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ADVANCED GEOTECHNICAL ENGINEERING

Prof. B. V. S. Viswanadham
Department of Civil Engineering
IIT Bombay

Lecture No. 10

Module – 1

Effective stress and Capillarity

Welcome to lecture no 10 module 1, in this lecture w are going to introduce ourselves to concept of effective stress and capillarity, in the previous lecture we try to understand about compaction of soils and factors effecting compaction and methods for the deep compaction this particular concept of effective stress has lot of prominence in geo technical engineering.

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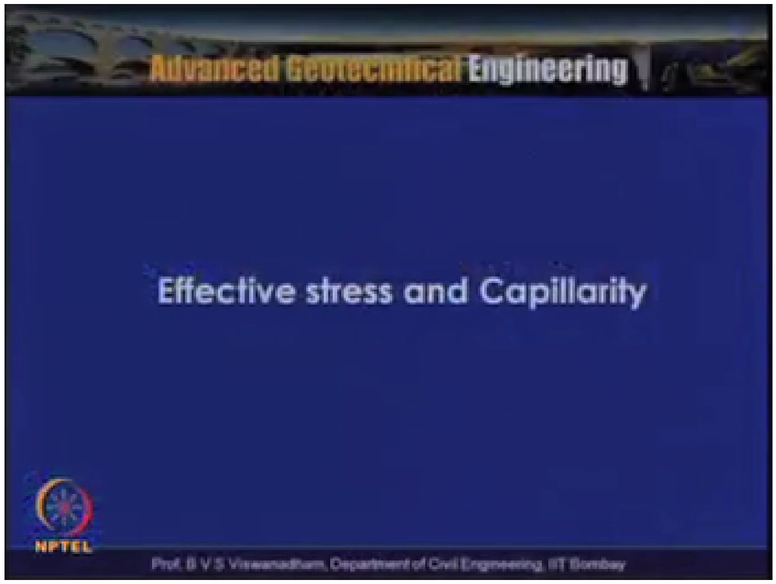

So the title of the lecture module this lecture is effective stress and capillarity.

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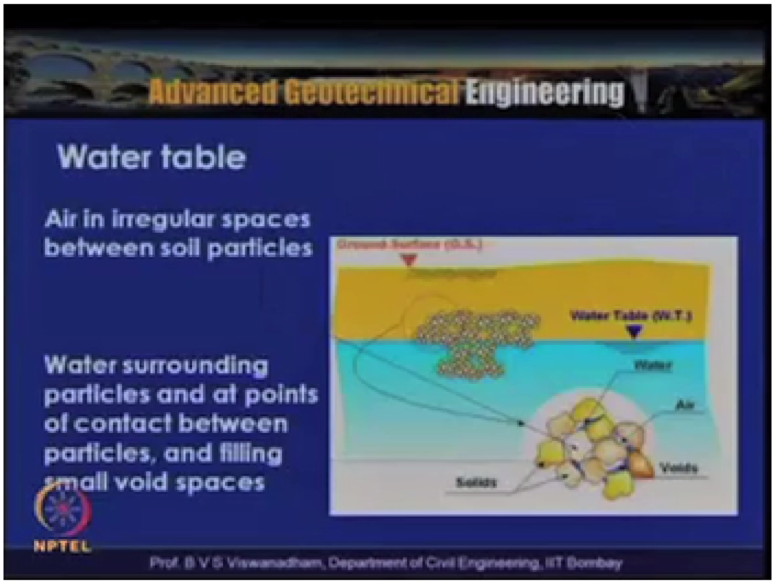

So as you can see in this slide a cross section of soil profile is shown with ground water table so the zone below the ground water table that is the soil below the ground water table is completely saturated with water filling all the voids within the soil. So here this particular zone here it is shown that a partially saturated nature where you have got a and also at the part of water.

So mostly soils are actually completely saturated below water table and above water table the soils are partially saturated in nature, so we have some phenomenon depending upon the type of soil a capillarity phenomenon which occurs above the ground water table. So here the water shrouding particles at point of contact between particles and filling the small void spaces are shown see here.

So this particular portion which is within the soil solid space is called pores space or pore this is indicated as a small d it is pore diameter or it can also be called as pore radius.

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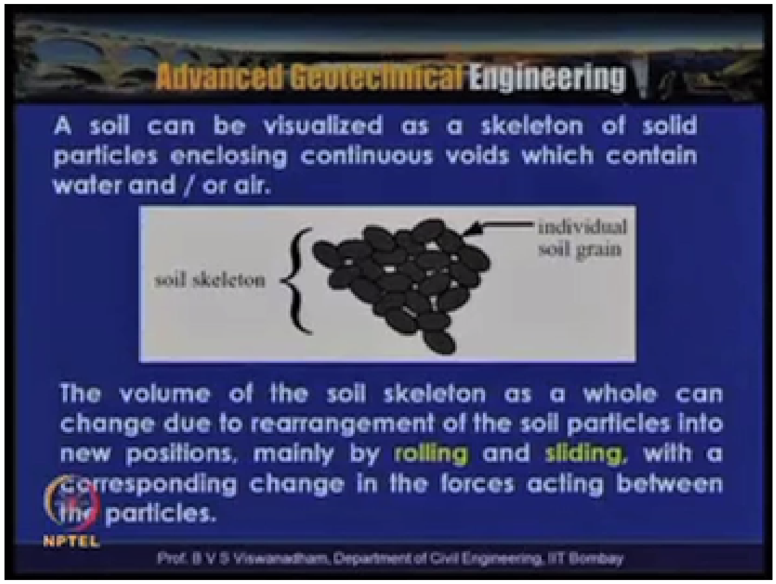

As we can see from this slide soil can be visualized as skeleton of solid particles enclosing continuous voids which contains water and air or air. So soil skeleton which individual soil grains and the arrangement which is actually shown here and the volume of this soils skeleton as a whole can change due to rearrangement of soil particles in to new positions, the new positions they require mainly by a rolling and sliding.

With a corresponding change in forces acting between the particles, so the soil can be visualized as a skeleton of the solid particles enclosing continuous voids which contain water and or air, if you look in to in a fully saturated soil.

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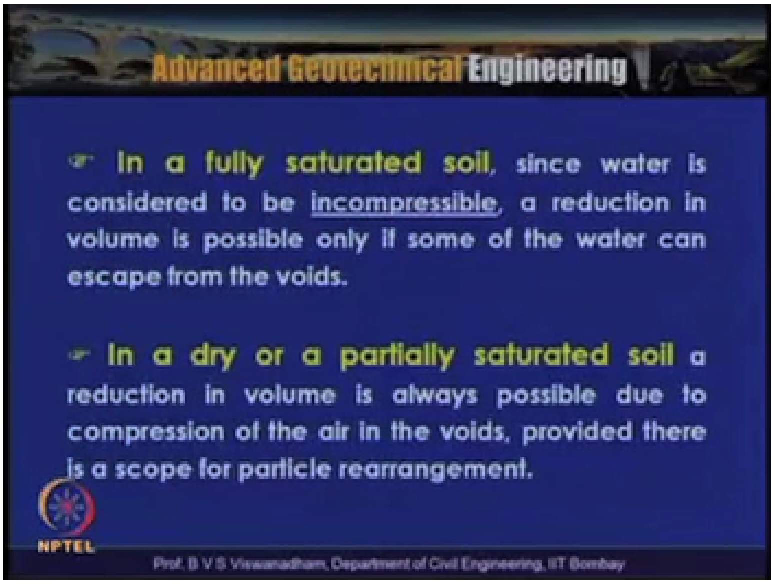

Since water is consider to be incompressible, a reduction in volume is only possible if the water can be escaped from the voids, if the water can escape from the voids. In case of a dry or a partially saturated soil reduction in volume is always possible due to the compression of the air in the voids provided there is a scope for particle rearrangement, so in dry or partially saturated soil a reduction in volume is always possible due to compression of air in the voids provided there is a scope for particle arrangement.

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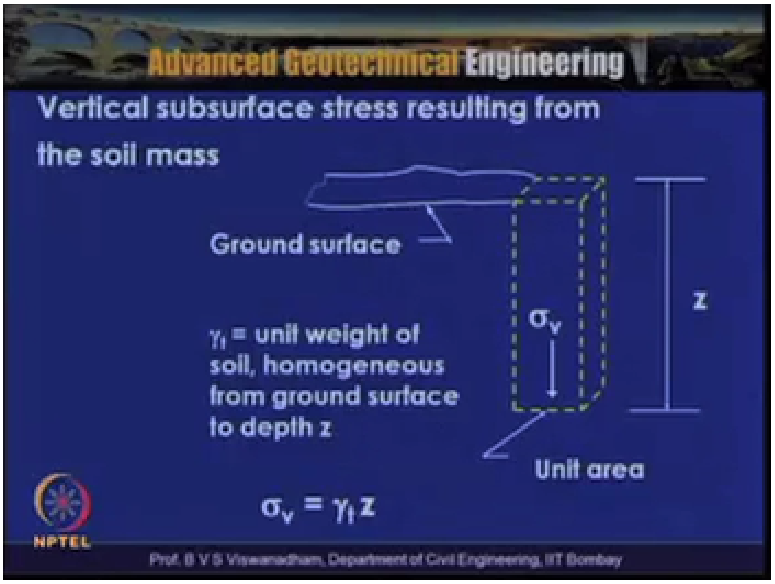

Before introducing the concept of effective stress we have to introduce ourselves to what is total stress, this water vertical surface sub surface stress resulting from the soil mass because of the self weight alone is actually shown here suppose if this is a portion of the ground surface and if you consider the unit area and ex-turning up to depth z the σ v is nothing but weight of the soil in this zone divided by the unit area.

So if γ t is the average unit weight of the soil in this zone γ t in to the volume of this particular element divided by the cross section area which is unit area so with that σ v is = γ tz. So γ t is nothing but the unit weight of the soil, homogenous from the ground surface to the depth z, so σ v which is also if the ground surface is horizontal which is actually called as geo static vertical stress. So σ v = γ t z and is also referred here as total stress which is resulting at a given point because of the self weight of the soil.

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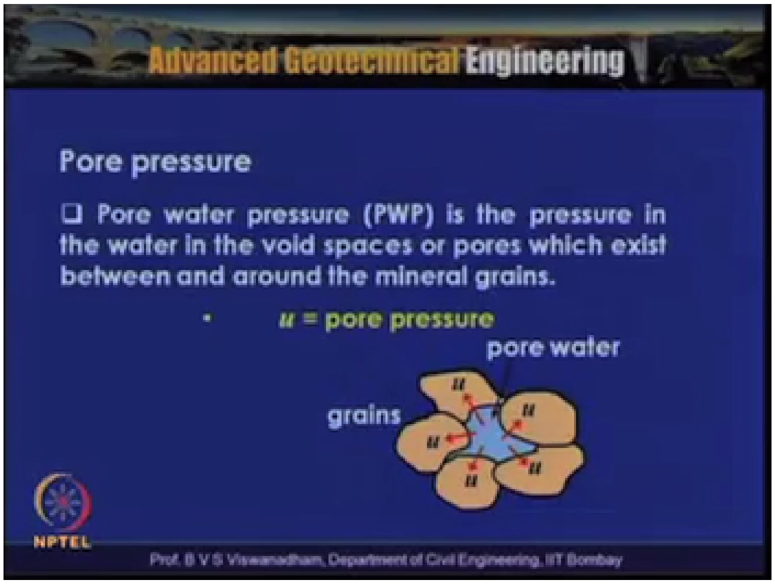

Then pore water pressure or pore pressure is the pressure in the water in the void spaces or pores which exist between and around mineral grains. So here a schematically arrangement of the grains are shown here and this is pore water pressure existed in all directions along the inner surfaces of this soil solids can be seen from this slide, so this is the u pore water pressure which is multi directional orientation, so pore water pressure is the pressure in the water in the void space pressure in the water in the void spaces or pores which exist between and around the mineral grains.

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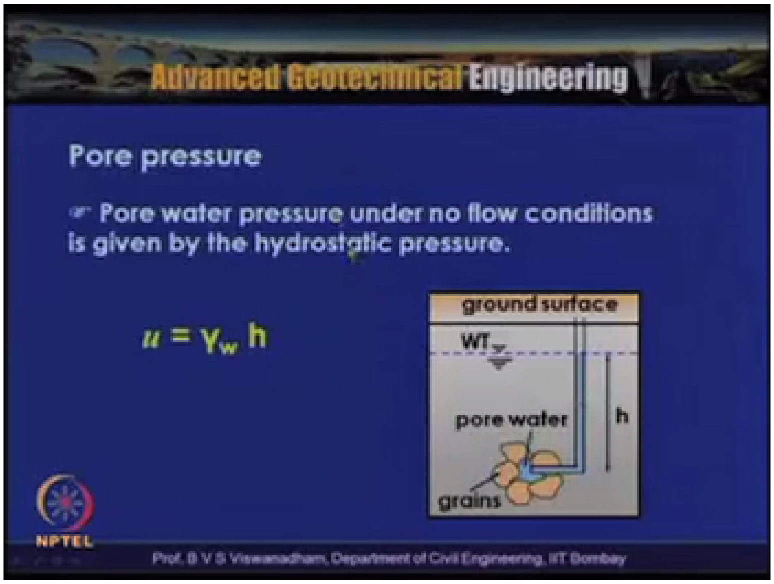

So pore water pressure under no flow conditions is given also given by the hydrostatic pressure, if you assume that there is a ground water table and if this is the point way the pore water pressure is say taped through a stand pipe then h is the height of water in the stand pipe the pressure is nothing but $u = \gamma w \times h$, γw is nothing but the unit weight of water.

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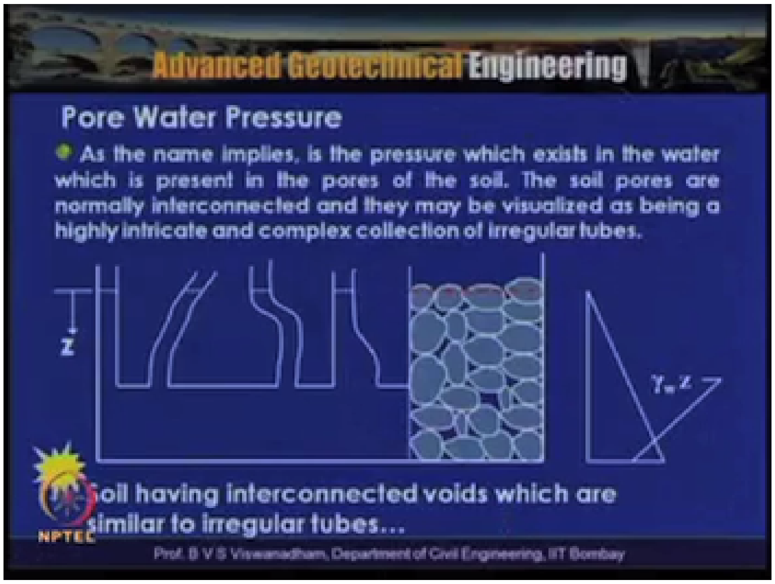

As the name implies this is the pressure which exist in the water which is present in the pores of the soil that is the pore water pressure as a name implies is the pressure which exist in the water this is present in the pores of the soil. So the soil pores are normally interconnected and they may be visualized as being a highly intricate and complex correction of the irregular tubes. So if I have a straight tube even then that a pressure is same and if you have got a interconnected void which is of this shape or this shape or this shape the pressure is actually is nothing but the water pressure which is actually connected through along the voids.

So the soil that having interconnected voids which is similar to this is analog as to irregular tubes connecting the or passing through the voids. The size of the tubes depend upon the size of the pores within the soil.

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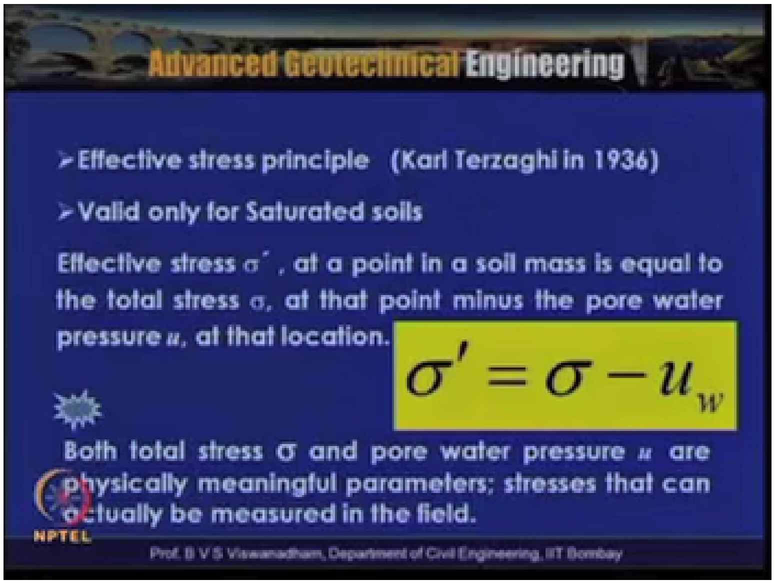

So the effective stress principle the way back in which is given by Karl Terzaghi in 1036 is valid for only saturated soils, this effective stress σ' so effective stress is indicated by σ' and which is at a point in a soil mass is equal to total stress σ at that point minus the pore water pressure u at that location. So σ total stress is a portioned by σ' effective stress and pour water pressure or effective stress is nothing but σ – uw.

Both total stress σ and pour water pressure u are physically meaningful parameters and stresses that can be actually measured in the field, so effective stress σ' can only being computed and from the measurement s made from the total stress and pour water pressure, so the effective stress σ' at a point in a soil mass is equal to total stress σ at that point – the pore water pressure u at that location.

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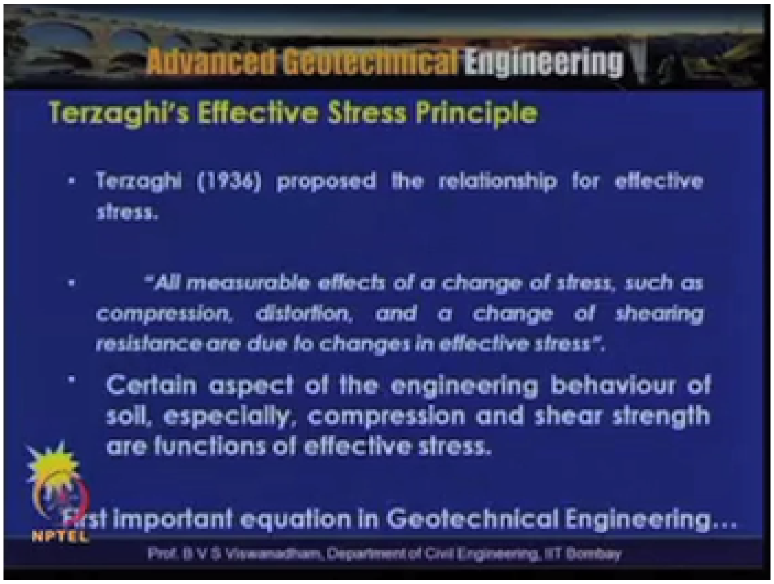

Terzaghi in 1936 proposed the relationship for effective stress and what he coated is mentioned here all measureable effects of a change of stress such as compression distortion and a change of shearing resistance or due to changes in effective stress, all measurable effects like change of the stress such as compression in the soil or distortion or change of shearing resistance or due to the changes in the effective stress.

So certain aspect of the engineering behavior of the soil, especially compression and shear strength are functions of effective stress which will be discussing these aspects in forth coming modules. So first this is Terzaghi's concept of effective stress is the first important equation in geo technical engineering, so effective stress by definition now what we discussed is that can be determine only by arithmetic manipulation.

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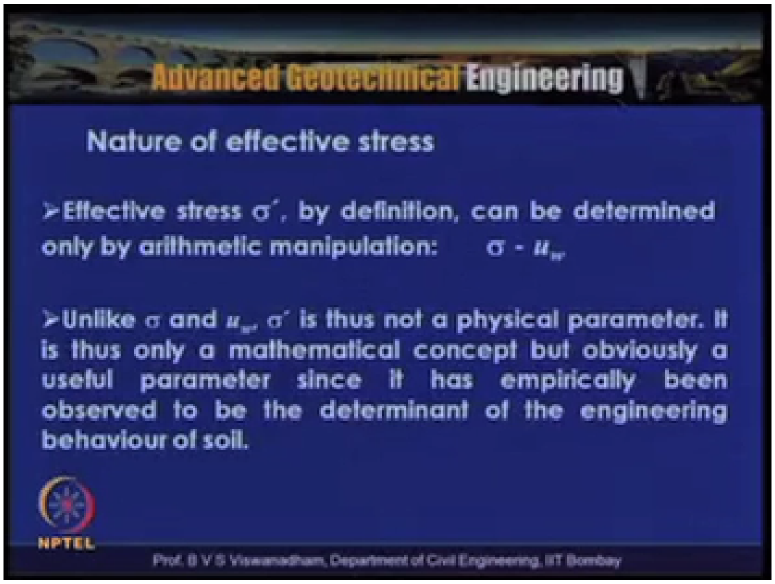

That is σ – uw, unlike σ and u w σ' is does not a physical parameter it is only a mathematical concept but obviously it is useful parameter since it as empirically been observed to be determinant of the engineering behavior of the soil. So though it is cannot be measured it is actually has got lot of physical significant and as empirically been observed to be determinant of the engineering behavior of the soil.

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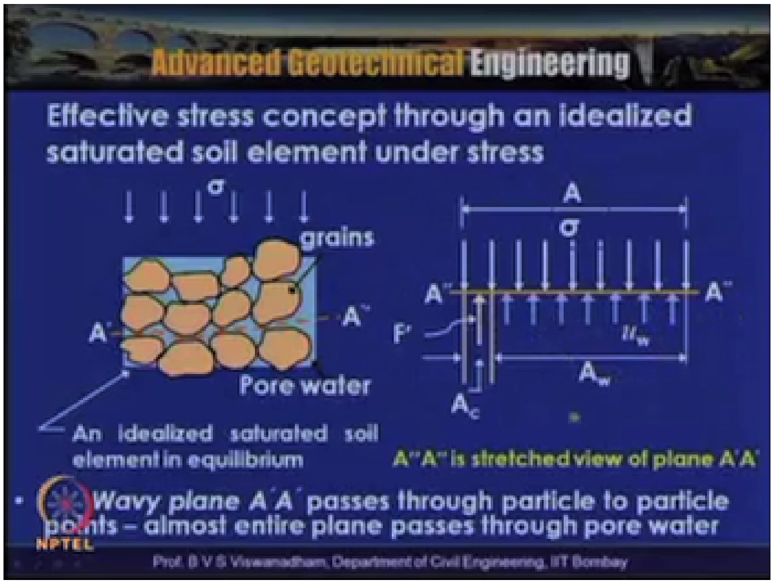

So effective stress concept through idealized saturated element under stress can be considered like this so here in this particular slide a cluster of soil grains are shown and a' and a' is the line passing through the voids so a' and a' is the line passing through the voids and this is a something like a VV shape it can be because the pores or the line cannot pass through like a straight line.

So this is the pore water and σ is nothing but the total stress and now here we knew that σ total stress is = pore water pressure and effective stress so this is an idealization saturated soil element in the equilibrium and VV plain a' and a' passes through the particle to particle points, so VV plain a' and a' passes through particle contact points almost entire plan passes through the pore water here you can see here this one. So here you consider you got imaginary line a' and a' is stretched view of plan a' and a' so a'' and a'' is the stretched view, so here you can see ac is the area of the contact between the soil grains and aw is the area of the water.

So total area is equal to ac + aw and ac on this is the area of the contact where in the force f' which actually acting on the granular matrix and, so uw is the water pressure acting in the area w aw.

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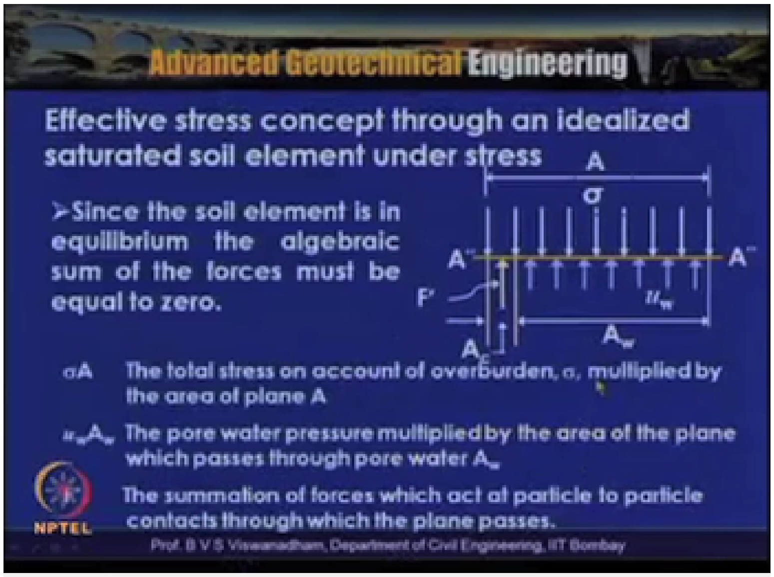

So further once you extend this one so here σ x a is the total stress an account of overburden so σ multiplied the area of the plain a this is nothing but the force which is acting because of the sulfate of the soil above that plain a' and a' and a' and a' is the imaginary line which is the representation of the VV line connecting the particle to particle contact points. Since the soil element is in equilibrium the algebraic sum of the forces must be equal to 0.

And µ w, uw, aw, is the pore water pressure multiplied by the area of the plan which passes through the pore water. So aw is nothing but the area which is passes through pore water and f' is nothing but hr summation of the forces which act at particles to particle contact through the through which the plain passes, let us say that you have got say you know 100 number of particles then f1 + f2 + f3 + f100 = f' okay.

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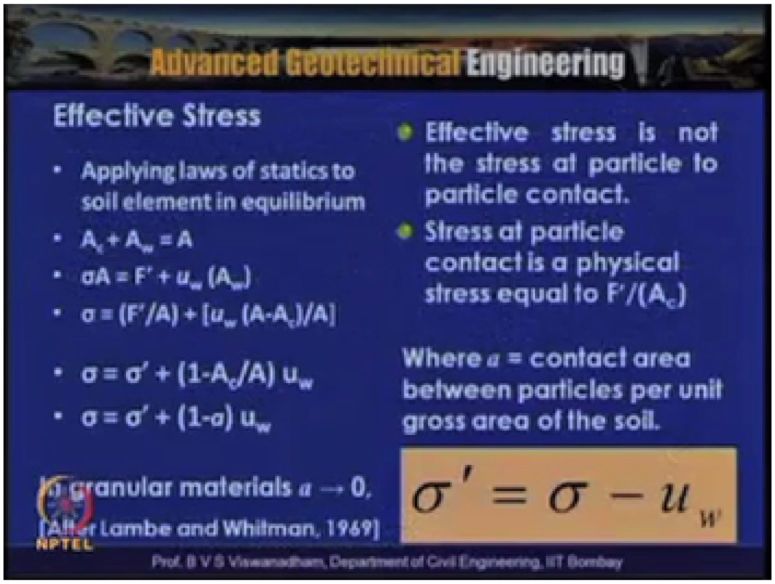

So applying the loss of statics soil element in equilibrium we can write that ac + aw = a, so with this we can write σ x a = f’ + uw x aw so σ = by taking a this side we can write f’ a + uq x aw we can write it as a – ac is nothing but areas of the water that is area occupied by the pore water is nothing but the a – ac. So I can write uw x a – ac / a so σ = σ’ + 1 – ac / a x uq. So I can write here σ’ that is σ’ + 1 – a x uw = σ.

So a is nothing but contact area between the particles per unit cross area of this soil that is nothing but a is nothing but ratio of contact area between the grains to the total area which is under consideration, in granular materials because the contacts will be like minuend contact points like point, point contacts, so a tends to be 0 in that case σ = σ’ + uw σ’ when σ = σ’ + uw. So effective stress is not the stress at particle to particle contact and a stress at particle contact is physically the stress equal to f’ / ac, ac is nothing but the area of the contact between the soil solids.

So here with this what we have reduce is that we have reduce the equation which is proposed by Terzaghi that is σ = σ’ + uw. For granular materials between were a =0 for when with area of the contact into consideration we can write σ= σ’*1-a*uw .

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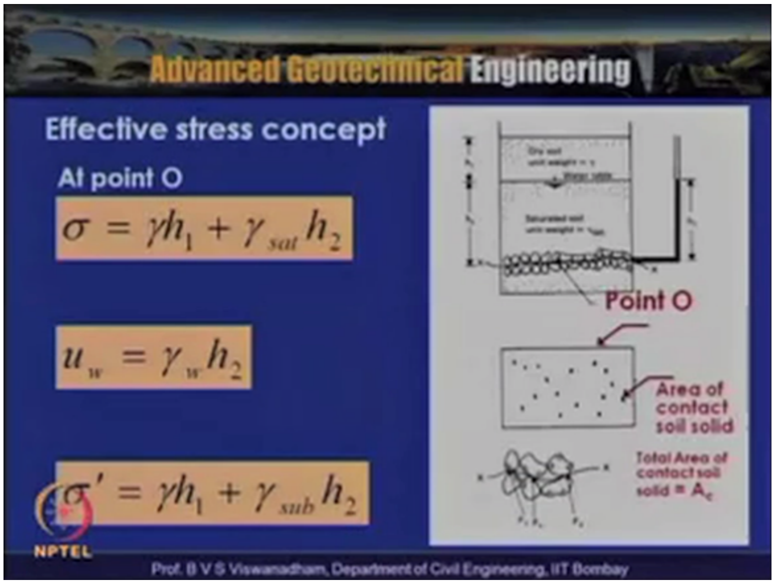

Now in this slide further extending to the effective stress concept here consider you got this line passing through this point and this is the line which is actually imagined rain which is extended and so at point O that is at this point O the water table is here so the stress at this point is nothing but γh1 that is dry soil*this saturated soil because the unit weight will be saturated being γ sat*h2.

So the total stress is γh1+γsat h2 water pressure is nothing but uw is nothing but γwh2 spo effective stress at point O is nothing but γ sat h2+γh1-γw h2 with that I can write σ'=γh1+γsub or γ'h2 so this is you know how you can actually determined vertical stresses effective stresses by knowing total stresses and for water pressures.

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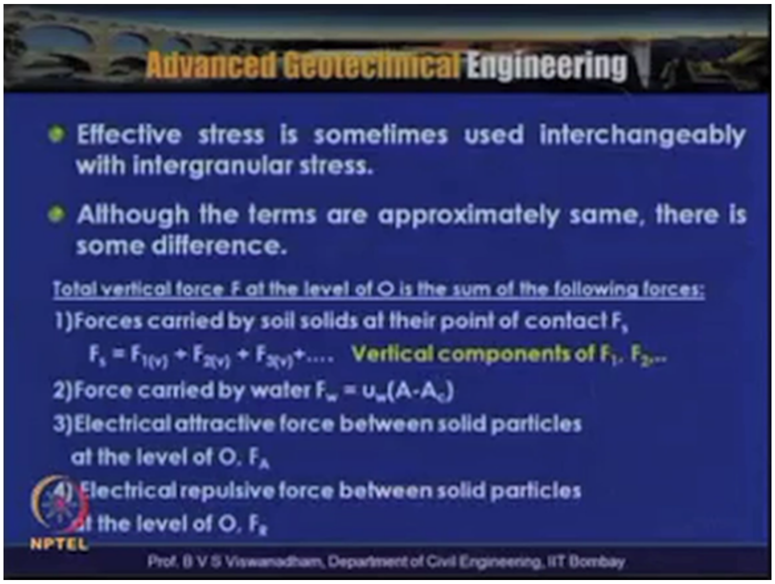

So effective stress is sometimes interchangeable with intergranular stress although the terms are approximately same there is some difference total vertical stress f at the level of O that is the point O what we have seen in the previous slide is the s0oem of the following forces one is that forces carried by the soils solids at their point of contact that is Fs so fs =f1vertical that is nothing but the vertical component of each contact force we are taking f1v+f2v so on to f3v.
And forces carried by water which is nothing but fw=uw*a-ac electrical attractive forces between solid particles at the level O.

That means that if you have what say some soil solids which actually have got mineral interaction then electrical attractive forces will be there between the solid particles t the level of O that is fa electrical repulsive forces between solid particles suppose if they are disperse in nature then they can may dispersion that is fr so the we have net forces acting on the grains that one is due to the contact.

Other one is forces carried by the water and other one is forces due to attractive forces and another is that repulsive forces.

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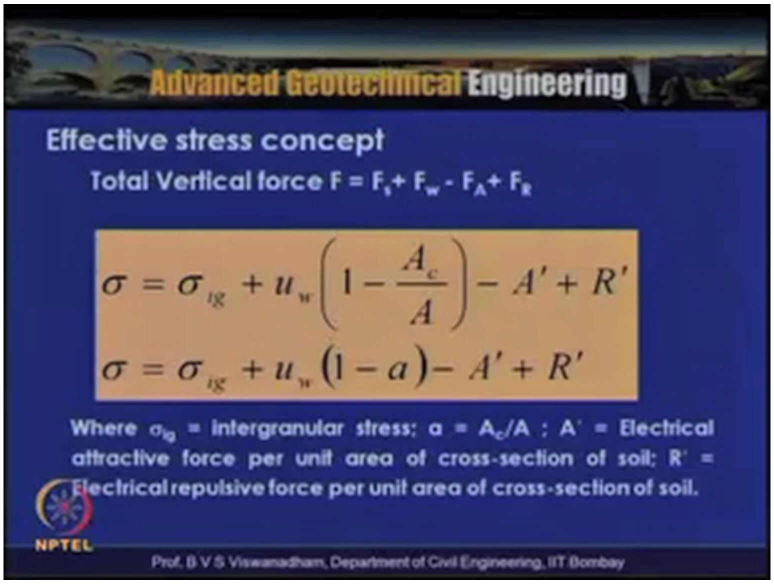

So the total vertical force we can write it has fs=f is equal to Fs that is due to contacts+fw carried by the water-fa+fr so here σ we can write as by dividing by a σ_{ig} which is internal log that is fs/a+uw*1-Ac-A-A'+R' so σ= σig+uw(1-a)-A'+R' where σ_{ig} here is nothing but intergranular stress and AC=A/A that is the contact ration and A' is nothing but the electrical attractive force per unit area of the cross section R' is electrical repulsive force per unit area of the cross section of the soil so A' and R' are the electrical attractive forces or repulsive forces per unit area of cross section.

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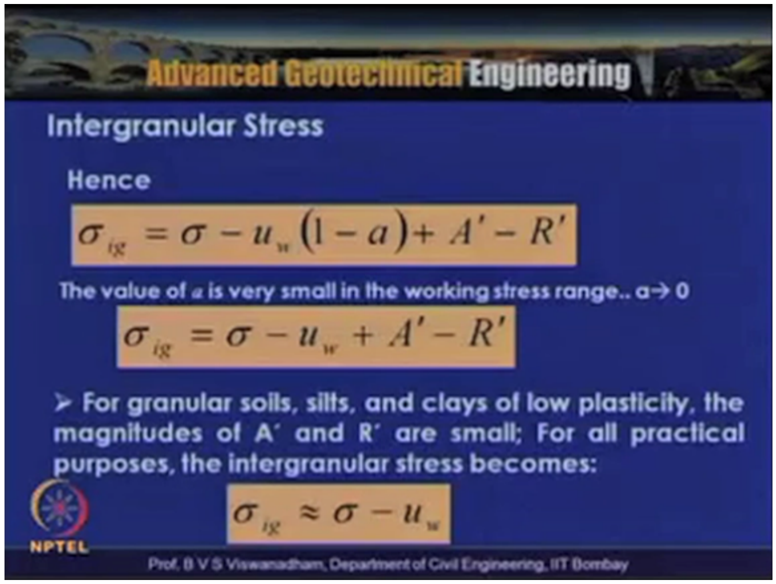

So we can write here as σig= σ-uw*1-a+A'-R' so the value of A is very small in the working stress range because of the minute contact points so A tensed to be equal to 0 so with that we can write σig= σ-uw+A'-R' so for granular soil and silts and clays of low plasticity fort the granular soils and silt soils are clays having low plasticity the magnitude of A' and R' are very small. So for all practical purposes the intergranular of the stress becomes effective stress which is nothing but σ'= σ-uw.

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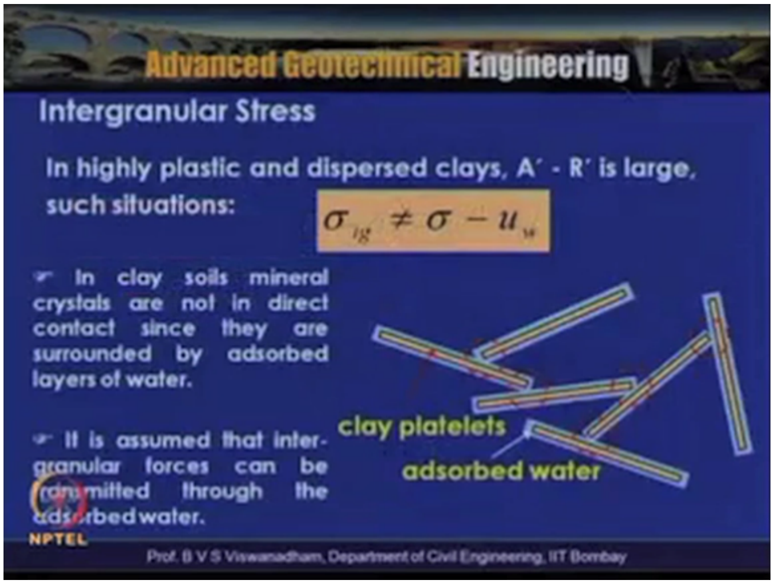

If you have highly plastic and dispersing clays then A'-R' is large such situations we cannot say that σ_{ig} that is intergranular R σ_{ig} which is nothing but the effective intergranular stress is not equal to σ-uw because here you clay soils inter crystals are not in direct contacts since they are surrounded by the absorbed water layers so here the plated particles are shown with the absorbed water layers surrounding the absorbed water layers are shown here.

And here this is the phase to edge attractive so phase to edge attraction you can see here edge to phase attraction of the clay plated shown here so this type of configuration here in clay soils mineral crystals are not in direct contact and since they are actually several by the absorbed layers so it is assumed that the intergranular forces can be transmitted through the absorbed water layers so intergranular soils are assumed to be transferred though the absorbed water surrounding the clays plated particles.

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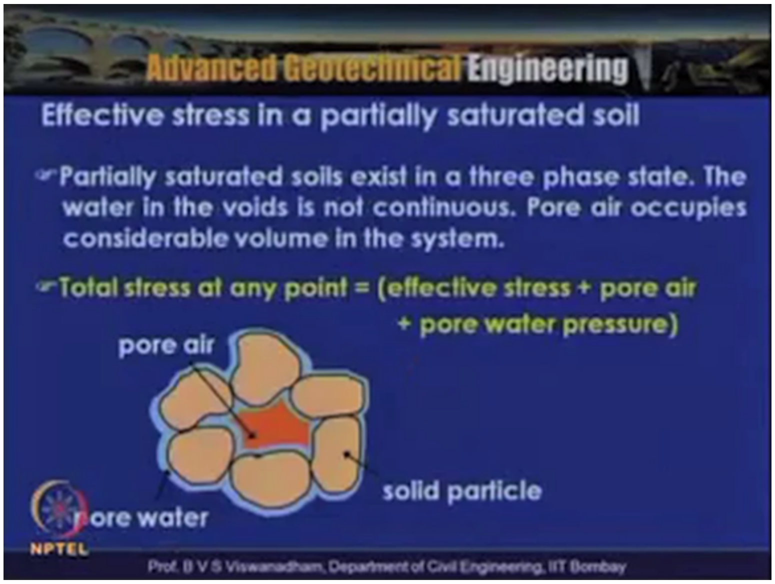

So we have seen that the concept of effective stress is valuable for the saturated soils nowadays lot of working actually happenings on unsaturated soils so the effective stress in a partially saturated soil can be define like this will partially saturated soils they are basically three pause straight the water in the voids is not continuous and pore air occupies considerable volume in the system.

So here you have water and pore air within this so in the pore space you have got the pore air as well as pore water so here without two components one is air and other one is the water became the voids so these re the solid particles and this is the pore water which is actually shown here so total stress at any point is nothing but effective stress+ pore air +pore water pressure so based on that discussion.

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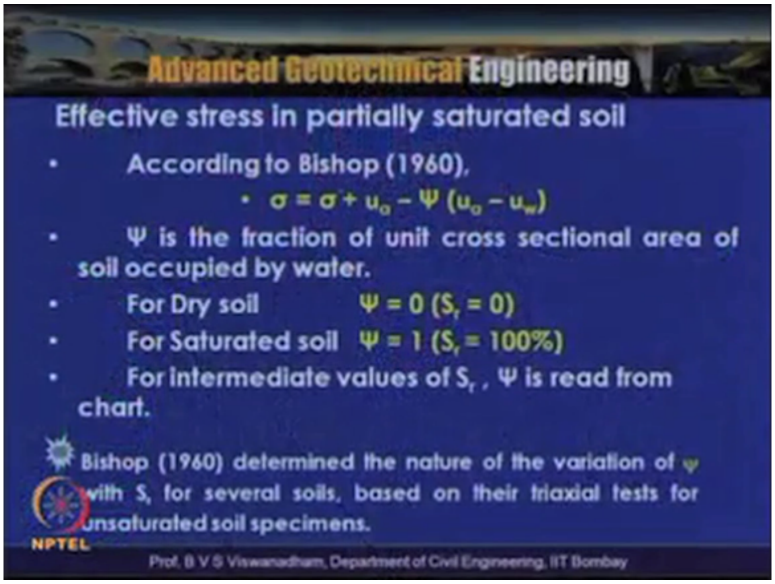

We can actually say according to bishop 1960 σ that is total stress is equal to σ'+ua-ψ(ua-uw) so ψ is the fraction of the unit cross sectional area of the soil occupied by water for dry soil degree of saturation is 0 the ψ=0 for saturated soil ψ=1 that is for the degree of saturation=100% so for intermediate values the for Sr ψ is actually red from the chart which is actually given by Bishop from the triaxial test from by conducting triaxial test the values of ψ that is the fraction of the cross sectional area of the soil are based on water.

So Bishop 1960 determined the nature of the variation of ψ with degree several degrees of saturation of several soils based on the triaxial test for the unsaturated soil specimens.

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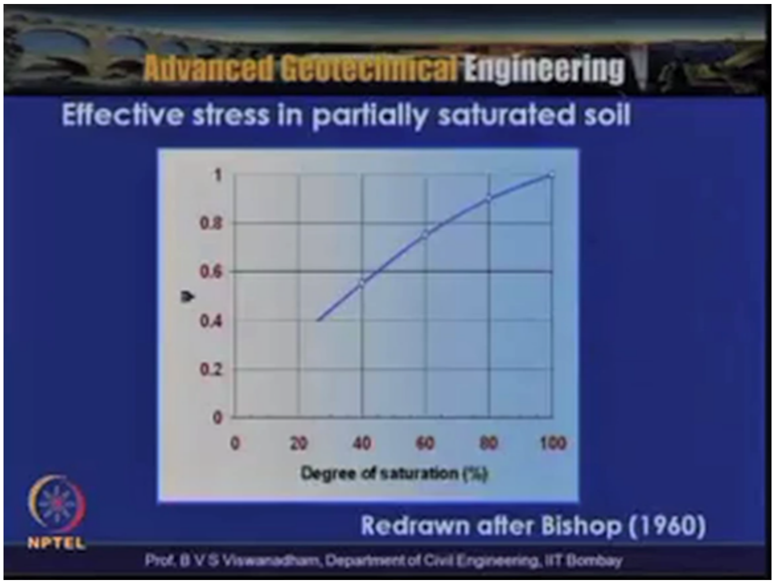

So in this slide this particular graph which actually gives variation of degree of saturtion this ψ so as can be seen is that with increasing degree of saturation the value of the ψ tends to become 1

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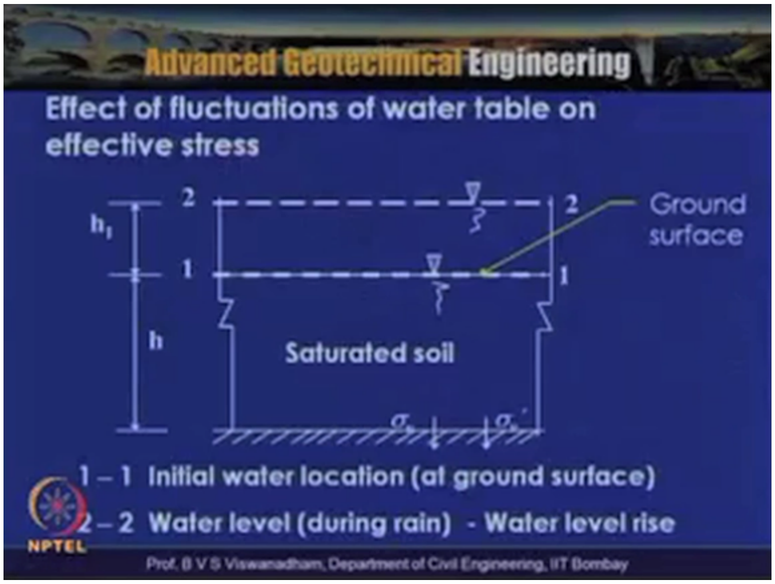

Effect of fluctuations of water table on the effective stress so here in this particular slide a soil which is actually shown here a saturated soil and the vertical stress at this point σv and this line that is at this point were z=h1+h that is at this point σv and σv' so we need to determine σv and σv' along this particular plane so 1, 1 is the initial water location at down surface and 2, 2 is the water level during say rain so water during by rain is water table from 1, 1 to 2, 2.

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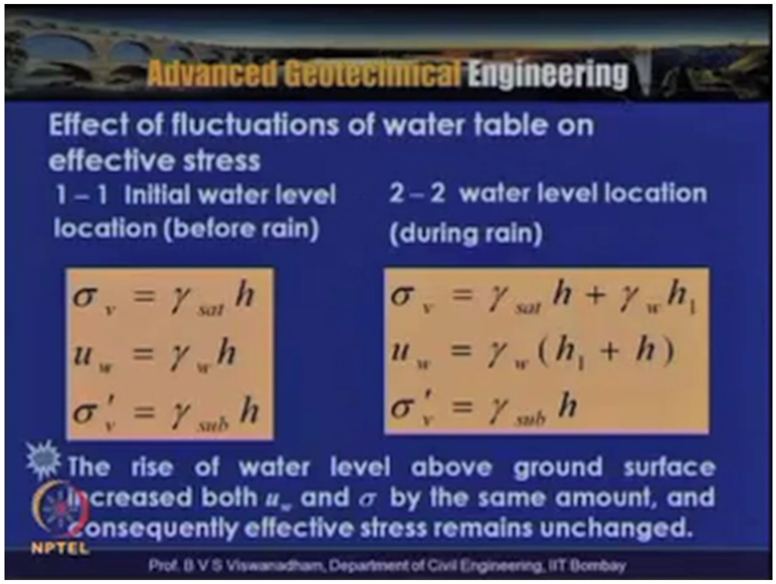

So if you consider situation t 1, 1 initial water level location before rain so σv we can give as γ st*h uw is nothing but γwh so effective stress is nothing but γ' h 2,2 water level location during rain σv=γ sat h+ σw h1 with that uw=γw*h1+h so we can say that σv' rain =γ'h so the rise of water level above ground surface increased both u_w and σ by the same amount what you can see.

I that the rise of water level above ground surface increased the u_w that is water pressure in the soil and σ by the same mount and consequently the effective stress is the remaining unchanged so heads with water level is say 2 meter above ground surface or 100 meter above 5 kilo meter above the change in effective stress in saturated soil mass will not be there.

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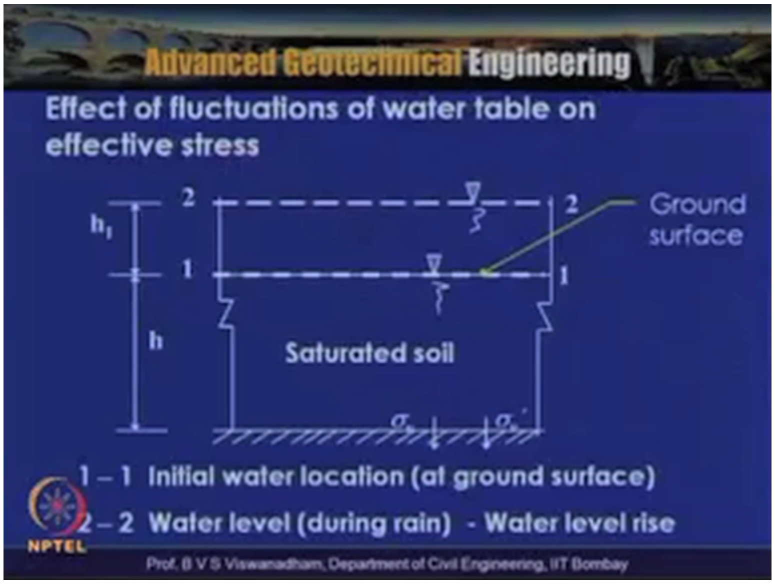

Now here the ground surface which is actually shown here a water table is at the ground surface and 2, 2 is the awter level after rain so there si the depletion of water table so we need to determine water at vertical stresses total stresses and effective streseess at this point

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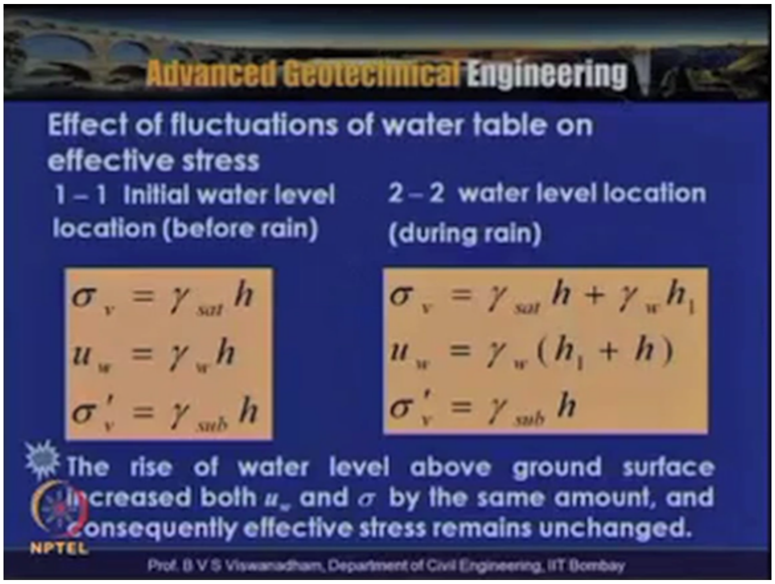

So case 1 again initial water level before rain so as we have don we have got σv'=γ'h or γ sub h in 2,2 water level after location σv= γdh1+γsat(h-h1) so with that u=uw=γw(h-h1) well you have got here σv' is now more than γ'h so decrease the water table causes the increase in the effective stress, so any change in the water level within the ground, within the soil surface causes the increasing the effective stress.

So could we do sudden depletion of water table let us say that if there is an exploration or there is a sudden depletion of water table it cooling to the increase of the effective stress, if the increase in the effective stress is nothing but the increasing the inter granular stress and could let to the high increase in the contact stresses and this met to the crushing of the grains, and consequently this results in the settlement of the and joining structures infinity a course of exploration. So this is the summary what we have actually discuss with a shift in water table.

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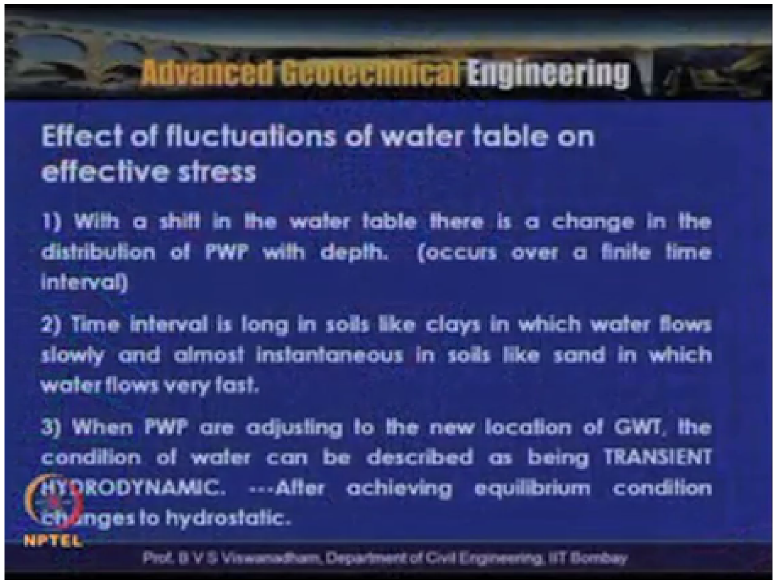

There is a change in the distribution of PWP with depth and the time interval is long in soils like clays in which water flows slowly and almost instantaneous in soils like sand in which water level very fast. So when pore water pressure are adjusting to the new location of ground water table the condition of water can be described as they transient hydrodynamic phenomenon and after achieving equilibrium condition it changes to the hydrostatic conditions.

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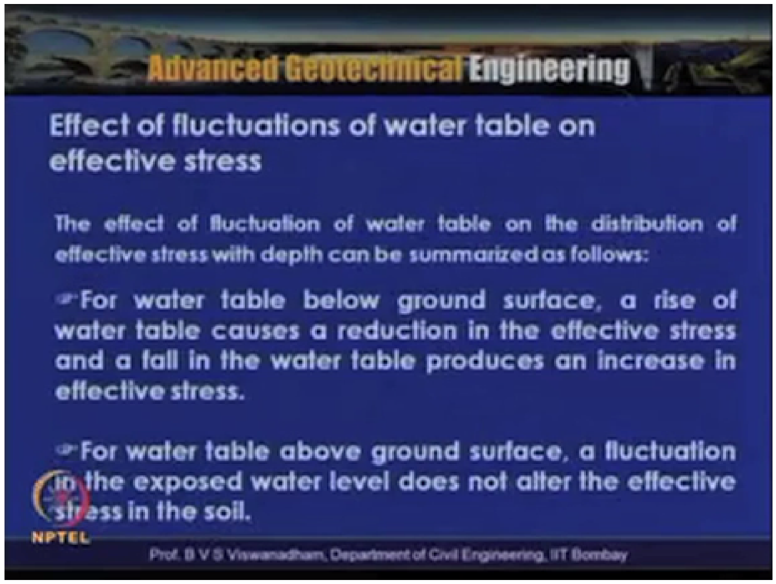

The effect of the fluctuation of water table on the distribution of effective stress with depth can be summarized further as follows for water table below the ground surface here is a water table causes a reduction effective stress and falling water table produces and increases the effective stress, so if there is a reason water table then it causes a reduction effective stress and if fall in the water table produces an increase in the effective stress.

So water table above the ground surface fluctuation exposed a water level does not alter the effective stress in the soil that is what we have actually discuss in previous slides. So during monsoon the ground water table is known to rise and hence effective stresses reduces so does illustrate.

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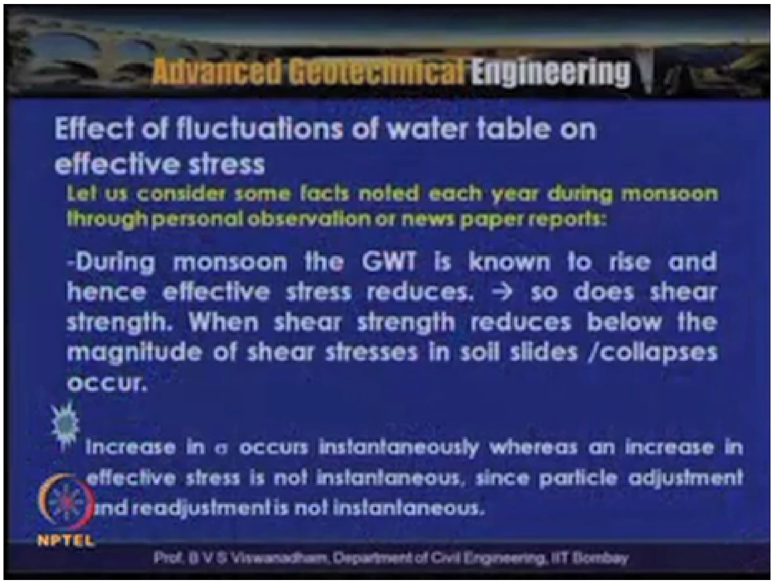

So in the effective stress reduces when there is a volume changes when take place in the soil sample so thus the shear strength also reduces when shear strength reduces below the magnitude of shear stresses in soil then slides and collapse take occurs, so increase in σ occurs instantaneously whereas the increase in effective stress is not instantaneous since particle adjustment and readjustment is not instanteous.

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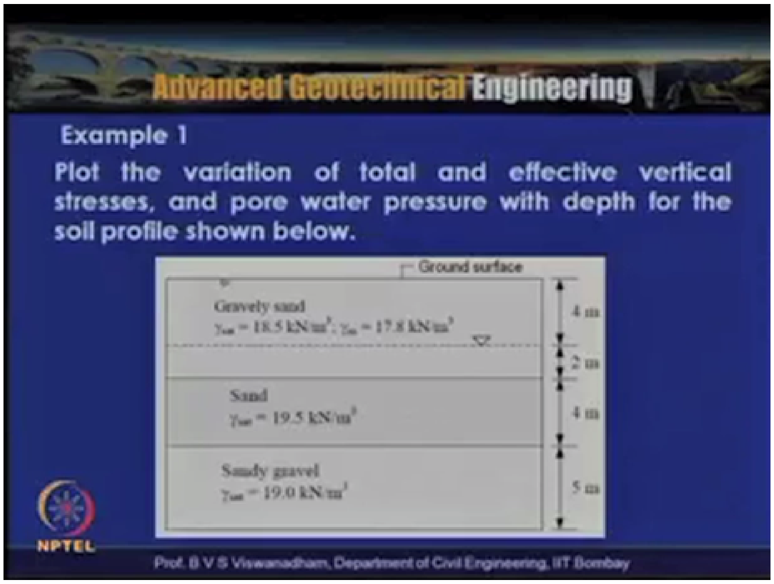

So let us after based on the discussion what are all we had let us look into the this particular example one, so here a soil data which is actually shown in the slide where is about gravel is sand γsat is 18.5 kN/m^3 γm is 17. that is γm is nothing but the γbulk is 17.8 kN/m^3 and this depth is 4m and this depth below the water table is 2m up to the top surface of the sand layer, sand layer γst is 19.5 kN/m^3.

Sandy gravel γsat=19.0 kN/m^3 and the depth is 5m, so we have a data of 5+4 9, 9+6, 15 m so we need to plot the variation of the start to stress effective and vertical, effective vertical stresses and pore water pressure with the depth for the soil profile shown below, so here what we have is that if you take the γsat here then what we can actually plot this the plot which is actually shown here.

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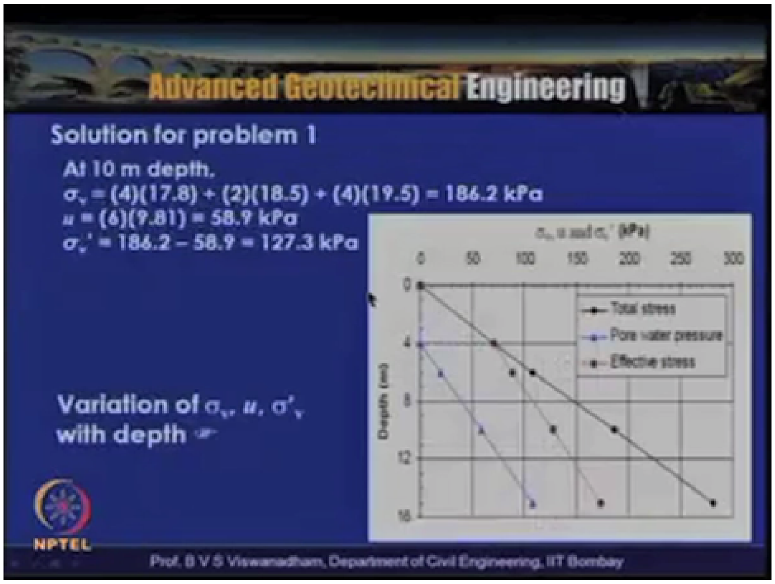

Let us see here this particular variation shows the total test here. So you can see that this is a point let us say a point 10m that is here we need to find out. So here what we use is that σv is nothing but the 4 x 17.8, 17.8 point is nothing but the bulk unit rate of the soil because here it is partially saturated below the water tables same layers it is saturated so we need to take this one.

So here what we do is that 4x 17.8 + 2 x 18.5 that is the saturated portion, so now we have come to the water table, so water table is at this particular location. So 4 x 19.5 that is another layer, so with that we can actually find out the stress here 186.2kp. U that is water pressure here it is 0 and then water tables from 4 meters so it is 0 here and this point at 10 meters because of this 6m that is 10 – 4 6 x 9.81 which is nothing but 58.9 Pascal.

This – this you are actually having this is the profile for the this is how the variation of the effective stress would did that for the given problem is shown here and this is the variation of the water pressure with determine 0 here and it actually starts like this.

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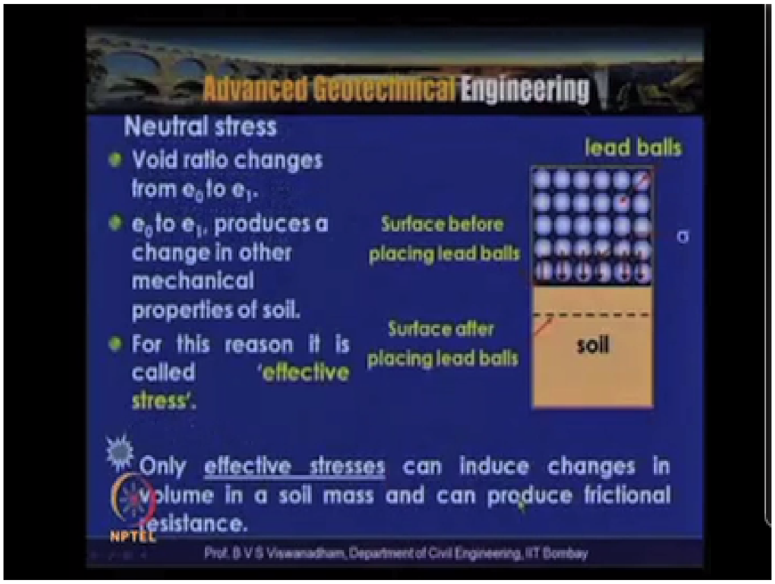

So then one more interesting issue we should understand is that the pour water pressure is also called as neutral stress. Why you know this can be demonstrated through a simple instruction here. Let us assume that you have got a soil having certain thickness and it is loaded with lead balls. And if that actually induces the change in void ratio from e0 to e1 the void ratio changes are reduces from e0 to e1.

So e0 to e1 produces the change in another mechanical property of this soil so for this region it is actually called as a filter stress. Here only the effective stress can induce changes in the volume of the soil and can produce resistance. So here σ which is this is the location, this is the level before placing the lead balls. And this is the surface after facing the lead balls that means the Δe is nothing but the Δh that is the change in you thickness over certain edge.

So Δe which is nothing but the change in the void ratio and there is reduction in the volume also.

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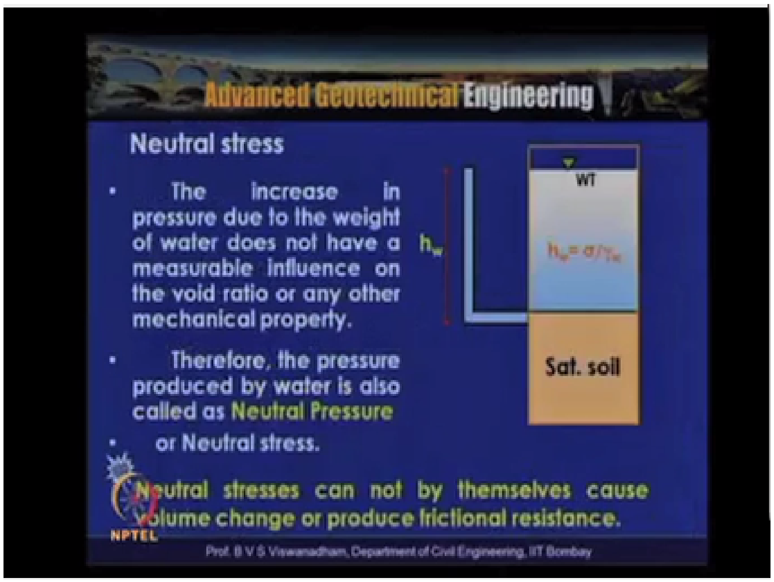

So the increase in pour pressure due to the weight of the water does not have let us assume that now same σ we have replaced with you know having σ/γw so we have maintained hw water, the pressure is = that of the σ which we have induced in the previous slide. So the increase in pressure due to the weight of the water does not have a measurable influence on the wide ratio or any other mechanical property. So here this the provision of this will not change in the effective stress.

Therefore the pressure produces the water is called as neutral pressure, it cannot themselves cause volume change or produce any frictional resistances that are the reason why because on it is own it cannot actually produce any changes and the neutral stresses cannot themselves cause any volume change. When volume change is not there and they cannot produce any frictional resistances.

So increase in the pressure due to the weight in the water does not have the influence on the void ratio or any other mechanical property.

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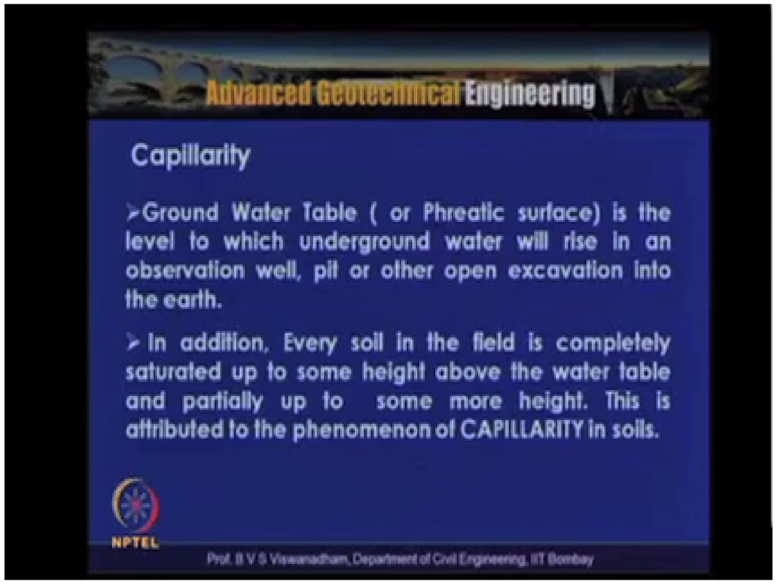

Now this capillarity which is a extension to whatever we have discussed and the reason for understanding capillarity gaining interest in many problems. Particularly in the issues contaminate migration and other issues in the ground water. So the ground water table or the phreatic surface is which they underground water will raise, in a observation well pit or other open expression into the earth.

In addition every soil in the field is completely saturated up to some height above the water table and partially up to some more height, this is attributed to the phenomenon of capillarity in soils, so capillarity is the phenomenal which is actually caused by interaction between soil solids air and water interactions.

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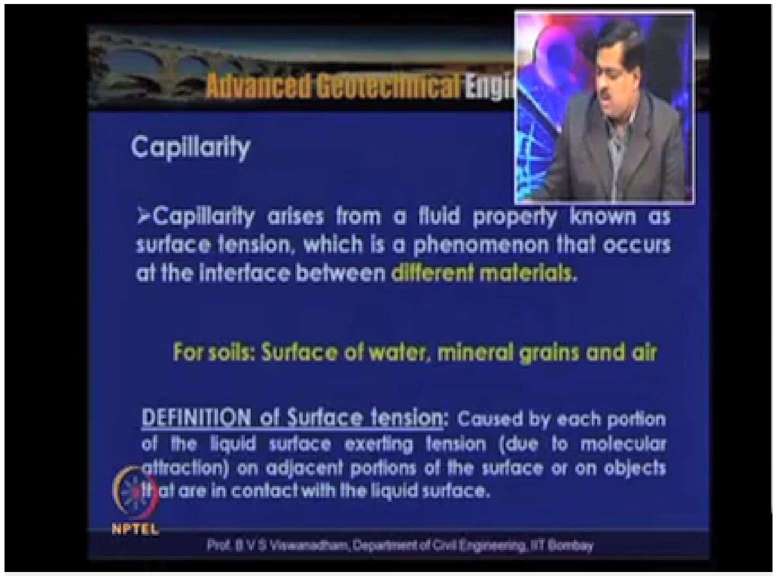

So capillarity arises from a fluid property known as surface junction which is phenomenon that occurs at the interface between different materials, so capillarity arises from a fluid property known as surface junction which is phenomenon that occurs at the interface between different materials, so for soils the surface of the water and the mineral earth. So here the capillarity the surface tension phenomenon.

Basically takes place because of the surface of the water mineral grains and air that is the resulting because of capillarity resulting because of interaction between surface of water mineral grains and air. So here the diffraction of surface tension is given for the interest to the students caused by each course of the liquid surface, expecting tension due to molecular attraction on or the objects that re in contact with the liquid surface.

So here we have got a you know this capillarity phenomenon causes few issues one is the capillarity rise there is the rise of the water above the ground water table then the rate of the rise of water that is the capillarity time and velocity with which it raises that is called capillarity velocity. The phenomenon which the water rises above the ground water table against the pull of gravity but it is in the contact with the water table as it is source is refers to as capillary rise.

So the phenomenon which the water rises above the ground water table against the pull of gravity but it is in the contact with the water table as it is source is refers to as capillary rise. So water is picked up into the pores of the soil in this zone on account of the surface tension of water.

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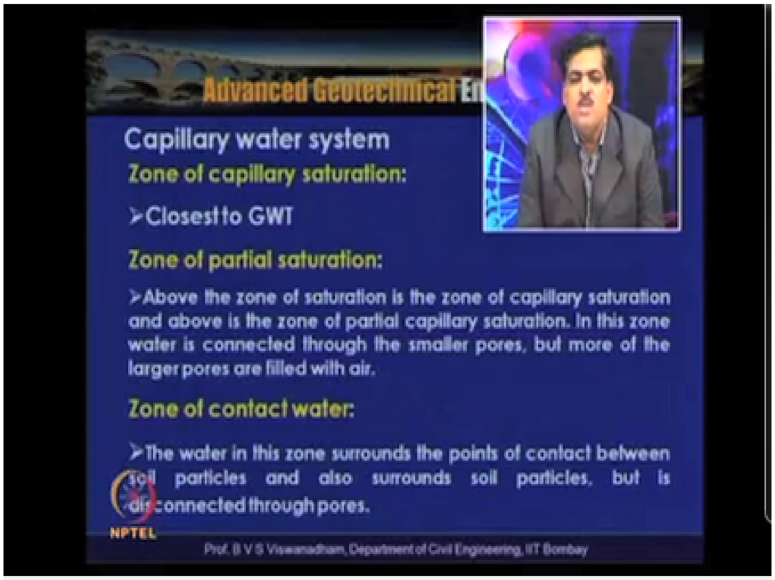

So we have in the capillarity water system the zone of the capillarity saturation close to the ground water table we can actually expect 100% and the zone also depends upon the types of the soil and zone of partial saturation which from where the capillary saturation it will be just above the zone of completely. And the above is the zone of the partially capillarity saturation. In this zone the water is connected through these smaller poles.

But more of the larger poles are filed with the air, so here there is the possibility that interfaces the air entry takes place and zone of contact water , this is the water that the zones surrounds that points of the contact between the soil particles and also surround the soils particles. So we have 3 zones, 1 capillary saturation which completely statured and zone of partial saturation that is above capillary saturation. So here in this particular slide.

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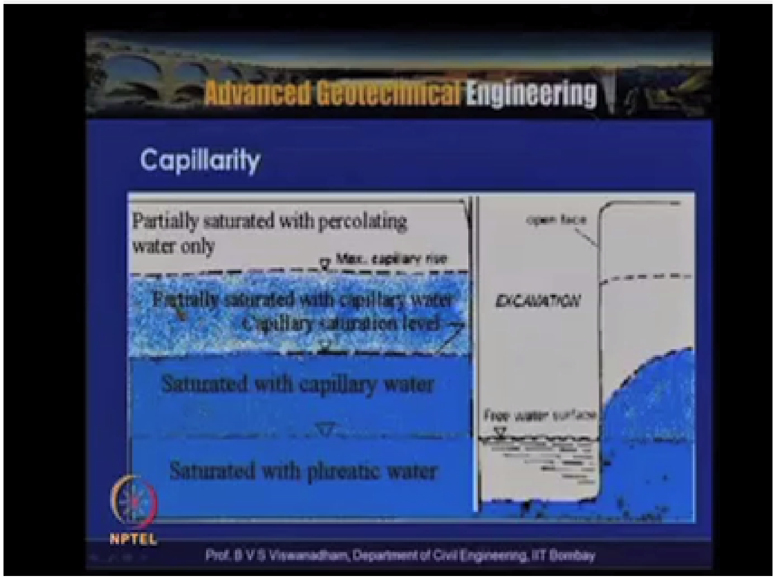

Suppose this is the ground water table this is saturated with phreatic water and hence this is saturated with capillary water and this is the partially, saturated zone with capillary water. So here there is the possibility that in case of the rain water can come. So this is partially saturated because of the peculating water and this is due to the capillary water but it is partially saturated and this is, so here the degree of saturation is 100% here.

Then the degree tends to reduce from 100 to 20% also because of you know the presence of the partially saturated that is because of the presence of air.

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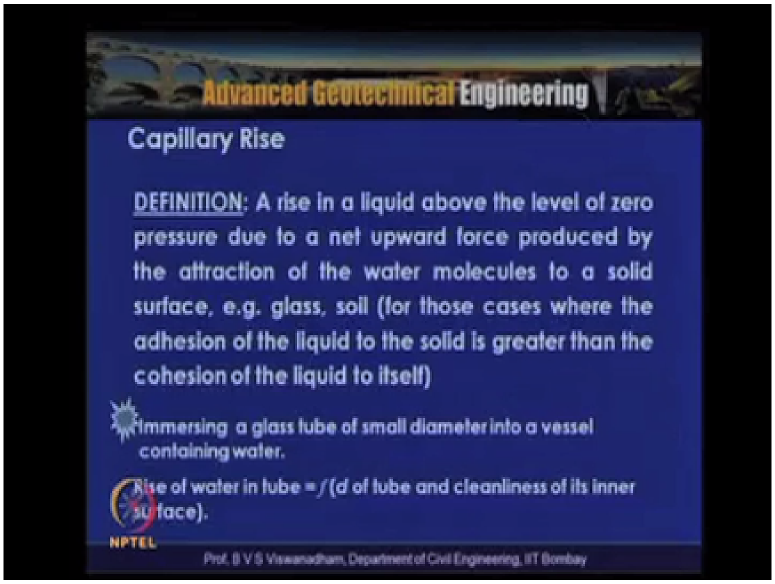

So capillary rise which is the definition a rise in a liquid above the level of zero pressure due to a net upward force produced by the attraction of the water molecules to a solid surface, e.g. glass , soil. If you visualize the all tubes as a length as glass tube or soil for those cases where it is greater than cohesion of the liquid to itself.

So immersing a glass tube in a small diameter a glass tube of small diameter into vessel containing water, you can actually say that the rise of the water in the tube is the function of the diameter of the tube. So here diameter of the tube is nothing but the pore diameter and also the cleanliness of is inner surface that is something like we have got soil solids which are not contaminated.

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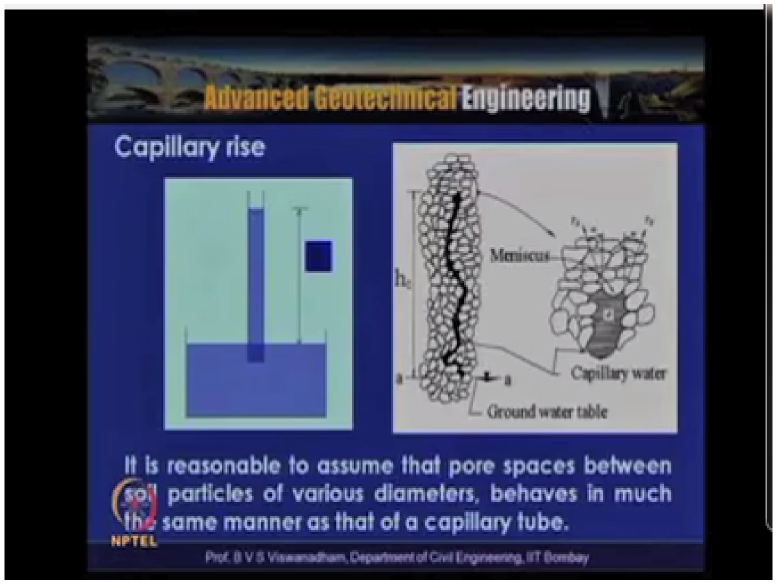

So in the capillary rise what we said this that is the phenomena where the water can rise in the zone of completely saturation above the grown water table so here this is the real you know the path of the capillary path and at this point what you can see is that these are the surface tension forces which are actually acting in pulling the water against the gravity. So this is idealized here and shows here the water table water against the gravity.

So it is reasonable to assume that the pore spaces between this soil particles of the various diameter behaves in much similar to, that is the tube of fine diameter so if you look into this we can calculate.

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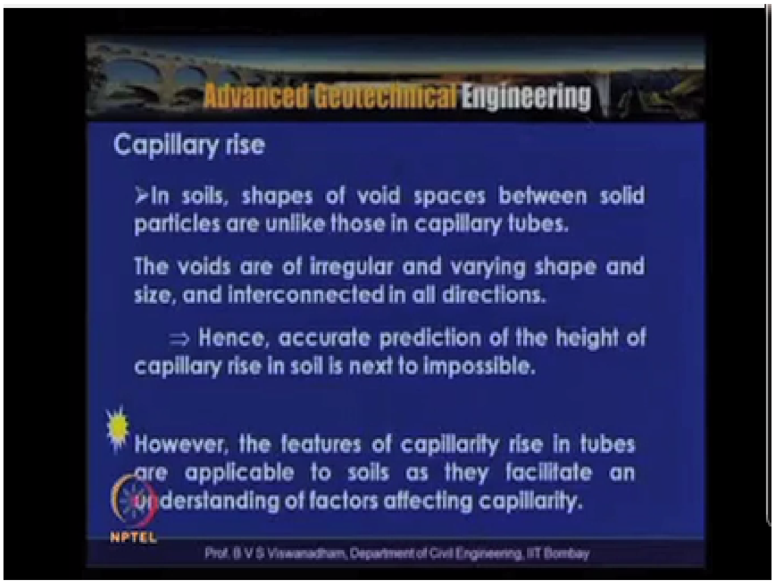

Capillary section which is nothing the section 4 with which the water is pulled again is the gravity, so here uc is nothing but force that is nothing but the surface tension force / area the pore area. So here uc = T the surface tension πd is the perimeter d is the diameter and cos α component. So uc is nothing but $4T\ \pi d/ \cos \alpha$. Uc is nothing but now$4T\ \pi d/ \cos \alpha$ for clean tubes $\alpha = 0$, or the interconnected voids whatever we are seeing here.

If they are non contaminated then we can take $\alpha = 0$, $4T\ \pi d/ \cos \alpha$, so you can see here the smaller the pore radius the larger is the capillarity sections. You can see here, uc is the capillarity sections > fine grain soils. Now we can also use this further to calculate the capillarity sections that is nothing but the rise of the water against the ground water table. So here the weight of the water is acting downwards.

The weight of the water is nothing $\pi d^2/4$ x hc if hc is zone of the complete saturation $\pi d^2/4$ x hc x γw which is nothing but the weight force, T x $\alpha = 0$, so cos α component is 0, cos α component is 1, so with that we can get T $\pi d^2/4$ x hc x γw with that hc = $\pi d^2/4$ x hc x γw d is nothing but the pore diameter. So you can see here now this capillary rise is also is appear to be higher, the soils which are actually having finer pores.

So now soils particularly the shape of the void spaces between the soil particles is unlike in those in the capillary tubes, voids are irregular and varying in shape and size in interconnected in all direction, hence accurate prediction height of the capillary rise in soil is next to impossible but this can be estimated or can be also be model. However the features of capillary rise in tubes are applicable to soils as this facilitate and understanding of factors effecting the capillarity.

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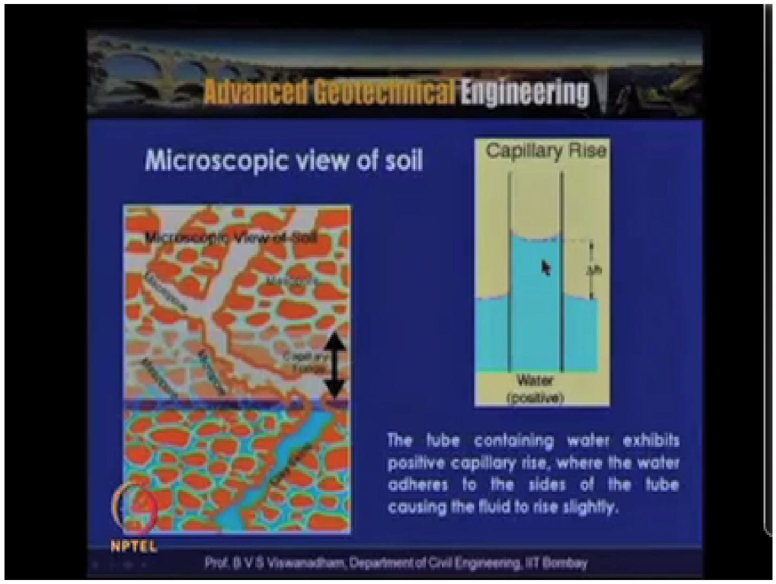

So here the microscopic view of the soil is shown and here this is ground water table and this is the capillary rise so the tube containing water exhibits positive capillary rise, where as the water adhere sides of the tube causing the fluid to rise slightly above.

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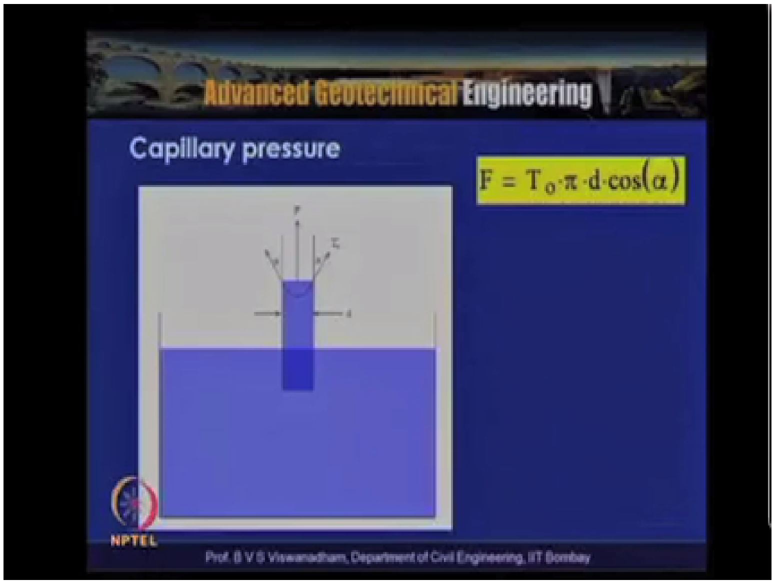

So this is an already we have discussed the capillary pressure or capillary section, so this show we have obtained like f=t0.t or t0 is nothing but the surface tension of water and πdcosα and uc=2f/a so thus that is actually given as πdcosα/fd^2 and this is now uc=4tcosα.d and with α=0 it becomes 2 4t/d.

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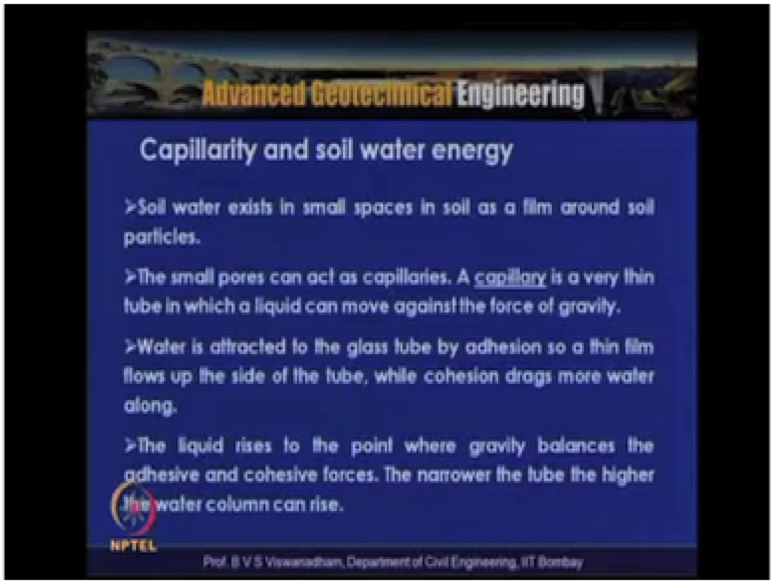

So capillarity and soil water energy if you look into this the soil water exist in small spaces in soil as film around the soil particles the smaller pore can act as capillaries a capillary is a very thin tube in which a liquid can move against the force of gravity so water is attached to the glass tube by the adhesion so a thin film flows up the soil slide of the tube so while cohesion drags more water along.

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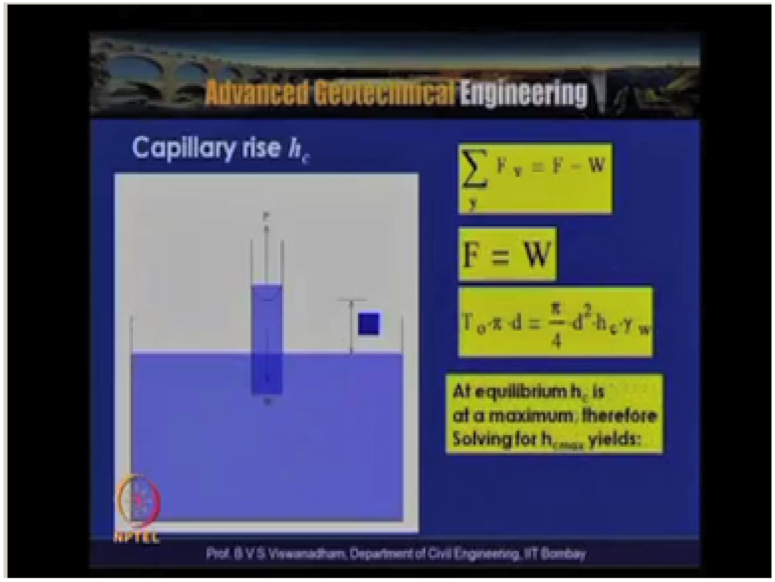

So the capillary raise is discussed here which is the thing but the vertical equilibrium of at equilibrium we have equated this surface tension forces with the weight of water which is been lifted against the gravity so at equilibrium hc is the maximum so that is actually nothing but which is given as 4td/γw now we have actually seen the expression for capillary rise now we also have two issues one is that capillary velocity and other one is the time of capillary rise this discussion can be obtained like this considering here.

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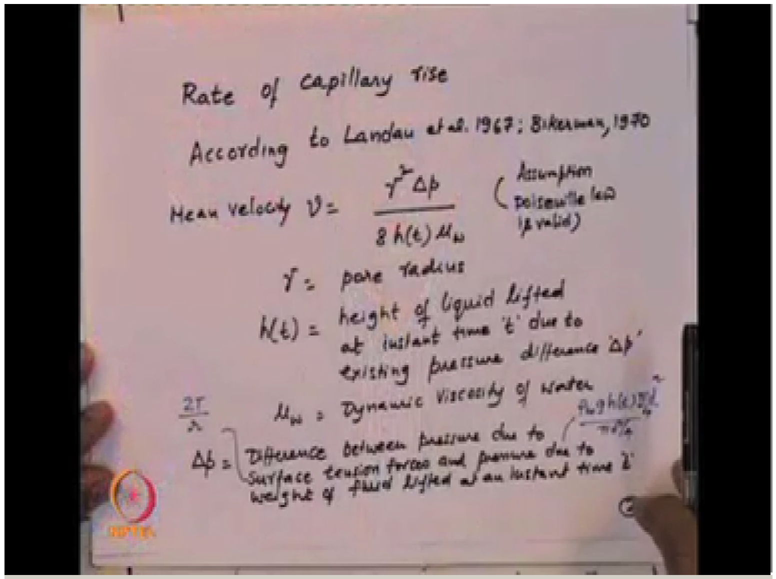

In order to reduce the rate of capillary raise according to landau at all 1967 biker man 1970 the mean velocity with the assumption that position law is valid we can write v mean velocity which is nothing but the velocity with which the raise of water is taking place above the goal water table $v=r^2\Delta p/8ht\mu w$ so r is nothing but the pore radius ht is the height of the liquid or fluid lifted at any instance of time due to existing pressure difference Δp so Δp is nothing but the pressure difference between the surface tension pressure it is difference between the surface tension pressure and weight pressure, weight pressure is nothing.

But the weight of water is column of water being lifted against the gravity so μw is nothing but the dynamic viscosity of the water or the fluid so Δp is difference between the pressure due to surface tension forces and pressure due to the weight of the fluid lifted at an instant of time so ht is the height of fluid from the at any time t if suppose here if this is maximum hc and ht is nothing but anytime t the raise of water within the some soils the capillary raise rate of raise is very, very slow so in that case ht is nothing.

But the rate of rise of water above the ht is nothing but the height of rise of water at a instant of time t so Δp is nothing but the difference between the pressure j2 surface tension forces which is nothing but we have derived that is 2t/r or 4t/d for clean shoots and weight pressure that is pressure due to the weight of water which is nothing but $\sigma wg.ht$ that is nothing but the and this is nothing.

But the weight of water in the column that is the weight of water in the column here divided by the pore area pore area is nothing but the d is the diameter so d is the diameter means here what we have is that $\pi d^2/4$ so with that $\Delta p=$ we can actually say that it is the pressure difference between the surface tension forces and the weight pressure due to the weight of water so further we can deduce this expression using

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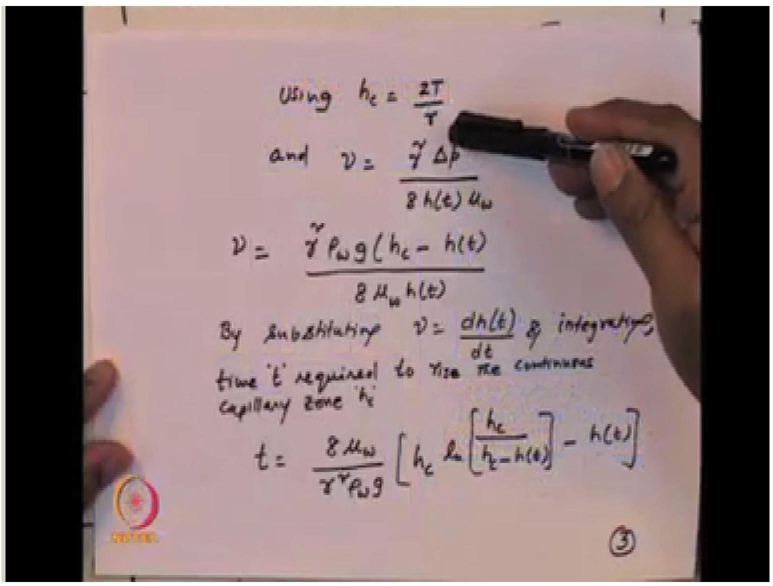

$hc = 2t/r$ we are substituted that hc is $2t/r$ and using $v=r^2\Delta p.8ht\mu w$ so substituting here and writing in case of $2t/r$ for surface tension forces so for Δb I am substituting here $r^2.\varrho wg.hc-ht$ so this is nothing but the expression for this is nothing but the expression for Δp this is actually substituted for Δp in the derivation here by $8\mu wht$ now by substituting $v=dht/dt$ and integrating now the time required to raise the contusions capillary joule hc is obtained like this by substituting $v=dht/dt$ and integrating the time t required to raise the continues capillary is given like this $t=8\mu w/r^2\varrho wg$ and hc.lnhc/hc-ht.ht.

So here also you can see these smaller the pore size the smaller the pore size the larger the time which is actually takes from the capillary rise the rate of rise will be smaller so t is actually here $8\mu w/r^2\rho wg.hc$ ln.hc/ht-ht so here we have the expression for the rate of the raise of the due to rate of water due to capillarity this further has given by using with help of dark law by assuming that dark line valued for the phenomena of the capillarity in principle we knew that capillarity phenomena is not a flow situation.

Because if you consider this as the data if you consider this as the data and if you take this as if you take here if this is the data the pressure here is 0 and elevation here is 0 so the total head is equal =0 here now let us assume that from the data the elevation of this point is hc units and the pressure here is –hc so pressure here total head is here is –hc+hc which is equal to 0 but so the capillary phenomenon is not a flow situation is a phenomenon which is actually resulting due to interaction between soil water and a interaction so but here the derivation

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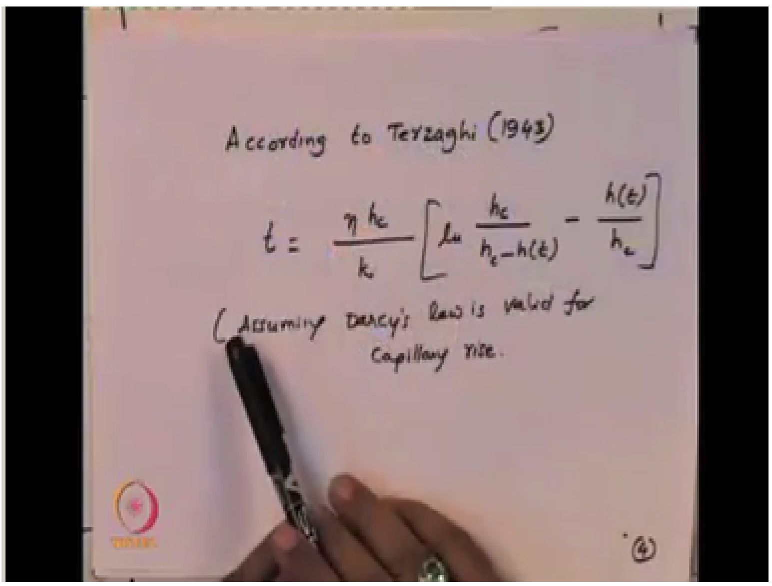

Which is actually obtained from the rate of time required for the rate of capillarity based on the assumption that decries law is valid for capillarity which is given by t=n is nothing but the approximate jc/k ln.hc/hc-ht-ht/hc so this is an expression for determining so here also in the previous expression whatever we have seen we notice that the lower the value of larger the time it takes for erase of water.

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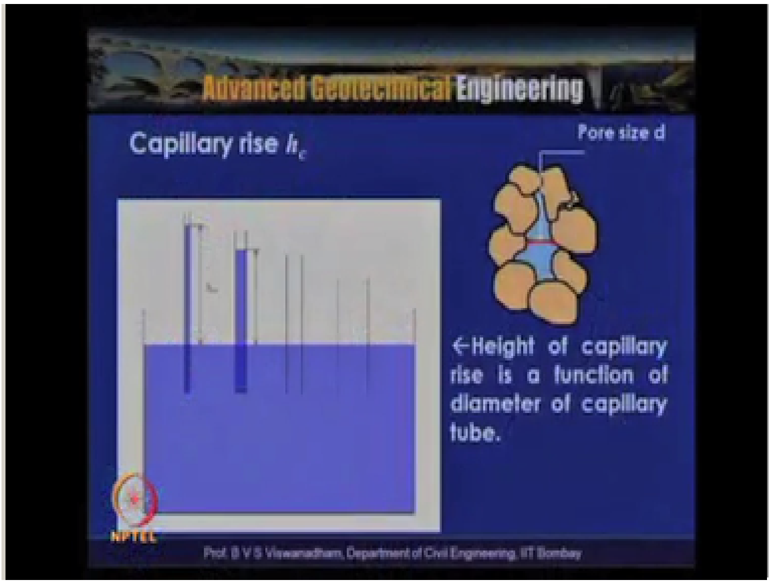

So here in this particular slide a demonstration which is actually given here that if you see here larger the pore spaces the raise of water will be less that is what we have discussed larger the pore spaces for examples sandy soils the raise of capillarity raise of water due to capillarity will be close to 0 so height of the capillarity capillary raise is a function of diameter of capillary tube.

So that is what is actually shown here and one more interesting thing is that the pore diameter is approximated as $1/5^{th}$ of the effective particle size that is the 20% of the particles size is approximated as so if you a fine gain soil the pore spaces are very fine if you take a core line soil if it is having a detail is equal to 0.55 mm then it is around 0.1 mm.

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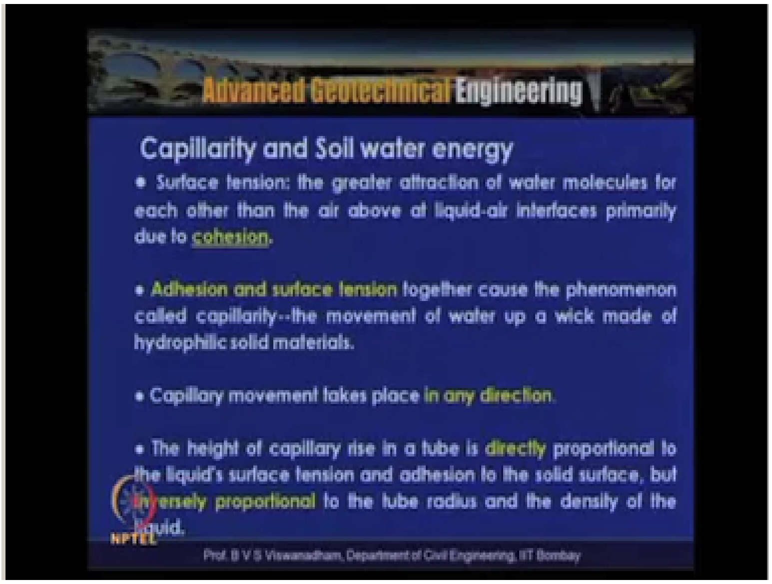

So if you look into the capillary raise what we have discussed is that $hc=4t\cos\alpha\gamma wd$ so this is an approximation for soils if you take $t=0.0074$ kilo in per meter and $\gamma= 9.81$ kilometer cube and $\alpha=o$ with d is equal ed10 we can write this expression as 30/ed10 when d10 is weight x so which is nothing but the capillary raise is given by c/ed10 and this estimate may be improved to allow for the effect of the grading gain characteristics such as irregularity and flakiness etc so hc that is capillary complete zone of saturation is nothing but the c constant by ed10.

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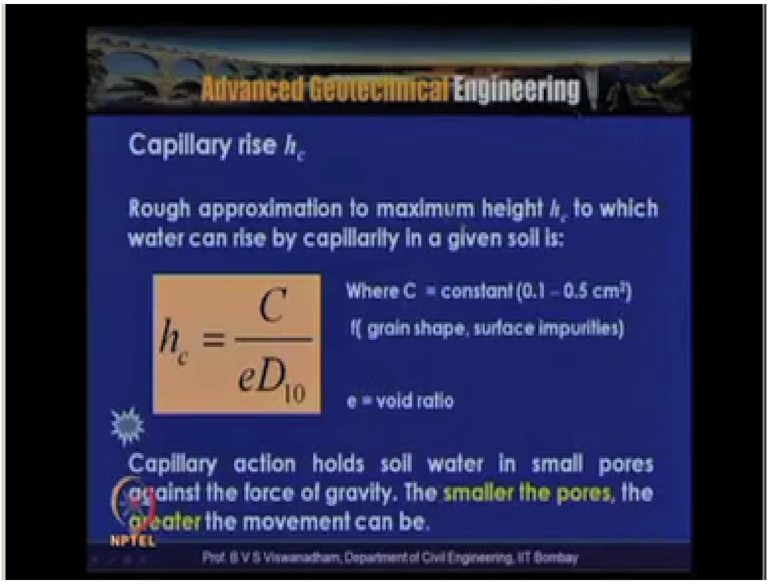

Further c is nothing but the constant which is 0.1 to 0.5 to centimeter square is function of the grain shape and the surface impurities and e is the void ratio so capillarity action holds the soil water in small pores against the force of gravity the smaller the pores the greater is the moment can be.

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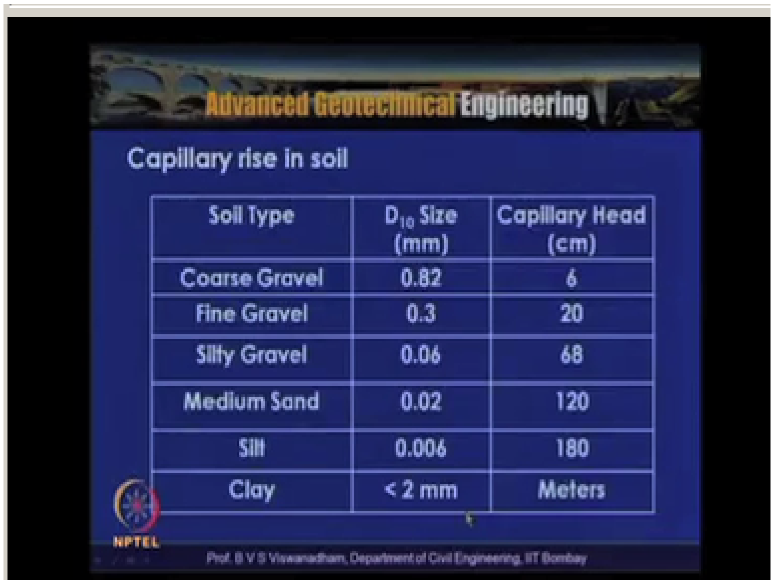

Soil Type	D_{10} Size (mm)	Capillary Head (cm)
Coarse Gravel	0.82	6
Fine Gravel	0.3	20
Silty Gravel	0.06	68
Medium Sand	0.02	120
Silt	0.006	180
Clay	< 2 mm	Meters

So here in this slide the capillarity rise in soil for different soils is shown and here different effective particle sizes are shown and here the capillarity height are shown here so you can see that for soil which is actually having less than 2 microns the clay which is actually having 0.002mm size the height will be several meters height of rise of water above the ground water level is several meters for soil is about 1.8meters and for coarse gravel it can be just of 6 centimeters.

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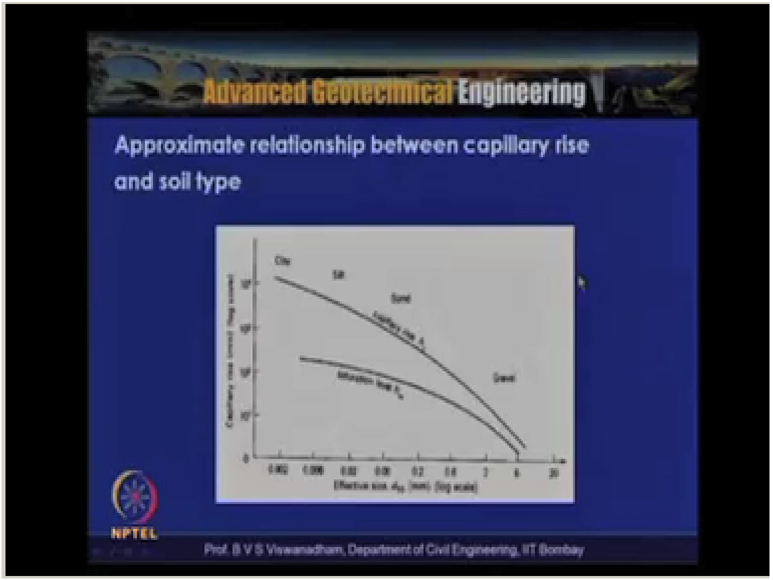

So here this particular whatever we have discussed in shown through a slide here this is the saturated level and this is the complete capillary rise including the partially saturation we can see that as you can see for increasing the size effective particles size there is the decrease in the height of the capillarity.

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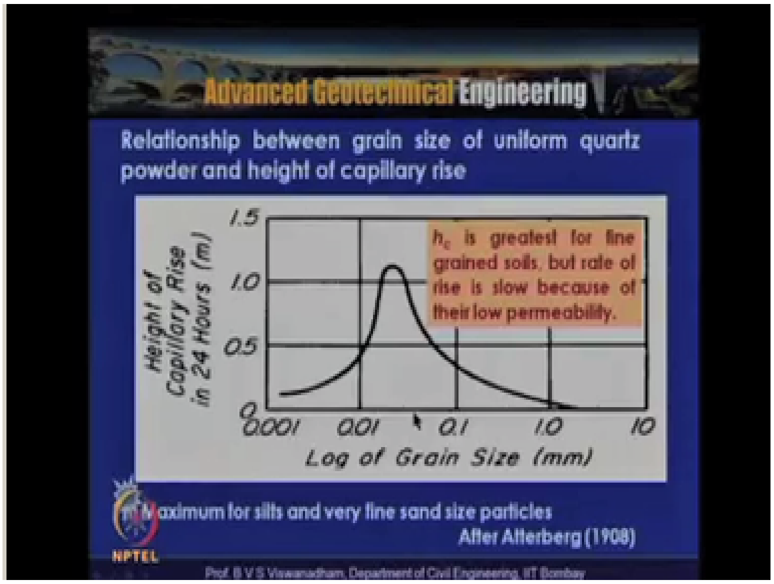

And as we discussed here they relationship between the grain size of uniform quad powder and height of the capillary rise so hc is greater for the fine gain soils but the rate of rise is slow because of the low preambilty from the discussion also we have seen that the maximum for slits and very fine grain soil particles.

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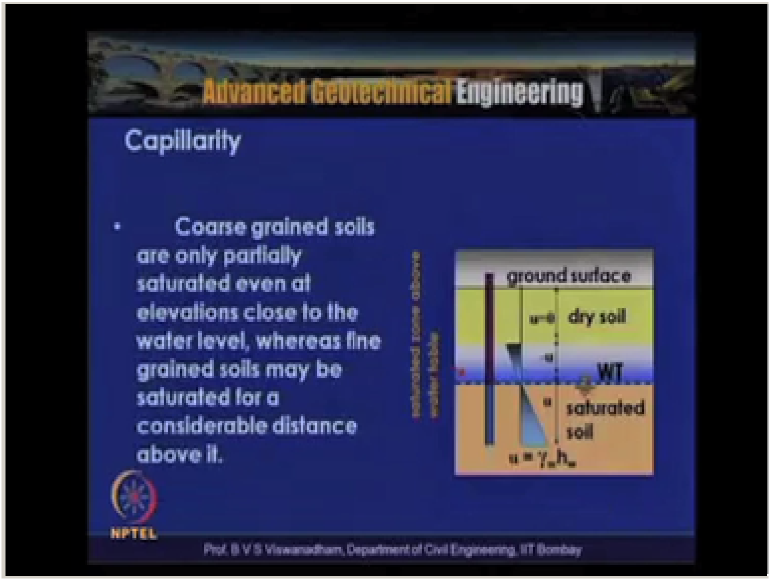

The capillarity particularly for course gain soils if you wanted to estimate then you have got a situation here for dry soil it will be 0 and here you have got a negative for water pressure will be there because of the phenomenon of the cold water table the capillarity phenomenon.

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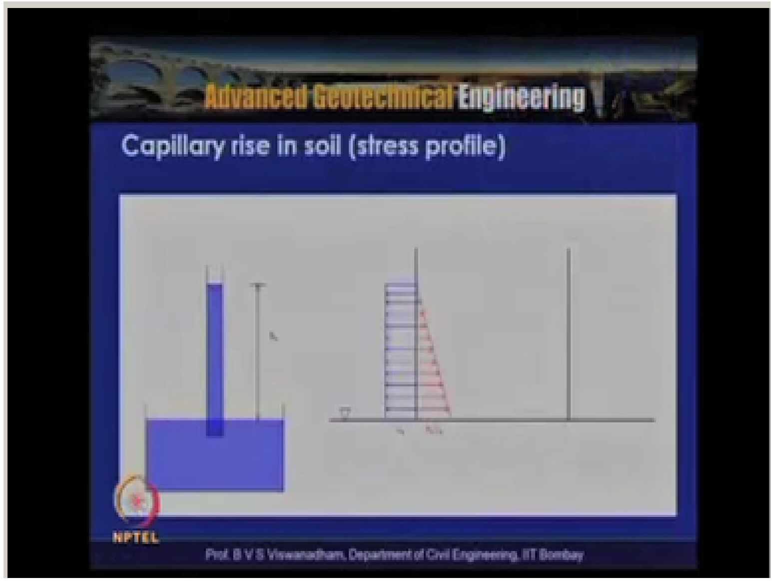

So this is how the capillarity rise stress profile is drawn.

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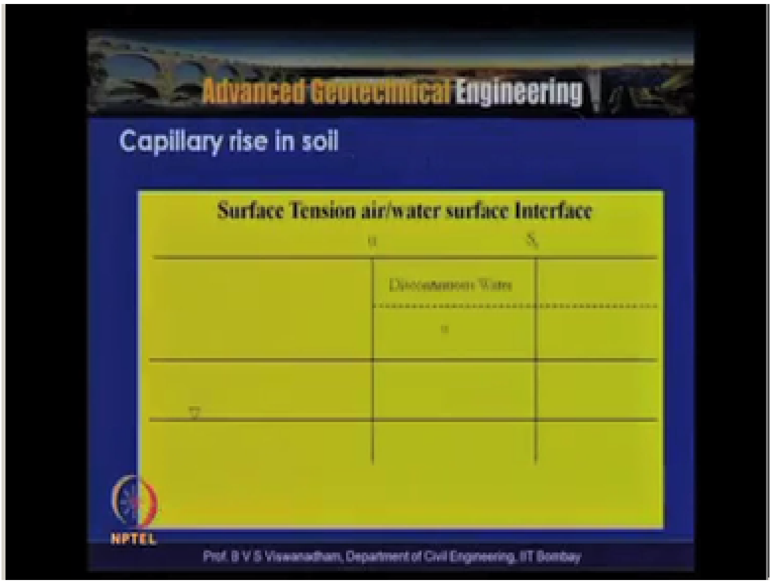

But if you look into the stress profile for

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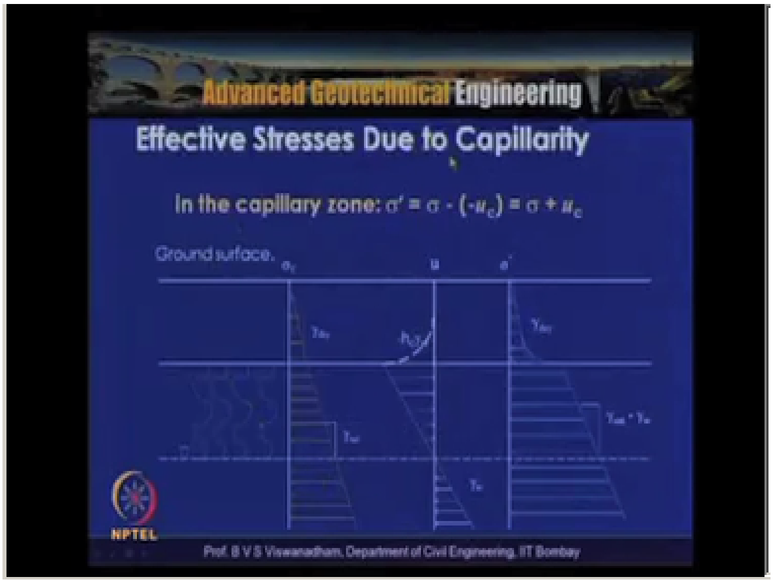

Effective stress due to capability so here you can see that these particular water pressure reduces to 0 because of the increase air at this zone so here this is the ratio will be effective stress will be like this and then this particular variation will be like this so this is particular because of the end of the zone of the completely saturation shown and this is nothing but the capillary which are actually called so this is for total stress and this is for the day two for the water pressure in the zone of the capillarity and then about this reduces to degree of saturation from here to here reduces to from 100% t0 20%.

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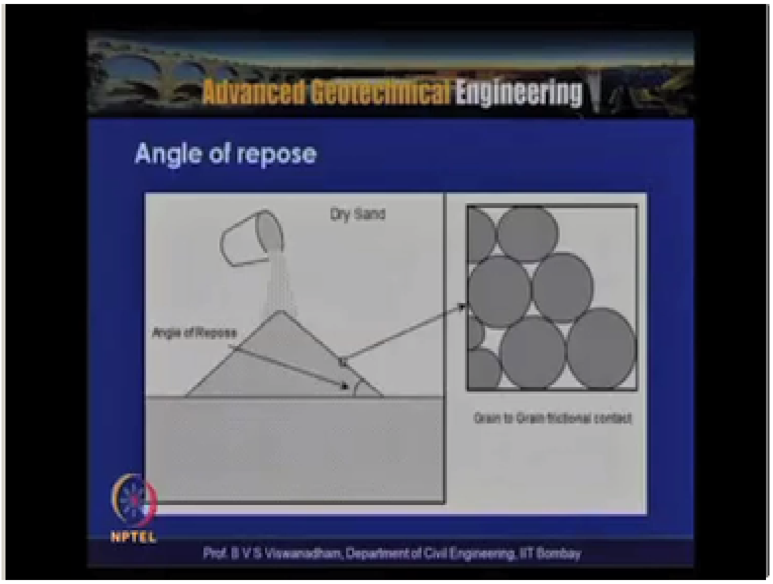

So further you know many interesting phenomenon can be with the importance of the capillarity particularly like when you have got if you got a phenomena like near the beaches or we have got with the you got the soil which is with the less amount of moisture the capillarity phenomena can be explained in length so what we have understood in this particular lecture is that the concept of the effect stress can be introduced and we also have reduced to the expression for the height of capillary rise and the last capillary velocity.

And time required capillary rise then we have discussed with that the fine gain soil which is actually having very, very small force the time for the rise for the rise of capillarity may take long time but if so this particular phenomena can be advanced used particularly for construction particularly if you have got the ground where if you constructing on a soft soil.

Then if you prevent the interest of the water into the feel there is the possible that we can actually use the course gain materials to as it cut off so nowadays with adventure of new materials in civil engineering you also have materials like non joule synthetics which also they can be used as capillary cut off layers.

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NPTEL
Principal Investigator
IIT Bombay

Prof. R. K. Shevgaonkar
Prof. A. N. Chandorkar

Head CDEEP
Prof. V.M. Gadre

Producer
Arun Kalwankar

Project Manager
Sangeeta Shrivastava

Online Editor/ Digital Video Editor
Tushar Deshpande

Digital Video Cameraman
Amin Shaikh

Jr. Technical Assistant
Vijay Kedare

Project Attendant
Ravi Paswan
Vinayak Raut