Geotechnical Engineering – II

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Lecture 08

Direct Shear Interpretation of Test Results I

In previous lecture I have been discussing about determination of shear strength of soils. And one of the simplest tests which is normally performed to obtain shear strength parameters, as we mentioned c and ϕ in the last lecture is, direct shear box test sometimes also known as box shear test. There are different types of boxes which are available, and you can make your own box also in fact for research and development (R and D) purpose.

What I have been discussing in the lectures is a direct shear box which is of size 6x6 centimetre cross section area and height of the sample could be 25 to 30 mm. For research purpose people use 10 x10 centimetre cross section box. And for field engineers sometimes particularly if you are trying to create a, let us say, rock core dam or if you are testing bigger size aggregates even 1x1 m^2 or 1 m^3 box is also sometimes used for getting the shear strength parameters.

IIT Bombay had this type of a setup long back now we have dismantled it because of the obvious reasons difficult to maintain such type of setups. So, in today's lecture what I will do is I will continue with where I left in the last lecture that is the analysis of the test results which we obtained from the direct shear box test. And we will also talk about the disadvantages and advantages of conducting direct shear box test and from this point onwards I will touch upon the theory of shear strength of soils.

So, if you remember just a quick recap. What we do is we apply normal stress on the sample in the box and we measure the shear stress. And this shear stress would tend to shear stress at failure, τ_f, failure is the one where I showed a peak or sometimes the residual strength. So, this could correspond to τ_{peak} or τ_{residual} and sometimes we also we have denoted this in fact as tau control volume and what else we require to analyse from this test is. I am very eager to know how the volumetric deformations occur when you strain the sample, when you shear the sample. Remember the whole response of the material is during shearing not under static condition.

So, what we want to obtain here is δ_{v} and δ_{h}. So, this is the vertical deformation of the sample and this is the horizontal deformation of the sample as a function of shearing. It's very important. So, the moment we say shearing, the rate of shearing is the first parameter which governs the shear strength of the soil. And rate of shearing is adopted in such a manner that you want to simulate the response of the drainage conditions, that is the response of the material over a period of time. So, time is included in this time history of shearing.

The obvious question is that why we are doing all this? As an engineer we want to characterize the soils, as a technologist we want to you know dictate with the material we want to utilize the material in the best possible manner that is the whole idea and that is the reason we are trying to simulate these conditions to obtain the response of the material when it is getting sheared.

So, the peculiar response of the sample we call it when you shear it would be, as I discussed in the previous lecture if I plot shear stress this is some units kPa whatever and this is ε_a, percentage axial deformation. So, if this is the box to begin with or if this is the sample to begin with, this happens to be the cleavage plane. We have two halves of the sample after shearing this is the situation. And this is how the sample looks like. So, there is a vertical compression, δ_{v}, and there is a horizontal deformation, δ_{h}. And this is the plane of shear. We call this as the shearing plane.

One of the disadvantages of these tests is that the plane of shear is predefined. You cannot alter the plane of stress, plane of shearing. So, this is one of the disadvantages. But advantages are very simple test to do, very quick, ease of doing testing and it gives you the parameters which are going to be upper bound, maximum parameter because it is a two-dimensional situation. correct? So, this is what is going to give you the maximum possible capability of the material clear. Now, as a captain you have to utilize what fraction of this should be utilized to design the systems and we will talk about this slightly later.

So, this is a peculiar response of a dense soil, particularly sands I would say. Direct shear box test is normally done for granular materials, alright? Particularly sands, fine-sands, at the most silts. It is never done for clays. Why? The reason is clays are mostly prone to development of pore water pressure. And one of the limitations of the direct shear box test setup is you cannot maintain the pore water pressure, you cannot measure them. Because it is a preliminary test, it is a very simple test so for research purpose of course you can modify it and you can measure it but truly speaking conventional directional box test setups were not used for measuring the pore water pressure.

So, if I do a slow test and if I allow pore water pressures to dissipate slowly and slowly, still I would like to know the pore water pressures. If I do a fast test, I am not allowing any pore water pressure to develop to get dissipated even then I am interested in noticing down the pore pressure. So, the limitation of this test is it is not done for clays, fine grained materials, silty clays we will never perform a direction test but a sandy silty material of course yes boundary case condition. Otherwise, it is quite useful for fine sands and coarse sands. Gravels will also not be falling in this category. The reason is a particle might get trapped between the cleavage and then when you are shearing it, it might get crushed.

So, rather than getting the shear strength of the material you might be getting the crushing strength of the particles. So, these are the issues which force us to adopt something better than this we will talk about this later on. So, this is the dense sands and this is going to be the loose sands. Yesterday I discussed about this that this type of a characteristic curve is normally utilized for characterizing the soils as an engineering material. Now, what I will do is corresponding to these two, I will show you how in the previous lecture I have depicted compression and dilation otherwise.

Now, if I measure let us say the volumetric deformation because area of cross-section remains constant here only the vertical height is changing and horizontal length is changing for a given length of sample *l*. If I say the deformation and if I plot it on the scale with respect to ε_a for loose sands, the deformation curve would be like this. And for the dense sands the deformation curve would be something like this. I will write this as positive compression and this is as negative compression, the positive is compression and the negative is dilation.

I can depict this on e-scale which I did in the previous lecture. So, this is how I plotted *e* versus ε_a how the void ratios change. And this is how we plot for the loose sands and this is for the dense sands.

Now, concentrate for few minutes on the blackboard stop writing a bit of the philosophical interpretation of the characteristic curves which we have got. What is happening here? Now this is the critical state of the material, if I draw a line over here, this is the critical state of the material we represent this as either T_{cr} or τ_{cv} control volume. After achieving this state of shearing the sample does not show any volumetric deformation either δ_v or δ_h. δ_h is in our hands so what we do is normally $\left(\frac{\delta_\mathrm{h}}{l}\right)$ is approximately 6 to 10% in conventional test.

The reason is very simple the more and more you shear it may so happen that δ_h might become a very big overhang on the sample and the sample may get tilted when you are shearing it. So, this is the biggest disadvantage of doing this test. So, δ_h has to be limited it cannot be more than 6 to 10% if I want to know shearing strength of the material for very high axial strains, what I should be doing? I should be going for a ring shear test or sometimes we call this as a tor-shear test so this becomes a ring shear test.

So, you have a circular sample like consolidation cell and in which you try to rotate the entire sample with certain angle. So, anything which is lying above this line is the state of the material. Clear? So very dense sand when they are sheared, what happens? The energy gets stored in the system and because of the storage of the energy there is the hump formation. Now the question is what happens after this peak? At very near to peak shear strength, the material has a tendency to crack. And once the cracking occurs, air enters into the system the density becomes less and that is the reason there is a drop-in shear strength from peak to the residual. So, if you keep on shearing the sample a stage comes where the shear strength becomes almost constant and this is what is known as residual shear strength.

Now, this portion of the graph corresponds to dilation. What dilation means? Remember we have confined the sample by applying σ and truly speaking when you are shearing the sample what is happening? The sample is defying the confining stress and the whole system is moving up. Now this is a very peculiar property of the sands which are either very dense, clear? or which are interlocked. Interlocking of sands.

Why interlocking of sands occurs? If you look at the microstructure of the sands, you will find that this is how the grains would be. This we had talked about in the first course, if you remember. And this type of a shape of the grains is going to an interlocking effect something like. This is also known as a gearbox assembly two gears put together. I get lot of strength against shearing.

So, this is the situation which is responsible for a hump formation. Very peculiar characteristics. So, dilation is a function of σ. And σ is the confining stress. This type of a phenomena is normally observed for very small confining pressures, approximately 25 kPa let us say. 25 kPa is approximately 0.25 kg/cm^2. So, for very small stresses dilation occurs as σ increases what will happen? This whole portion of the curve will get compressed in the compression zone so there will not be any dilation.

So, that means if I draw an arrow over here and if I say with increased σ value the dilation will vanish and what will happen? The dilation response will get reflected into compression response only. So, these are the peculiar characteristics of a shearing phenomenon of the material which is soils. Any questions? And then I discussed about, you know the critical value of if I say that this is the $e_{critical}$ or e_{cv} control volume, constant volume sorry not control volume. I said most of the systems are designed in this range so that they remain stable and the earthquake effect is not there much.

The reason is simple within this band of void ratios, the compression and dilations are going to be extremely small and hence the foundations which you are going to design would be more stable. Now, if I repeat this phenomena, two three times by changing σ value so this is for one sample remember.

If I do now if I make three four identical samples. Identical means the densities are same, the way of formation of the sample is same, and they are identical for all practical purposes. What I am going to get is, I am going to get the response where the shear strength and if you plot axial strain. So, if I say that this is the direction of increasing σ each of this curve corresponds to one sample. Sample A, sample B, sample C and so on and what is changing is only σ value. So, you can connect this response with this response. The moment σ increases the dilation vanishes the whole response is compression. The moment confining stress increases the shear strength also shoots up.

And then if I pick up these peaks or the residual thing here in this case there is no peak. An easy way to plot this would be, what is known as a shear envelope or shear strength envelope. Envelope is something which covers the entire mechanism. So, if I plot τ vs σ now each of this test is going to give me a Mohr circle. Because the Mohr circle is symmetrical about the x-axis, we always plot only half of it, fine? So, this is the sample A, depending upon σ_1, σ_3 values what is going to happen? We will be getting another Mohr circle and the third one would be because the σ value is extremely high. This is how it would look like.

So, this is sample A, sample B, sample C. Three identical samples tested with different values of σ this is the response which you are going to get. If I draw an envelope which is nothing but the shear strength we call this as a failure envelope. Now, what I have to do is I have to draw a tangent which is touching all the three circles, and which might be cutting, this is the tangent actually. Now, this becomes the Mohr-Coulomb envelope or sometimes people call this as Mohr envelope, Mohr-Coulomb failure criteria. Having done these tests by maintaining the rate of shearing constant, density constant, I have got these three circles and I have drawn a common tangent.

The intercept of this line on the y axis is defined as cohesion c and the slope of this line is defined as ϕ. ϕ is the coefficient of internal friction and c is the cohesion. Now, most of the time people misinterpret these graphs, remember first thing is the scale of τ and σ should be same then only you can draw a circle. So, the first thing which is important is τ and σ scale should be same draw these circles draw the tangent interpret c and ϕ.

So, word of caution here is you have to go back to the soil classification which you did in the first course because c and ϕ cannot be unique for the material. Try to characterize the soil first and see what type of soil is this, superimpose that information on the graph which you are going to get. So, if I am working on the soils which can be classified as coarse material, it is understood that c will be zero. Clear? so this is where the pathological examination is very important. Doctors never diagnose a patient based on what he or she says they just listen the story. Correct? And what is important is that I will be getting all the pathological reports and I have a conceived idea about the illness I try to match between what this person says and what the reports say and then prescribe a medication.

So, this is like selecting the right parameters. As long as you sit in my class please do not do any mistake in this because it is not a mathematics that you just plot a circle draw a tangent. So, please remember this there should not be any goof up with this information. I mean you have to understand the soil you might be getting the results but then be careful in interpretation of the data, otherwise it is not correct. Agreed?

The cohesion in sands is possible under two-three situations either they are interlocked or they are cemented. So, this cohesion could be because of interlocking. We just talked about interlocking effect. This could be because of cementing agents which are present in the sands. So most of the time sands are calcareous in nature they have calcium.

And this calcium binds the particle together. This could be because of aging of sands also. I hope you can realize how difficult it is to deal with the natural materials. And that is why we require technologists and the right doctors who can deal with the material. Most of the problems in the contemporary society are misinterpretation of the results. The point is, it is a very difficult situation to interpret the results and these are all-natural process.

What is the aging of sands over the period of time millions of years you know the silica, which is present in the sand might ooze out, come out and bind the particles. So, this is what is known as aging of sand, cementing materials you have calcium carbonate you might be having different type of sulphates different type of bicarbonates and they might be forming the bond between the two.

The only possibility is where the environmental geomechanics comes in the picture if there is an acid contamination of sands suppose there is a spillage of acids hydrochloric acid, sulfuric acid. The industry where these types of acids are being produced, what these acids will do they will try to eat up the carbonates which are present in the sands. Clear? And that is the only possibility when c is going to become zero, again. Otherwise, you have to do, you have to give due weightage to the material. You cannot say this this is the frictional material and density is not going to be zero.

So, this is the subject where lot of interpretation is required understanding of the material is required. It is not the mathematic that you got three points and you just join them together and say that this is done. I hope this point is clear. Interlocking because of the grains which are highly irregular. There could be another possibility. Suppose the material gets inundated too much of soaking in water because of flooding. And now I think you can realize why structures are failing because we have not selected the parameters rightly. So, the moment I put water in the system the chances are that this cohesion may get lost. And that is the reason we call all these three terms under the head of you know we call them as effective cohesion? apparent cohesion? apparent cohesion.

So, these things are responsible for apparent cohesion, fine?

Now, you have to go through the statement of the problem very carefully when you are diagnosing a report. See what is the geological age of the of the sands? what type of activity they might have gone through in the days of formation and what type of cohesive mechanisms might be occurring in them. Once you have done all these straightforward get c and ϕ parameters and job is done. Fine? So, this will give you c and ϕ our objective is over. The whole idea of doing direct shear box test, box shear test was to obtain shear strength parameters.

Remember this is the two-dimensional situation, clear? Plane strain, why because you are straining the sample at a constant rate of shearing.