Geotechnical Engineering-II
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Lecture No. 15
Triaxial Test

Triaxial testing. Take out the sample from the field, which is a Triaxial sample. These are mostly cylindrical samples. So, you insert a barrel into the ground and then take out a cylindrical sample. Mount it on a porous stone. And I hope you can realize why this is being mounted on the porous stone, because I want to control the drainage conditions. If I want to do both side drainage, then I have to keep a porous stone at the top also.

This thing is sandwiched in between a loading plate. And at the base, this sample is mounted on a pedestal and pedestal is connected to a sort of a system in which I can provide drains. So, this is a drainage facility. I can connect it with the valve. Before the testing is done, we try to cut off this sample or isolate this sample from the cell water. And hence, what is done is we take a thin rubber membrane, and this thin rubber membrane is installed on the sample.

Now because I am doing a triaxial testing and I hope you understand what we do is on this base plate we mount a cell. So, this is how the cell looks like. So, this becomes a cell, on the top of this there is a drainage valve and there is an arrangement by which I can keep a circular ball over here so that it transmits the load, and I can connect the whole thing to a plunger. And this plunger is leak proof. So, no leakage will occur.

This plunger is normally connected to a proving ring. And this proving ring is, suppose I draw it as a circle, this is connected to a load frame. So, this is the load frame. This whole system sits on a device, which is motor controlled, and it can be moved up and down at a constant rate of shear.

So, this becomes a constant strain test because you are straining the sample. Before we start doing all these things. What we do is there is another drainage system, which is in built in it, look at the position what I have done is I have taken it to the cell, and this is also connected to a wall. Through this we will apply water, which is used to apply σ_3, confining stress. Fill up the entire space with water.

And then this drainage valve helps you in filling the cell because until you open this wall, water cannot go inside. So, what we have done is this is a cell of high capacity of pressure. It can bear very high pressures to accommodate σ_3. Sometimes σ_3 is also replaced as σ_c, which is a better term. So, σ_c is the confining stress. So, what essentially, we are doing is in what we have 1-dimensional and 3-dimensional loadings are different. I am incorporating the effect of confinement also on the sample.

So, what is going to happen the moment you fill up the water in the cell, and then you apply the stress. I hope you can realize that this is the σ_3 or σ_c, which is acting on the sample. Now, what is the purpose of this wall? Under the consolidation process, if I want to see how much consolidation is going to occur, because there is a porous stone here, there is a porous stone here. What we do is we interconnect these two by a system.

So, this is also a drainage system. Water will come out of this porous stone as well as this porous stone. And if I open this wall during the shearing process, I know what the volumetric deformation is the sample is undergoing. Sometimes, this system is also used for applying back pressures to saturate the sample. We will discuss about this.

So, this is a typical arrangement. Now what I want to do is I want to measure the deformation of the sample when I am shearing it. So, I have to put a dial gauge over here, and this dial gauge is going to give me the deformation undergone by the sample during testing. Now modern-day setups are where I would like to measure the pore water pressure.

So, this valve itself can be utilized either to apply the back pressure or to measure the pore water pressure. Either you can have electronic device, or you can connect it to a burette. So, this in short is the assembly.

And what we will do now is we will use this assembly to obtain the situation A, B and C parameters. And as I discussed, we will be talking about three tests. That is a CD situation, consolidated drained test. We will be talking about CU consolidated undrained test. We will be talking about UU test unconsolidated undrained test.

Suppose if I do not fill up any water in the cell, this becomes a typical case of UCS when,

$$\sigma_3 = 0$$

So, this becomes unconfined compression or compressive strength test. So, this is as far as the drainage has been allowed, suppose if I do not allow drainage to occur, clear? So, from a simple test assembly, I have created four types of tests.

Now, mind it carefully. And this is where the complication starts. If I do not allow the pore water pressures to dissipate. And if I measure the pore water pressure, what I am going to do is I will be introducing a term known as, these are known as consolidated undrained test with pore water pressure measurements. This will become unconsolidated undrained test with pore water pressure measurement.

So, that means the series of triaxial testing, which is normally done is contains 1, 2, 3, 4, 5, 6 types of tests. A million-dollar question is you have the sample, you have conducted the test, how to use the parameters, how to analyse the parameters. We have been talking about the triaxial testing, how the triaxial tests are done and what are the different types of tests, which you would like to be done.

And so, the issue which I wanted to highlight was how to analyse the parameters so that we can do the proper designs. So, Triaxial testing is sort of a Bhramastra, for Geotechnical engineers, it was invented long long back, but till date, there is no substitute for triaxial testing. And it is a sort of a holistic test, which a Geotechnical engineer would like to perform on soils of different types.

And as I emphasized in the last lecture, the basic idea is to create circumstances or the conditions under which you want to determine the material properties. Ultimately, the objective is to obtain the shear strength parameters that is cohesion and internal friction.

So, from this point onwards, I will pick it up further. And, uh, we talked about different tests that is the CD test, a CU test, a UU test, a UCS. And if you are very much interested in finding out the influence of pore water pressure on the samples, we have introduced this concept of a bar. So, this bar indicates the pore water pressure measurement.

So, if you go into the historic development of the Triaxial testing, and when we were students, we used to use the mercury column to apply the pressures on the system and to measure the pore water pressure, but now things have changed it is an electronic age, you have different types of transducers and the pressure sensors, which are being used in the triaxial testing that have become very advanced testing.

So, if you remember in the previous lecture, I introduced this concept of a triaxial specimen, which I might have brought from the field.

Correction: Typically, the length of the sample is two times the D the diameter of the sample.

So, this is what is known as a typical Triaxial sample. We had mounted it on a porous stone, if I am doing a drained test and there was a loading plate on the top of this, we call it as a steel plate, which is normally used for distributing the pressure on the system on the sample.

And this will be having a sort of an arrangement, which will be connected to a proving ring. And this is sitting on a pedestal. Before the testing is done, we tried to cut off this sample, or isolate this sample from the cell water. And hence, what is done is we take a thin rubber membrane, and this thin rubber membrane is installed on the sample.

Now, there are special devices when you will be doing these tests, you will know how these membranes are installed so that the, the rubber membrane remains fixed and does not get detached. What we do is we use O-rings. So, this is an O-ring at the base also, we use an O-ring. So, both at top and bottom, you have two O-rings.

They have a tendency to clamp the membrane with the sample, and then we can apply confining a stress or σ_3. We have included a dial gauge over here to know what the volumetric deformation or the actual deformation sample is. So, DG is the dial gauge and then the whole system is pushed up at a certain rate of strain.

This strain rate is obtained based on your design requirements, whether you are trying to do a slow test or you are trying to do a fast test. It depends upon that. So, if I want to give some, let us say Δl to a sample of l length, the deformation $\left(\frac{\Delta l}{l}\right)$ is the percentage strain, which is known as axial strain.

And what I can do is, this much of the strain I would like to give in a certain amount of time. So, this becomes the rate of strain, which is given to the sample. Now, you must have realized that once we have encased the soil sample in a membrane, whatever results you are going to get are not corresponding to the sample. Because there is a membrane effect which is going to get implicated on the sample.

So, there are few corrections which are to be done. I am not going to go into the details of these corrections. Normally, when you perform this test in a laboratory, you should be applying these corrections. The first one is the rubber membrane correction, how much confinement the rubber membrane is going to exert on the sample, because that gets added to the strength parameters of the sample.

So, what is going happen typically is if I do a, this type of relationship with the rubber membrane, what you are going to get is always the higher results as compared to the original sample. So, this is the, let us say soil sample, and this would be the rubber membrane plus sample. So, we apply two types of correction over here. One is the shear strength, which is getting added up and the strains, which are going to be eliminated from the composite sample.

So, rubber membrane plus sample might be giving you more axial strengths as compared to sample when it is going to fail. So, this part you have to apply. So, we apply two corrections. One is for the, the shear strength. And the second one is for the axial strains. You can create a dummy sample of wax, and you can coat this sample with the rubber membrane, and then you can perform these tests. You can get the values.

And this, the most important correction which is done. And once this is done, you can go ahead with the testing procedure. So, this part is also important.

And if you remember, I had, which is suggested Bishop and Henkle. This was in 1957, where the failure time, this is the same time as this I am defining here is related to,

$$t_f = \frac{\pi l^2}{C_v}$$

Now, this is where the intricacies can be included much more into these triaxial testing. This is a simple case of two side drainage. In one dimensional consolidation we have talked about the two side drainage.

So, as if clay is sandwiched between sands hence, if I am trying to simulate this condition, which occurs in the nature, there is a clay seam sitting in between the sand deposits, these are the two drainage conditions which I have included. There could be a situation where you have drainage from one side only that can also be done. I can remove this porous stone at the top, and I can only have this.

Sometimes if you remember, when we were talking about band drains and the PVD design, we had considered three-dimensional consolidation case. And this is where the radial consolidation is also required. This is a very clever of doing the thing. On the sample, if I want to include the effect of radial drainage, right now the drainage is in the axial direction, top and bottom. And this happens to the centre line, what I will be doing is I will be taking a piece of filter paper of the same size and slightly bigger in length as compared to sample.

And then in this filter paper, cut out slits. So, if I remove this portion, what I have done is I have created a filter paper, which is with slits, is this okay? Now this thing can be wrapped all around the sample. The top portion can be folded at the bottom of the top plate and the bottom pedestal plate. And what I am doing here is by simple manipulation like this, I have induced radial drainage also, this function will change accordingly.

So, whenever you get time, you go through the Bishop and Henkel book on triaxial testing and complete details are given for rubber membrane correction, as well as for the drainage condition, correction and inducing the radial drainage corrections. Ultimately, the idea is I get t_f and this t_f can be utilized for selecting the strain rate at which I should be doing the test. And rest is all mechanical.

Imagine if this is a sample and if I, encase it in a membrane, because the hoop is stresses of the membrane, what is going to happen, the sample is going to get confined clear. So, this is not the real sample which you wanted to test. So, what we do is we take a standard sample made up of wax. You can cast a sample, you can encase the sample in the rubber membrane, the one which are going to use for this, these are standard membranes, which are available. Shear the sample, you will be getting the shear strength and the axial strength clear.

Now, what you have to do is you have to find out the properties of the membrane itself, that portion you have to deduct from the shear strength and the axial strain, and you have to apply it to get the shear strength and axial strain properties of the sample. Membrane is a flexible system. So, truly speaking, what is happening is the sample is not so elastic in nature. Soil samples are not elastic in nature.

So, by encasing in a sort of a membrane or a balloon, what you have done is you have induced more elasticity to it. And that is the reason the strains will get elongate, will be more at failure and the shear strength comes because the hoop stresses, fine? So, all this has been done. This is to induce the radial drainage.

You see, in this case, what you have done by compressing the sample, you have induced drainage only in the axial direction but suppose if you want to simulate 3D condition. So, what you are doing is by putting these drains, you are allowing water to percolate through the radial direction also. So, this becomes a 3D case.

Imagine this is a slit of the filter paper all around the sample. So, when you are compressing, the water is free to move from centre portion to the radial direction. Also because of this drainage condition. No. This will be, you remember your three-dimensional consolidation case? This is a one-dimensional case. I wanted to accelerate the consolidation process. So, what did I do?

I inserted a PVD or a band drain or a sand drain clear? So, initially drainage path was H. And by putting two bands or the PVDs, what I have done, I have reduced the drainage path to X by X and the drainage path would be now X by 2 and hence the consolidation process enhances becomes accelerated, fine? The same thing we are doing.

So, imagine that this becomes a curved boundary of the sample. So, this is a sample and you are inducing the drainage condition all around its surface. Clear? So, this becomes a radial drainage case. It is a very intelligent way of doing testing. So, now let me start discussing about these tests and their philosophies and what type of parameters they are going to give you in what circumstances.

Circumstances are two, depending upon the material, what type of loading is being imparted and what type of drainage conditions are being installed or fixed. So, two things we are interested in knowing. The response of the material for a given loading and under a typical boundary condition of drainage.

So, to begin with, let us discuss the case of a CD test. The first part or the first component C corresponds to consolidation. So, we write it as consolidated, and the second part corresponds to drained. As a technologist, I want to understand if I squeeze out all volumes of moisture, which is present in the sample, clear? How the sample will behave. So, the philosophy is like this, I want to test the sample under the worst circumstances where no fluid remains in it, clear? Triaxial testing is mostly philosophical.

So, you want to understand what the resilience of the material to the situation is when all amount of volumetric moisture has been removed from it, two ways are there to do it. First, you take the sample, consolidate it, try to consolidate as much as you can, later shear it under drained conditions. What is the meaning of this? As long as I am doing consolidation, my valves are closed. Sorry. They are open.

So, the way you do this is you start with the sample, triaxial sample. Initial condition is all-round pressure is σ_3 hydrostatic condition. She stress is 0 because you are not shearing the sample. Both sides drainage is occurring, consolidation process. What about the pore water pressure? So, you have squeezed out all the water under confining stresses, just by application of σ_3.

So, what type of response I am going to get from this? I can get, what, what will we getting? Consolidation is a function of time. So, what I am going to get is with the time, how much volume of the water is going to come out of the sample, which I can measure by connecting a burette, you remember? So, if this burette is connected and I am consolidating the sample under a σ_3, I know what is a ΔV of water, which is coming out, is this part okay?

So, it will be very interesting for me to see when I am consolidating sample under a triaxial condition. Initially, the volume will increase as a function of time and ultimately what will happen, this will become constant. Now remember this consolidation characteristic is a function of σ_3. So, the moment you enhance σ_3 value, what going to happen? There will be a change in the curve.

So, I can say that as σ_3 increases, this curve will keep on shifting down. Now that depends upon the σ_3, which you are applying on the sample. Is this part clear? The thing important, remember here is when you are doing a triaxial test and consolidation, you are going to get the best possible C_v value. Why? Because this C_V is under three-dimensional condition, all round pressure, σ_3 clear? even from top and bottom also, which you could not get from one dimensional consolidation test. So, this is the best way to get C_v value.

You know the time where this attains the constant volume condition. Now this time I can include in that equation. So, I have,

$$t_f = \frac{\pi l^2}{C_v}$$

l is known for the drainage condition. I can obtain C_v value. So, this is the best way to obtain C_v value, coefficient of consolidation. Fine? Remember the soils for which the sample can be made, not the very sensitive and soft clays. For that, then we have to do vane shear test. Is this part, ok?

So, important thing here to remember is during consolidation state, there cannot be pore water pressure. I normally define this as UC. Today I am introducing the concept of pore water pressure though we studied in one-dimensional consolidation. If you remember, and there we use this term as Δu, which is getting generated because of application of $\Delta\sigma$. All right, what is $\Delta\sigma$?

The external the stress changes will have two components. One is u_c, another one is u_d and *d* corresponds to drain. So, that means from this point onwards, if I shear the sample extremely slowly, what type of loading condition is this? extremely slow loading strains. Drained or undrained, understand. Very slow shearing rate, what slow shearing rate connotes to? Pore water pressure develops gets dissipated. When you are making an embankment, remember embankments are made layer by layer clear.

So, the first layer you put on the mass, some pore water pressure generates. If the material happens to be freely draining, what is going to happen by the time the second layer comes, this pore water pressure gets dissipated and sequentially you are making an embankment. Long term performance, extreme possibilities, clear? where you are just going to collapse. Remember you are sweated out and I am not allowing you to drink any water. And still I am asking you to run what is going to happen? You will collapse.

So, this is the ultimate strength a material can exhibit fine. Now, as a geotechnical engineer, I am more interested in upper bounds and lower bounds because I cannot say that this is what the strength of the material would be. So, by doing a CD test, I have got an upper bound on the properties of the material. Those of you who will be doing courses on limit equilibrium, plasticity theory, and all you must have come across this term upper bound and lower bound.