Soil Mechanics/Geotechnical Engineering I
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Lecture - 18
Effective stress

Good morning. Once again I will come you to this soil mechanics courses, and we have completed a few topics and now you are going start a very important topics, that is effective stress concept and because this is actually now will be applicable in everywhere, whatever when you go for strength, when you go for compressibility, and when you go for earth pressure, everywhere that effective stress, is a very important topic or important term to be used throughout soil mechanics course.

So, one has to understand this effective stress calculation, because there are many application, this initial part will be calculation of effective stress. And so, we have to learn the concept, how to find out effective stress?; Because the effective stress can be can vary place to place, time to time, because of the variation of soil variation of water table variation of flow condition. So, we will show one by one those things.

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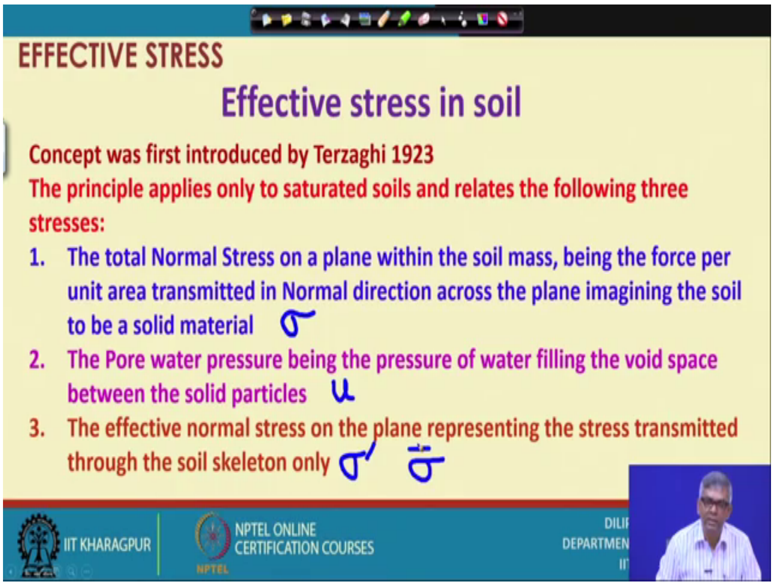

So, first this is a effective stress concept, actually whatever given in the Terzaghi, given by Terzaghi 1923 and this effective stress concept, applies only to saturated soil and relates three important components, and they are actually one is total normal stress on a plane, within the soil mass being the force per unit area, transmitted in normal direction across the plane imagining the soil to be a solid material.

So, like if a block, there and if I apply a force P that then if it is a solid one, then in generally we can find out what is the stress, at any point that we generally do P by A. So, that is the one normal stress that is 1st one, one total normal stress generally we will tell that, we will use the term total normal stress now onwards. So, that is nothing but P by A, if the a cross sectional area of the soil, through which force is applied, then the total stress is a normal stress is P by A and then, the second one is pore water pressure, the pore water pressure being the pressure of water, filling all the void space spaces between the soil particles.

So, I will show in the next slide, that is how the soil particles are together and make the soil mass and what are the voids, between the particles and then this when saturated condition, then those void spaces will be filled up with water, and that water definitely based on the water table location, we can find out what is the pressure, in the pore water pressure the hydrostatic pressure acting through in that soil grain.

That is one, generally we use this as a sigma, if I take this as a sigma and these we use as U and effective normal stress this is a concept actually, on the plane representing the stress transmitted through the soil skeleton only; that means, we will see the soil skeleton, there will be number of contacts and this force will be transmitted, through the contact only. So, that is what the effective normal stress on the plane, the same plane where you have imagine, but the stress transmitted through the soil skeleton only. So, I will show to the next slide, the mechanism. So, generally we use sometimes this is effective stress, either by sigma dash and sometimes it is sigma bar.

So, these are the things terminology, that is sigma is the total stress total normal stress is that is which is, P by A or if it is a (Refer Slide Time: 04:50) of soil, how to find out sigma? That we will discuss subsequently, and pore pressure is that is actually U; that means, with the soil range, that is the void spaces. The void spaces in saturated will filled up with water and pressure will depends on, at what depth actually it is there. If the water table it the water table, it depends on the height of the water table and the effective normal stress is another thing actually relates this sigma then, how it is relating? That we will see in the subsequent slides.

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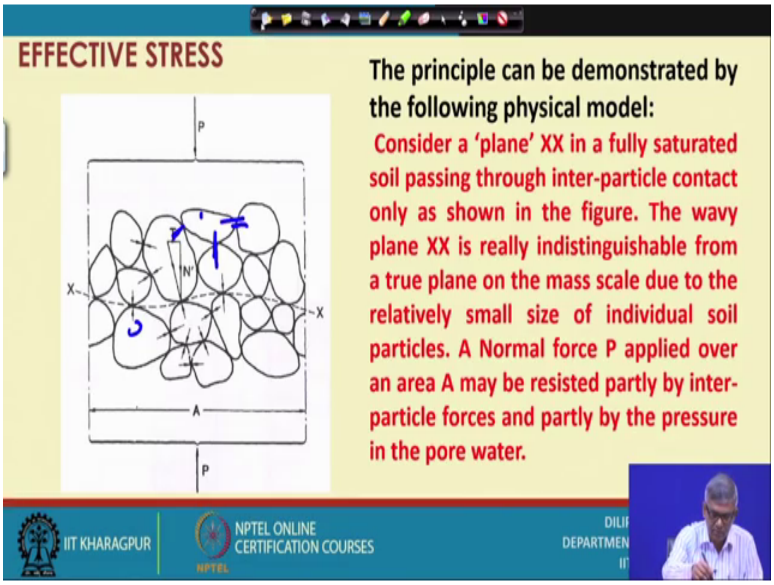

So, this is actually, if I see if I see in the soil mass and in the very large view, if you think of then you will see these are actually, these are all soil grains these are all soil grains and they have the number of contacts, between the soil grain and the remaining portion between the contacts of particles, this portion is voids, these are voids, these are voids and these voids will be saturated condition, will be with filled up in the water and otherwise it will be filled up with air.

Now, we can imagine a plane actually, XX and through the contact points and see the grains are very small, with the enlarge view it looks like a wavy, but it is generally (Refer Slide Time: 06:20) in a in a actual grain. If you draw it looks like a horizontal line and when you draw this line, it will pass through a number of contacts points, like this is one contact point, this is a another contact point, this is another contact point, this is another contact point like that.

So, this whatever force if you are applying, the this force is some giving here and these particles will be giving something here, something here, something here and when this will transfer here, this will also be equal and opposite reaction. So, like that at the at this is the plane, you can imagine the number of contacts and each contact point, there are the number of forces acting, those forces actually we can imagine you can now you can divide in to take a two components, one is in the perfectly vertical direction see like that one I have shown here this is normal and that is tangential.

So, two directions so, like that if there are N number of contacts. So, N number of normal force will be there and they are random in direction, the direction is not known depending upon this, the orientation of or position of the particles. So, their directions are generally not known and then, but we can take now two components, one is vertical or horizontal, then the components in horizontal direction you can summit to get the horizontal component pressure, or force and we can add the vertical component, all components then we will get the net vertical force. So, like that we get. So, after getting this so, we can see how this can be used for, developing the effective stress concept.

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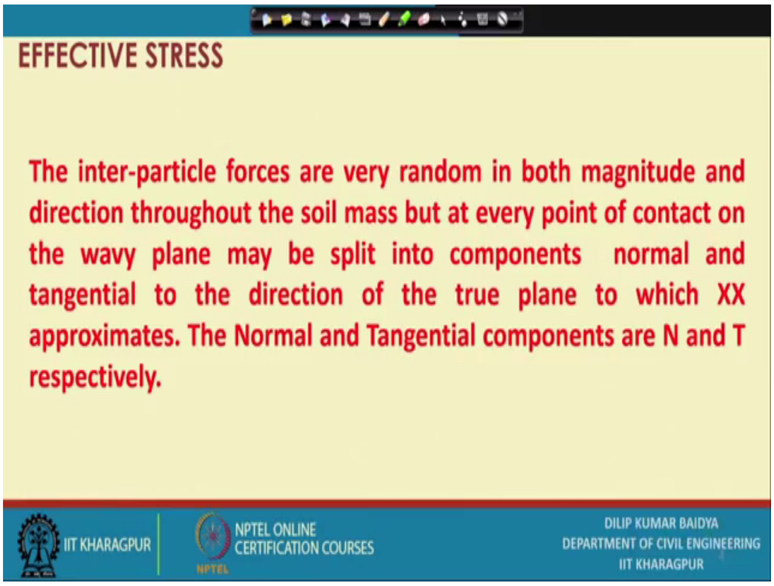

Now, the inter particle forces are very random, in both magnitude and direction throughout the soil mass, but at every point of contact on the wavy plane, may be split into components normal and tangential to the direction of the true plane to which XX approximates. The normal and tangential components are N and T suppose, N dash is the normal force at the contact points and if I take a component then suppose that is N and T.

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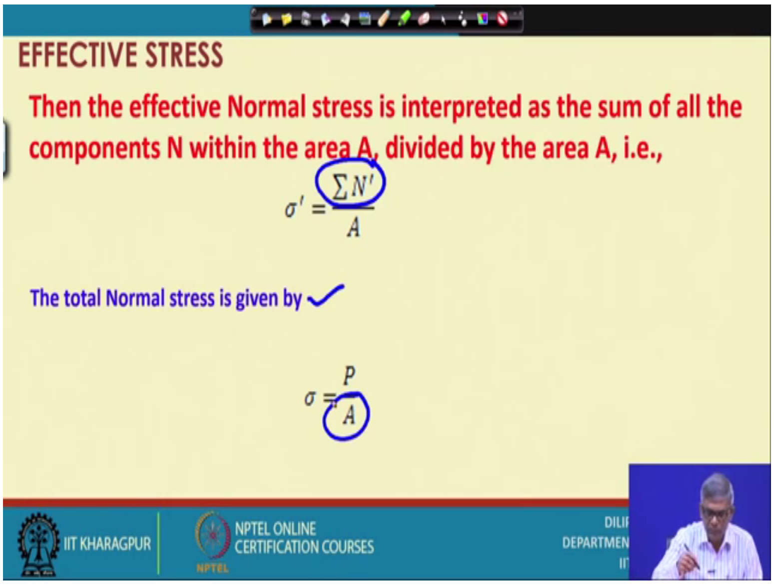

And finally, we can take that, as per definition that effective normal stress is the interpreted as the sum of all the components N, within the area A. So, within the cross section or whatever number of contacts are there, that contacts points whatever normal force is there, their particle component will be taken, and then summed it up like this sigma N dash we can do, and divide by this cross-sectional area.

So, that is the actual by definition is the effective stress. So, this is the definition of the; that means, through soil skeleton whatever force transmitted, that divided by the actual cross section area is the effective stress. So, this is the by definition and total normal stress, as we have defined that sigma will be force P applied over cross sectional area A. So, that is actually by definition as total stress sigma.

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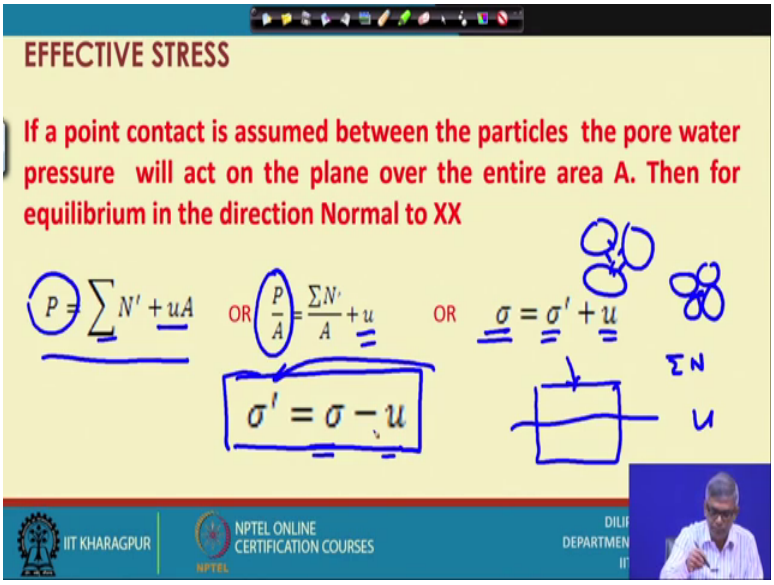

And now, if I consider A that plane XX where you have calculated considered, that place if you consider particle equilibrium; that means, all particle summation of particle forces, will be equal to 0 or applied force will be equal to the resisting force. So, like that I can use then I will get this equations. So, this is the force P applied externally and that that is like you have applied here, and P and we have taken the section here and through inter particle forces, suppose sigma N is there and then those void spaces there is a suppose pressure, water pressure is acting is u.

Suppose there is a two voids, or sometimes voids are like that, in this there is a pressure that is suppose u then u, I have taken a cross sectional area. So, over the entire cross sectional area u is acting suppose, because u is changing with the head water head. So, since we are at a particle head, we are considering u is constant, over the entire length and then or entire area. So, u multiplied by area will also give you the, this is actually u is the pressure that pore water pressure multiplied by the cross-sectional area, will give you force and sigma N is also force the normal particle direction u also force in a particle direction.

So, this can be taken. So, u actually when there is u when there is a grains like this, when there is u acting u will be acting equally all directions. So, I am considering only vertical direction. So, u into A is force sigma N dash also force, these 2 together will be equated by the external force P, now if I divide by A to all, then we can see P by a sigma N dash by A plus u.

Now, this we have defined in the previous slide that it is nothing but nothing but, is sigma P by A and sigma N dash by A is nothing but sigma dash that is effective stress and u is nothing but pore water pressure u. So, this can be finally, our interest to find out the effective stress then, your effective stress it become sigma dash, will be equal to sigma total stress minus u that pore water pressure. So, total stress if you can calculate, and then if you subtract pore water pressure at a depth, then you will get the effective stress at that point.

So, this is the concept of effective stress. So, this is the formula or relationship, between u sigma dash and sigma and this will be applicable throughout the soil mechanics, and we have to learn very carefully this one, until and unless you calculate properly then other things will be also will not be able to do correctly.

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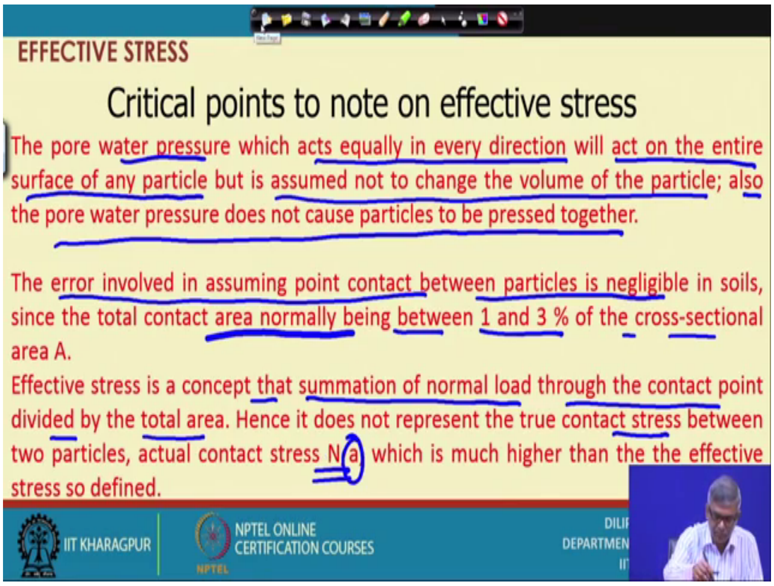

And now these, 2 3 points to be remembered that effective stress is a concept actually, and here number of things we have assumed, the pore water pressure is there, within which acts equally in every direction, will act on the entire surface of the particles. So, there is a particles, there are number of particles and very large number of particles, and compared to the number of particles and volume the contact is very, very less. So, if contact total contact area is very less. And so, because of that, that u is assuming to be applied to surface of any particles full, but is assumed not to change the volume of the particles.

So, when there is a pressure acting to particles from all direction, we are assuming that it is not causing any volume change, even when you apply pressure that is supposed to be the volume change, but in a static condition there an equilibrium, but they are not causing any volume change. So, that is the assumption, if we do not do this assumption, this cannot be developed. Also, the pore water pressure does not cause particles to be pressed together. So, there is because of this pressure, they are not forcing two particles to come closer or going away, in the static condition that is another assumption.

Now, the error involved in assuming point contact, between particles is negligible in soils mainly because, the total contact area normally being 1 to 3 percentages only, whatever the total area and if you find out the summation of the contacts points and if you take area, it comes only 1 to 3 percent. And so, whatever assumption, we have made based on this point contact. So, it will not give much error, similarly effective stress is a concept that is, what is the meaning of? That is summation of normal load through the contact points, divided by the total area. So, that is the effective stress.

So, summation of the normal component through the contact point, divided by the (Refer Slide Time: 15:36), hence it does not represent the true contact press stress; that means, when the 2 particles are in contact and between the contact, what is the stress? That is not really this one. This is actually is a concept; we are getting that divided by area. So, because of that whatever effective stress is getting, that intensity or magnitude is mass molar, then the actual contact stress, or actual contact stress what it will be? it will be N by A which will be much higher than the effective stress, whatever we have defined.

What is N? N is the total load and what is the small a? Small a is the actual contact area and which is actually, on the 3 to 4 percentage. So, you can imagine that actual contact stress, will be much higher than whatever, we have defined by effective stress and though we have defined the effective stress, as the force transmitted through the soil skeleton, but that is the only for consideration of force, but when you are considering area, we are taking entire area. So, that is the concept as a concept has to be used that is being used. So, that is the thing to be remembered.

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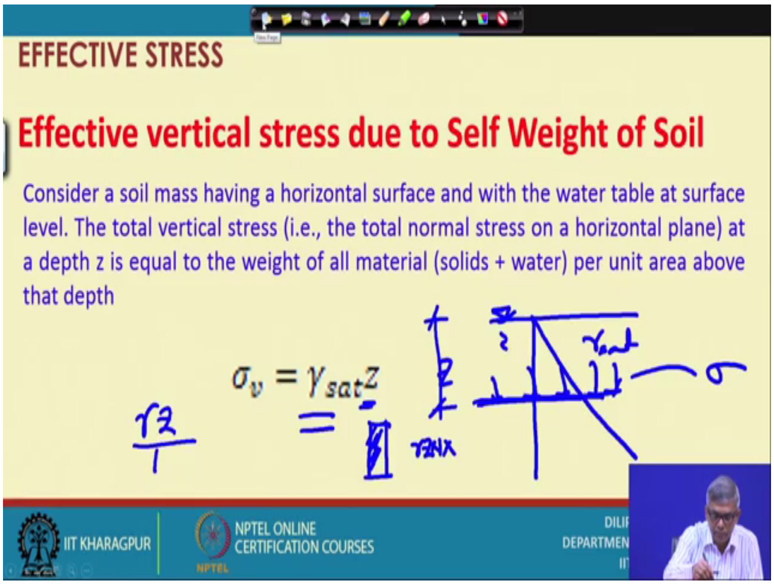

Now, as I have mentioned that, if you apply force how stress will be distributed, that will be come later, on we will discuss that when you force apply on the ground surface. how stress is developed within the soil mass? How it is distributed if you go deeper? How it will be changing all those things? We will see later on. But the sort of time being, when there is a soil and water only in mass and because of sale poet, what is the stress?

So, consider a soil mass, having a horizontal surface and with water table at surface level so; that means, we can take a something like this, the total particle stress that is the total normal stress on a horizontal plane. So, suppose the soil mass is extending here and I just draw a line here, and what is the total stress acting, at this level I will have to access. So, for that what we have to this is the total; that means, because of this soil above this level, how much pressure is giving at this level? So, that is the thing to be, that is the thing defined as sigma total stress.

At a depth just how this depth is this depth is suppose Z. So, at a depth Z I have imagined a plane and, on that plane, because of this self-weight of the soil whatever pressure is coming, that is actually total stress. So, and solid plus water per unit area above the depth. So, you know that because of this, if there is water table also here or whatever may be. So, water table also. So, suppose here then the unit weight to define here, as gamma saturated and then it is actually, if I take a soil column like this sorry.

Ah if I consider, a soil column as I have drawn before, we have done this at a depth Z and this is water table also here, this zone gamma will be gamma sat and I want to find out, because of this; what is the pressure at this that is nothing but sigma. Now, while doing this we have to do. So, if I consider a soil column of unit cross section area, this is unit cross section this a soil column if I do, then what is the weight of this soil column, this will be gamma into Z into 1 into, gamma Z into 1 and since unit ratio it will be gamma into Z ultimately.

So, total weight will be total weight will be gamma into Z only, and divided by again cross-sectional area 1 so, ultimately gamma Z it will be. So, since this unit weight is saturated. So, it will be gamma saturated into Z. So, with increase of the Z, the total stress also will be increased; that means, if I draw. So, it will be something like this. So, with the change of depth your sigma v is increasing.

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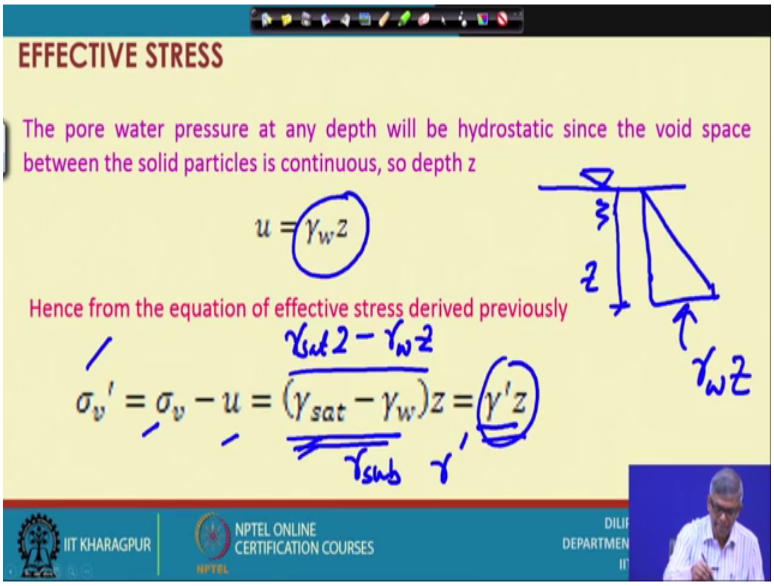

Now, the pore water pressure again I can think of, suppose this is the on the other and this is water table is here, and because water pressure hydrostatic pressure you know, it will be increasing with depth like this, and this will be how it will be, this will be gamma w times suppose if it is Z. So, gamma w is z. So, this is that u at any depth same depth, if you want to calculate that become gamma w times Z, because this is all fluid mechanism many places you do that, hydrostatic pressure at any depth.

And now, you have got by definition sigma dash, will be equal to sigma minus u and then you can see, that it is become gamma sat, actually it is gamma sat into Z minus gamma w into Z, this is the thing we have. Now, if I take Z out, then gamma sat minus gamma w and this gamma sat minus gamma w, we use another different term that is actually called gamma submerged, or sometimes it is called gamma point or sometime use gamma sub symbol, sometime gamma dash also you use.

So, that is the thing is given gamma dash into Z, means gamma submerged unit weight, gamma submerged into Z and gamma submerged is what? Actually, it is gamma saturated minus gamma w. So, this is the principle generally to be used for finding out the stress, because of the self-weight.

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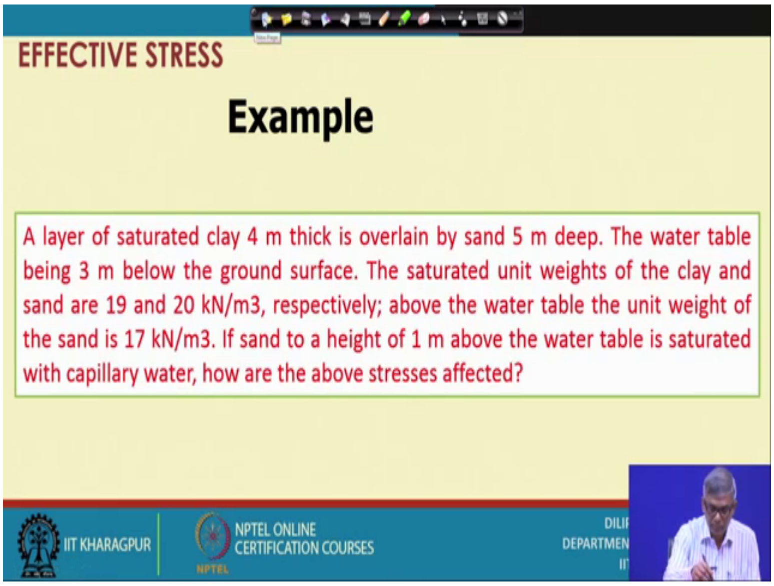

Now, suppose this is a problem a layer of saturated clay, 4-meter-thick is overlain by sand by sand 5-meter-deep, a layer of saturated clay 4-meter-thick is overlain by sand 5-meter-deep, The water table being 3 meter below the ground surface. The saturated unit weight of the clay and sand are 19 and 20 respectively; above the water table the above the water table, the unit weight of the sand is 17 kilo Newton per meter cube. And if sand to a height of 1 meter above the water table is saturated with capillary water, how are the above stress affected?

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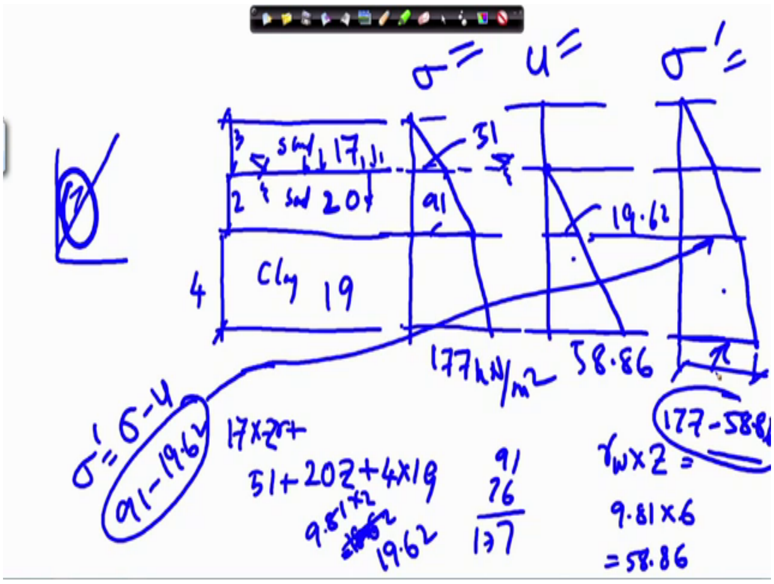

So, this part I can discuss later on, but other part we can do like there is a 5-meter sand saturated clay 4-meter-thick is overlain by sand 5-meter-deep, And the water table being 3 meter below the ground and. So, these are the things I will take, suppose you have this is 5-meter sand and this is 4-meter clay and water table 3 meter below this. So, you have to find out and this is unit weight is 17 and this one is 19 and 20.

So, I have to go back, we can see the saturated unit weight of the clay, and sand clay is 19 and sand is 20 sand is 20. So, this will be 20 and this will be 19, and this is 3 this is 2 and this is 4 and then, you have to find out the reason of stresses, what is the total stress? Total what is the pore water pressure?

And what is the. So, generally we will do this way we can take 3 divided 3 part for that sigma, and we can see up to this, it is this is sand this is also sand and this is suppose clay and then, this is actually it will be 0 here no depth soil so, no weight. So, 0 into 0 so, 0 and it will be increasing with depth that will be 17 into Z it will be increasing so, at this level. So, 3 into 17 (Refer Slide Time: 26:06) 51 and then.

So, at this level that much pressure already there, then because of this layer again, the further addition will be there. So, that will be gamma total; that means, 20 plus. So, that will be 51 plus 20 into Z, if I consider Z from here. So, if it is 2 meter. So, 20 into 240. So, at this level it will become it will become 91. So, this is 51 this is 91 and then again 4 into 19 plus 4 into 19. So, it will be.

So, 91 plus. So, 177 kilo Newton per meter square and then, you will be considering water table is here only. So, hydrostatic pressure will be 0 here; that means, atmospheric and then, it will be increasing over depth and it will become it will become, say gamma w is gamma w into Z. So, gamma w is the 9.81 into Z actually will be increasing. So, this will be 2 plus 4 6. So, 6 into 9.16 58.86. So, this is sigma and this is U then I will get now effective stress.

So, effective stresses in above water table, since a dry unit weight is used there will no change. So, this portion will be remain unchanged, and when you go beyond below the water table and then your sigma dash will be equal to sigma minus U, and this sigma minus u; that means, here this value will be there at this level 91 and at this level it is 9.81 into 2 so; that means, 2 18. 19.62 this is 19.62. So, this is 19.62. So, your 91 minus 19.62, this will be whatever value will be here. So, this value will be here and similarly, at this point you will have 177 this one will have 177 minus 58.86. So, whatever value comes that will be come at this point.

So, so; that means, this is the procedure and to be followed, while sometime in many places that strengthen or the axis versus stress, when you can calculate will do in this direction ok. Stress is going this direction and, but we generally not familiar with that type of thing, always ground surface to be taken as 0 and when you are going downward, that with the increase pressure.

So, we will be doing this direction only it is not in the reverse direction, it always in this direction and it will be shown, diagram sigma diagram u diagram and the sigma dash diagram. So, these 3 diagrams should be side by side. So, that I will get this and then get this, once you get this and this, then this minus this become this. So, that is the way one has to complete.

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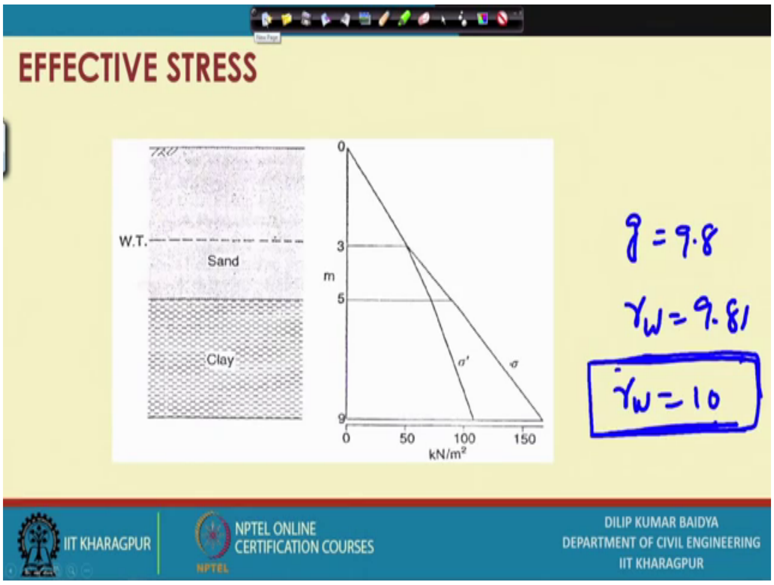

So, this is the way actually and, the entire diagram is drawn like this, but here actually sometime instead of using in civil engineering particularly g value or 9.81 or gamma w as 9.81, many times actually civil engineering application using gamma w 10 also can be used, but since the in the most of the competitive exam etcetera, we do not know what value they expect.

So, better to use the correct value of 9.81 and then that is better. So, if you use 10 actually this type of value will get whatever I have got before, and you will get this one actually. So; better to use 9.81 for gamma w and I have used also in my calculation.

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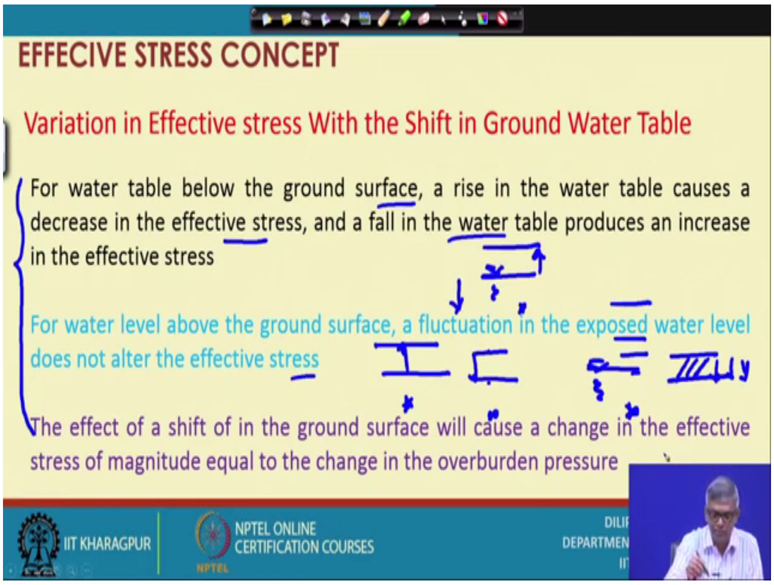

Now, actually variation in effective stress with the shift in ground water table, actually that is what I have mentioned that, the effective stress it change with the variation of different things, like water table is one of the most significant parameter with variation of that, your effective stress can change and we can see for water table, below the ground surface and when suppose this is the ground and water table is somewhere here, a rise in the water table causes decrease in the effective stress.

So, if water table from here, it goes up then at any depth below the ground this level will effective stress will be decrease, that application I will show later on. So, that is what this is this should be remembered as a as a rule almost, a rise in water table causes decrease in effective stress, and a fall in water table fall in water table produce an increase in the effective stress, suppose water table is here and then water table goes down, this direction then at the same point we will see increase in effective stress.

So, because of that many situation; many excavation time if the high-water table is there, and then we have to lower the water table, because to make the soil stronger. So, that application I will show later on, and for water table above the ground surface, a fluctuation in the exposed water level does not alter the effective stress; that means, what? If the water table is somewhere here already, now water table goes 2 meter or 5 meter or 10 meter or again come back, and if I consider at this point, because of these changes water table water. Generally effective stress effective stress will not change, because that calculation also I will show you later on so; that means, if the above ground water level, if there is any change in ground water table, it will not make any change in effective in the soil below the ground level.

And effect of a shift of in the ground surface, will cause change in effective stress suppose ground was here today and because of deposition ground mark is here. So, at this point, definitely effective stress will increase and suppose ground mark was here, because of erosion it has decayed. So, it came down here, it was gone up and it gone down, at then this point same point it because of the erosion if it comes down then effective stress will decrease, that is what the ground surface will (Refer Slide Time: 34:09) cause a change in the effective stress, of magnitude equal to the change in the overburden pressure.

So, if this is the layer, if this much overburden we have to calculate. So, because of that overburden what is the pressure that much will change? So, that it the thing you have to remember. So, these 3 points; that means, water table change when water table from the inside the ground it goes up, then effective stress decrease water table goes down from the original ground level.

If the effective stress increase and above ground level, if water table any change does not make change in the effective stress and of course, change in ground level itself will cause the change in effective stress. So, that how it will be, that is actually if it is overburden added, that equal to overburden if the overburden decrease then minus overburden pressure. So, that is the thing I have shown here, with this I just effective stress just complete.

Thank you.