to influence the whatever is the strength that is available and of construction is most vulnerable phase where undrained condition and u will be highest.

So, UU shear strength is more relevant for such cases when there is end of construction phase this is very easy to understand, because we have already discussed this total stress variation with time in one of our previous lectures. So, this is their quick construction of embankment over a soft clay it gives S_u now, this S_u is there for a particular state of the soil sample. And that is not going to change with the construction sequence that remains the same only aspect is if it is a quick construction.

Then the undrained condition prevails and S_u becomes active or S_u becomes more prominent short term load capacity of piles is also based on the total stress analysis where S_u is relevant. I hope you remember in foundation design for piles, there is a short term analysis, where we consider that the soil exhibit and undrained behavior in that case, what we have is the undrained shear strength S_u so, for designing of piles or determining the pile load capacity one need to know the value of S_u.

So, that is what is shown here undrained modulus now if you want to determine the elastic settlement or the cube settlement, what that happens immediately after loading we need to have what is known as undrained modulus it may be initial or secant modulus it is obtained from UU test and use for determining the immediate settlement.

(Refer Slide Time: 34:26)

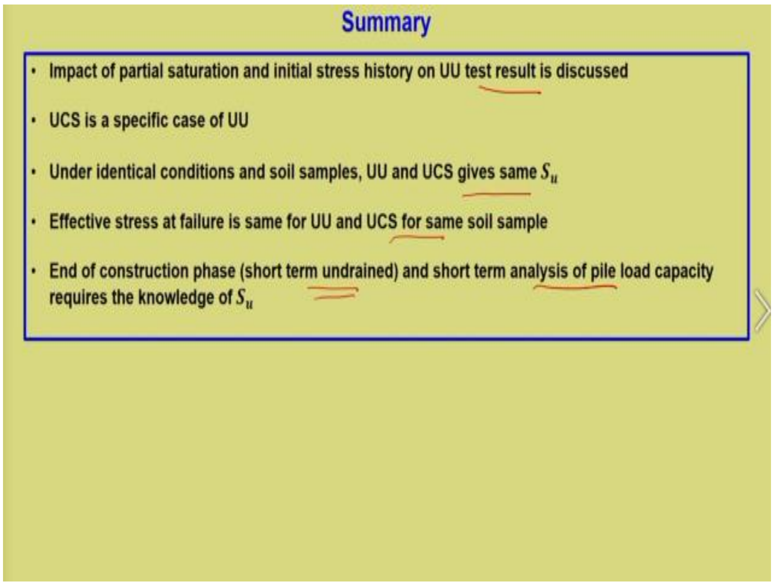


So that is all about the interpretation of UU and UCS. So let us try to summarize what we have learned in this lecture. UU test is a quick test pore water pressure is not monitored and measured. The reasons we have stated sampling of soil in the field induce negative residual pore water pressure that holds the soil intact that is minus u_r for soil samples with same initial state.

Different confining stress results in the same magnitude of deviator stress at failure for identical samples there is no change in the initial effective stress condition in the confining stage. So, even if you apply σ_3 that is not going to affect the initial effective stress condition and that results in the same deviatoric stress. UU and UCS are total stress analysis which gives undrained shear strength S_u.

S_u is independent of normal stress and that is what the Tresca criteria. Tresca criteria is based on S_u, S_u exhibits wide variability, it depends on initial condition and it is not considered as a fundamental property of soil.

(Refer Slide Time: 35:43)



Impact of partial saturation and what is the influence of stress history on UU test result is discussed. UCS is a subset of UU is a specific case of UU under identical conditions and soil samples UU and UCS is expected to give same S_u effective stress at failure is same for UU and UCS for the same or the identical soil sample and of construction phase, which is essentially a short term undrained and short term analysis of pile load capacity, request the knowledge of S_u.

So, that is all for the interpretation of u u test results. In the next lecture we will continue with the interpretation of other triaxial tests, which is essentially CU and CD so that is all for now. Thank you.