Shear strength of cohesive soil
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Lecture - 21
Shear Strength of Cohesive Soil

Welcome back in the last lecture, we have seen shear strength of granular soils. So, in this lecture we will see, we will begin with shear strength of cohesive soils. Now, you may be wondering why such a distinction in fact, the response that you obtain when I say response it may be shear strain response or the manner in which you interpret shear strength the output may be similar for these 2 soils.

But the conditions leading to that output or the initial conditions of soil may be different and the factors contributing to that final output may be different in both. So, in this lecture, we will see shear strength of cohesive soil.

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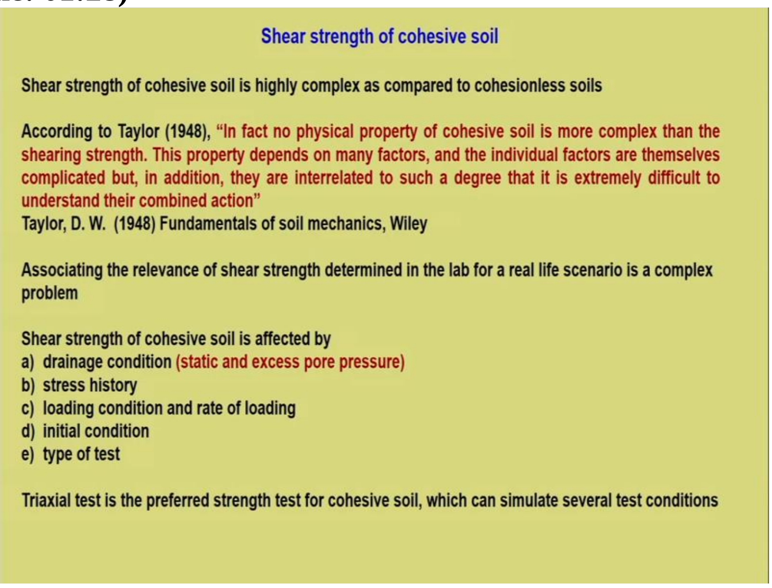

Now, let us start with this introductory remark that shear strength of cohesive soil is highly complex as compared to cohesionless soils. Now, is it really true or not? We will have to see as we proceed, I would also like to add the statements from a popular book by Taylor fundamentals of soil mechanics were in his states. In fact, no physical property of cohesive soil is more complex than this shearing strength.

This property depends on many factors and the individual factors are themselves complicated. But, in addition, they are interrelated to such a degree that it is extremely difficult to understand their combined action. What more we need to know to understand the complexity of shear strength of cohesive soils. You remember I told this sentence in the very beginning of this module, when we introduce this module.

That interpretation of shear strength of soil to some extent lies with the reader himself. So, I am reading certain concepts, I have my own perception of conceiving how or what a shear strength is all about. So, there will be some differences that is mainly because of the complexity associated with so, for cohesive soil, the complexities are more because there are more factors which governs its final shear strength.

Also associating the relevance of shear strength determined the lab for a real life scenario is a complex problem. Now, where is this complexity coming from, we will see what are the factors that governs the shear strength of cohesive soil. Before going to the factors, we need to understand the sentence like we try to simulate the actual field conditions in the lab but many times we may not be able to achieve due to some sort of oversightness.

Hence, how much our laboratory test results represent the actual field condition. There is something difficult to tell and you will be able to understand a bit of it as we proceed in the lecture because we normally perform to axial compression tests. Now, whether this particular test is suitable for all the conditions in the field, we will see this as we proceed in the lecture.

Also, in the case of cohesionless soil, we have seen that the drainage is instant. There are very very few cases where pore water pressure becomes an issue but that is not the case with cohesive soil. So, let us move on to the factors affecting the shear strength of cohesive soil. So, the first factor is drainage condition as I have told and the controlling or maybe the inherent drainage property results in pore water pressure.

If the drainage condition is not good, then it would result in pore water pressure. Now, this dynamics itself is a big issue and that will depend upon the soil flow properties. The second is stress history. Now, if you consider the shear strength of undisturbed soils, then stress history becomes its initial state like what the soil has been subjected to in the past. I hope we all agree to the fact that soil carries certain memory along with which gets erased and rewritten every time when we load it.

This aspect also will become clear as we proceed. So, stress history becomes very important loading condition and rate of loading well that does not need any explanation initial condition, initial compaction state for example, what is the water content or the dry unit weight specifically in case of remoulded samples, the type of test this also we have discussed a bit like depending upon the type of test the shear strength characteristics also changes and that is the reason why we need to state categorically what type of test we have adopted.

But that is on a general terms as you proceed again, by the time you finish the fourth module, you will understand that there is a sort of fundamental characteristics of soil shear strength characteristics of soil which you can very well capitalized and use it as a fundamental property. Now, just like direct shear tests that we used for explaining shear strength of cohesionless soil we will use typical triaxial conditions are to actual testing for cohesive soil. Because you need control of 2, 3 factors specifically drainage border pressure measurement, so on because these are important factors as you could see.

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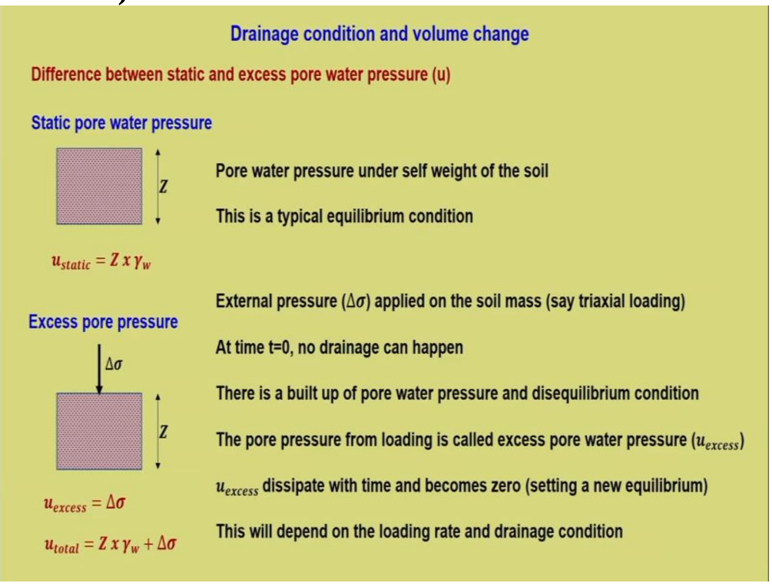

So, let us first discuss a bit on drainage condition and volume change some of these aspects will be quite explicit and some of you would have understood this very well during your undergraduate. Now, this refreshing of these portions is only for those who have not understood it well and there are certain editions also which you may find in these explanations which is important for our subsequent modules.

So, difference between static and excess pore water pressure, why soil mechanics is different from other mechanics, it is because of the presence of voids and the relative content of water and air in it. Now, we are talking about only 2 phase system saturated systems. So, voids are filled with water. Now, when there is soil on its own, there is no external loading acting on it whatever is the pore of pressure, the hydrostatic pressure we call it as static pore water pressure.

So, this is what it is, we have a soil in place which has saturated soil Z is the height. So, u static or the static port a pressure is Z into γ_w understands this is an equilibrium condition and pore water pressure is merely under the self-weight of the soil, there is no external loading acting on it and this is a typical equilibrium condition that means flow has taken place.

Soil is not changing and whatever is the condition of the soil and the water within this is under equilibrium condition. Now to this equilibrium condition, let us say that there is a load which is acting $\Delta\sigma$, the external load or increase in total stress. Now when we say total stress, we understand this is some additional or extra load acting on the soil. So, external pressure, $\Delta\sigma$ applied on the soil mass, let us say triaxial loading.

Now at time t = 0 there is no drainage that can happen because this is first of all cohesive soil. So, at time t = 0 there is no drainage now, what is the result of no drainage. So, there is a built up of pore water pressure and there is a disequilibrium condition. So, $\Delta\sigma$ is entirely taken up by the water. So, pore water pressure increases by the same amount of $\Delta\sigma$ at time t = 0.

So, the pore pressure from loading is called excess pore water pressure you excess now, this excess pore water pressure makes all the difference in soil behaviour with respect to its stress strain as well as shear strength behaviour. So, we need to understand the difference between what sort of pore water pressure causes changes in soil and what sort of pore water pressure is going to influence the shear strength behaviour or the mechanical behaviour of the soil.

It is essentially the excess pore water pressure and u excess to start with when time t = 0 = $\Delta\sigma$ and total pore water pressure will be Z into γ_w that is static component + this additional component. So, u excess what happens to when something is not in equilibrium. Nature if you observe if something is not in equilibrium, it always tried to achieve equilibrium by some means, in the same manner.

Because there is disequilibrium under applied load condition u excess will not exist as it is. It is a transient quantity and there is always a tendency for the soil to dissipate this and reach to a new equilibrium condition. So, u excess will get dissipated over a period of time. Now, the important question is how this will get dissipated. In what manner it will get dissipate this will depend upon again the soil property.

Which is the hydraulic behaviour of soil property, hydraulic conductivity, how fast the water can move out of the soil also, what are the drainage conditions which are possible whether there is a pathway for water to move out all these factors determine how you access is going to dissipate. So that is why it is written it is it will depend upon the loading rate and drainage condition.

Drainage condition hydraulic conductivity of the soil on one hand and on the other hand, the loading rate, the manner in which the load is applied, let us say it is an earthquake loading; the whole of the loading is going to impose in this very small amount of time. So, the built up of pore water pressure will be quite high. Whereas, if it is a very staged loading slowly, then pore water pressure may even not develop, because it will have sufficient time to dissipate. So, this is the 2 different extremes which we need to keep in mind and this is going to influence the mechanical behaviour of cohesive soil.

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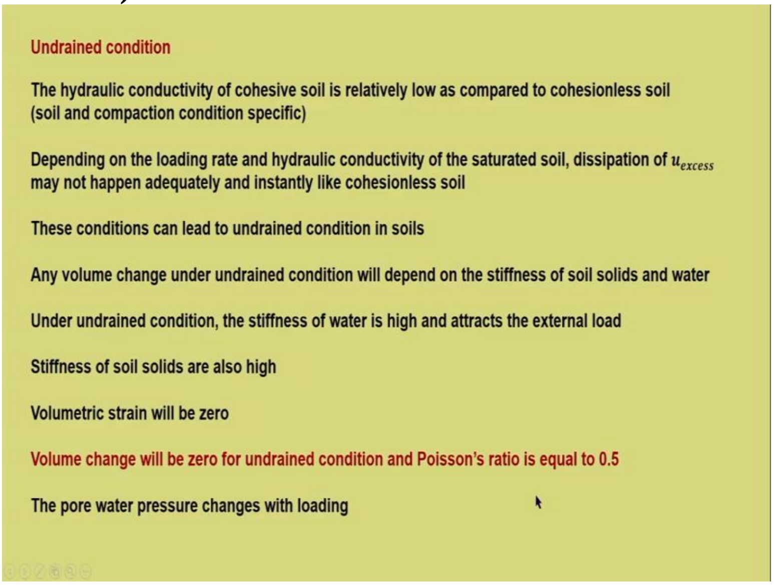

So, now, let us start with undrained condition. Now, what is meant by undrained condition, the hydraulic conductivity of cohesive soil is relatively low as compared to cohesionless soil and it is soil and compaction conditions specific it will depend upon what is the type of soil a clay soil will be having extremely low hydraulic conductivity as compared to a silty one. Similarly, for the same soil the compaction state may alter the pore structure.

So, all this is going to govern what kind of hydraulic conductivity it has depending on the loading rate and hydraulic conductivity of the saturated soil dissipation of u excess may not happen adequately and instantly like cohesionless soil which means to say u excess is going to remain there. Because of this stiffness water attracts the load and it holds it. Now, only when the water is allowed to move out to expend the energy then only it will come back to its original state.

And when it comes back to when it tried to achieve its new equilibrium state. There will be some changes that will happen to soil and that is how we say the total stress is transferred to the soil as in the granular stress or effective stress. Now, depending upon fast loading rate and low hydraulic conductivity, also the access for the water to move out these 3 conditions can lead to undrained conditions in soil.

So, any volume change now, the question associated with undrained condition is yes we understand what is not allowed to move out u excess will remain there. So, what, what is the net effect of undrained kind of when we say it is an untrained condition. What should we understand from it now, let us say from volume change perspective of the soil now, for during undrained condition.

We know that water is not going to move out so, fast then any volume change other than movement of water will be associated with the volume change due to compressibility of the water and or compressibility of the soil solids. So, under undrained condition the stiffness of water is high and it attracts the external load. Since it is undrained, it is not able to move out. So, naturally the stiffness of the water will be high and it has the tendency to attract all the load to itself at the same time, stiffness of soil solids are also high.

So, what does this mean water is not allowed to move out both water and soil compressibility there is no response or there is no volume change associated with well compressibility of water and compressibility of soil solids which means to say that volumetric strain will be 0 and volume change will be 0 for undrained condition and Poisson’s ratio is equal to 0.5.

Now, when whenever we hear the term undrained condition, the first thought that should come to us is it is going to be a no volume change condition.

And we have already seen this in the previous lecture, when the volumetric strain is 0; the poisons ratio goes turns out to be 0.5. So, undrained condition, no volume change Poisson's ratio equal to 0.5. So, these are some of the facts which we need to keep in mind why I am repeating this, why we need to understand this, you will understand its significance as we move forward in the lecture, especially in module 3 and module 4. So, basically we are laying foundation for a better understanding to deal with module 3 and module 4. So, pore water pressure changes with loading. So that we have already discussed.

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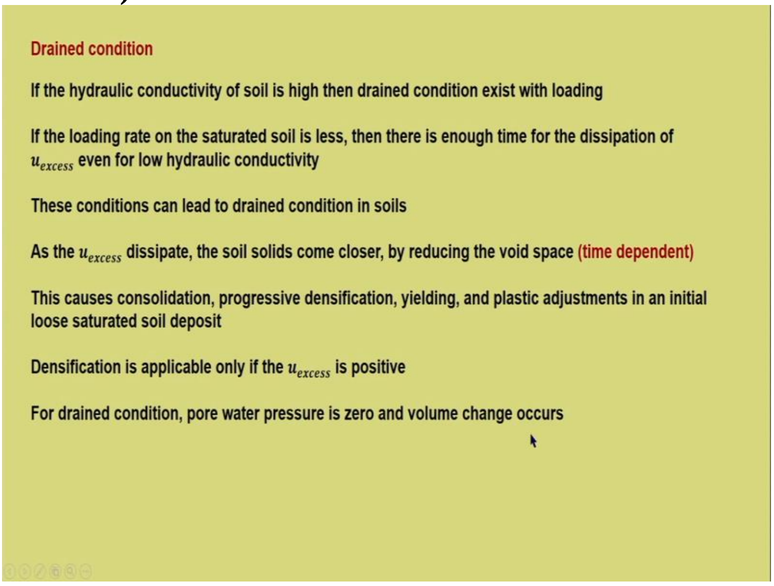

Now, some thoughts about drained condition because these facts are important before we actually start understanding the shear strength behaviour of cohesive soil. So, if the hydraulic conductivity of soil is high then drained condition exist with loading or if there is proper access or if there is proper venting or pathway for the water to move out of the cohesive soil. If the loading rate is very low and the hydraulic conductivity is fairly good or high then the u excess whatever got developed may get dissipated fast.

Now, such a condition is called drained condition where drainage of pore water is possible the loading rate is less than there is enough time for the dissipation of u excess even for a low hydraulic conductivity case. Now, these conditions can lead to drain condition in soils. As the u excess is dissipate, what happens as the u excess is dissipate. Now, this is another important aspect which we need to understand clearly as the excess water pressure dissipate. What is the net result?

When the water moves out of the voids the voids will try to come closer the packing is better. So, whatever stress which the water has carried before dissipating that will get transferred to the soil solids. Along its point of contact and that is what is intergranular stress any loss importer pressure is the gain in intergranular or effective stress. So, it comes closer by reducing the void space. Now, this is very important aspect.

Such a process is time dependent. Now that adds complexity to the behaviour of cohesive soil. Whereas in the case of cohesionless soil, it is an instant response and drainage is also more or less instant. So, you do not have to wait to see its final response. But that is not the case with cohesive soil. It is time dependent and what time in what manner we do not have any clue at the beginning. So, it depends entirely on the soil characteristics.

This causes consolidation which we know consolidation leads to progressive densification and this is known as yielding which is nothing but plastic adjustments or readjustments. You can call it in an initially loose saturated soil deposit, I have added this specifically loose saturated soil deposit because only loose soil will densify so that is very important. So, you need to understand that it undergoes consolidation; consolidation is a process of densification for loose samples.

And when it happens, there is an elasto plastic response there will be a kind of yielding that will happen to the soil and plastic adjustment of particles. Now, densification is applicable only if the u excess is positive yes only positive pressure leads to densification if it is not what is the other case u excess can be negative, we will see that later. But densification is possible when it is loose, loose soil pore water pressure excess pore water pressure will be positive and that dissipation causes densification.

For drain condition, pore water pressure is 0 and volume change occurs. So, now, this is another important fact which we need to keep in mind when the condition is assumed to be drained, we understand that there is no pore water pressure development and volume change happens when we know it is undrained pore water pressure develops volume change is 0. So, this are the 2 important aspects which we need to keep in mind and this influences the soil behaviour.

But in actual field condition, this will be a combination like we cannot exactly have a clear drain condition or very specific undrained condition. This aspect we are talking with respect to the laboratory test we are conducting because we have proper control of drainage but in field which will not be and there will be a combination of both conditions. Now that is where we started off saying that a laboratory tests how good it translates to actual field condition.

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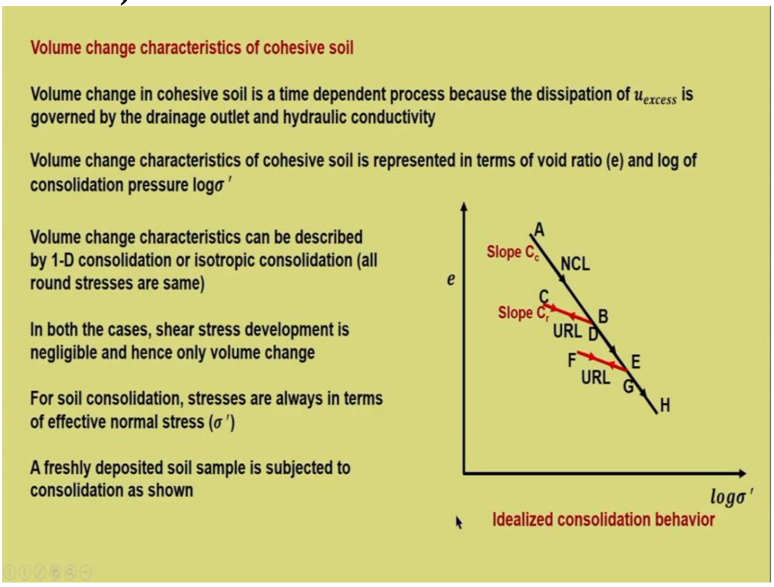

So, volume change characteristics needs some more discussion let us see, volume change in cohesive soil is a time dependent process because dissipation of u excess is governed by drainage outlet and hydraulic conductivity. Volume change, characteristics of cohesive soil is represented in terms of void ratio and log of consolidation pressure which is the net result of consolidation test.

So, this is what it is there is a response between void ratio e and log sigma dash which is the consolidation pressure is the idealized consolidation behaviour. So, volume change characteristics can be described by one 1-D consolidation this is 1 dimensional consolidation result or it can be due to isotopic consolidation which we can carry out in a triaxial testing under the consolidation that happens under all round stress condition.

In both the cases shear stress development is negligible. Hence we are talking only about volume change behaviour in both the cases because of infinite rigidity or in the case of isotropic consolidation all round specifics are same, there is no possibility of development of shear stress. So, we are basically understanding volume change behaviour specifically the way we discussed in module 1 like no shearing only volume change

For soil consolidation stresses are always in terms of effective normal stress, second statement of effective stress principle which says that all compressibility behaviour is entirely governed by the effective stress. Let us say a freshly deposited soil is subjected to consolidation as shown.

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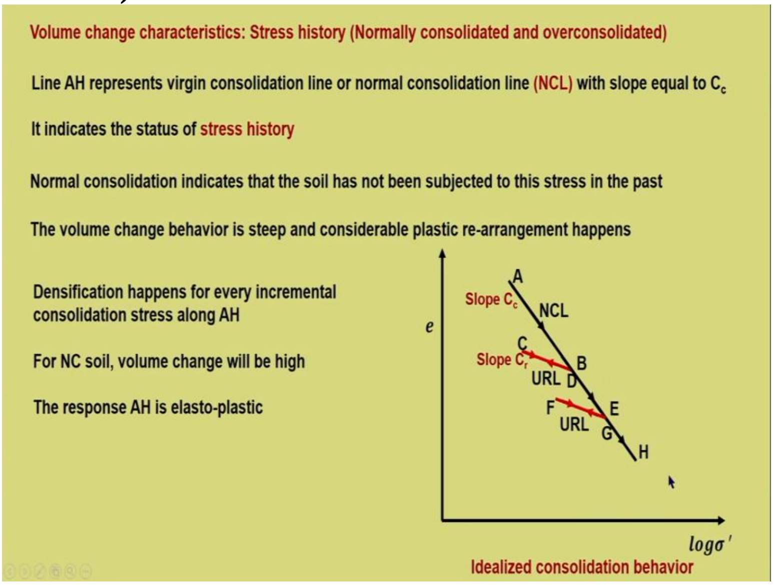

So, in this line AH is known as virgin consolidation line or normal consolidation line, NCL and it have got a slope of C_c which is which is known as compressibility index. Now, why this is called virgin consolidation line I hope you would have understood during your UG because any stress on this AH it is for the first time the soil is experiencing that is the reason why it is called virgin consolidation line and very popularly known as normal consolidation line.

So, this whole response, the consolidation response indicates this status of stress history. Now, let us say that you have a soil from the field, it is subjected to the stress of consolidation, how it gives its response will depend upon what is the stress history it has been subjected to. Now, history means, what is the kind of memory which the soil holds whether it has been subjected to a higher stress or a lower stress, this we will understand from this response.

Normal consolidation indicates that soil has not been subjected to this stress in the past we have already seen that the volume change behaviour is steep and considerable plastic rearrangement happens for a so, now, this is another important fact which we have to keep in mind and normally consolidated soil undergoes high volume change, because it is experiencing that stress for the first time.

When it is overloaded before it will have better stiffness and this is very important philosophy when you experience more stress in the past it makes you more strong let us the same philosophy that the soil also exhibit. So, when it is experiencing for the first time it will have less resilience to it and that is why it undergoes a very high plastic rearrangement. Densification happens for every incremental consolidation stress along AH so, we are talking only about the NCL for NC soil volume change will be high the response AH is elasto-plastic.

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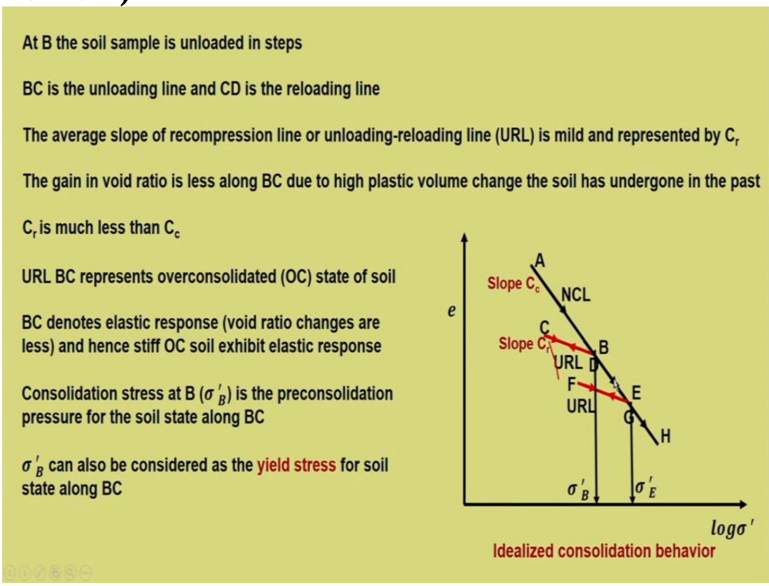

So, this much we need to keep in mind. So, a normally consolidated soil undergoes elasto-plastic response. Now, let us say that at B the soil is unloaded and it is unloaded in steps BC is the unloading line and CD is the reloading line. So, it is an unloading reloading line the slope of this unloading reloading line or it is called recompression line it is mild and it is represented by Cr.

Which is much less than Cc now, the gain in void ratio now, whatever wide ratio it gains, it is also less because this much of densification has already happened. Now, there will be some amount which it gains and that is the elastic component which we have already seen in module 1. Cr is less than Cc now, URL BC this particular stretch of response this represents the over consolidated state of soil.

Now, why it is over consolidated at this particular point it has been unloaded. Now, if you consider any stress state along this line BC, this stress state is less than what has been subjected to in the past that is σ'_B is the stress which it has been subjected now, because of this BC is more stiff till it reaches σ'_B because it has already subjected to in the past to σ'_B and it knows the soil knows that I can withstand σ'_B.

So, up to σ'_B any stress which is less than that, soil can take it without any issue. So, it exhibits a kind of elastic response. So, void ratio changes are less so, if you load along CB the change in void it is not going to step down steeply like this. So, it is not going to go if you start loading from C it will not take this route, it will still go along CB. So, why? Because it has already reached a stiff state and hence it will exhibit an elastic response.

So, void changes are very less. So, consolidation stress at B σ'_B is then known as the preconsolidation pressure for the soil state along BC and this we have seen during UG classes. What additional we need to understand about preconsolidation pressure is that σ'_B can also be considered as the yield stress for soil state along BC.

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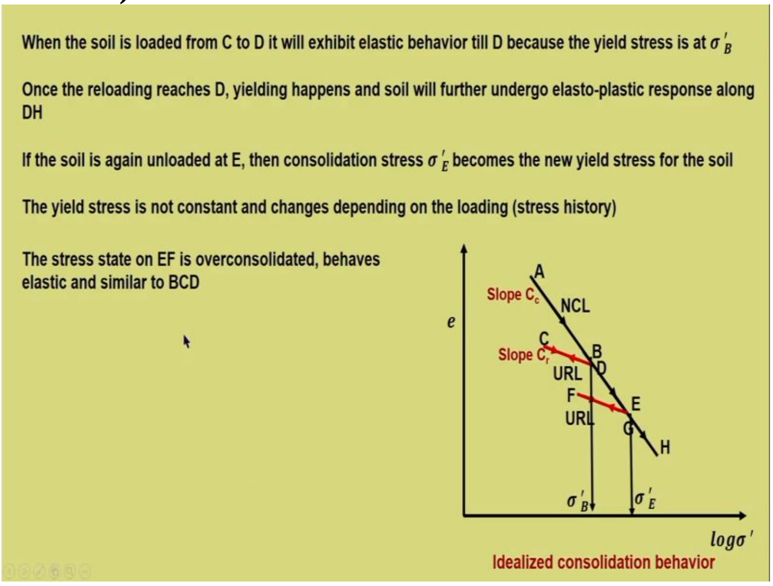

So, when the soil is loaded from C to D, it will exhibit elastic behaviour till D because the yield stress is at σ'_B. So that is an important aspect which is very important for module 4. So, up to σ'_B since the yielding has not occurred, so, up to σ'_B it will exhibit and kind of elastic response, the moment it crosses point D once the reloading reaches D again the yielding happens and soil will further undergo elasto-plastic response along DH.

So, you can see that along DH, it will again show the same elasto-plastic response. If the soil is unloaded at E, now, there is a new yield stress the preconsolidation stress then consolidation stress σ'_E becomes the new yield stress for the soil. So, then the question arises what happened to the previous yield stress σ'_B. So that is what we told soil keeps things in memory but it gets erased also.

When the new loading comes, so that is what has happened from D to E again some plastic rearrangement happened. So, from E if you unload the new yield stress for that particular soil is $\sigma'_{E.}$ So, yield stress is not constant and changes depending on the loading that is stress history. So, this we need to keep in mind unlike other materials yield stress in soil keeps changing and it depends upon the previous loading or the stress history, the stress state on EF is over consolidated and it behaves elastically similar to BCD.

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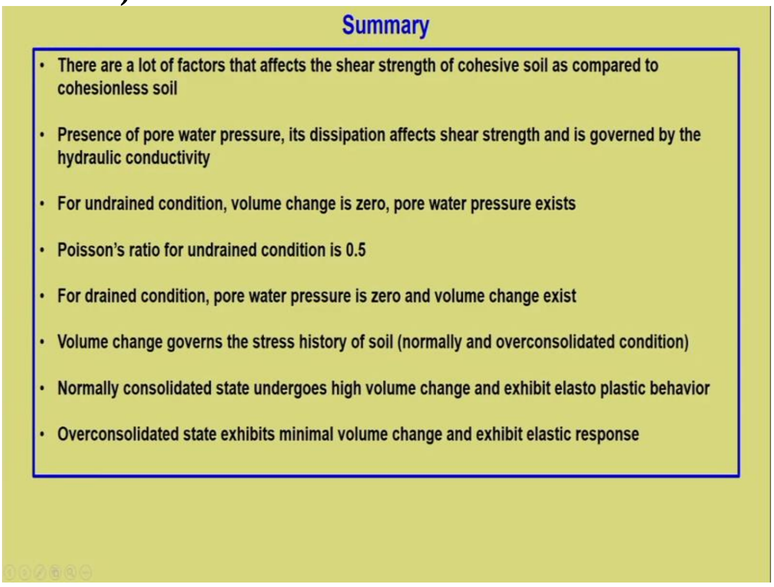

To summarize, there are a lot of factors that affects the shear strength of cohesive soil as compared to cohesionless soil. Presence of pore water pressure its dissipation effects shear strength and are governed by its soil hydraulic conductivity. For undrained condition volume changes 0 and pore water pressure excess. Poisson's ratio for undrained conditions 0.5 for drain condition pore the pressure is 0 and volume change exists.

Volume change governs the stress history of soil normal and overall consolidated condition. So, volume change it governs the stress history of soil to how much it has been subjected to in the past. Normally consolidated state undergoes high volume change and exhibit elasto-plastic behaviour and an over consolidated state exhibits minimal volume change and exhibit elastic response.

So that is why in certain construction if we know that the soil is heavily over consolidated then we do not have to bother too much about its settlement. Because it will be mostly in elastic limit the moment the load which is acting on that soil exceeds its preconsolidation pressure yes then the settlement will be more.

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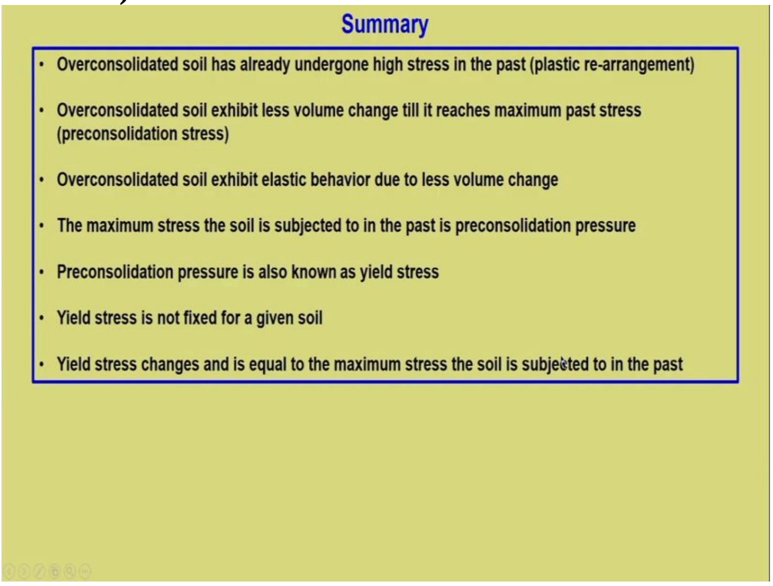

Over consolidated soil has already undergone high stress in the past which is plastic rearrangement. So, over consolidated soil exhibit less volume change till it reaches the maximum past stress which is the preconsolidation stress. Over consolidated soil exhibit elastic behaviour due to less volume change. The maximum stress the soil is subjected to in the past is called preconsolidation pressure.

Preconsolidation pressure is also known as yield stress. Yield stress is not fixed for a given soil and yield stress changes and is equal to the maximum stress the soil is subjected to in the past. So that is all about this lecture, we have discussed basically about 2 important aspects that governs the shear strength of the soil that is drained and undrained characteristics. A lot more is going to come in the similar lines related to undrained characteristics as well as drain characteristics.

We will see that as we proceed in the lecture. So, in the next lecture, we will see because of this how the stress-strain response of cohesive soil. So, we have completed the first part of shear stress of cohesive soil. We will see now the stress strain response and the shear strength the way we have seen for granular soil. So that is all for now. Thank you.