Expansive Soil

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Lecture: 3

Engineering Properties of Soil

Hello everyone, welcome to the course expansive soil. This will be the third lecture of this module one, and we will continue with the introduction to soil mechanics. Today we will be learning about the engineering properties of the soil. This lecture will be divided into two class, and today I will be discussing about some of the engineering properties of the soil. And the remaining we will discuss in the next class. First of all, what is the meaning of engineering properties of the soil?

In the previous class, we learned about the index properties of the soil. In that class, we learned about the Atterberg limits, like liquid limit, plastic limit, shrinkage limit, and the soil classification. Generally, the index properties of the soil tells the qualitative analysis or qualitative behavior of the soil under any given condition. For example, if a soil is having a higher value of liquid limit, then the soil will be subjected to a higher compressibility, or soil will be having a lower value of hydraulic conductivity.

Similarly, a clayey soil is expected to have lower value of bearing capacity as well as low value of hydraulic conductivity. But the index properties will not tell about what will be the its compressibility, or what will be its permeability, what will be its shear strength. The index properties will only inform us about the qualitative behavior, not the quantitative behavior. So, in order to understand the quantitative behavior of a soil, like a quantitative analysis, like how much soil is going to settle under a given load, what should be the permeability under a given load, we need to understand the engineering properties of the soil.

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So, by definition, the engineering properties of soils are those properties, which can be used for quantifying the engineering behavior of the soil, and they can be listed below as the compaction characteristics, the permeability, the compressibility and consolidation characteristics and the shear strength. These are the four main engineering properties of the soil which we should be quantify to know about the soil behavior. The first of all, I will start with the compaction characteristics.

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Generally, if a soil is loose, it will have a lower value of shear strength, and when we construct any structure above that soil, the soil will undergo a large amount of settlement, and also since its bearing capacity will be low, the soil may also fail in shear. Therefore, we need to compact the soil to a higher density to achieve a higher value of bearing capacity, and lower value of settlement when a structure is constructed.

Therefore, compaction we need to carried out on a soil to densify it to increase its bearing capacity, or increase its shear strength. The compaction can be defined as a process of densifying the soil by application of mechanical energy. In the process of compaction the soil grains are arranged in more closely fashion, and the volume of the air gets reduced and the density will get increased. Here we should not get confused between the compaction and consolidation, in both the process the volume of the soil will get decreased.

But in compaction, here we can see, the soil will be unsaturated state; whereas, in consolidation soil will be in saturated state. In compaction the air will be there and during the compaction process the air will get expelled out from the soil. Therefore, there will be a volume change will occur due to this expulsion of the air. Whereas, in consolidation, here we can see, since the soil is fully saturated, there will be no air in it and the volume decrease takes place only because of the expulsion of water.

Therefore, in compaction the volume decrease takes place due to the expulsion of air, whereas, in consolidation the volume decrease takes place because of the expulsion of water. So, compaction when we do it increases the shear strength of the soil, it increases the bearing capacity and stability of the soil and also it reduces the compressibility and reduces the permeability of the soil. So by definition, compaction is a process by which the soil particles become close to each other by some mechanical method. The degree of compaction of soil measure in terms of its dry density, that is the amount of soil solid that can be packed into a unit volume of soil.

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The advantages of a compaction process is to increase the shear strength of the soil, to increase the load bearing capacity of the soil, it reduces the settlement of soil, it reduces the permeability, it reduces the swelling and shrinkage behavior and it increases the stability of the soil. By doing the compaction we can achieve all these parameters which will be required for a stable structure.

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The compaction generally when we do in the laboratory, we need to determine two factors. One is its Maximum Dry Density which is known as MDD and the other one is known as OMC. So, MDD is the maximum dry density to which a soil can be compacted by a given compactive effort and OMC is Optimum Moisture content is the water content at which this MDD is achieved. So, when we do a laboratory test, we determine the MDD and OMC for a given compactive effort. Going by the methods which are available in the laboratory, generally, there are two methods by which we can do this compaction, one is modified Proctor test and another one is standard Proctor test.

As far as IS standard is concerned, the standard Proctor test can be carried out as far as IS2720, part seven and modified Proctor test generally carried out by IS2720 part eight. Here we need to understand that in modified Proctor test, a large amount of compactive effort is used and this method is used when a large amount of compaction is expected to carried out in the field. Say for example, during the construction of a runway in an airfield. There we need to have a large amount of compaction. Therefore, we need to go for a modified Proctor test rather than a standard Proctor test.

To determine the MDD and OMC, as far as the standard Proctor test, we need to take a mold, here we can see, the mold over here. The mold will be of a diameter 100 millimeter and with a height of 127.3 mm and the volume of this mold is 1000 cc. And then we have to use a rammer which will be of weight 2.6 kilogram and it will fall from a distance of 310 millimeters. Then we need to compact the soil inside this mold and the soil has to be compacted in three different layers.

So first, we will take a soil sample and we can start with a water content say about four percent if it is a coarse grained soil, and eight percent if it is a fine grained soil. So we will take a soil sample with an initial water content of 4 percent or 8 percent, then we compact the soil inside this mold in three layers and each layer will be given a 25 number of blows.

Once the layer is compacted, then another layer will be compacted over here again by giving it 25 number of blows and then third layer will also be given like this. Once the soil is compacted into this mold, then its weight will be determined and the water content of the soil will be determined. From the weight and the volume of the soil we can determine the bulk unit weight or γ and from the water content and bulk unit weight relationship we can get the,

$$\gamma_d = \frac{\gamma}{1+w}$$

Now for another, water content, again we will determine the γ_d value γ_d corresponds to that water content.

Say for example, γ_{d1} corresponds to water content w_1 γ_{d2} corresponds to water content w_2 and so on. Then we will plot a dry density and water content plot and we will get a compaction curve of this shape. Similarly, we can use a modified Proctor test, for compacting at a higher energy. In the modified Proctor test, the volume of the mold can be 1000 cc or 2250 cc depending on the soil type.

If the soil retains more than 25-20 percent on a 4.75 mm sieve, then we have to take the bigger mold, otherwise we can take the small mold. And in this case since the energy is more, we have to use a larger or heavier rammer which will be of weight 4.9 kilogram and this will fall from a distance of 450 mm. And the soil will be compacted in five layers and each layer will be given 25 number of blows and then we can plot the dry density and water content relationship. From this compaction curve, we can determine the OMC value and the MDD value. So, this MDD and OMC value corresponds to for the standard Proctor test method. Similarly, for modified Proctor test, we can also determine the MDD and OMC value.

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There are a few factors which can affects the compaction. The first one is water content, as we have seen in this graph, as we increase the water content, the dry density of the soil gets increased. The increase in the dry density due to increase in the water content can be explained in terms of diffuse double layer theory as well as lubrication theory.

At this is the plot for dry density and water content. At dry side of the OMC, generally, if this is the OMC this side is known as the dry side and this side is known as wet side. On the dry side of the OMC, when the water content is very less, the soil will be very stiff in nature and also a large number of voids will be there. When we add water these soil particles get lubricated and when we compact the soil they move into a closer packing, therefore, the density of the soil gets increased. Once they reach to the peak value, over here that is the γ_{dmax} value, the amount of air volume will remain constant. So, a further addition of the water will not increase the density of the soil or not decrease the volume of the soil, rather it will increase the volume of the soil and therefore, the density of the soil will get decrease. In terms of the diffuse double layer theory, the soil on the dry side of the OMC at less water content will be in a flocculated state. Therefore, there will be a large number of void present in between them. Once we apply or once we compact the soil this soil bonds get broken and the soil moves to a more oriented way therefore, it will move to a closer packing.

And once we reach the OMC value, it will give a maximum density. After a further addition of the water content, the diffuse double layer developed completely and that will also increase the repulsive pressure between the soil particles and a further compaction of the soil will not increase the volume because the repulsion of the particle will resist the further movement of the soil particles.

Therefore, the density of the soil will get decreased. In summary, with increase in the water content, the dry density of the soil will get increased up to OMC value and once we reach the OMC value, the dry density of the soil will decrease.

The next factor which controls the compaction is the compactive effort. When we compact the soil with a higher energy, the maximum dry density of the soil will increase and the water content of the soil will decrease.

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We can see that one in this graph. Here we can see the modified Proctor test in which the compactive effort is quite high in comparison to the standard Proctor test where the compactive effort is less. So due to this high compactive effort in modified Proctor test the maximum dry density of the soil will be higher in comparison to the standard Proctor test. But if we compare the OMC value, the soil compacted with a high compactive effort will have a lower value of OMC in comparison to soil compacted at a lower value of compactive effort.

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Therefore, higher compactive effort gives a higher MDD maximum dry density and lower OMC value.

The next factor which controls the compaction of the soil is a type of soil. Here we can see different types of soil and their compaction curve for a given compactive effort. Depending on the soil type, the MDD and the OMC of the soils are also found to be different.

A well graded soil generally possess a higher density at a lower water content comparison to a high plastic clay. Say for example, a well graded sand can be compacted up to a density of 1.8

gram per cc at a water content of say 16 percent, whereas, for a high plastics clays such as bentonite will have a density of 1.3 gram per cc and at a water content of 34 percent.

So, this is the MDD and OMC for a well graded sand and this is for a high plastic clay such as bentonite. This indicate that soil containing a higher amount of clay will have a lower value of density at a higher water content and the soil which is well graded can be compacted to a higher density at lower water content.

There are a few other factors which can also affect the compaction. First one is the method of compaction. Generally, the soil can be compacted in three ways; one is by kneading action, second one is the dynamic action and a static by static action. Depending on what type of compactive effort we are giving to the soil, the density of the soil can all also be different. Apart from this, there is if we add admixture to the soil, the MDD and OMC value of a soil can be changed. Say for example, if we take this clayey soil and if we add some cement or lime to it, then this soil can be compacted to a very high density at lower water content. Therefore, by adding admixtures the maximum dry density and optimum moisture content of a soil can be changed.

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Next is the soil properties which gets affected due to the compaction. The first one is the structure of a soil. This is a compaction curve which shows for two different compactive efforts, a high compactive effort and for a low compactive effort. And the three different points has been taken point A the soil is in very dry state, B the soil is it at OMC and MDD state, and C is in wet side of the OMC. At A point, where the water content of the soil is less, the soil structure will be flocculated. We can see over here, but with the addition of the water the particles orientation will change and it will be moved toward more parallel structure.

So, here we can see at B the soil will be more parallel structure. And once we again move from B to C by adding more water more of the structures will becomes oriented or dispersed. Therefore, when we compact a soil from A to B or and B to C the randomness or flocculated structure of the soil changes to oriented or dispersed state.

Therefore, for a given compactive effort soil compacted on dry side of the OMC exhibit a flocculated structure and soil compacted on the wet side of the OMC will have a oriented or dispersed structure. So, here we can see at A the most of the particles are random or flocculated, and at C most of them are oriented or dispersed for any compactive effort.

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Here also we can see the amount of randomness and parallel structure for different water content. This is at dry side of the OMC, this is OMC, and this is at the wet of OMC. So we can see over here, at dry side, the particles are more random and as we increase the water content, the particles move toward more oriented structure or becomes more parallel, and when we increase the water content up to the wet of OMC over here, most of them are parallel. So, therefore, with addition of the water, the particle structure changes from random to parallel or then flocculated to dispersed.

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Next is the permeability of the soil.

The permeability of a soil for a given compactive effort also depends on the way in which the soil has been compacted. If the soil is compacted on the dry side of the OMC, it will have a more flocculated structure, therefore, its hydraulic conductivity will be higher. As we increase the water content, the particles become more dispersed and the hydraulic conductivity will keep on decreasing. So here we can see, the hydraulic conductivity is decreasing with the addition of the water to the soil sample and once it is reached to its OMC value, then it will become almost constant and with the further addition of the water the hydraulic conductivity will not decrease significantly.

Therefore, for a given compactive effort, the permeability decreases sharply with increasing the water content on the dry side of the OMC. This reduction in the permeability with the increase in the water content is less on the wet side of the OMC in comparison to the dry side of the OMC. The next comes the compressibility of the soil. The compressibility of the soil depends on the stress level, whether the low stress is applied or high stress is applied. Depending on the stress level, the behavior of the soil will be different. Say for example, if we take a soil sample which is compacted on the dry side of OMC and soil compacted on the wet side of the OMC assume both the soil are having the same void ratio.

Now, if we compact both the soil then the soil which is compacted on the wet side of the OMC will be compressed to a higher value in comparison to soil compacted on the dry side of the OMC. This is because of this structure or this flocculated structure will prevent the soil from getting compressed. Therefore, at low stress, it will be difficult to break this bond, therefore, the soil will get compressed to a less extent in comparison to wet side of the OMC structure where due to high void ratio the particles can be compressed to a large extent. But once we reach to a high stress level, the high stress can break this bond between the particles or the structure between the particles, therefore, the soil compacted on the dry side of the OMC will be compressed to a higher value. At the same time the soil compacted on the wet side of the OMC has already been compressed to a lower void ratio and the particles will come very close and now their repulsive pressure will resist the further reduction in the void ratio. Therefore, the soil compacted on the wet side of the OMC will be compressed less. Hence, we can say that, depending on the stress level, the compressibility of the soil will be different. A soil compacted on the dry side of the OMC will be compressed to a lower value at low stress level in comparison to a high stress level where it can be compressed to a higher void ratio it can be compressed to a lower void ratio.

Similarly a soil compacted on the wet side of the OMC at low stress level, it will be having a higher value of compressibility. But at a high stress level, the compressibility of the soil will decrease. And the soil compacted on the dry side of the OMC will have a lower value of compressibility at low stress level and at high stress level the compressibility of the soil compacted on the dry side of the OMC will be more.

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Next is the swelling and the shrinkage phenomena. The swelling of a soil compacted on the dry side of the OMC will be more in comparison to the soil compacted on the wet side of the OMC.

With increase in the water content, we can see, the swelling tendency of the soil will decrease. This is because at dry side of the OMC the soil will be in a desiccated state and the suction value will be more therefore it will tends to swell more when the water is allowed to absorb. Therefore, the swelling of a soil compacted on wet side of the OMC will be more in comparison to soil compacted on the wet side of the OMC.

Similarly, if we consider the shrinkage behavior, when the soil is compacted on the dry side of the OMC, less amount of water will be available for the shrinkage, therefore, the total shrinkage of the soil will be less. But soil compacted on the wet side of the OMC, over here, will have a more amount of water and therefore, the shrinkage will be more since the shrinkage takes place because of the evaporation of the water from the soil. Therefore, large amount of water means large amount of shrinkage. And, hence, we can say that with increase in the water content the shrinkage of the soil will also increase.

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Next is the stress-strain relationship. This graph compares the stress-strain relationship between a soil compacted on dry side of the OMC and soil compacted on the wet side of the OMC. A soil compacted on the dry side of the OMC resist the deformation upon application of deviatoric stress, and then the stress strain curve will rise steeply to a peak value and then it is falls off as the inter particle bond gets broken at this point.

However, if the soil is compacted on the wet side of the OMC it will have a flatters stress-strain curve without any peak. Therefore, the soil shows a brittle behavior when it is compacted on the dry side of the OMC and it shows a ductile behavior when it is compacted at the wet side of the OMC.

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So, all can be summarized over here. This is a water content-dry density relationship. This is a compaction curve. This is the OMC. This side of the OMC is known as dry side of the OMC, water content higher than the OMC is known as the wet side of the OMC. So, depending on whether the soil is compacted on the dry side of the OMC or wet side of the OMC, the behavior of the soil will be different.

Structure, if it is compacted on the dry side of the OMC it will be flocculated, if it is compacted on the wet side of the OMC it will be dispersed. The water deficiency will be high if it is compacted on dry side, low it will be compacted on wet side. The permeability will be high if it is compacted on the dry side and low if it is compacted on the wet side.

The compressibility at low stress will be low for dry side compact dry side compacted soil and high at high stress level for dry set of the compacted level. Similarly, if a soil compacted on the wet side of the OMC, at low stress level the compressibility will be high and at high stress level the compressibility will be low.

The swelling of a soil compacted on the dry side of the OMC will be high in comparison to wet side of the OMC. The shrinkage for a soil compacted on the dry side of the OMC will be low in comparison to compacted on the wet side of the OMC. And stress-strain relationship for a soil compacted on the dry side of the OMC, it will be brittle with a peak value, whereas, on the wet side it will be ductile with no peak value. So, these are the different properties of the soil which we can obtain by compacting of the soil.

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Now, there are several methods by which the soil can be compacted in the field. Mostly it will be it can be done by some rollers or tempers or vibrating plates. So, depending on the soil type we can use different methods. For example, if it is a cohesion less soil, then smooth wheel rollers are suitable for compacting layers of in small thickness, whereas for large thickness, we can use the vibrating rollers. If the soil is a cohesive soil, say for example clayey soil, then in that case we can use a sheep foot roller for compacting the soil.

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The next is the permeability of a soil. The permeability of a soil defined is the property of a soil which describes quantitatively the ease with which water flows through a soil. If we take a soil sample and if we look through the soil carefully we will find the void space. If the voids are interconnected, then water can flow through the soil very quickly. If the voids are not interconnected, then water will flow through the soil very slowly.

So, depending on the water can flow through the soil quickly or slowly, the soil can be termed as pervious soil or impervious soil. In impervious soil, the flow of water will be very slow, whereas, in pervious soil the flow of water will be very high. In order to do the seepage analysis or flow through a soil, we need to understand the permeability behavior of a soil.

Generally, the permeability behavior of the soil is explained in the terms of Darcy's law, the law says that, for a laminar flow, in a homogeneous medium, the velocity of flow is proportional to hydraulic gradient. That means, v is proportional to i, where v is the velocity of flow inside the soil and i is the hydraulic gradient which is the, the ratio between the head loss to the length of the soil. Say for example, in this case take a soil sample with the length L and one head is provided to cause this flow. And, in here we can see, the water is escaping out here and the head loss which is causing this flow is H_L that is the head the head difference between the entry point and the exit point.

So,

$$\text{Hydraulic gradient} = i = \frac{\text{Head loss}}{\text{L}}$$

And the velocity at which the water is flowing inside the soil let be v, then

$v \alpha$ i; and $v = k i$

k is known as coefficient of permeability. So, depending on the soil type the k value can be different. Say for example, for a gravel, which is very pervious in nature, the hydraulic conductivity can be 10 to 100 millimeter per second if we take fine sand the k value can be 10^{-4} to 10^{-2} millimeter per second.

If it is a clay soil, then it the hydraulic conductivity can be 10^{-8} to 10^{-5} millimeter per second. So, depending on the soil type, the permeability can also be different. If the permeability is more than 10^{-3} millimeter per second, the soil can be known as pervious. If it is in between 10^{-3} to 10^{-5} millimeter per second, it will be known as semi-pervious. And if it is less than 10^{-5} millimeter per second, then it will be known as impervious soil.

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The permeability of a soil can be determined in the laboratory by two methods. One is known as constant head method, the other one is known as falling head method. So, depending on the soil type, either of these method can be used. Say for example, if it is a coarse-grained soil for which the hydraulic conductivity will be very high, then we can use the constant head method, if the soil is a fine-grained soil, where the hydraulic conductivity is expected to be very low, then we can use the falling head method. In constant head method, the head which is causing the flow will be kept constant.

For example, in this case, the h or the head which is causing the flow will be kept constant during the flow and the water which is being discharged through the soil will be collected. Let Q amount of water get discharged in time t and which is caused by a head h which will be kept constant and if L is the length of the soil,

$$\text{Permeability} = k = \frac{\text{QL}}{\text{Aht}}$$

So, this is applicable for a coarse-grained soil. But for fine grained soil it will be very difficult to keep the head constant.

So, therefore, we can go with the falling head method in which h_1 is the initial head and at a time t the head decreased to h_2,

$$\text{Hydraulic conductivity} = k = \frac{\text{aL}}{\text{At}} \log\left(\frac{h_1}{h_2}\right)$$

Where, h_1 is the initial height which had decreased to h_2 value in time *t*, *a* is the cross sectional area of this tube, *A* is the cross sectional area of this soil sample, *L* is the length of the soil sample and *t* is the time required to decrease the head from h_1 to h_2. So, by knowing this we can calculate the permeability of the soil and this method is suitable for a fine-grained soil.

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Next, we will see what are the different factors which controls the permeability. Permeability is directly proportional to particle size of the soil. Permeability is directly proportional to square of the particle size of the soil sample, higher is the particle size higher will be the void between the soil and higher will be the permeability.

Next, it depends on the soil structure. The permeability is higher for a soil with a flocculated structure in comparison to soil with a dispersed structure. So, which we have seen earlier also that in flocculated structure, there will be large amount of void present between the soil sample and therefore, the permeability of the soil will be higher.

Whereas, in dispersed structure permeability will be lower. Similarly, it also depends on the stratification of the soil layer. For a stratified soil deposit the permeability will be higher for a flow which will be parallel to the plane of stratification and permeability will be lower for a flow perpendicular to the plane of the stratification.

Then the void ratio. Void ratio plays an important role in defining the permeability of the soil. Higher is the void ratio higher will be the permeability of the soil, there are different equations given. This is given by Taylor's.

So, other researcher says that, it can also depend on

e^2 or

$$\alpha \frac{e^2}{1+e}$$

But if we plot between the hydraulic conductivity and the void ratio, we will see that hydraulic conductivity of the soil will increase with the void ratio of the soil. Now, if we draw the *e*-log *k* plot for two different soil, say for example, this is soil one and if we draw for another soil sample like this, and if we draw a line correspond to the same void ratio, we will see that the two soil at same void ratio will exhibit two different values of *k*.

Therefore, this relationship holds for any particular soil. That means, for this soil only the relationship between *k* and *e* will be only valid, whereas, for this one, the relationship between *k* and *e* will be valid. So, therefore, we can see that the permeability of the soil will increase in this way for this type of the soil, whereas, for this soil it will follow this curve. Therefore, depending on the soil type or for different soils, the curve between the *e* -log *k* value will be different.

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Next is the properties of the Permeant fluid. The coefficient of permeability is inversely proportional to viscosity of the fluid, higher is the viscosity of the fluid lower will be the permeability. And we know that the viscosity also depends on temperature, generally viscosity will increase with increase in the temperature. Therefore, the permeability also increase with the increase in the temperature. We can see over here, the variation of permeability with the viscosity over here. If the k_{27} is a permeability at 27 degrees centigrade and kt is that permeability at t degrees centigrade that will be equals to μ_t by μ_{27}.

So, that means, the permeability of the soil also get changed due to the change in the viscosity of the soil.

Next comes the degree of saturation. The permeability of the soil gets affected in the presence of air. Generally, the decrease in the degree of saturation, the permeability of the soil will gets decreased. Since the presence of the air will block the flow passage, therefore, the permeability of the soil will also decrease.

There are a few other factors which also can control the permeability of soil sample. Say for example, presence of impurities, in the form of salt solution or contaminants. So, presence of salt solution or contaminants can adversely affect the permeability. With increase in the salt concentration, the permeability of the soil will increase. Similarly, if there is a contaminant present in the terms of organic or inorganic or heavy metals, the permeability of the soil will also gets affected. Generally, it will increase with the due to the presence of impurities in the pore fluid.

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Now, when we talk about soil sample, we know that in actual field the soil are present in different layers. So, depending on whether the flow is flowing along the plane of stratification or flowing perpendicular to the plane of stratification, the hydraulic conductivity value can be different. Say, for example, take a soil sample which is consisting of three different layers, layer

1, 2 and 3 with a thickness of H_1 and permeability value k_1, H_2, k_2, H_3, k_3. If the flow is moving parallel to the plane of stratification like this, then the

Permeability in horizontal direction $=k_h = \frac{k_1H_1 + k_2H_2 + k_3H_3}{H_1 + H_2 + H_3}$

Here we need to remember that, the head loss of water from moving from point A to B will be same, whereas, different amount of discharge will be taking place through each layer and the total discharge;

$Q = q_1 + q_2 + q_3$

Where, q_1 is the discharge in layer one, q_2 is the discharge through layer 2, q_3 is the discharge through layer 3.

In this case, the flow is taking place perpendicular to the plane of stratification and the k_v value the hydraulic conductivity in vertical direction will be equals to

Permeability in vertical direction $=k_v = \frac{H_1 + H_2 + H_3}{\frac{H_1}{k_1} + \frac{H_2}{k_2} + \frac{H_3}{k_3}}$

So,

$$h = h_1 + h_2 + h_3$$
$$q = q_1 = q_2 = q_3$$

and here the discharge through each layer will be same, and here we need to remember that the k_h will always be greater than the k_v, that means, the flow perpendicular to the plane of stratification will always be slower in comparison to the flow parallel to the plane of stratification.

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Next comes the effective stress. Generally effective stress is useful in deriving the soils engineering behavior particularly consolidation and the shear strength behavior. So, these two behaviors mostly governed by the effective stress of a soil sample. Say for example, take a soil which is fully saturated, here, when we apply a load say P initially all the load will be taken by the water and as a result of which the pore water pressure will increase. And with time this pore water pressure starts to dissipated. As the pore water pressure starts to dissipated, the soil will get compressed and then the load will be transferred gradually through this point of contact between the solid particles.

So, this point the stress at the point of contact between the solid particles is known as the effective stress. So by definition, effective stress is the total amount of force transmitted at the point of contact divided by the total area of the soil is known as the effective stress. And total stress is that the load which is coming on to the soil and pore water pressure is defined as the pressure which is exist in the water present in the soil pores. So, we need to determine the effective stress from the total stress and the pore water pressure.

Here we need to remember one thing that effective stress has no physical meaning and it is cannot be determined, it has to be determined indirectly from the total stress and the pore water pressure. And the shear strength and consolidation characteristic of a soil is a function of the effective stress, higher is the effective stress, higher will be consolidation or settlement of the soil and higher will be the shear strength of the soil. And when there is a decrease in the depth of the water table, the effective stress of the soil will gets increased.

For a partially saturated soil, the effective stress can be expressed using this formula,

$$\sigma' = \sigma - u_a + \chi(u_a - u_w)$$

Where,

u_a =Pore air pressure

u_w = Pore water pressure

χ =Fraction of area of soil occupied by water

For a dry soil this χ value is 0 and for a fully saturated soil it will be equals to 1. So, for a dry soil when it becomes equals to 0,

$\sigma' = \sigma - u_a$

$\sigma' = \sigma - u_a + (u_a - u_w) = \sigma - u_w$

So the final equation becomes like this for a fully saturated soil sample. So, with this I am concluding today's lecture. In the second part of this lecture, I will be discussing about the consolidation and shear strength characteristic of the soil. These are the few of the references which has been used for preparing this class. And thank you for your kind attention.