Geotechnical Engineering - II

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Lecture No. 17

Triaxial Test III

We have all studied this one-dimensional consolidation process, a typical relationship is between void ratio and σ', do you remember this? When we define this tip as something, what is this? Pre-consolidation pressure. So, this is the pre-consolidation pressure, never do the mistake of delinking the chapters or the concepts which you have studied in geomechanics from your Geotechnical Engineering-I to last chapter of this course because everything is interrelated it is only 50% of the material, we could understand in the first course.

And now rest of the 50% of the response we are trying to understand in this course, Now, this is the major player, and this controls everything, sometime back I was talking about that the Mohr circles may shift from the left-hand side, or they may get shifted on the right-hand side also.

That means, in short, the pore water pressures could be either positive or they could be negative. So, the material is same. Now, if you look at this curve carefully, you will realize that on this curve if I consider two points, 1 and 2 the stress is same, but what is changing? The mechanism, is this part, okay? The stress is same, but what has changed?

We started loading from here, we brought it up to this point and then we started unloading and this thing we defined as NC behaviour normally consolidated, and this is over consolidated. That means, this type of soil is going, or the soil response is going to exhibit maximum settlements because this has never been exposed to the pre-consolidation pressure in its past.

Having come up to this point, we are unloading the samples, sample has already got this thing in its memory that has already undergone this much of the high pressure and now you are releasing the pressure from it. So, it is behaving in a swelling manner it is the swelling part this is the compression part. So, the pore water pressures here are going to be positive, and what about these pore water pressures? These are going to be negatives.

So, we have introduced another classification scheme for the soils today which is much more you know liked by engineers and technologist. And that is based on their pore water pressures. So, ultimately what I want? I want to talk to in such a manner that your pore pressure does not increase, your blood pressure then only you will be friends. At the same time, I do not want to make you so dull that you die out of low blood pressure, both possibilities are there, is it not?

Low and high and this is just emotions, I may say something you may collapse, I may something you become so furious that you will collapse both sides are problematic. So, now we have got a better way of controlling the material. We know that NC material is going to show positive pressures, pore water pressures, why? Too much water is present in them.

These materials by virtue of positive pore water pressures will always show $c = 0$ cohesion equal to 0, you remember the logic which I had gave given you some time back, take the sand particles, fill them in a bottle make system saturated and shake it you see a lot of noise and that noise is because of the friction. That means NC material is going to give you mostly the friction component, life has become simple $\tau = c + \sigma.tan\phi$ which I wanted to use there I have eliminated one term very coolly.

However, the OC materials are the tricky systems, why? They do not sit silent. The moment you have loaded a system or to this point and you do unloading the chances are the failures will occur because of the negative pore water pressures. And by virtue of this, these types of materials will show you $c \neq 0\ and\ \phi = 0$.

So, I have been using this term very, very wrongly, the materials material is same, what has created the distinction between the response of the material is pre-consolidation pressure, you got this point? The material is same, the same soil sample, which is exhibiting the positive pore water pressures and negative pore water pressures, and hence what is going to happen?

This gets reflected over here, either the Mohr circles are going to move on the left-hand side or on the right-hand side depends upon the pore water pressures.

That is the reason we wanted to measure pore water pressure here, it becomes like the sample is in ICU and we are doing the best possible monitoring of all sorts of pressures and the body parameters, you know being displayed on the monitor for the doctors to decide.

That is the reason why I have introduced this term over here, the pore water pressure measurement. Computationally I can obtain like this. So, this philosophy now I am going to extend to the shear strength theory.

If I say e vs. σ' has given me pre-consolidation pressure, if I write a situation, σ_c is greater than or let us say $\sigma_3 > \sigma_c'$, what is going to happen? Meaning thereby I have crossed this limit of stress in the sample I am working in a higher stress range. If you complete this curve, what is going to happen? This is how it is going to traverse, and it will cut at this point and this point becomes the pre-consolidation pressure.

And this system behaves as if nothing has happened to it, so this becomes NC material. So, remember, as long as the confining stresses are more than the pre-consolidation pressures, the pore water pressures are always going to be positive it is like balloon, the balloon is filled with water or air and if I keep on pressing it, what is going to happen? The more and more pressure is going to build up which is going to be positive in nature.

So that means under these circumstances, the pore water pressures are going to be positive. However, the reverse is going to be true when I am working in a stress range which is going to be less than σ_3'. So, if I reverse this, this is going to be negative pore water pressure, is this concept clear? So, if this concept is clear to you, I will extend this to shear strength envelopes.

So, if I plot now, τ vs. σ', now if I project this information on a τ-σ' plane, what is going to happen is I am going to get something of this type and I hope you can easily guess that this point of discontinuity is going to be σ_c', the soils are so intelligent, you know they behave in this manner.

Now, if I extend this portion, what you will find is that this is your friction angle. And hence, I can say that anything which is beyond σ_c' in terms of σ stresses, this is going to be NC response and less than this is going to be OC response. In real life, what we do is, if you do perform a test at very very small confining stresses of let us say 25 kPa, 50 kPa, you will be going to get this type of hump.

What we do is we average it out and we plot it like this. So, this is the term which we ascribe to see for OC material average value of A to B. So, this is the average of AB and at this point we have pre-consolidation pressure and then this continues as the NC material. What is the practical applicability of this situation?

If I rotate this curve by 90°, what is going to happen? This becomes your undrained shear strength S_u, which is equal to two times C_u, because what is C_u?

$$C_u = \frac{\sigma_1 - \sigma_3}{2}$$

$$S_u = \sigma_1 - \sigma_3$$

This is undrained shear strength, this is undrained cohesion, σ' term is a function of Z, Z is the depth of the deposit.

This curve remains same, because τ is nothing but S_u, σ' is nothing but a function of Z and this is what I am talking about the natural deposits, what is happening there. So, if you look at the natural deposits, what you will observe is that shear strength most of the times in marine environment particularly where you are doing most of the projects of national importance, international importance, this is how the shear strength decreases and then it picks up and it goes linear. And this is how we can extrapolate this.

This is the zone in which what we call as a tricky zone, this is approximately 1 metre 1 to 1.5 metre, and this is what is known as desiccation zone. Most of the time in the marine environment particularly in the coastal areas because of the very high humidity very high temperatures, the top layer of the soil gets desiccated, like cake, when you bake a cake, what happens? The top layer and the bottom layer are stiff and inside you have quite soft material.

So, something like this happening. Now, imagine if by virtue of your mistake and less understanding of the material, if you create an embankment on the top of this, what is going to happen? The strengths are going to be less over here and the embankments are going to collapse. So that is the reason why OC behaviour cannot be ignored.

And by investigations normally, we fix the desiccation zone thickness. Here again, we can apply this as a normalization, and we can say that this the average value we can assume as the variation in the desiccation zone to be constant followed by a linear increase in the shear strength of materials.

So, one part which I have not discussed yet about the CU test is, how to identify the material based on A_f parameter? So, if I do continuous monitoring of the pore water pressures, and if I say that this is a parameter at failure, what I can do is I can plot A_f versus ε_a (%) and the way cardiologists see the cardiogram of a patient, I can tell you how the material is behaving and how should I use this material for construction.

So, until now you have understood that A_f is going to be positive for NC materials, is this correct? Because the pore water pressures are going to be positive. So, if I plot A_f as a function of strain and this is how I get it is a typical NC response. However, in case of OC materials, what is going to happen? There would be a response like this, there will be slight positive pore water pressure followed by rest of it would be a negative pore water pressure.

So, just by looking by doing an online test, where I am instrumenting everything, I can plot these types of graphs and I know how the soil sample is behaving. And ultimately what we are going to do is we are going to use these parameters to classify the soils.

The last in the series is the UU test. Later on, what we will do is we will link this A_f with OCR over consolidation ratio, and we will define this OCR as the σ_c' over cell pressure. So, I hope now you can realize σ_c' is the pre-consolidation pressure divided by the σ_3 which you are applying to the sample and then we will correlate these effects again and we will characterize the soil whether it is an OC response or NC response.

Now, let me come back to UU test the third one. Now, as I said this is another category of the response which we are trying to capture, unconsolidated undrained. Typically, offshore environments, unconsolidated undrained soil samples are saturated, there is no way they can get consolidated. Young materials they are all being deposited by the rivers into the ocean bed they will take millions of years to get consolidated because of the self-weight. No drainage conditions all marine clay. Peculiar example of offshore construction piling everywhere in the world.

So, no consolidation no drainage. So, what you are going to get is something known as total stress parameter undrained total stress, we talked about effective, we talked about CD and now we are talking about the total stress analysis. So, this is what is going to be UU test normally we define the parameter which we get as ϕ_u undrained, c_u as untrained and we make sure that this is equal to 0.

Remember, another request is ϕ is never computed in decimal places 23.2, no ϕ in geomechanics is always an absolute number, it cannot be 23.23 it cannot be 23.1 even because the degree of accuracy is not so much. So, this is the condition which we are creating where we are not allowing any friction to get mobilized even if it is coming out to be 2 to 3 degrees. We always assume this to be 0, the reason is simple.

Unconsolidated test, pore water pressures are building up. I can measure it also by doing a UU prime test and then what I am doing is I am shearing the sample under undrained conditions to get the response of the material typical UU response would be, any guess? When ϕ is 0 what is going to happen? Is the horizontal line. So, all your Mohr circles are going to be perfectly sitting like this and I can give a reasonably average value as ϕ_u equal to 0 and this becomes my Mohr-Coulomb envelope.

In effective form if I have to write, what is going to happen? All these Mohr circles are going to get overlapped on one. So, this is how the effective Mohr circle will look like. By subtracting the pore water pressure, you will be having a unique circle, what should I do then? Should I allow ϕ or c or what NC material c is going to be 0 and only ϕ will get mobilized? So, this is your effective stress envelope, have you understood this?

I can measure the pore water pressures and I can compute the or I can compute the pore water pressures and I can apply this correction from σ_1, σ_3 to get the effective stress envelope. It is very important that the type of testing which we are doing and how we are going to interpret the results, one more thing which I will just take another one minute.

Once I have got the total stress and effective stress, I would like to see what is going to happen if I test the sample in the UCS, unconfined shear strength of the material. So, a UCS will always show you the negative pore water pressure always. Negative pore water pressure because there is no confinement. So, what we have done by creating situations of loading and drainage, we have characterized the soil in the best possible engineering way.

So, the last remark would be as a designer you will be confused what I should be doing I have CD, CU, I have UU I have UCS what I am supposed to do? Plot all of them on a same scale and in general, you will be getting the CD like this, CU like this, UU like this. So, this is the relative strength parameters which we will be getting from here.

So, CD gives the upper bound UU gives the lower bound, CU is in between, if I can perform test CD or UU, I can extrapolate interpolate in such a manner that I might be getting the range of parameters in which I am working. It might be possible because normally a CD test would take you at least a month to conduct on clays continuously.

Because you are consolidating the sample it will take you two weeks and when you are shearing it very, very slow test slow rate is going to take you another two weeks, you might not be having so much time in the real-life practice. So, CD test unless somebody specifies is not done, and the quick test would be which I can do from the body of the ship is UU I will lower down a plunger, a vane. I will do the test I will get the UU parameters, or I will retrieve the samples, bring them to the laboratory conduct the test superimpose this condition gets c parameter.