Geotechnical Engineering - II

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Lecture No. 11

Direct Shear Interpretation of Test Results I

Today I wish to introduce the concept of analysis of the experimental results or let us say selection of parameters. And these are shear strength parameters for real life situations or for design purpose. So, until now, what we have discussed is that if I perform a direct shear test/ box test, I get a typical relationship between the shear stress which is being applied normally shear stresses in kPa or kN/m^2 and this is in percentage we call this axial strain.

Now, typically we get a graph like this, up to this point is the elastic limit. So, this is the elastic limit and beyond this strain we enter the domain of plasticity. Now, the issue is even you get this type of relationship, how are you going to use it for your design purpose or for the analysis of the foundation which you have to design or which you have to construct.

So, apart from the c and ϕ which we have discussed in detail, these are the shear strength parameters under undrained conditions or drained conditions. So, apart from this, this is essential, apart from this I would also want to find out the E_u which is the elastic modulus of the soil. If you remember when we were discussing the consolidation settlement, we defined consolidation settlements as ρ_s or whatever.

Now, before this before the consolidation occurs there is a state where the immediate settlements are going to take place. So, this theory we have already discussed in Geotechnical engineering-1. Now, this stage is followed by the stage which is elastic in nature and we call those type of settlements as immediate settlements.

So, this becomes A, B and followed by the creep. Most of the settlements which the soils undergo particularly fine-grained would-be consolidation settlements. But I am sure you must have seen the cases of the railway tracks. So, you have Ballast system over there and ballast is holding the rails on which the vehicles are moving or the trains are moving.

So, the question is why do we need to design the Ballast system? Mechanistic answer is to take care of the immediate settlements, or this is the negotiator between the loads which is getting transmitted from the rails, which is because of the trains which are moving to the foundation system. Now, during Geotechnical engineering-1 I told you that I am not going to talk about immediate settlements in this course.

And that we will be discussing later on. The reason is simple. Immediate settlements are defined as ρ_i and these are defined as,

$$\rho_i = \frac{Bq(1-\mu^2)}{E}.I_B$$

I hope you have remember these terms I_B is the influence factor, which I can obtain by using different types of charts, Fadum's charts or the different types of equations which are available, μ is the coefficient, I hope you understand what μ is Poisson's coefficient, q is the load per unit area and B happens to be the width of the foundation. So, B is the width of the foundation so, when you will take up this course next semester in the fourth year first semester and when you will be doing a foundation analysis.

Suppose, this is a foundation which I want to lay on the natural deposit. So, this is a soil mass and most of the time these foundations would be strip foundations. So, this is a sort of a strip foundation, all sorts of embankments, railway tracks, where the length is infinite as compared to the width, height of the embankment all the foundation system fall in this category.

Peculiar 2D condition, plane strain condition, direct shear parameters can be utilized to solve these types of problems provided the soil mass happens to be granular. And on the granular system, consolidation settlement is not going to prevail, immediate settlements will prevail, we have only defined the term B this is the B which is the width of the foundation system, we call this as *l* which tends to infinity.

So, most of the foundations which have been done for the fencings where the lengths are again very high as compared to width they fall under 2D category. So, this is a width of the foundation and this foundation is taking load q. Now, the question is how I am going to get the value of E? E is the elastic coefficient or elastic modulus. Why I have written here u because this is under undrained conditions if drainage starts immediate settlements are not valid consolidation settlements takes over.

Now, the question is how to obtain E_u value. So, there are 2 methods of doing this, one of the methods is what we call as a Tangent modulus, on this graph having obtained τ versus ε_a relationship if I draw a tangent, if I draw a tangent to the linear portion, the slope of this line is E_u that is why the name is tangent modulus. So, the graph which you have got draw the tangent to the initial portion, the slope of this line is tangent modulus, E_u.

Now, many times what happens is there could be if I zoom this portion of the curve, what you will observe is that there could be some in very low stress ranges, there could be some irregularities in the curve this might start like this. This is because of the poor contact between the loading plate and the sample or maybe the roughness of the two.

So, normally what we do is we apply a correction we ignore this portion of the graph, we start we shift our origin at this point which is almost linear, we apply this much correction to all the data and then we assume this point to be matching with the point which is O'. So, this care has to be taken.

Now, those of you who are in design offices and many times when I review your reports, my question is how did you obtain these parameters and this is what is becoming very, very important for all of you to understand that for optimal designs of the foundation, where the money can be saved, where the material can be utilized properly in poor country.

So, we cannot afford infinite amount of funds being dumped into a project. So, the question is this is where the judgement becomes very important. Now, judgement comes when you have this type of relationship and what I define as the factor of safety parameter.

So, suppose if I define the factor of safety as 1.5 or 2, normally these are the magic numbers which are used for designing the foundations under ordinary circumstances. So, what it indicates is the point where I am getting the peak value, I will reduce the peak by one and half, 1.5 or 2. So, this becomes the factor of safety τ working would be will equal to,

$$\tau_{\text{working}} = \frac{\tau_{\text{peak}}}{\text{Factor of safety}}$$

So, this becomes my stress of interest. I will mark this on the graph. So, this is the safe value of the shear stress, which I am going to consider for my analysis. So, this is corresponding to τ_w by applying factor of safety. Now, if I join the origin with this point. And if I obtain the slope this is also E_u, but this is what is defined as the secant modulus.

So, the second method of obtaining the E_u value would be secant modulus. Fine? Once you have obtained E_u. Now, the question is how to obtain μ value. Unfortunately, μ value cannot be obtained by conducting only direct shear box test. So, what we have to do is we have to go to the triaxial testing. So, we have to go to the triaxial testing to obtain the value of Poisson's ratio.

This is a typical triaxial sample and if I load it by applying some confining stress and what I have to do is I have to put what we call them as micro strain gauges. So, 2 micro strain gauges have been installed, strain gauge number 1 and 2 and ultimately these strain gauges are connected to a Wheatstone bridge. Normally this test is done under unconfined condition. Today I will be discussing about this or maybe in the next lecture. So, this is an unconfined compression test which is going to give unconfined compressive strength of the material. There is no confinement from the lateral direction.

So, when you apply the stress what I am interested in is I am interested in noticing the strains, which the sample undergoes in the axial direction and in the lateral direction. So, that means, what we have to do is, this is the confining stress and if I define this as ε_a and this is ε_r the radial strain. So, ε_r is in this direction and ε_a is in the direction of confinement. So, the typical graph which I will be getting would be something like this. And so, this is for let us say strain number 2, strain gauge number 2, and this would be for strain gauge number 1.

Now, you must be noticing that intentionally I am drawing a non-linear or a curvilinear type of a graph. And I will explain this today that what is the meaning of this, beyond a certain limit of elasticity, the material tends to show a non-linear response. At a given stress, if I obtain the ε_a value and ε_r value the ratio between the two is what is known as Poisson's ratio, simple method to obtain this whole thing. When Bandra Worli sea link was being done, all the foundations are designed by me, and we might have done at least 20,000 samples from different depths of the different locations and we developed a very big database that became very unique later on and this was the first time when the Poisson's ratio were obtained in the laboratory or else people has to assume.

Now, it is so happened that typically for clays particularly the saturated clays, this value is 0.5, Is this okay? What is the significance of this is a magic number. As you move on towards the sands, it decreases, it becomes almost 0.2 or so. So, this is another scheme of classification of the material, better engineered way of classifying the formations. I hope you are realizing what is the importance of getting this type of a simple relationship using them in the real-life practice. So, once you get the E Poisson's ratio value over here, you can substitute it over here, this equation is workable, you can obtain the initial settlements.

Now, those of you who might be doing finite element methods for your BTP or may be higher studies or whatever, you will realize that this type of relationship is quite interesting to define the as constitutive laws. And constitutive laws are nothing but one of them is here we write as,

$$\tau = f(\varepsilon) = E.\varepsilon$$

Now, this type of a relationship has to be fed into the computer to obtain the load deformation characteristics and then doing the stress-strain analysis.

Now, one more thing which I wanted to discuss in details is about the curvilinear behaviour of the graph which we get. In general form what we do is if I plot τ versus σ, I will be getting a failure envelope and this failure envelope would be something like this. The general form of this envelope is,

$$\tau = A\,\sigma^{B}$$

Depending upon what type of analysis you are doing total stress analysis or effective stress analysis this either becomes σ or it becomes σ' where A and B are material constants. So, Now be careful, I hope you are realizing that what I am going to talk about is the selection of the material properties, there is nothing known as the constant c and ϕ value.

So, c and ϕ do not remain constant, why and they depend upon the stress range in which you are working. So, c and ϕ are strongly dependent upon the range of stress. What it indicates? if I am working in very, very small ranges of confinement, this is valid. So, c is 0 let us say, ϕ equal to ϕ whatever you have got the slope of this line.

But as the confinement increases, I hope you are realizing the nature of the graph is non-linear. And within this range of normal stress confinement, what is happening is, if you draw a tangent over here, now, this is what is going to be the c value and ϕ_1 value, c_1, ϕ_1 what happens subsequently, as you move on with the high stresses, you know a situation comes where c vanishes sorry, ϕ vanishes and c prevails only.

Are you realizing this important thing? So, the issue there is the transformation from a pure frictional material to a pure cohesive material. Did you understand this? And that is the beauty of the material and the way we deal with it. So, there is nothing known as c and ϕ constant.

See beautifully I have explained here a material which was initially a frictional, you are asking this question sometime back, clear. So, what has happened? I did the same test. So, c and ϕ are nothing but the attributes of the response of the material. And what is the response? If I overload you too much what is going to happen? Initially you will cry for some time, this is too much ultimately, what is going to happen suppressed completely.

So, look at the graph the initial tendency was to go up linearly, but because of the confinement what is happening the material gets suppressed. Now, second thing is we are working on granular materials. Now, this is the zone in which the material is getting crushed very high stresses cause crushing of the grains. So, now you have to be careful. So, this is the zone in which the crushing prevails. Crushing of what? Crushing of particles or grains. So, you have to be careful if I am designing an embankment.

I know what is the amount of stress, which is going to come on the contact between the embankment and the soil mass. Now, this becomes my stress range in which I will be selecting the parameters that is what they call geomechanics as a subject, which deals with paradox, material has vanished. You started working with a frictional material.

Now, what happened ultimately? We call a loading it got converted into a cohesive response. So, after you have conducted the direct shear box test, take out the sample, sieve it and see whether the grain size distribution has changed or not. And that is how you have to define the limit of shearing and the limit of stress which you are going to apply on the system.

Well, that depends upon the mineralogy, that depends upon the angularity, that depends upon the sphericity, that depends upon the flakiness, that depends upon the crushing strength of the particle, that depends upon the density. So, this is a difficult question to answer. And that is why each sample has to be tested before you start utilizing it. Otherwise, as a captain, I do not have much faith in the material. Whether this guy will be able to bowl for 20 overs or not, you are getting my point.

So, this is this process is going to be a function of so many parameters morphology, mineralogy, granulometry, density, intergranular porosity, so on make it more complicated. So, those of you who might end up in your own start-up and maybe manufacturing something like some of your seniors are doing. So, what do they do? They dose rubbers with sands so they create a composite out of it. So, even composite has to be tested for the shear strength characteristics.