Soil Mechanics

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Lecture – 17

Effective Stress-I

Welcome to the effective stress concept lectures. We are going to cover the concept of effective stress and inter-granular stresses between the solid grains. In the past lectures we have covered about the origin of soil and their fabric that is structural arrangement and interaction with water with that we have also attempted to classify the soils. We also discussed about the compaction characteristics of soils both course-grained soils and fine-grained soils. We will be discussing about the concept of effective stress which is very important concept to be understood in geotechnical engineering subject.

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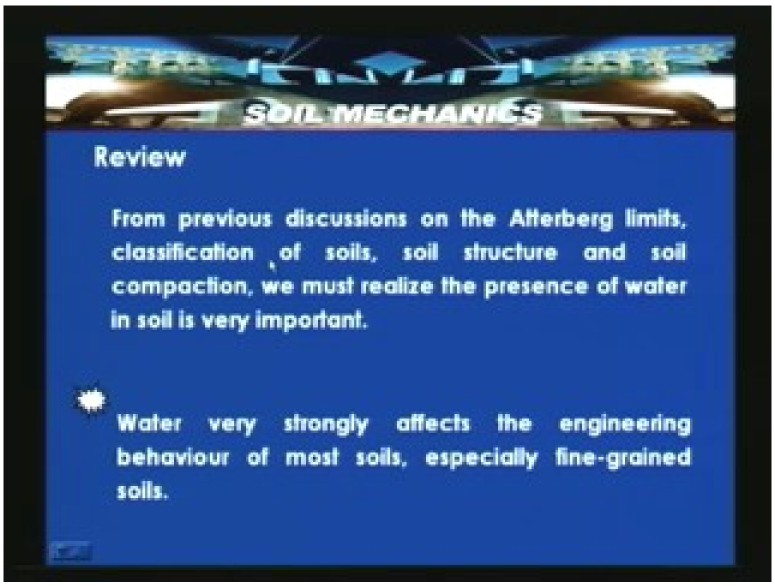

From previous discussions on the atterberg limits, classification of soils, soil structure or soil fabric and soil compaction we must realize the presence of water in soil is very important. From the previous discussions from the atterbergs limit point of view or from the compaction characteristics point of view or soil particle arrangement or a soil fabric point of view, the role of water is having a great prominence. Water very strongly affects the engineering behavior of the most soils especially when it comes to fine grained soils. When it comes to fine grained soils the role of water is having greater relevance. Let us define before introducing the concept of effective stress. Let us define a water table or a ground water table which we refer in geotechnical engineering.

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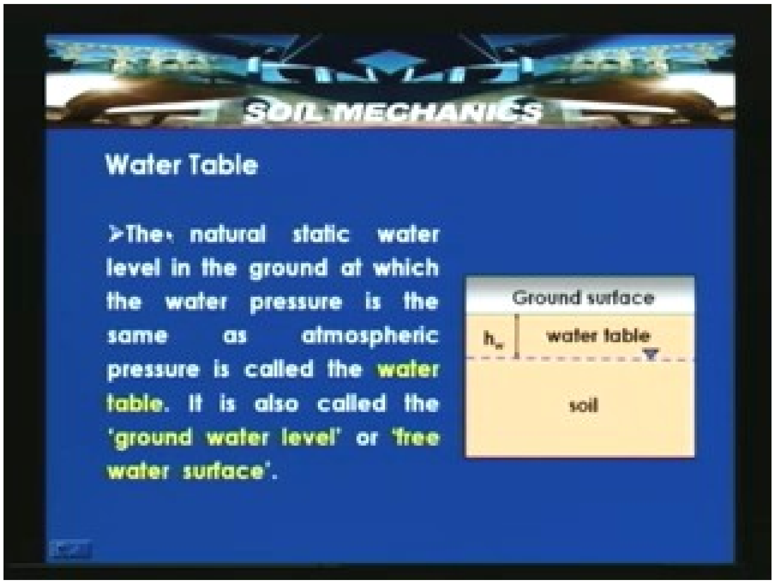

The water table which is defined as the natural static water level in the ground at which the water pressure is same as atmospheric pressure is called water table. It is also called as ground water table or free water surface or priotic water surface. The natural static water level in the ground at which the water pressure is equivalent to the atmospheric pressure is referred as a ground water table. A cross section is shown, the soil strata and the dotted line is the level at which the water table occurs. At this point the water pressure is the same as the atmospheric pressure which is equivalent to 0 and the ground surface is also shown in the above slide. The ground water table that we have tried to define in this slide is a water table and is nothing but a static water surface in the ground at which the water pressure is same as the atmospheric pressure which is equivalent to 0 in this case. This is called a water table and ground water table or free water surface. This water table levels can fluctuate, rise and it can deplete. Thus these facts can be discussed in the due course of these lectures.

Below the water table as we have discussed most of the soils are saturated that means all the voids are filled with water and above the water table they remain saturated depending upon a climate conditions or particle size and the distance from the water table. Below the water table as you seen most soils are completely or almost completely saturated. Above water table, the degree of saturation depends upon the climatic conditions whether arid climates or other such climatic conditions, the grain size of the soil and the distance to the water table. Below the water table most of the soils or basically remain in saturated condition that means that all the voids within the soil are filled with water and the degree of saturation depends upon the climatic conditions. One is climatic conditions the other one is the grain size of the soil and the third one is the distance to the water table. Grain size of the soil which is having a very great prominence, for example if you consider here a fine grain soils like clays which remain saturated even above the ground water table and for course grain soils like sands and gravels they remain dry or partially saturated even above the ground water table. This fact is owed to the capillary phenomenon which will be discussing in the due course of effective stress concept lectures. The following slide we have seen earlier also. A cross section of the ground surface is shown in which yellow color is the ground surface and the blue color is the ground water table. In the zone above the ground water table, depending upon the climatic conditions and grain size and distance from the ground water table it is possible that this soil can remain saturated or partially saturated. If it is partially saturated it will have some air voids in between the solid grains and some of the voids can also be filled with water. Waters surrounding the particle and at points of contact between particles and filling the small void spaces can be seen from the slide which is given below.

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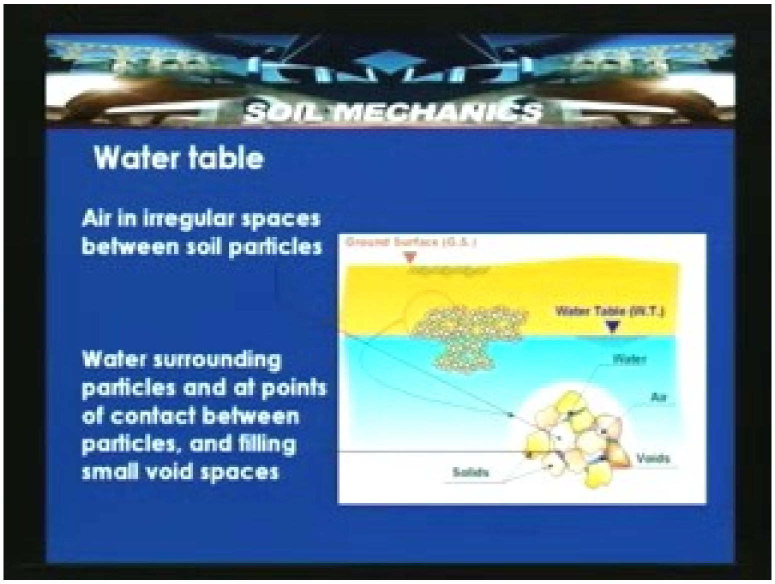

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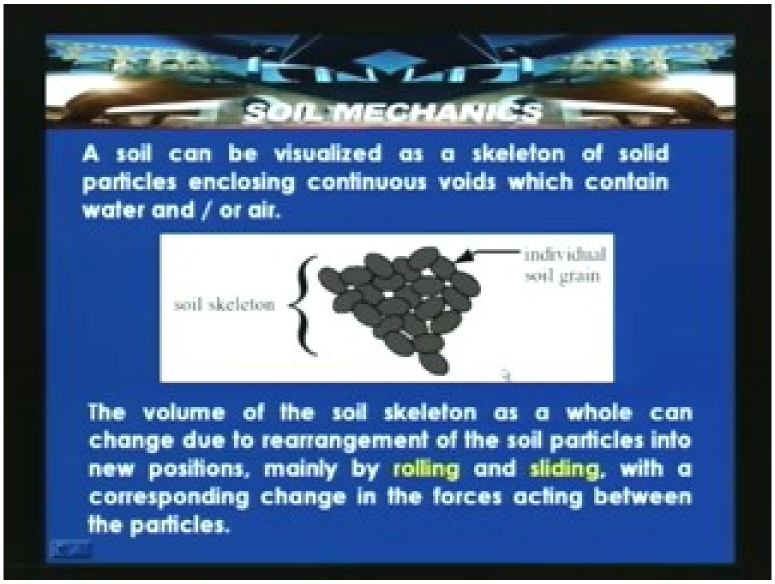

As we have discussed earlier, we can visualize soil as a grain skeleton. A typical individual soil grain is shown in the slide below with certain fabric or certain arrangement and this is the soil skeleton. A soil can be visualized as a skeleton of solid particles enclosing continuous voids which contain air or water. The volume of the soil skeleton as a whole can change due to rearrangement of the soil particles into new positions, mainly by rolling and sliding, with a corresponding change in the forces acting between the particles. Depending upon the stresses which are being experienced upon the grains, they can be subjected to volume changes either by rolling and sliding which can take place among the grains.

In a fully saturated soil since water is considered to be incompressible, a reduction volume is possible only if the some water can drain out of the soil. That means in a fully saturated soil, since water is considered to be incompressible, a reduction in the volume is possible only if some of the water can escape from the voids. Any reduction in the volume is expected only when water starts draining out of the soil. In a dry or a partially saturated soil, a reduction in volume is always possible due to the compression of the air in the voids, provided there is a scope for particle rearrangement. That means whether in a dense state or in a loose state depending upon, the particle arrangement will take place.

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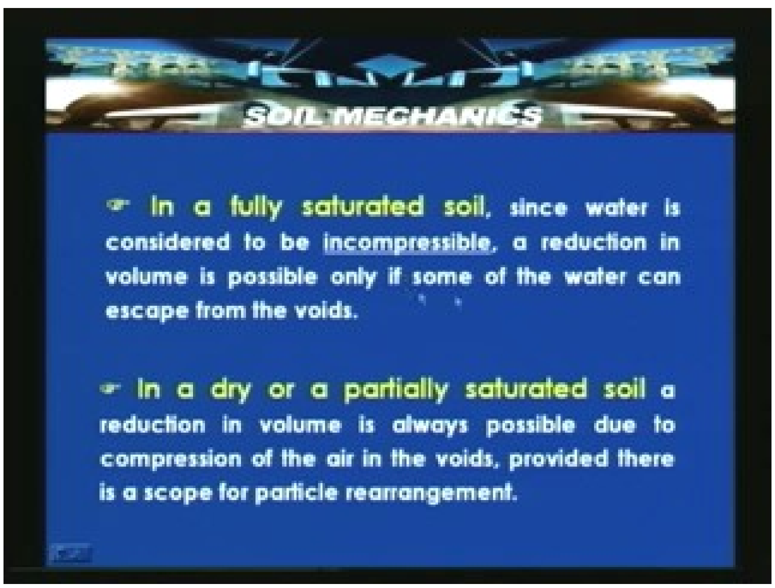

In a fully saturated soil since the water is considered to be incompressible the rearrangement or a change in volume is only possible when there is a scope for the water draining out of the soil mass. In the case of a partially saturated soil or an unsaturated soil which it is possible above the ground water table in the vodus zone, where in a dry or a partially saturated soil a reduction in volume is always possible due to the compression of the air in the voids, provided there is a scope for particle rearrangement. We have seen here a definition of a ground water table and the state of the saturation levels below the ground water table and above the ground water table.

Let us try to define the stress acting on a certain area due to its own self rate of the soil mass. So a vertical subsurface stress resulting from the soil mass. The stresses in the soil mass can be resulted due to its own weight that is the body forces and any external loading which is because of any manmade structures or any fills which are coming up on the soil mass. The vertical subsurface stress resulting from the soil mass alone can be computed in the following way.

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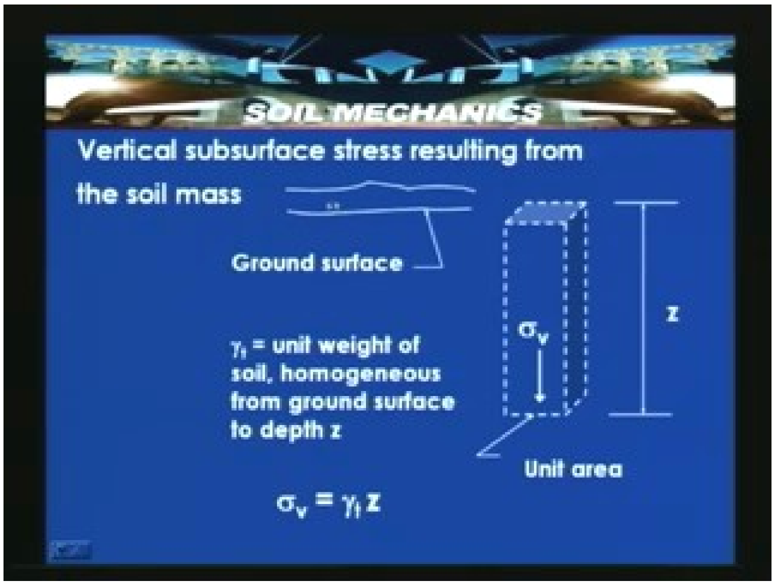

Suppose if this is the ground surface which is given in the above slide. Let us consider the average unit weight of the soil, homogeneous from ground surface to depth z is γ_t. So let us consider a depth under consideration is z from the ground surface. In order to determine the vertical stress that is the subsurface stress due to soil mass alone, let us consider a prism which is having a surface area $\frac{1m}{1m}$.a unit cross sectional area perpendicular to the application of the stress that is a unit cross sectional area $\frac{1m}{1m}$.

If you are required to determine the σ_v at a depth z. This is entirely due to the self weight of the soil which is within the block. If I take a cross sectional area 1×1 and the depth of the difference is z, so the volume is z m^3 $\times$the unit weight of the soil mass which is γ_t. So $\gamma_t \times Z$ is γZ that is the stress acting or a unit cross sectional area at a depth z. We write σ_v is equal to γ_t z.

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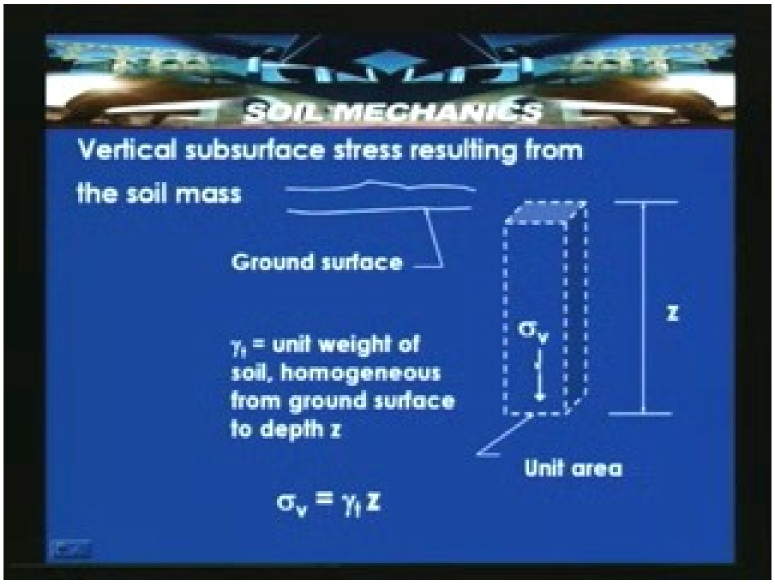

If t is homogeneous then if it is a stratified soil then it is required to be considered depending upon the requirement. This particular vertical subsurface stress is also referred as a geostatic vertical stress. Vertical stress due to strata of different soil types. Suppose if you are having a stratification, like layers which are deposited of thickness z1, z2 and z3 and having unit weights γ1, γ2 and γ3.

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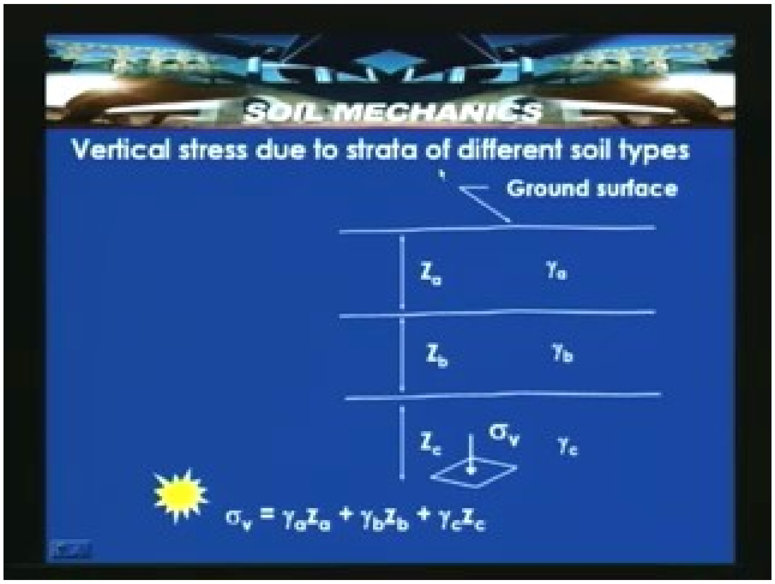

Suppose if you are required to determine stress at a certain depth z below the ground surface, then we have to follow this particular procedure. That means the unit weight which are referred as the layer a γ_a, Z_a and γ_b, Z_b and γ_c, Z_c. The vertical stress σ_v

acting at a depth z which is nothing but $Z_a + Z_b + Z_c$ is equal to $\gamma_a Z_a + \gamma_b Z_b + \gamma_c Z_c$. σ_v = $\gamma_a Z_a + \gamma_b Z_b + \gamma_c Z_c$ the vertical stress due to strata of different soil types base can be computed by σ_v is equal to the summation of the unit weights multiplied by the layer thicknesses. The stress in a soil at any point is the result of the soil lying above the point or by any other loading imposed on to the soil mass. As I informed earlier the stresses in soil mass can be due to its own self weight and due to any other loading imposed on to the soil mass.

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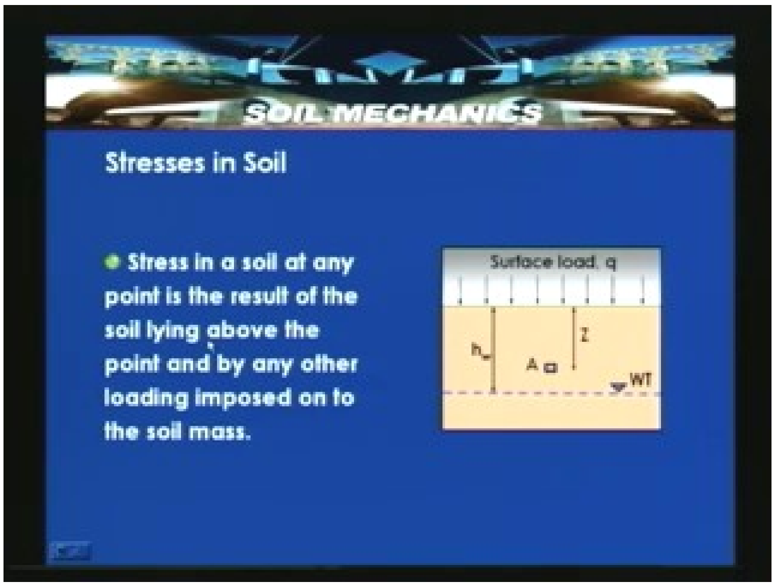

Suppose a loading can be a concentrated load, a line load like a wall which is running over a length l or a line load representing the railway tracks that can be also referred as a line load. It can be a uniformly distributed load representing a fill soil above the certain ground surface. In that case the dotted stress can be due to the self weight as well as due to the vertical stress resulting due to the external loading.

This will be discussed while discussing the stress distribution in soils due to external loads. In this we are considering the geostatic vertical stress that is the stress resulting due to self weight of the soil mass.

Whatever the stress which we are referring is called the total stress which is due to the resulting load. This is indicated by σ. The total stress is carried by soil solids and water present in the soil mass. Stress carried by the solids influence the strength and the compressibility characteristics of the soils. Total stress has a physical meaning and making it to be measurable. That is the total stress has got a physical meaning in which it is measurable.

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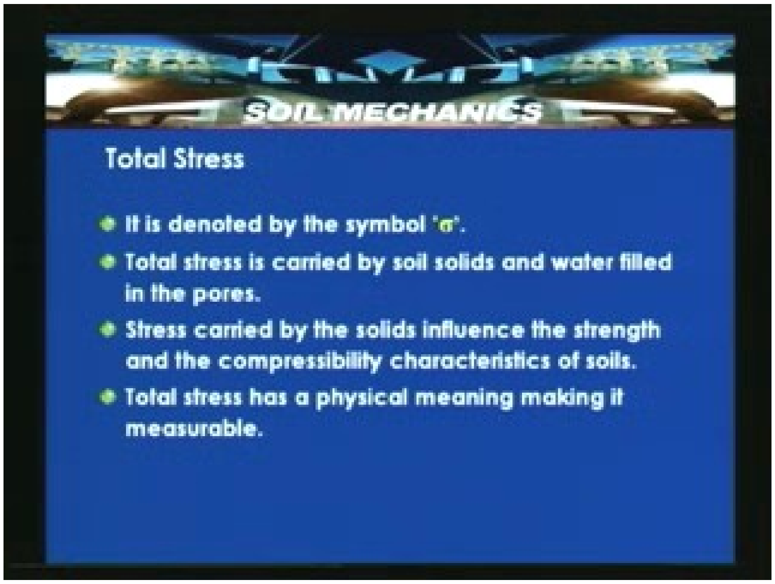

Let us consider a different case like homogeneous soil mass which we already discussed. Let us consider here as a case1 with a homogeneous soil mass.

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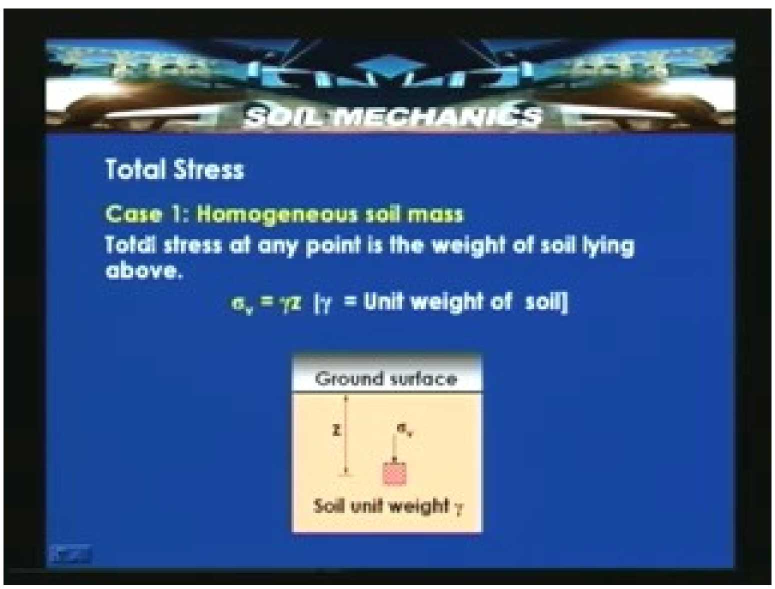

The total stress at any point is the weight of soil lying above. That is what we have discussed; total stress at any point is the weight of the soil lying above that plain at which we are determining the stress. $\sigma_v = \gamma Z$. The σ_v is the element in which the vertical stress acts on the horizontal area at depth z from the ground surface. So σ_v is equal to γZ and here the unit weight of the soil is assumed as γ ,which is constant for the homogeneous soil mass. This unit weight generally has got a tendency to increase with the depth because of the densification which can result with the overbed lying above the soil mass. Because of that there is a chance of the increase in the density due to possible densification which results due to the deposition of the over bed.

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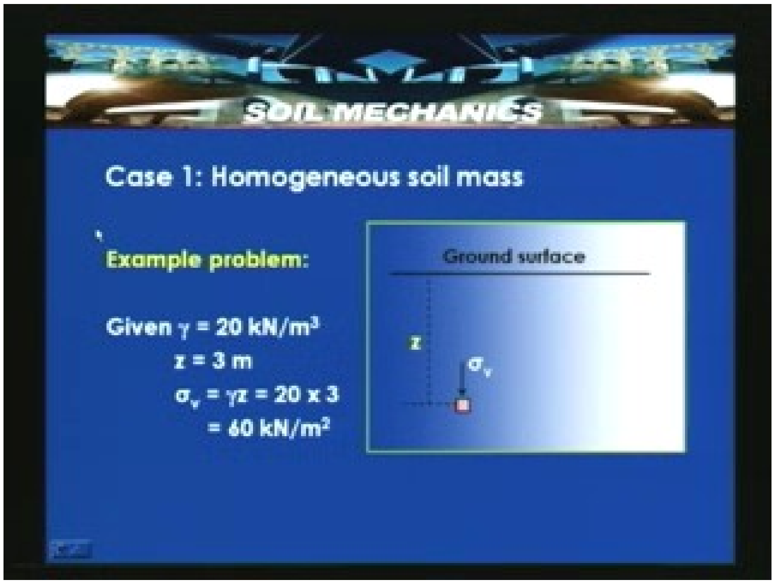

For a homogeneous soil mask let us consider a small example problem to demonstrate how this can vary and how it can be computed. Take a simple case, in this problem γ is equal to 20kN/m^3 that is the unit weight of the soil given to us is 20kN/m^3. The z is equal to 3m. From the previous deliberations we can say that σ_v at a depth of 3m that is z which is equal to 3m, the vertical stress σ_v is equal to $20 \times 3 kN/m^3$ that is 60kN/m^2.

Let us look into the problem. Suppose these are the given parameters z is equal to 3m and γ is equal to 20kN/m^3. The distribution varies like this at depth z is equal to 0, the stress is equal to 0 at depth z is equal to 3m the γz is equal to 60kN/m^3. That is γz is equal to 60kN/m^3. So the variation of the stress is the geostatical vertical stress or geostatic vertical total stress variation with the depth. The depth of the soil and the stress is plotted, and then the plot can be obtained like this. This is an example problem for a homogeneous soil mass. Let us consider a stress below an impounded water. Soil mass is homogeneous but an impounded water is acting on the soil mass. So impounded water acts like surface loading and adds to the geostatic stress at any point in the soil. This can result like, for example in lakes or river beds, if 5 m water level exists above the ground surface then that can act as a total stress at a certain depth below the river bed.

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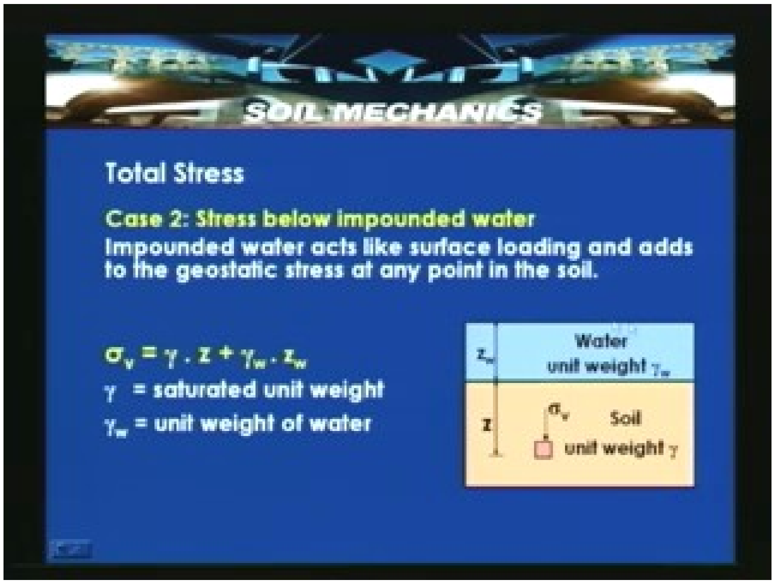

So impounded water acts like surface loading and adds to the geostatic stress at any point of the soil. How this can be determined? The σ_v is equal to γz $+\gamma_w.z_w$. That is $\sigma_v = \gamma.z + \gamma_w.z_w$. So σ_v is equal to the vertical stress, at a particular depth z below the ground surface is γ and z. That is γ is the unit weight of the soil and z is the depth within the soil and zw is the weight of the impounded water and γw is the unit weight of water. The total vertical stress at a point z below the ground surface is γz $+\gamma_w.z_w$. Let us look into the example problem relevant to a ground surface with an impounded water.

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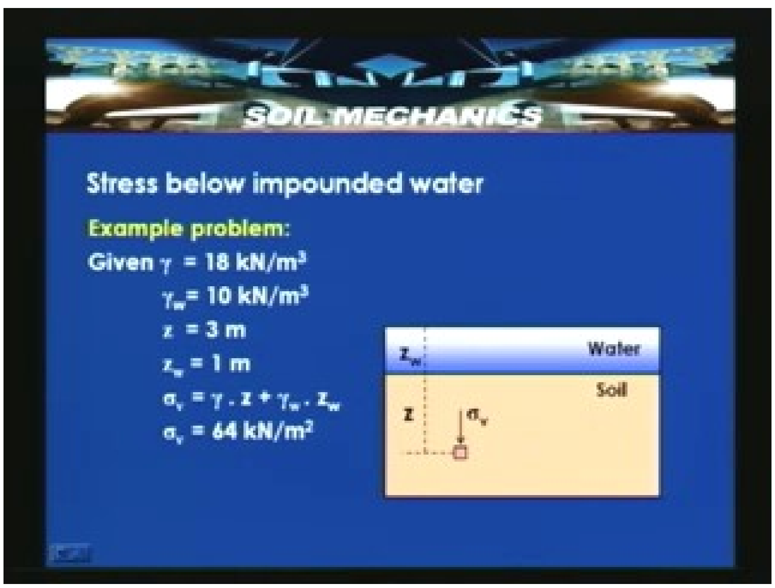

The example problem states like this. Given γ is equal to 18kN/m^3 and γw is taken as 10 kN/m^3. The z is equal to 3m, zw is equal to 1m, σ_v is equal to γz $+\gamma_w.z_w$ that is equivalent to 64 kN/m^2. Let us look in to the problem, z_w is the height of the impounded water and z is the reference at which we are trying to determine the vertical stress due to soil mass as well as due to impounded water depth above the ground surface.

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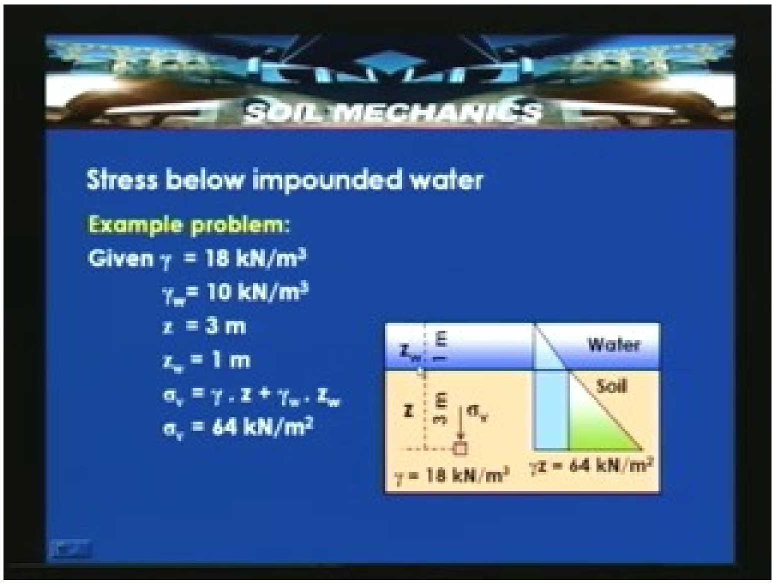

If you look in to it the depths which are given are 3m and 1m. In this example problem we have taken as 1m and unit weight of the soil is 18 kN/m^3. As we discussed below it can be soil mass and it can be saturated. In that case if the soil mass is completely saturated like river beds then the γ has to be considered equivalent to γsat that is the saturated unit weight of the soil mass, while determining the total stress at a particular depth.

If you consider that deliberation, we get a vertical stress due to water which gets added in the blue region of the above slide and then the stress resulting due to soil mass. The entire vertical stress at a depth 3m ground surface is due to the impounded water as well as due to the soil mass stress. That is γz is equal to 64kN/m^2.

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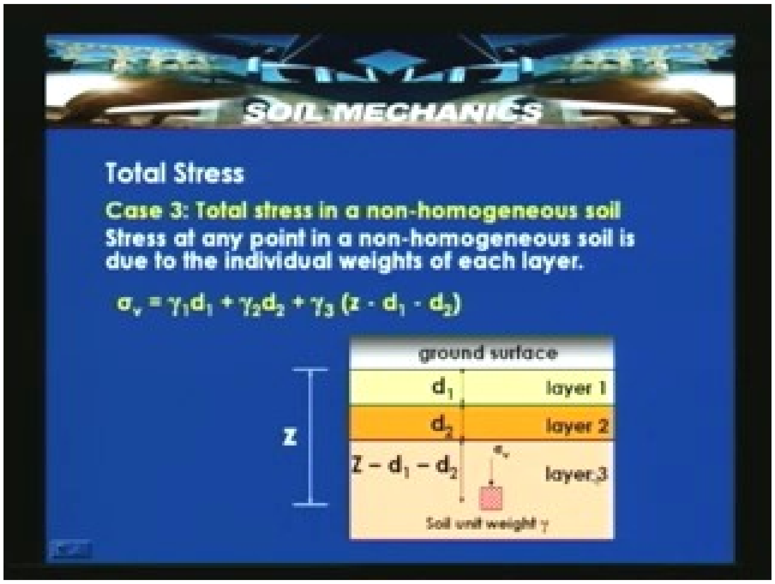

So having seen the cases of homogeneous soil with and without the impounded water. Let us consider a total stress in a non-homogeneous soil which is possible when the stratification takes place during the formation of the soils. When the soil formation takes place, there is a chance of the stratification to occur below the ground surface.

This is a case 3 which we are discussing. The stress at any point in a non-homogeneous soil is due to the individual weights of each layer. That is individual weights of each layer over a cross sectional area one meter by one meter which we require to determine. $\sigma_v = \gamma_1 d_1 + \gamma_2 d_2 + \gamma_3 (z - d_1 - d_2)$ That means z is the total depth from the ground surface. The vertical stress resulting due to individual soil weights σ_v at a depth z can be given like this σ_v is equal to $\gamma_1 d_1 + \gamma_2 d_2$ and $\gamma_3 \times$ the thickness that is $z - d_1 - d_2$. That is the layer 3 thickness which we are referring now. Let us look in to the example of total stress in a non-homogeneous soil mass which is the example for case 3 which we introduced in the previous slide.

We said that in the previous slide $\sigma_v = \gamma_1 d_1 + \gamma_2 d_2 + \gamma_3 (z - d_1 - d_2)$ that is the depth from the bottom of the second layer surface to the point of the reference at which the stress is being determined. Let us consider in this example that the layer one has got a thickness of 1m and has got a unit weight of around 16kN/m^3. The layer two has got 2m thickness and got unit weight of 17 kN/m^3 and layer 3 has got a thickness or a depth at which the stress is being determined is 3m which is having a unit weight of around 18kN/m^3.

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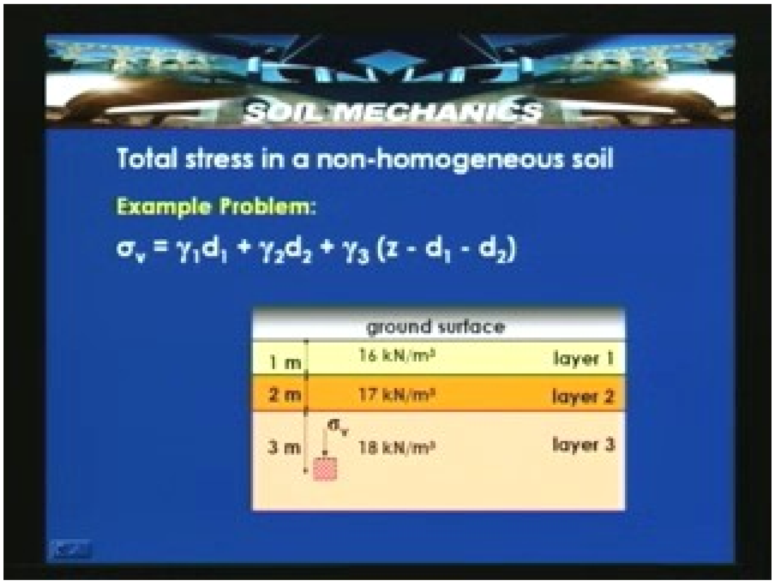

In that case we can determine the resulting vertical stress and it can vary like this. There is a chance of varying slopes because the unit weight is changing with that there is a change in the variation or a slope of this vertical stress with the depth variation. So σ_v is equal to 104 kN/m^2 , that is what we determined from this example.

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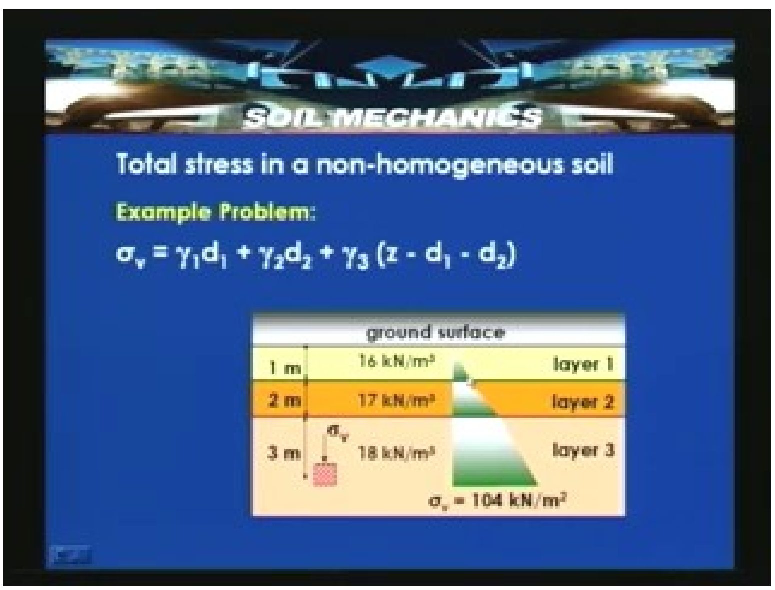

We have seen a homogeneous soil without any impounded water and with impounded water and a stratified soil something like a non-homogeneous soil or stratified soil and then we tried to determine a total stress at a particular depth below the ground surface with these three examples.

In the case 4, for the determination of the total stress, let us consider a total stress in an unsaturated soil or partially saturated soil.

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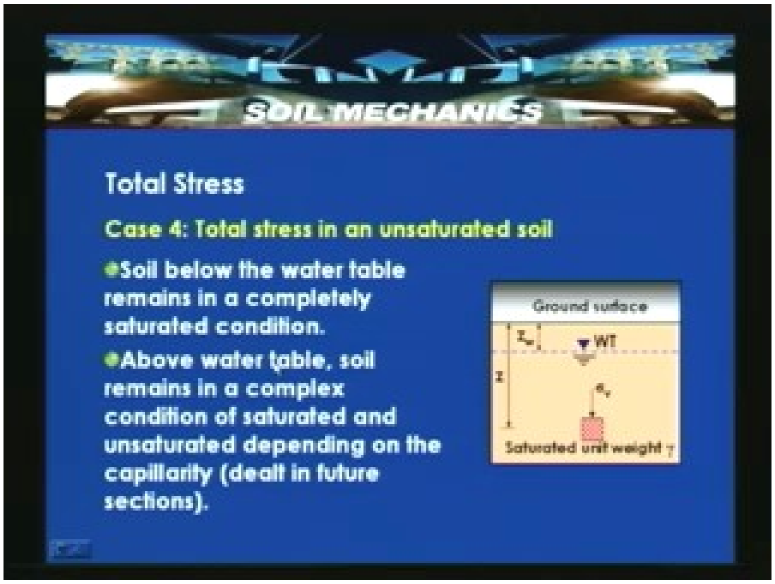

The soil below the water table remains in a completely saturated condition. That is what we discussed in the beginning of this lectures, the soil below the water table remains in a completely saturated condition. Above water table, soil remains in a complex condition of saturated and unsaturated depending on the capillarity which will be dealt in the future lectures.

Let us consider a saturated unit weight below the ground water table. The horizontal dotted line in the above slide is the ground water surface which is indicated and above this is the zone which can be saturated or can be partially saturated, depending upon the reasons we discussed earlier.

The case 5 is the total stress with surface loading. This can be like which we have discussed, the surface loading can increase the total stress. The load acting on the wide areas are assumed to be constant with depth. Suppose if the acts over a wide area, something like a wide area fill or an example with the existing ground level, say if you are reclaiming the ground that represents the wide area fill or an existing ground surface.

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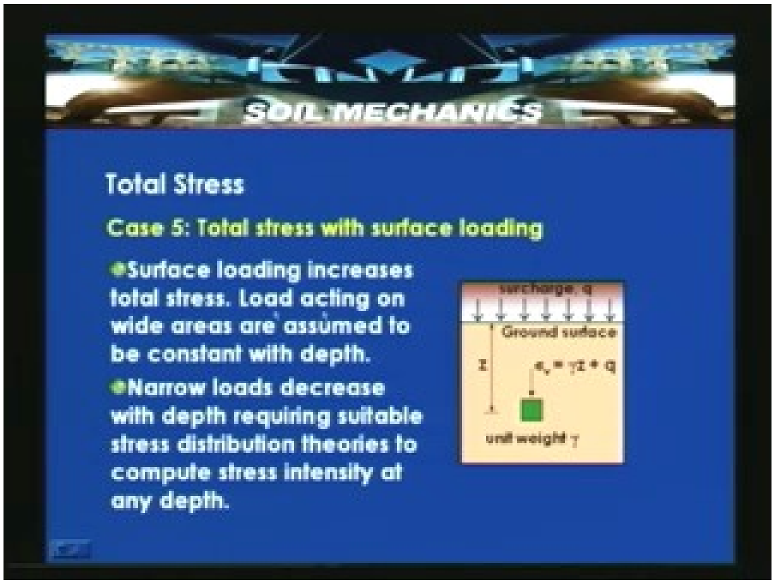

In that case the entire stress transferred directly to the soil mass. It is something like a stratified layer which is coming on above the existing ground surface of a given soil site.
So narrow loads decrease with depth requiring suitable stress distribution theories to compute stress intensity at any depth. The narrow loads like point loads, uniform distributed loads or strip loading or line loads tend to decrease with the depth and require a suitable stress distribution theories to determine the variation with the depth or determine the stresses to soil mass as well as resulting due to these narrow loads. The total stress if it is there with the surface loading, it has to be determined with soil mass and then the resulting due to the surface loading.

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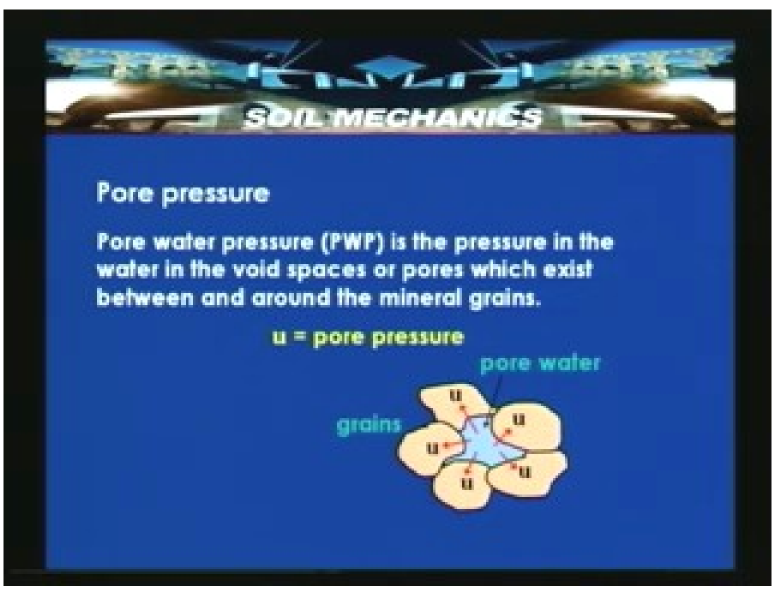

After the introduction of the total stress, it is required for us to understand and define what is meant by a pore water pressure. We have discussed that the void spaces which exist in between the solid grains are called as voids or pore spaces. If this pore spaces are filled with water then water exerts pressure in all directions within the solid grains.

The pore water pressure which is designated as PWP or also with a letter small u is indicated and it is the pressure in which the water in void spaces or pores which exists between and around the mineral grains. The illustration is shown in the above slide where u is the pore water pressure which is designated and these are the individual grains which are with certain arrangement.

If you assume that entire pore space is filled with water, so that water is called the pore water. When this gets under pressure, the pressure which is exerted on to the internal boundaries of the particular pore space is called pore water pressure. This can be in any direction because of the Pascals law principle.

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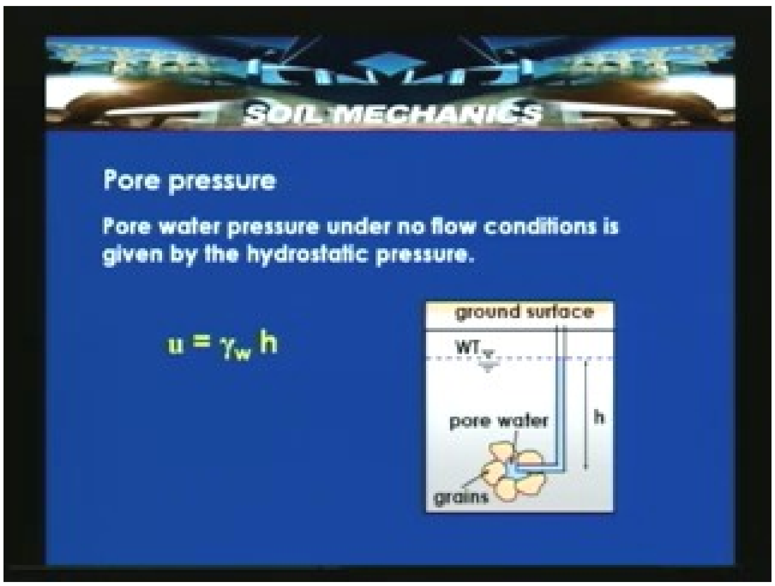

How to determine this pore water pressure at a certain depth, if it exists in a ground surface or below the ground water table. The pore water pressure, under no flow condition is given by the hydrostatic condition. When there is no ground water flow either from top to bottom or bottom to top that is upward flow or the down ward flow. In these cases there will be variations in the pore water pressure which will be discussed. Assuming that a simple case for the todays lecture, it can be considered like a static ground water table conditions.

In that case the pore water pressure under no flow conditions is given by the hydrostatic pressure, u is equal to $\gamma_w h$. Suppose h is the depth at which actually the pore space exists. The blue color thing in the above slide is the pore space which is filled with water and this depth at reference what we are determining is the h. We have the devices to measure this pore water pressure at a certain depth below the ground surface. The h is the piezometeric head we refer, that is the one with which we indicate the pressure.

Pour water pressure, as the name implies it is a pressure which exists in the water which is present in the pores of the soil. That is what we have discussed in the previous slide; it is the pressure which exists in the water which is present in the pores of the soil. The soil pores are normally interconnected. We have seen that the soil pores is something like skeleton which is having interconnected voids.

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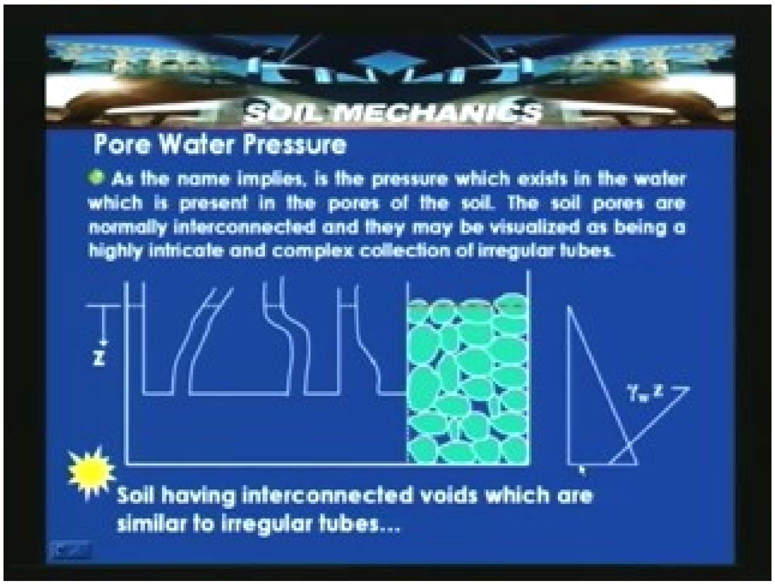

They may be visualized as being a highly intricate and complex collection of irregular tubes. In this particular slide a soil mass, let us assume that this red line which indicates the ground water table and below that all the voids which are filled with water and when this is under no flow conditions, the pressure at the ground water surface which is equivalent to the atmospheric pressure is zero.

At a depth z below, what we discussed is that the variation is linear that is the depth is equal to zero, under no flow conditions. When the hydrostatic condition prevails then at a depth z below the ground water surface, we can determine the pressure as $\gamma_w z$.

Let us consider suppose if these interconnected voids which are represented as a regular tube with certain diameter or a certain tube with certain inclination or a tube with this type of geometry or a tube with this type of arrangement. The z is the water level maintained and only at the bottom of the green colored thing there is a way for escaping water and everything is interconnected. In that case at each and every point the water pressure is 0 and this particular distribution ($\gamma_w z$) is valid.

The soil having interconnected voids which are similar to irregular tubes. What does it indicate is that, the soil is something like having interconnected voids. When they are below the ground water table at a certain depth the pressure is equal to 0 and below that the pressure increases as we go away from the ground water table surface. So pore water pressure is the pressure which exists in the water which is present in the pores of the soil. From this slide what we discussed is that the soil pores are normally interconnected and these soil pores are represented by using some intricate tubes. We said that even the soils having interconnected voids which are similar to this irregular tubes. So something analogue representation we have used here to represent the interconnecting voids within the soil mass. So pore water pressure it has a physical meaning and as I said here it can be measured.

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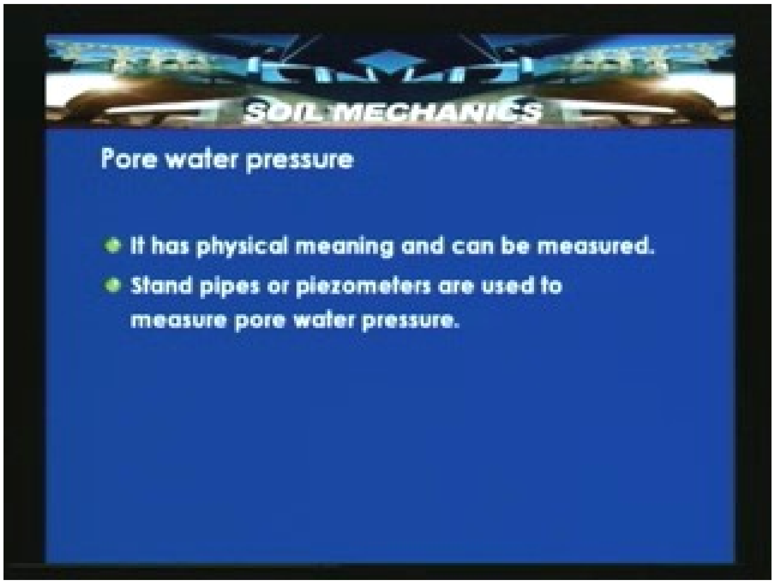

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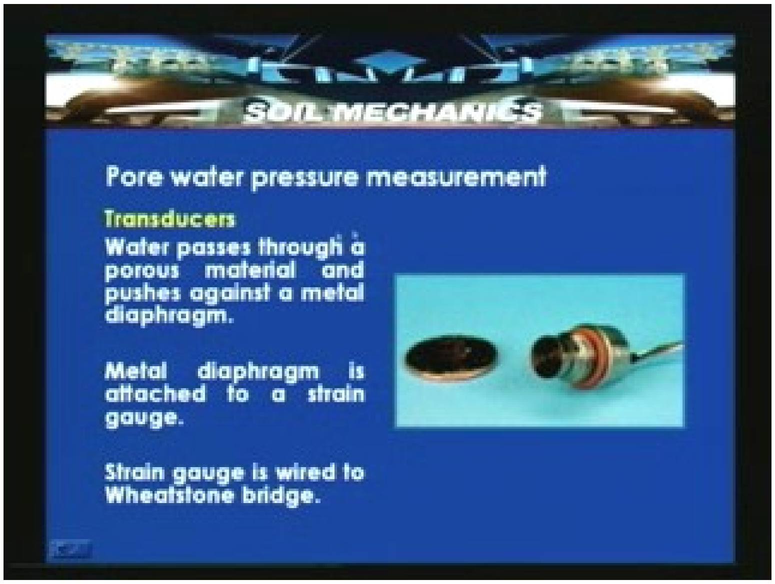

It can be measured by using stand pipes or piezometers. With modern development strain gauze based transducers are also available to measure the pore water pressure. For a pore water pressure measurement a typical transducers are shown to illustrate the application how this pore water pressure can be measured in the soil mass.

The device shown in the above slide will have a diaphragm fitted with a strain gauge connected to a full bridge in a Wheatstone bridge. Strain gauge is wired to a Wheatstone bridge which is in full inform. The water passes through a porous material and pushes against a metal diaphragm. The metal diaphragm is attached to a strain gauge and the tension experienced from the metal diaphragm is reflected as a pressure in the pores in the soil mass.

The pore water pressure can be measured by using electronic transducers. When the water passes through this porous material, then it exerts pressure on the diaphragm and the diaphragm will be having a strain gauge arrangement with that it exerts a pressure. The deflection which is experienced by this diaphragm is registered as a pressure. This is how by using electronic transducer one can measure the pore water pressure within the soil mass, when the soil mass is completely saturated.

The pore water pressure measurement can also be done with the piezometers. Piezometers are porous tubes that allow passage of water and the height of water in the tube is measured from a fixed elevation.

If you insert some piezometers or a stand pipes, if it happened to measure the height of the water collected in the tube with a fixed elevation and that can also be indicated as a pore water pressure or a piezometric head. The pore water pressure is calculated by multiplying the height that is the head with the unit weight of the water. The boreholes cased to certain depth act like piezometers. Suppose while doing soil investigation the boreholes were drilled to access the soil characteristics as well as occurrence of the stratification and access the different properties of soil.

The boreholes which are drilled and bore holes with casing can also act like piezometers to measure the pore water pressure. The modern piezometers have transducers for electronic recording and data acquisition system. That is also we have said that modern piezometers have transducers for recording as well some automatic data acquisition. The typical piezometers are shown in the slide below. With the help of these things also one can measure the pore water pressure.

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Basically there are 2 types of piezometers exists. One is casagrandes piezometers, the other one is the bishop piezometers which are being widely used for assessing the pore water pressure in the field. Having introduced the total stress and the pore water pressure, we have come to an important milestone in our lectures to introduce the concept of effective stress or a terzaghi effective stress principle which is a very famous, particularly in the geotechnical engineering where it gives about portioning of the load carried by the mental grains and the pore water pressure.

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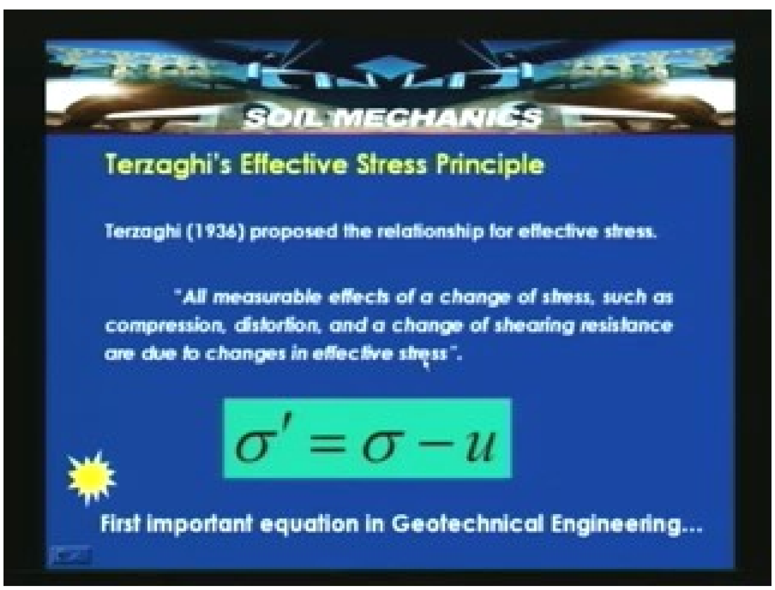

Terzaghi in 1936 proposed the relationship for effective stress. All measurable effects of a change of stress such as compression, distortion and a change of shearing resistance are due to changes in effective stress. The distortion can occur or a compression that is change in the volume can occur or a change of shearing resistance can occur if there is a change in the effective stress. What terzaghi has proposed is that an equation which is given like this ($\sigma' = \sigma - u$), that means σ is the total stress and u is the pore water pressure. The new term which is introduced is σ' which is called the effective stress or intergranular stress. The σ is equal to σ' + u is the famous and first important equation in geotechnical engineering. The geotechnical engineering students whoever lends this soil mechanics or whoever takes this subject, the first and foremost equation in geotechnical engineering is $\sigma' = \sigma - u$ which is a very important equation and has got many applications in soil mechanics.

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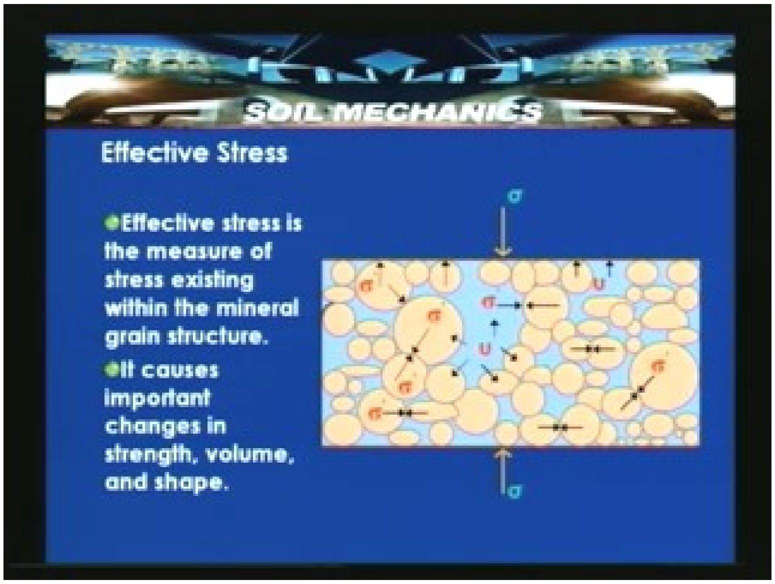

The effective stress is defined as the measure of stress existing within the mineral grain structure. It is shown in the above slide as σ', like a stress which is acting between grain to grain at points of contacts. The u is the pore water pressure existing between the grains and σ' is the stress acting at the mineral grain contacts. The σ is the total stress acting over entire soil mass.

The equation which has been proposed by terzaghi is to relate total stress, effective stress and pore water pressure. It causes important changes in the strength, volume and shape. Effective stress is the one which changes important changes in the strength, volume and shape because of this particular stress named as effective stress. The other name is intergranular stress, but the stress is called effective stress. Because it is very efficient or important causes important changes in the strength, volume and shape which can result because of the changes. Effective stress is the measure of the stress existing within the mineral grain structure.

How to define the effective stress? Just in the previous slide we have shown that there are 3 types of stresses. The one is the total stress and effective stress which is acting at the grain contact points and u is the pore water pressure which is exerted with in the pore spaces of the soil mass.

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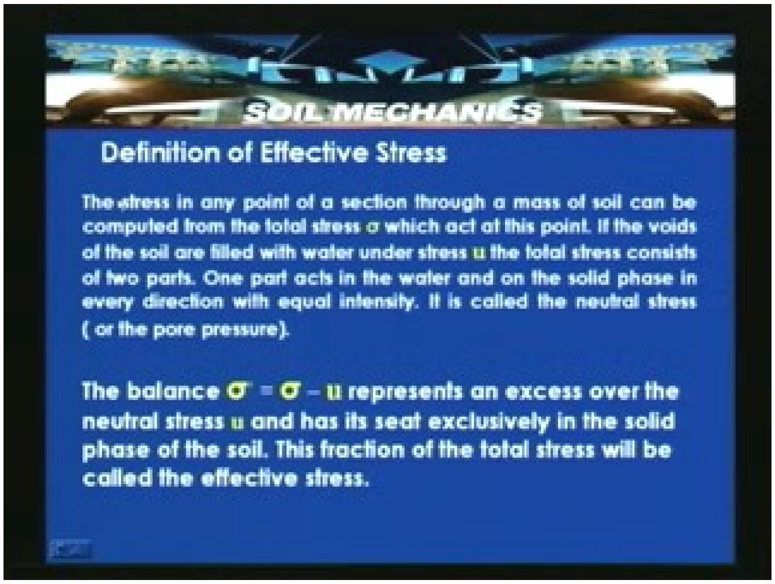

The stress in any point of a section through a mass of soil can be computed from the total stress σ which acts at this point. If the voids of the soil are filled with water under stress u, the total stress consists of 2 parts. One part acts in the water. Previous slide we have seen one part is acting in water and other part is acting in the solid phase in every direction with equal intensity which is called a neutral stress.

Thus water experiencing a pressure which can act in any direction with equivalent intensity is one part of the stress. The other one which is resulting due to grain to grain contacts is the intergranular stress. The balance of this total stress and pore water pressure is called effective stress. The $\sigma' = \sigma - u$ corresponds to an excess over the neutral stress and has its seat exclusively in the solid phase of the soil. This fraction of the total stress will be called as effective stress.

What we have discussed is that, there are 2 parts if in a portion of total stress, the one is effective stress the other one is pore water pressure. The difference of total stress and pore water pressure that is effective stress which is indicated as σ' which acts exclusively on the mineral grain to grain contact point. This fraction of the total stress is called as an effective stress

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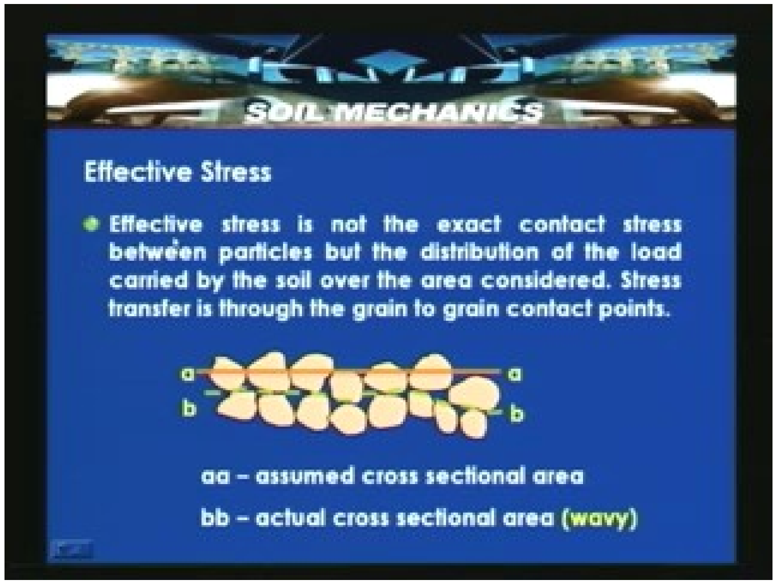

Effective stress is not the exact contact stress between the particles. Because if you take grain to grain contacts, particularly in case of granular soils or sandy soils, the grain to grain contact area may be very less. Because of that the forces, if I take the contact stresses at the grain to grain contacts are very high. Effective stress is not the exactly contact stress between the particles but the distribution of the load carried by the soil over the area under consideration. Stress transfer is through the grain to grain contact points.

If aa is the assumed cross sectional area which is passing through the solid grains and as well through the voids which can be filled with and without water. If you consider like this aa is the imaginary area passing through a soil mass at a certain depth. The bb is the actual cross sectional area which is wavy pattern. While determining this stress at a particular depth, which is bb is approximated as aa. We determine the average stress acting at grain to grain levels. If we take at grain to grain levels the actual stresses are very high.

What we discussed in this slide is effective stress is not the exact contact stress between the particles but the distribution of the load carried by the soil over the area considered. Stress transfer is through the grain to grain contact points. That is what shown in this slide below, 2 grains with a contact area ac is shown. If you see the actual area of stress concentration is less and stress will be more than the calculated.

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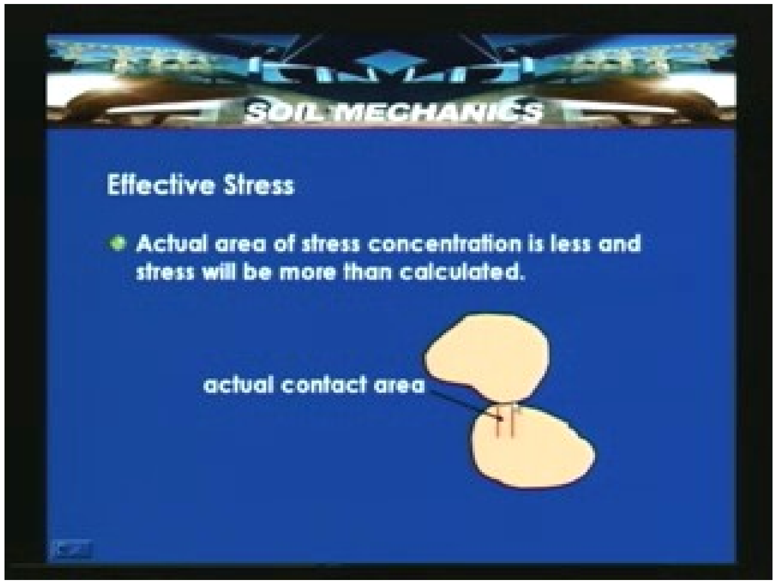

The actual contact area is very less. At the point of contact the stresses are very high, but what we generally determine is that, acting over an imaginary area passing through the grains as well as through the voids can be filled with and without water. For elaborating about this relationship $\sigma = \sigma' + porewaterpressure$, let us consider a piston analogy.

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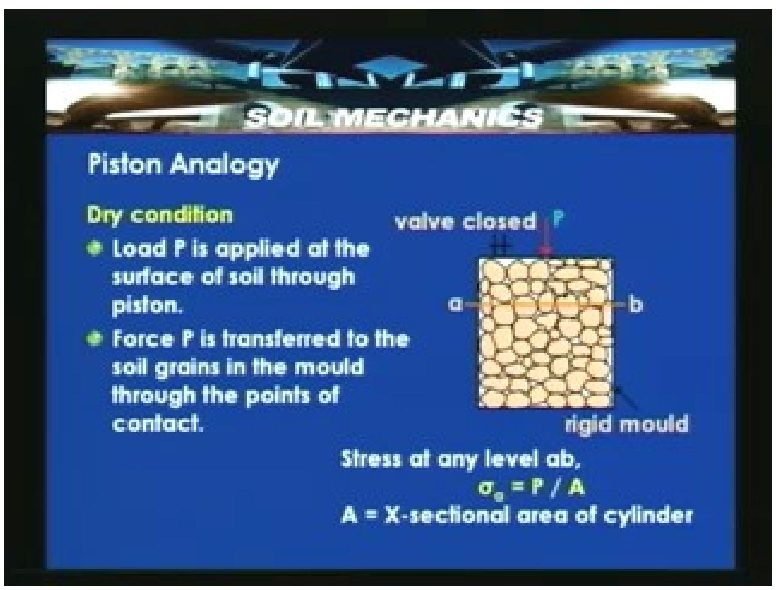

Consider a dry condition assuming that you are having a rigid mould in which the soil grains are filled and p load is applied over a cross sectional area a. So ab is the area which is passing through the voids as well as through the solid grains. And as we have seen the imaginary area passing through the solid grains and as well as the voids are considered in determining the stress at a particular depth within the soil mass. So load p is applied at the surface of soil through piston and assuming that the valve is closed at the top. The force p is transferred to the soil grains in the mould through the points of contact. The stresses at any level ab is equal to $\frac{P}{A}$ that is resulting due to the stress where A is the cross sectional area of the cylinder. Let us consider σ_a is the average stress and not the actual stress prevailing at the grain to grain contact points which is generally very high. That is what we have discussed in the previous slide also. The actual points of contacts exhibit a wavy form that is approximated below.

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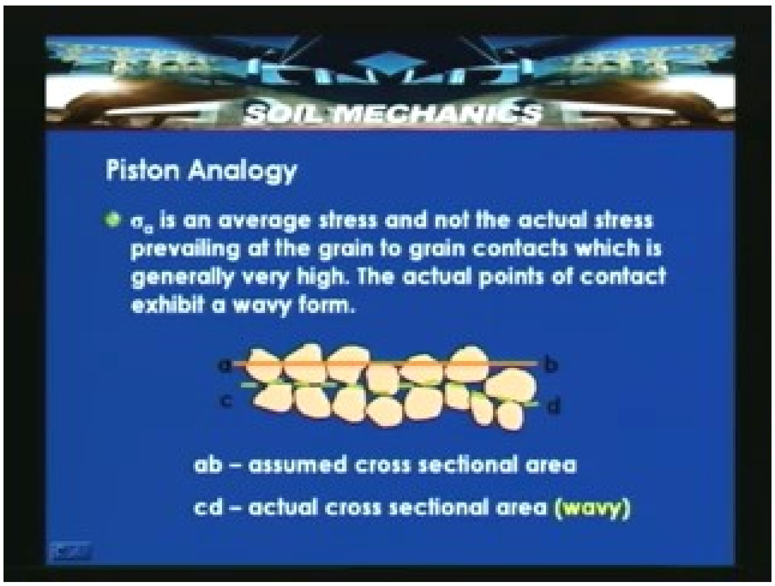

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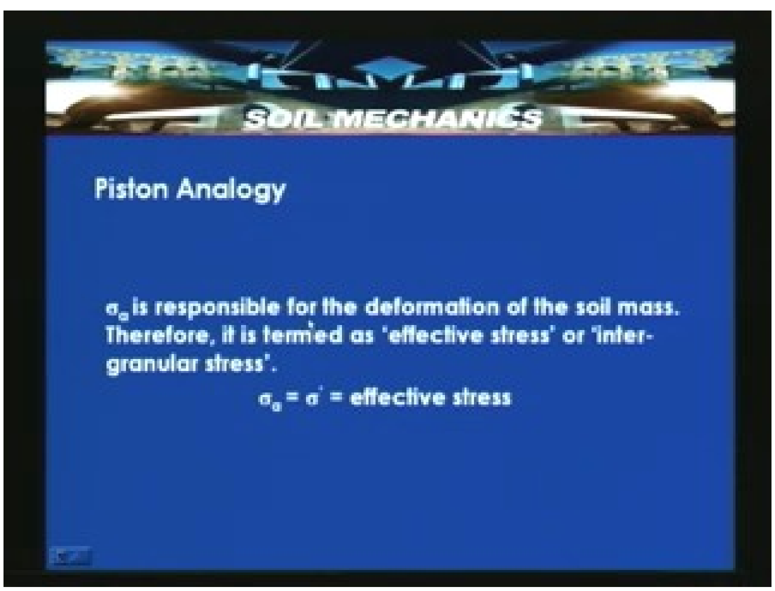

If I look in the piston analogy, σ_a is responsible for the deformation of the soil mass. It is also termed as effective stress. In the case of a dry soil, when there is no water within the voids and it can be referred as $u_w = 0$, then whatever the total stress applied is the effective stress which is responsible for the deformation of the soil mass. So $\sigma = \sigma'$, this is the effective stress in case of a dry soil mass.

In case of a saturated condition, let us consider the piston analogy assuming that the soil skeleton with certain arrangement filled in a same cylinder filled with water and the valve is closed. The rigid mould which is having a cross sectional area a and the pore water which is indicated with blue color and the valve is closed. The diameter of the valve indicates the permeability or the capacity to drain the water from the soil mass. Soil is fully saturated and the valve is closed.

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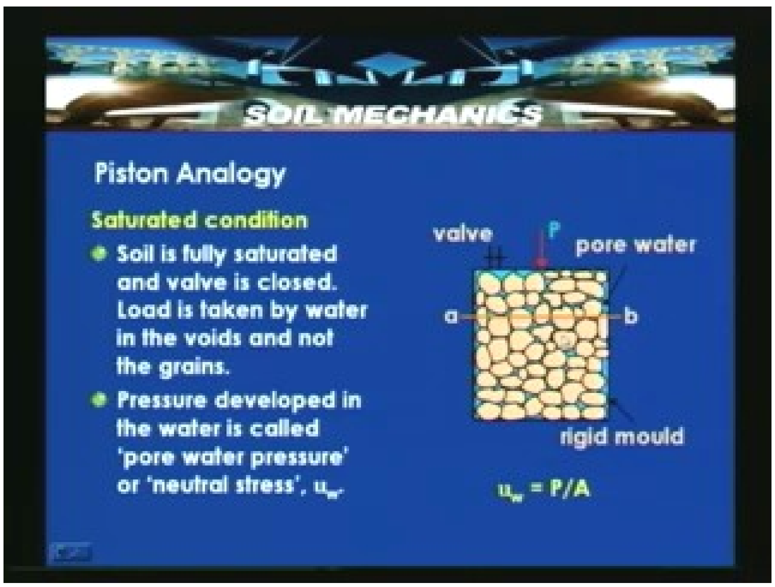

Load is applied through a piston, in that case load is taken by the water in the voids and not the grains. If you assume another analogy, that if I replace this soil skeleton with a spring. In that case what will happen is that the soil skeleton is represented by a spring of certain stiffness and if the same cylinder is filled with water and the valve is closed. When the load is applied and the spring will not experience any compression but the water will be under pressure.

Suppose if the water is allowed to drain by opening the valve, slowly the spring experiences the compression. At any point, time t after opening the valve we can say that the total stress which is applied onto this system is equal to the load taken by the spring plus water. That is nothing but the load taken by the spring which is analogously represented here as an effective stress or intergranular stress is $\sigma' + u$, so with that the $\sigma = \sigma' + u$ can be illustrated.

The pressure developed in the water is called the pore water pressure, this pore water pressure is also referred as neutral stress. The reasons we will discuss in the next lecture, but in the saturated condition the soil is fully saturated and the valve is closed, load is taken by water in the voids and not the grains. If I look in to it, opening the valve is analogous to drainage of soil. Water flows for some time and ceases. Drainage increases the inter-granular pressure.

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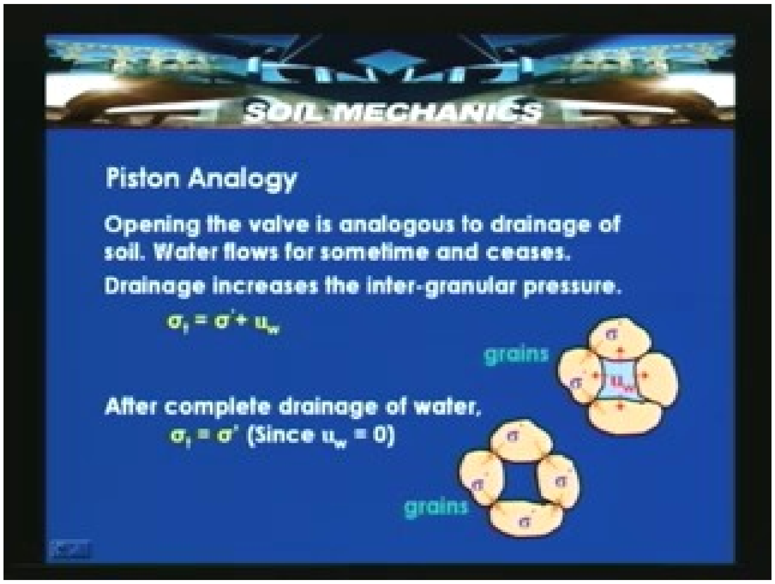

So once the water escapes from the pore spaces, previously the water which is there in the soil mass which is depriving from the grain to grain contacts. Because of this there is no chance for the grains to come in contact and then mobilize the stresses. Having water escaped from the soil mass, they are in a position to apportion the load by mobilizing the grain to grain interaction. So σ_t the total stress is equal to $\sigma' + u_w$. $\sigma_t = \sigma' + u_w$ after complete drainage of water σ_t is equal to σ'. Once the pore water pressure entirely escapes, since u_w is equal to 0 when the pressure is relieved then after complete drainage of water under no flow condition $\sigma_t = \sigma'$.

We have seen a concept of the effective stress and the first equation in geotechnical engineering which is defined as $\sigma' - u =$ total stress. We said that the total stress we applied to the soil mass is apportioned by the grain to grain contact level that is at the effective stress and as well as the pore water pressure.

This slide given below shows that intergranular stress or effective stress concept where we will try to derive or deduce the equation $\sigma = \sigma' + u_w$. In this lecture we have tried to introduce the concept of effective stress with a spring analogy or a piston analogy model and saying that the total stress is equal to effective stress plus u_w.

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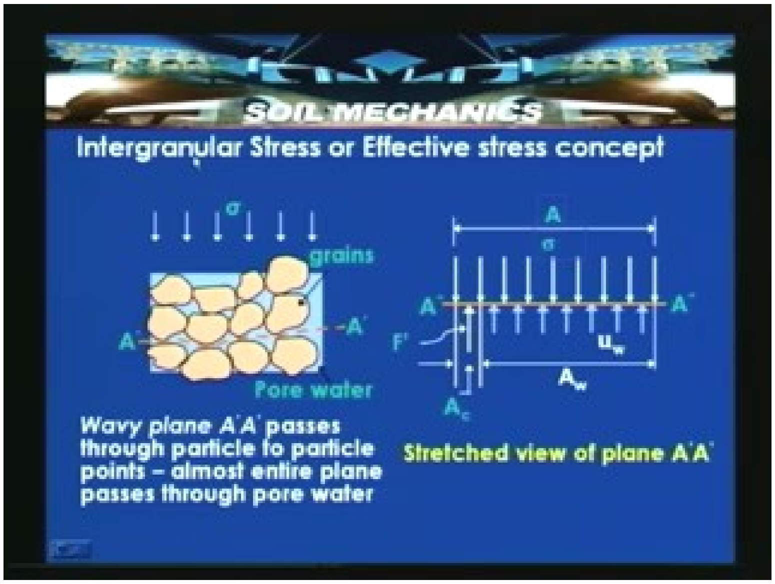

Also defined the total stress in case of a homogeneous soil mass with and without impounded water and subsoil with different stratifications as well as with different types of soils and then their contributions. We also defined the pore water pressure or neutral pressure. So in the next class we will introduce the effective stress concept and we will try to deduce these equations under no flow conditions and in the flow conditions.