Unsaturated Soil Mechanics

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Week - 10
Lecture - 29
Concept of "Suction Stress"- I

Hello all. Let us discuss Suction Stress Concept today. So, far we have discussed several extended effective stress approaches by Bishop and later this was modified by Fredlund and Morgen Strength and further Vanapalli at all have develop other variants of the shear strength envelopes for unsaturated soils. However, all these different approaches lead to the same approach proposed by Bishop where the contribution of matrix suction is contributed from effective stress parameter.

When effective stress parameter varies from 0 to 1; the contribution of suction on shear strength of soil can be estimated. However, due to the difficulties associated with the estimation of xi parameters that is a effective stress parameter; different approaches came up; however, the lead to the same concept as proposed by Bishop.

Today let us see a new concept proposed by Lu and Likos in 2006 called suction stress; which should incorporate all the physicochemical aspects and capillary forces that exist due to changes in the moisture content variation within the soils and also due to the different particle sizes associated within the soil mass.

So, in this lecture I will introduce the suction stress and I will also explain the suction stress characteristic curve concept for determining the effective stresses in unsaturated soils, so, that we can establish failure envelopes for unsaturated soils. Before introducing suction stress let me bring you back to Terzaghi's effective stress principle.

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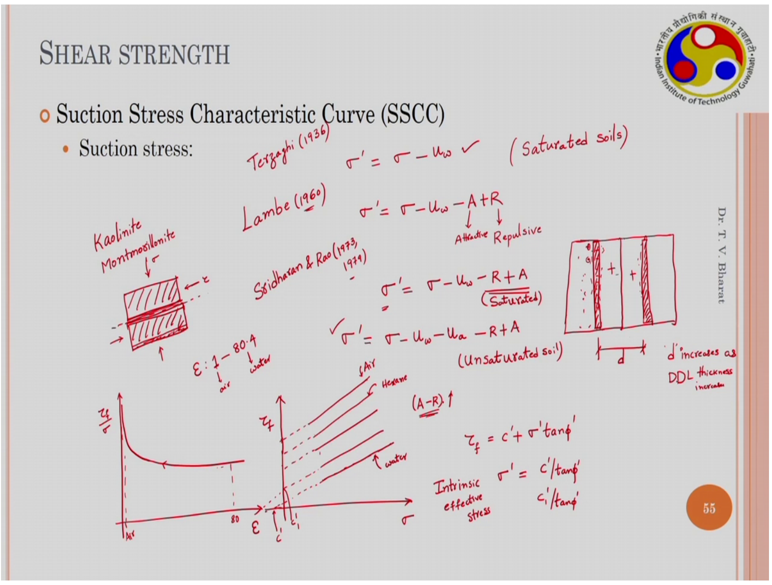

Terzaghi in 1936 proposed an effective stress concept which is a total stress minus uw.

So, because a contribution of pore water pressure should be taken into consideration; so, he proposed this particular equation which is very popularly used; however, this applicable for saturated soils. Bishop has extended this effective stress principal for unsaturated soils by introducing to stress state variables such as net normal stress and matrix suction; so, that he got the effective stress parameter and then the estimation of effective stress was possible.

However, before Bishop there were few researches who modified the effective stress principle for saturated soils itself. This is for saturated soils, for saturated soils our researcher Lambe in 1960 has come up with an effective stress equation for saturated soils which is sigma minus uw minus A plus R. So, this is repulsive force; R stresses due to repulsive force and this is attractive force.

So, the attractive forces in soils are due to Van Der waal attraction and repulsive forces are due to the electrostatic repulsion between a diffused double layers of the clay particles. So, essentially for clays; so there is a additional cohesion concept which needs be explained. So, for that they have come up with attractive force and repulsive forces. However, later by Sridharan or Indian researcher and Venkatappa Rao in 1973 and consequently so much of work in 1979 between 1973 and 79; they mentioned that this is this should sigma minus uw minus R and plus A.

So, this minus A R plus A; this repulsive force will reduce the effective stress and this attractive force will increase the effective stress. Essentially, if you take two clay particles which are placed at some distance d; now they have negative charge on the surface due to isomorphous substitution. So, therefore, there are some positive ions they are available around the clay particle. So, they are held at the surface, but when there is a water adsorbed water; there is thin films that form around the clay platelet.

However, as the water content increases the diffused double layers grow and there is a film that exists around individual particle. So, this is positive charge and another diffuse double layer around another clay particle; so this is again positive charge. So, there is repulsion between these two individual diffused double layers. So, this repulsion leads the particles to move away from each other. So, the d increases; d increases as DDL thickness increases; as DDL thickness increases.

So, therefore, as a particle distance increases the effective stress should decrease. Similarly as a particles come close to each other due to some clay water repulted interactions then the attractive forces should increase that causes increase in the effective stress. So, therefore, this is a expression that is given by Shreedharn and Rao. So, this is all these are all for saturated soils; he also extended effective stress principle equation for unsaturated soils by stating that this is minus u A minus R plus A.

So, this is for unsaturated soils also; this is for saturated soils. So, before I bring you to suction stress concept proposed by Lu and Likos; I just want to refresh you with the existing concepts of physicochemical forces within the soil particles; those are considered long back way back in 1960s and 1970s. So, then; so what essentially the suction stress given by Lu Likos consists is that; so, the physicochemical forces are considered in the Terzaghi's effective stress principle which are given by Lambe and Shridharan and Rao and these are extended similar to Bishop's principal.

So, that forms the suction stress concept. So, let me the detail about this things; here Shridharan and all to proof the existence of repulsive and attractive forces, they have conducted several box shear test there is direct shear test on several soils like a on kaolinite and a montmorillonite soils. So, some bentonite kaolinite; they have taken and they have compacted into shear box in dry state.

So, this is predetermined share plane; you have a pores plates. So, soil is compacted here a dry state they have oven dried the soil and a after oven drying to cool down the temperatures; they have kept it a designator at rh equals to 0. So, therefore there is no absorption of moisture that takes; so initially the soils are at fully dry state. And then they have compacted into the boxier test and they applied some normal stress and then they shared it and now before sharing it; they have subjected to the soil two different conditions.

So, all duplicate samples of same condition one test was conducted at a air dry state, one test is conducted at fully dry state and another tests are conducted at different pore fluids by saturating the sample with these pore fluids overnight using different directric fluids. So, the directric constant of the fluids varied from very small values a 10 for air it will 1; so 1, 2; so, 80.4; this is for water. So, this is for air and this is for water; so in between directoric constants are varied by choosing different pore fluids site like methylene excreta; so benzene excreta.

So, then the saturated the sample overnight with these pore fluids and after the shade the soil sample. So, the profiles they got interestingly tau f by sigma versus directric constant they have observe that; this way decrease. So, as a directory constant increases; this may be for water 80.4 or something and this is for air 1. So, the tau f value increases with decrease in the directory constant. So, this is what they have observed and which is expected and further they have and further they have observed that; when it is plotted tau f versus sigma for different pore fluids.

So, air short some value like this and hexane may be somewhat like this and different data you they got and so, this is for water and this is for air. In other pore fluids like hexane etcetera and between hexane and other pore fluids are here and when you extend this; they got different cohesion intercepts. So, this cohesion intercept c 1 with water and this maybe c 1 dash or something. So, that considering the more column or envelopes tau f equals to c dash plus sigma dash; tan phi dash.

At tau f equals to; so the effective stresses are c dash by tan phi dash. So, these are negative values; that means, these are tensile stresses. So, these are all c dash by tan phi values tan phi dash. So, these are values they got and where we c 1 dash by tan phi dash. So, these are the effective stresses when these are extended back onto negative access.

So, this is called intrinsic effective stress and here as the; A minus R; the attractive force minus repulsive force this value increases, the strength also increases. So, for air the directric constant is 1 and other attractive forces are very high and repulsive forces are 0.

So, therefore, the A minus R force is maximum for air; so for the therefore, the strength is highest and which has a very high intercept cohesion intercept. Similarly, for water attractive force are minimal because article distance is very high and repulsive forces are significantly high; therefore, this value is minimum here and for water the cohesion intercept is lowest.

The angle of internal friction slightly varied, but approximately they are nearly constant. So, therefore, they have proved that A minus R forces would definitely influence the strength aspects; so, we need to consider in the effective stress principle.

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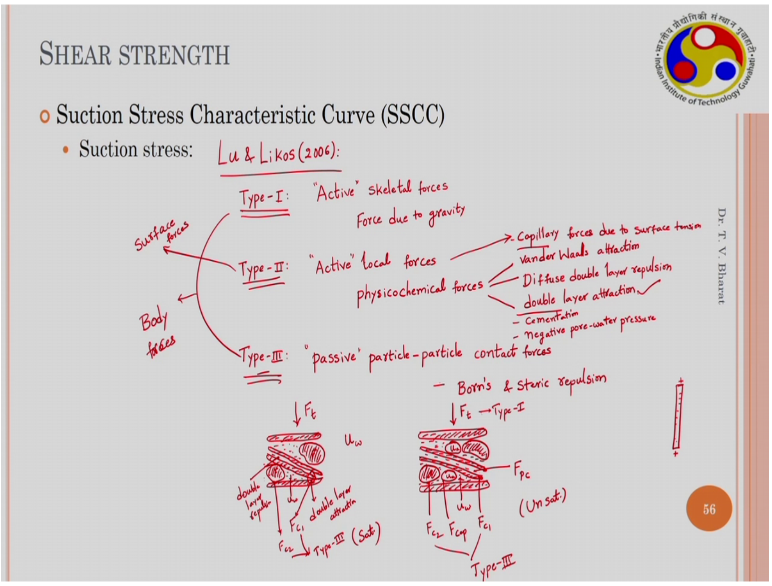

The similar approach is considered by Ning Lu and William Likos in 2006. So, they have given the concept of suction stress.

So, by considering particle scale forces for unsaturated soils; so, they construct three types of forces according to their work; they consider type I; type I force which consists of active skeletal forces; they propagate through soil grains and the considered type II. So, they are active local stresses or local forces.

And type III which is passive particle to particle contact forces. So, the active meaning this; forces do exits even without any application of loading. So, in the absence of external loads also these forces exist and passive force means; it exists only when there is external load. So, active skeletal force include the force due to gravity and any external force; you have then they are the forces are transmitted through the skeletal of the particles.

And active local force include the physicochemical forces; physicochemical forces that include Van der Waal attraction; Van der Waal attraction forces, diffuse layer repulsion, double layer attraction and net attraction due to cementation and which also includes negative pore water pressure and the capillary forces due to surface tension. So, these all are forces which are considered. So, physical forces include these three and rest other things are active local forces. So, it includes all these forces under active local forces; so, this passive particle contact forces include short range, Born's and Steric repulsion.

So, they the Born's and steric repulsion are very short range and they help in the particles to not paid trade one each other. So, therefore, the existed very short range and so these are the forces considered for developing the suction stress characteristic. So, once these forces are considered; generally that type I and type III forces together their called body forces and type II force is called surface force. So, when the surface forces should be equal to the body forces at mechanical equilibrium.

So, therefore, if you consider a representative volume within the soil mass; so, you may have particles arranged in this particular manner. So, this may be a face to face interaction between two individual particles and you may have one face here, another face here. So, all different particle to particle interaction or shown in this particular diagram; these are particle edges this is also particle edge and this is particle surface.

So, here these two particles are arranged in face to face interaction manner and these another particle two particles are in face to face interaction, but in between there are other particles held and this is face and this is face of clay particle consider. So, now, in this particular case when there is an external force applied; there are several forces such as the force between edge of this particle and with this particular parallel plate; so, you may have attraction.

Because generally the clay particles their negatively charged at the surface, but it just are positive because of the broken Born's excreta; they have positive at the edges. So, when there is a edge which is interacting with the face there may be a attractive forces between these two particles at the edge to face contacts. So, these are the diffused double layer attractive forces; double layer attraction is between particle edge and face and similarly here this is here double layer double layer attraction.

And in between these two you may have double layer repulsion. So, here you may have particle to particle contact forces also. So, particle to particle contact forces and here also you may have particle to particle contact forces. So, this two a type III and you have pore water pressure and these forces may exists in the soil, but if you consider an unsaturated soil in the similar representative volume there are two particles in face to face arrangement. So, this is one particle and this is another particle.

When you may have air inside in between these are eight pockets and this whole thing is water. So, you have air pressure u a here and similarly here you may have contact pressures F c 1; these are type III. And because air water interface that exists here you have capillary forces and you will have water pressure and here also you will have water pressure and here you may have negative water pressure and physicochemical forces between individual particles diffuse double layers.

You may have physicochemical forces such as the double layer attraction and double layer repulsion. And similarly here also you will have double layer attraction double layer repulsion, here double layer attraction you may have and here double layer repulsion you have for these soils. So, if we consider all these forces you have external force that is applied; say this is external force, this is gravity force; either the under the gravity they particles are coming close to each other are these external force that is applied.

So, this way you have type I forces, this is type I and all these are type II and this and this one and this one is type III. So, these many forces may exist within the soil and here in saturated soil the pore water pressure when we consider which is isotropic and the pore water pressure acts with the same value all around because there is a continuing pore water pressure.

But in case of unsaturated soil in case of unsaturated soils because there is a discontinuity the pore water pressure is negative and there is a air pressure that exist; therefore, the surface tension of contract scale that exist between air face in water face. So, the pore water is not isotropically acting all directions.

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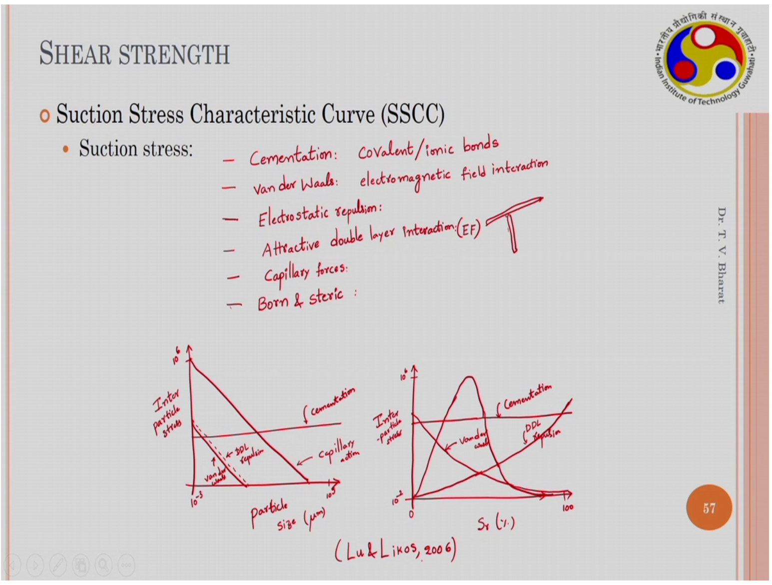

Several forces which we consider such as the cementation that is particles due to covalent or ionic bonds covalent or ionic bonds between the cementing agent and soil particles and similarly you have Van der Waals forces.

This is due to electromagnetic field interaction; electromagnetic field interaction between adjacent atoms of the approaching surfaces; so, therefore, this is cumulative. So, generally these forces are predominant when the particle distance is less than 2 nanometre. So, these are all short range Van der Waal forces short range and cementation covalent and ionic bonds between two individual particles. So, from the cementing agent and particle this does not depend on the water content are the particle sizes.

So, for the Van der Waal forces depend on the particle sizes and as a particle size decrease that is for clays Van der Waal forces are higher. And it does not depend on the water content, but due to changes in the water content, the particles may come close to each other that causes increase in the Van der Waal forces. So, then electro static repulsion are double layer repulsion.

This I have already explained that the particles are negatively charged due to isomorphic substitution. So, when the particles are formed there is a charge deficiency within the internal structure. So, because of it attracts positive ions and on to the surface and because of this even the water is absorbed in the dry state. And therefore, at adroit state we have seen that the some version that exists.

So, this air dry water content for clay soils especially bentonite or montmorillonite rich clays; c is very high, it can be as high as 15 to 20 percent water content by weight. And attractive double layers; double layer interaction is due to EF flocculation. When the particles are arrange this manner this is one particle and this is another particle.

So, the edge of the particle one particle and face of the another particle; when they are interacting. So, it generally have positive charge and face has negative charge therefore, there is attractive force between these two particles. So, these are generally EF flocculation causes these forces. Capillary forces are due to particle arrangement or structure.

So, when there is a capillary is within the particles there is a surface tension force that develops and then the water will be absorbed. And this inter develops forces within a soil particles; it has a very potential contribution for effective stresses at one particular water content. At very high saturation; so, nearly degree of saturation is closed on the person; it does not have much stone and even the water content is nearly close to dry state; where the water exists around particles is thin layers than these; the contribution of capillary force is negligible.

But in between the contribution is significantly high; the born and steric forces steric repulsion short range forces are highly dependent on inter particle separation mentioned. So, therefore, if this can be understood; particle size if inter particle stress are plotted. So, the inter particle stress is highest when the particle size is lowest; so, you have this kind of behaviour for capillary action. Similarly for diffuse double layers and Van der Waal forces this is of the vary and the cementation traction is constant it does not depend on the particle size; so this is due to cementation.

And this is double layer repulsion and this is Van der Waal force; so, this is how these forces depend on the particle sizes. And similarly how the vary degree of saturation; symmetric particle force this could be has highest 10 power 6 kilo Pascal. And the right size range is a constitution 10 power 5 micrometre and this is also 10 power 6 an inter particle force inter particle stress. So, this is varyingly x 10 power minus 2 to 10 power minus 6 and the this is 10 power minus 3 and degree of saturated is varying from 0 to say 100 percent.

So, DDL repulsion may be close to 0 when the degree of saturation is 0; that means, they when there is no water, the repulsive forces do not exist because the diffusible layers would not form when the water is not present. So, therefore, DDL does not form and it increases with increase in the motion content and reaches a constant value at 100 percent.

And the cementation forces are constant they do not depend on the water content and the Van der Waal forces they decrease with increase in the water content; assuming that the particles are getting separated from each other at very high particle interaction the Van der Waal forces are highest. Similarly here when the particle interaction is higher, but degree of saturation is close to 0. So, therefore, the water does not exist therefore, repulsive forces decrease to 0.

So, these are DDL repulsion and this is cementation and the capillary forces will reach very high value at some water content and the decrees to 0 as the degree of saturation increases. So, as I mentioned when the degree of saturation is close to 0; that means, water content is very less than the capillary forces do not have any role to play and then the water content is nearly saturated then also did not have any role to play. So, in between the have a significant role to play this is how they vary and this whole concept is taken from Lu and Liko’s 2006 people.

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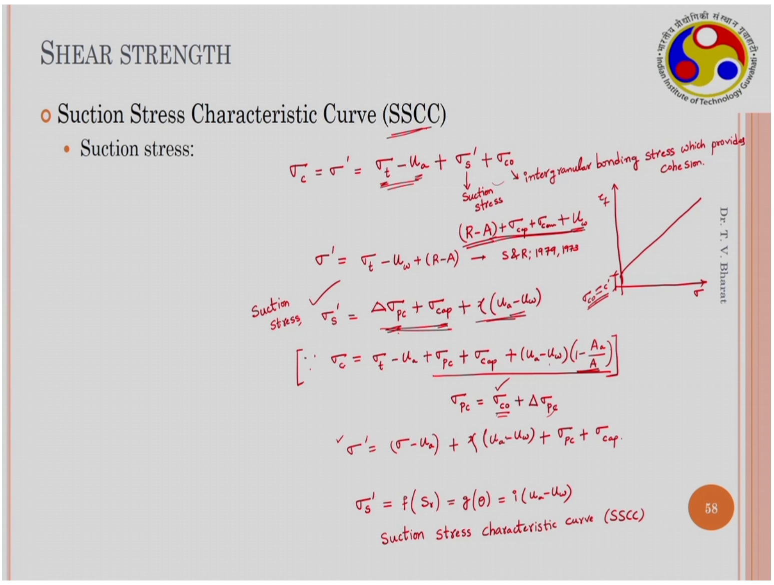

So, we have several inter granular stresses and unsaturated soil; they can be combined as like this which is sigma c which is equals to effective stress.

That is the total stress minus u a and you have minus w also, but which are all included in sigma s dash plus sigma c not. So, this the total stress and this is air pressure and this is suction stress; the suction stress includes the capillary forces, the physicochemical forces and any cementation force that may exits all are included in suction stress.

So, the suction stress is similar to R minus A forces in Sridharan and Rao; R Lambe 1960. But; however, so it also includes the capillary forces, cementation forces etcetera, but also it considers the unsaturated state. So, it has the pore water pressure which is negative which also includes in this. So, Sridharan and Rao considers only repulsive and attractive forces, but also it this one considers all other forces.

So, here the sigma c naught is inter-granular bonding stress; bonding stress that provides cohesion to the saturated soils. So, when we take more column envelopes when we draw the more column envelopes; when we plot towers sigma. So the first saturated place you have a intercept; so, this intercept for a saturated clays when u a minus u w is equals to 0 is c not; the inter granular bonding stress which provides cohesion in saturated soils.

So, that is the sigma c naught and therefore, the suction stress is understood to be inter particle forces that exists under different water contents and due to different interactions;

clay water electrolyte interactions that exists between different particles and which includes physicochemical forces, capillary forces and cementation forces are etcetera all these forces are included in this. So, this is similar to the Sridharan and Rao's equation for saturated soils. So, this sigma dash is equals to sigma t minus u a u w plus R minus A.

This is Sridharan and Rao 1979 or 73; this similar to that and therefore, suction stress is written as sigma dash; sigma s sigma s dash is equals to change in physicochemical forces plus capillary forces plus xi of u a minus u w. Because when you solve this equations and represent the whole capillary forces comes out to be sigma t minus u a plus physical forces or stresses due to physical forces plus stresses due to capillary forces plus u a minus u w times 1 minus area of air phase divided by total area; so, this is expression we get right.

So, therefore, the u w is included in this in the suction stress. So, what we consider is this whole thing is a suction stress, but the sigma P c is written as inter granular bonding stress which provides cohesion plus change in physicochemical stresses this is how it is written. Therefore, we get this expression sigma c s dash is equal to delta P c delta sigma P c plus sigma capillary forces plus xi into u a minus u w; if this is xi. So, if we considered the suction stress this considers stresses due to change in photochemical forces and stresses due to capillary forces plus u a minus u w matric suction contribution; this is similar to Bishop's.

So, if you consider Bishop's approach the effective stress is nothing, but sigma minus u a plus xi of u a minus u w. So, this is similar to that accept that there are physicochemical forces plus there are capillary forces; if you include this two stresses due to physicochemical forces and capillary forces; then this is nothing but what is given by Lu and Likos in 2006. So, therefore, the suction stress is a function of matric suction and water content because when water content changes, these forces would change; the capillary forces change has a water content of degree of saturation changes and similarly physicochemical forces change.

Whether may be increasing or decreasing or become constant depending on the degree of saturation changes. So, therefore, the suctions stress which is the unique function of degree of saturation or a function of volumetric water content, a function of matric suction. So, this characteristic of representing the variation in suction stress with respect to moisture content or matric suction is called Suction Stress Characteristic Curve or SSCC. So, we have reached to this stage; so this called Suction Stress Characteristic Curve.

So, how to determine this sigma c not? This sigma c naught is cohesion intercept for saturated soils. So, therefore, when we draw the tau f of sigma plot what are the cohesion intercept we get c dash is nothing, but sigma c not; so, this is known anyways to us. This is considered to be due to physicochemical forces; so, therefore, this component is known therefore, changes in the physicochemical forces; due to changes in the washer content can be obtained.

And therefore, this is how this is considered and this therefore, this is substituted here and they obtain the suction stress. We will discuss how the suction stress characteristic curve varies with degree of saturation or how this is dependent on soil water characteristic; we will learn in the next lecture.

Thank you.