Geology and Soil Mechanics
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Lecture - 29
Consolidation - A

So, today we will be taking one more example on seepage, so that is problem 15.

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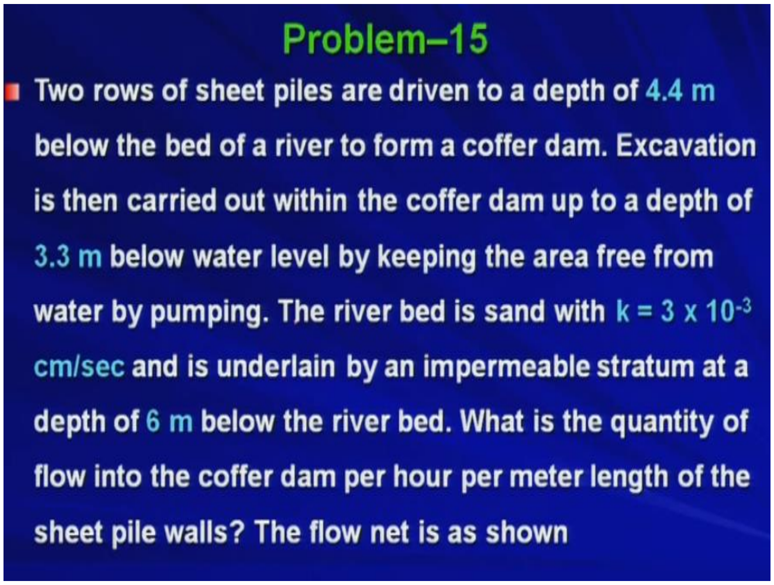

The problem says that 2 rows of sheet piles are driven to a depth of 4.4 m below the bed of a river to form a coffer dam okay. So, excavation is then carried out within the coffer dam up to a depth of 3.3 m below water level by keeping the area free from water by pumping. The river bed is sand with k that is coefficient of permeability is equal to 3 into 10 to the power of minus 3 cm/sec and is underlain by an impermeable stratum at a depth of 6 m below the river bed. What is the quantity of flow into the coffer dam per hour per meter length of the sheet pile walls. The flow net is as shown. So, flow net is shown there.

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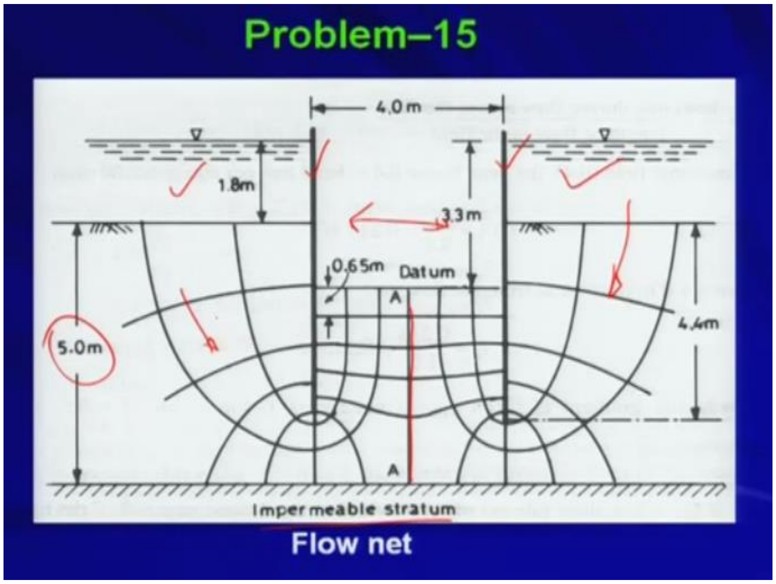

So, if you look at the flow net. So, first let us understand the problem. So, you have a row of sheet pile. So, this is one row of sheet pile. This is another row of sheet pile which goes parallel okay. So, this 2 sheet piles go parallelly and within that zone basically you want to excavate, so this is within that zone you want to excavate okay so and you need to find out the flow, seepage flow rather and you need to find out that how much or what should be the rate of pumping so that you will be having some dry working condition inside the coffer dam.

So, this 2 sheet piles I mean row of sheet piles will make the coffer dam will construct the coffer dam and inside the coffer dam then you will pump the water so that you will be having some dry working condition and you will be excavating the soil from the coffer dam. So, now you have water level on both the sides right. So, 1.8 meter height of water okay on the other side of the sheet pile and the depth of permeable stratum so that is 5 m okay.

After that you have the impermeable stratum and basically if you consider this problem this problem is very symmetric problem right. So, if you consider the line AA, so this is the line. So, with respect to line AA this problem is symmetric problem. Am I right? So, if you consider the left side of the dam I mean coffer dam or the right side of the coffer dam you will be getting the same amount of flow because I mean if you consider the right side of the coffer dam so flow will be happening in this direction okay.

If you consider the left side of the coffer dam so flow will be happening in this direction. So, any one side if you consider and if you can find out the seepage flow then that will basically serve your purpose okay. So, now let us solve this problem.

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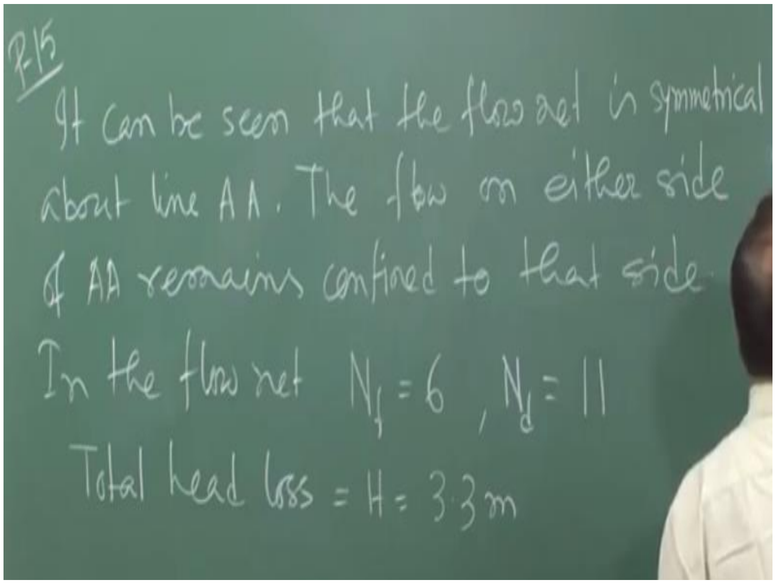

It can be seen as I told you that the flow net is symmetrical about line AA. The flow on either side of AA remains confined to that side okay. So, that means no cross flow is happening across the line or the plane AA okay. So, in the flow net what is your N f? What is your N f? So, number of say flow channels. So, if you consider left of the coffer dam that means I am considering this side of the coffer dam, so how many flow channels are there?

So, if you count so basically you can find out how many flow channels you will be having right. So, if you look at this flow net you will be having 6 number of flow channels right. N f equal to 6, 3 on either side. So, total number of flow channels will be 6 okay and number of potential drops, number of potential drops will be 11 if you see. So, total number of potential drops is 11.

So, total head loss is equal to H is equal to how much 3.3 m if you see that is the difference between the upstream side water top water level to the downstream side top water level. So, in the downstream side means within the coffer dam itself am I right. So, downstream side means within the coffer dam itself. In the coffer dam, itself you do not have any water level because you want some dry working condition okay. So, H is nothing but 3.3 m as shown in the problem itself.

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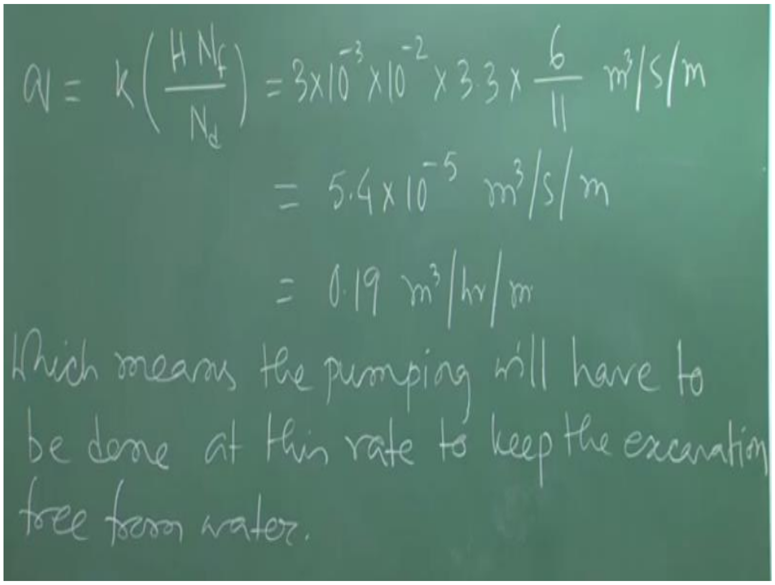

So, therefore we can calculate q is equal to K into H N f by N d which is equal to 3 into 10 to the power minus 3 into 10 to the power minus 2 into 3.3 m into 6 by 11 meter cube per second per meter width of the coffer dam. So, that gives me 5.4 into 10 to power minus 5 meter cube per second per meter width which is equal to 0.19 meter cube per hour per meter. So, which means the pumping will have to be done at this rate to keep the excavation free from water.

That means if you want to have some dry working condition inside the coffer dam so that means if you do not allow any water level in the downstream side basically you need to pump the water from the coffer dam at this rate that is 0.19 meter cube per hour per meter width of the coffer dam okay. So, I will I will stop here. So, this is this whole problems, 4 numerical problems we have considered from the seepage analysis. Now we will see the or we will discuss about the next topic that is consolidation or the fundamental of consolidation.

So, now we will consider another very important chapter in soil mechanics that is fundamental of consolidation.

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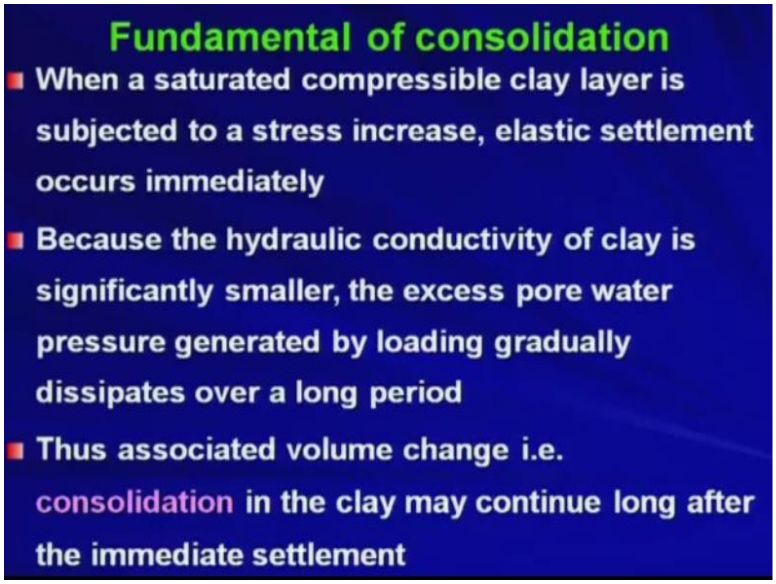

So, when a saturated compressible clay layer is subjected to a stress increase, elastic settlement occurs immediately right. So, you have some saturated compressible clay layer and on top of that you are increasing the stress that means you are applying some load and because of that you will be getting immediately you will be getting some elastic settlement okay. Now because the hydraulic so at that time so nothing is happening.

So, you are applying the load on top of the saturated clay layer so immediately you will be getting some deformation and that happens due to elastic settlement. So, that can be recoverable right. So, but because the hydraulic conductivity of clay is sufficiently smaller now after that what will happen so you apply the load and you keep the load there itself. Now immediately you will be getting some elastic settlement then after that what will happen?

Because the hydraulic conductivity of clay is sufficiently smaller the excess pore water pressure generated by loading gradually dissipates over a long period right because you know from your earlier discussion on seepage or maybe on permeability that clay is having very low amount of permeability right. Hydraulic conductivity is very low for clay. So, if you apply the load so what will happen? This load will try to I mean try to put pressure or put load totally on the water itself. Then water will try to expel out or drain out from the soil matrix and then basically the I mean your soil will be getting compressed right. But this process is very slow in case of clay because you know the permeability or hydraulic conductivity of clay is very low as compared to sand so right. So, if you apply the load then slowly or gradually the water will dissipate from the soil matrix or the soil body and then it will try to compress right. Thus, associated volume change that means the water will be going out through the pore space and finally will be draining out from the drainage path and when the water will go out basically you will be getting some reduction in the volume.

That volume will be I mean the void space the volume of void space rather the volume of void space will be getting reduced that will be squeezed right. So, this associated volume change that is known as consolidation in the clay may continue long after the immediate settlement. So, immediate settlement means that is elastic settlement so immediately some settlement will be happening but due to this expulsion of the water from the soil matrix you will be getting the settlement inside the soil I mean clay deposit and that is known as consolidation. So, consolidation is nothing but the phenomena by which the water will be going out or draining out from the soil matrix and due to which you will be getting some reduction in the volume.

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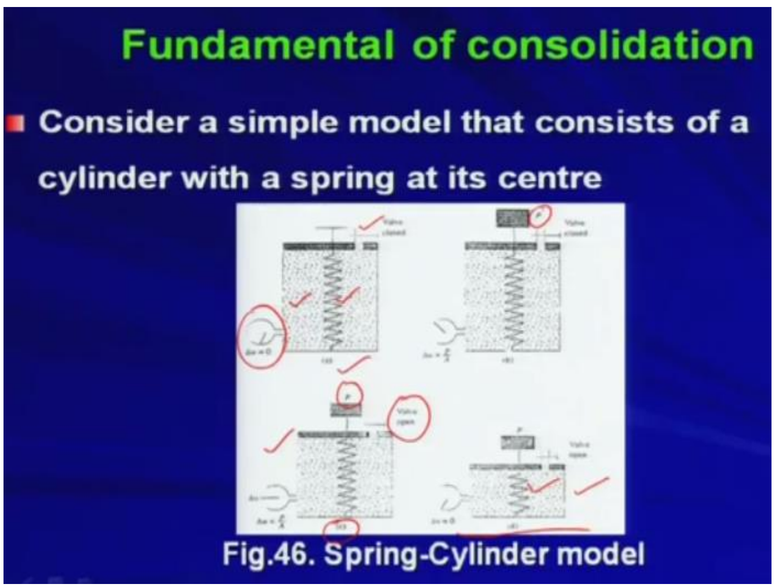

So, consider a simple model to illustrate this thing. Consider a simple model that consists of a cylinder with a spring at its center. So, this is the model. So, I mean we have 4 different steps in this model. So, in the first step the step A basically what you are considering. You are considering one cylinder okay and inside the cylinder you have some centrally placed spring okay so this is the spring which is centrally placed in the cylinder and the cylinder is full of water okay and you are you have some valve through which you can take out the water right.

So, that valve is closed initially and then you can measure the pressure I mean built up pressure inside the tank by some pressure measuring device okay. This is the arrangement. Now in this situation there is no pressure in the water as well as in the spring right. So, no extra load is coming in the water body or in the spring body right. So, in this problem basically we are considering the spring.

We are just mapping the spring as the soil solid and the water as the pore fluid okay. So, you have some soil solid and some I mean pore fluid that is water. So, soil solid is represented by the spring whereas the pore fluid is represented by the water okay so this is the arrangement. Now this is the first situation when you do not have any extra load applied on the soil body or rather on the spring.

Now what you are doing basically valve is closed so now you are applying some load on top of the spring. So, load P capital P you are applying on top of the spring. But valve is still closed right. So, if the valve is closed then you know that water is incompressible. If the water is incompressible then the whatever load whatever increment of load is happening inside the soil or the on top of the spring the whole load will be taken by the water itself because water is incompressible and you are not allowing the water to drain out that means there is no volume change or the deformation happening.

So, the total load instantaneously will be taken by the water itself okay. So, that is nothing but that is known as the I mean excess pore water pressure okay. So, those things will be coming later on when we will be discussing one by one. In the third figure, figure c what we are doing? We are now allowing that means we are now opening the valve and we are allowing the water to drain out.

Now due to this excess pressure whatever water was experiencing some excess pressure that water will be draining out and because of the water is coming out you will be getting some change in volume that means the spring will be I mean deformed right the spring will be squeezed. So, that is happening here. So, now what is happening? So, whatever water has gone out right through the drains now whatever load increment was there that is capital P nothing but capital P so that load increment now will be getting transferred from the water to the spring body and that is why the spring got deformed right.

Then in case of fourth figure so this is something like the continuous process. So, you open the valve and the water is slowly I mean going out slowly draining out and that load will be getting transferred to the water to the spring gradually. Now once at the final stage at infinite time say your total water excess I mean pore water pressure is getting dissipated so that means the total water whatever I mean the total load from the water excess I mean additional load from the water it will be getting transferred to the spring itself. So, now it is the stable configuration right. There is now if you keep the valve open there will be no flow of extra water right.

So, whatever was there for the extra load so that has come out I mean that water has come out. Now this situation is completely stable situation. There is no water is draining out and now the I mean whatever water is there will be no extra load in the water body rather the whole load will be taken by the spring itself right. So, this is the mechanical phenomena. Now we are going to establish that we are going to map this thing to our soil mechanics. Now let us let us do that.

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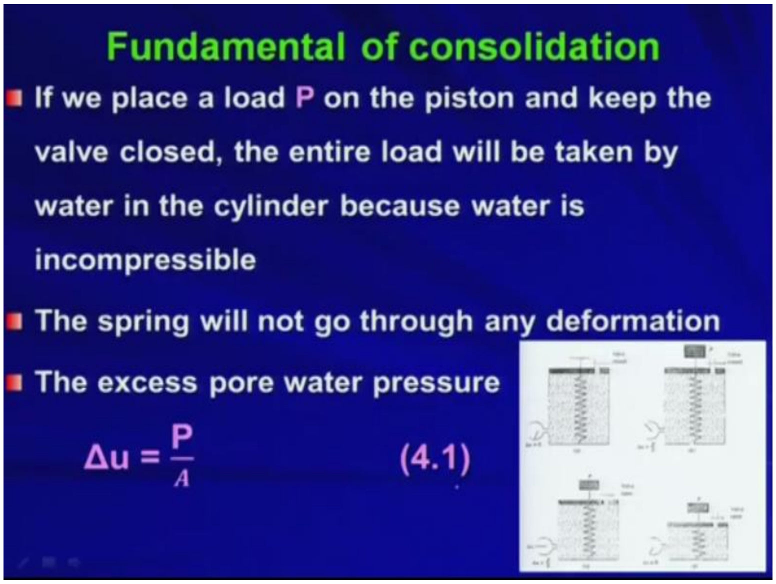

So, if we place, so we have discussed this thing now we are writing all those things and we will try to understand the phenomena clearly. Now if we place a load P on the piston okay and keep the valve closed the entire load will be taken by water in the cylinder because water is incompressible agreed. Already we have discussed and now we are I mean noting down all the things all the phenomena whatever we have discussed. The spring will not go through any deformation agreed because valve is closed.

The spring will not go through any deformation because to deform the spring you have to have some load on the spring itself but whatever excess I mean additional load you have applied that will be taken care of by the water itself. So, spring will not take care of any load. So, there will be no deformation in the spring. So, the excess pore water pressure of course will be equal to delta u is nothing but capital P that is the additional load applied on the piston divided by A that is the cross sectional area am I right. So, that is nothing but excess pore water pressure.

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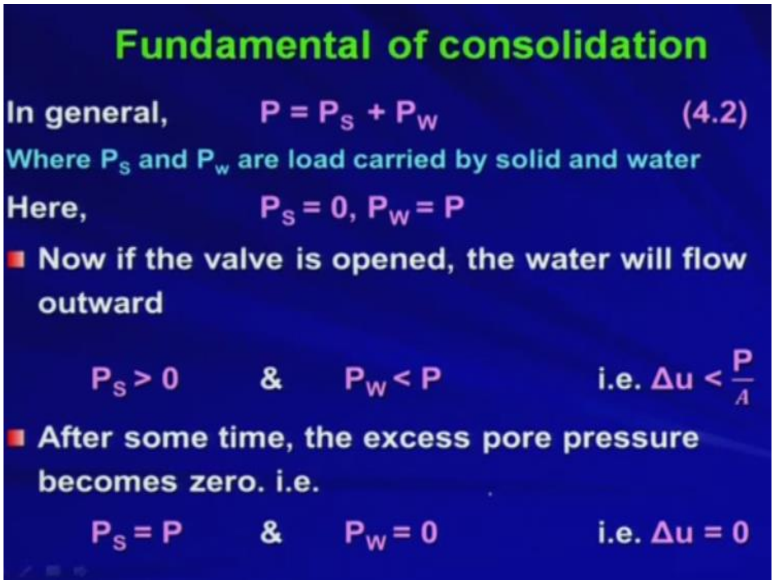

Now in general P that is the total load is equal to P s plus P w where P s and P w are load carried by solid soil solid and water right. So, I mean if you map this thing to our soil I mean soil body that is whatever I told you that spring will be representing the soil solid whereas the water will be representing the pore fluid. So, the total P whatever you have applied the total load it should be I mean carried out it should be taken care of by the soil solid some part will go to the soil soild some part will go to water.

Now based on the based on the arrangement I mean this load transfer will be happening right. If you go back to your very basic engineering mechanics or mechanics of solid class so that is similar to that right. If you have some sandwiched say material or if you have some say coupled material if you apply the load the load will be shared by those 2 different materials right. The same thing is happening here itself okay.

Now here in the initial phase when valve was closed and you have applied load P at that time P s is equal to 0 that means the spring is not taking any load that means the soil solid is not taking any load. So, P s is 0. So, whole load will be carried by the water itself. So, P w is nothing but equal to P agreed or not yes okay. Now if the valve is opened the water will flow outward. It will I mean slowly the water will be draining out.

So, P s will be gradually increasing. That means the sharing, load sharing will be happening. So, now some load will be coming from the water to the spring. Now water will say the spring okay you take care of some load because I am going out okay from the matrix. So, P s will be gradually increasing from 0 whereas P w will be gradually decreasing from P right. So, that is why P s is getting increased.

So, whatever load was carried by the water initially now that will be shared by the spring or that means the soil solid okay. So, that is the delta u excess pore water pressure will be gradually reducing from P by A. So, P by A was the actual initial excess pore water pressure. Now it will be going down, it will be reducing. After some time, okay the excess pore pressure becomes 0. So, if you consider the complete draining out of the water so whatever water will be was under pressure so that will be going out so after some I mean say significant time you will see that excess pore water pressure will be becoming 0. That means delta u is equal to 0.

That means there is no load extra load carried by the water itself. So, the whole load will be shared by the soil solid. So, that means now P s is equal to P okay. If you consider the fourth figure right there are 4 parts a, b, c, d. Now you are considering the fourth figure that is the part d. There you will if you see that P s if you try to find out P s is nothing but equal to P that means whatever load you applied initially so that was shared or that was taken care of by the water itself.

Now at the at certain time after certain time when the valve was opened and then you see the whole load was carried by the soil solid or that is nothing but the spring okay. Now in this situation what is your P w? P w will be equal to 0 because now water will not be taking any load. The whole load will be shared by the spring that is nothing but the soil solid. So, your excess pore water pressure is 0. So, you have understood the 3 steps right. One step in the initial step was P s was 0 and then the second step P s greater than 0 that is P s is gradually increasing and finally P s becomes equal to P that is the total additional load.

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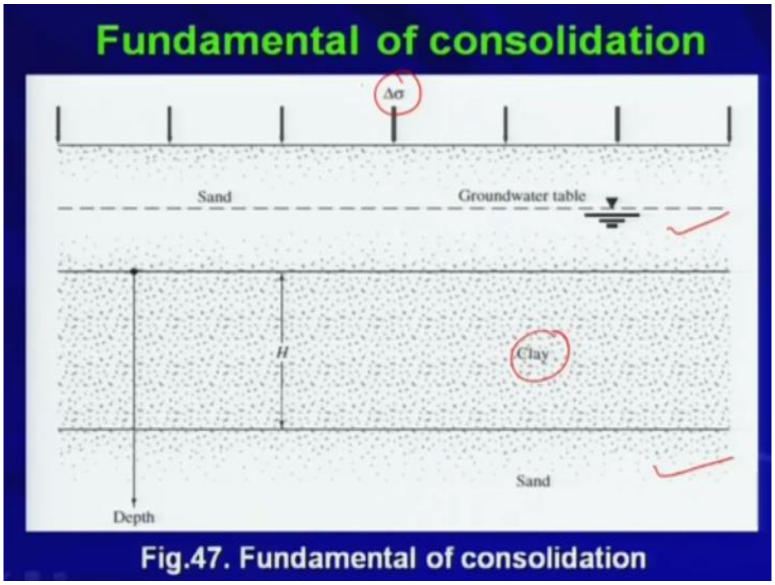

Fig.47. Fundamental of consolidation

Now if I consider some kind of say problem, say this problem says we have some sand layer on top. We have another sand layer at the bottom and we have clay layer which is getting sandwiched between these 2 sand layers okay. Now you are applying some delta sigma some additional stress additional pressure on this kind of deposit. Now what will happen? Let us see.

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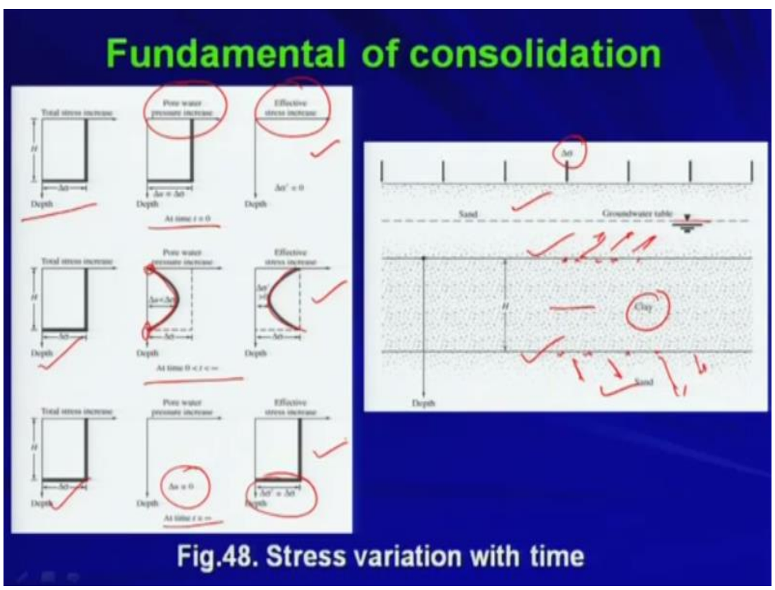

Fig.48. Stress variation with time

So, as I told you this is your clay layer. So, because if you have the water table here your sand the bottom sand layer and top sand layer will not be having any problem because if you apply the load immediately water will be draining out because of high permeability in the sand layer but in case of clay layer the water draining our of water will take some time. That is why the consolidation will happen with respect to with based on some time with respect to time right.

Now you see at t equal to 0 at time t equal to 0 just that means you just applied the extra load delta sigma okay.

Delta sigma is your extra load intensity you are applying and at t equal to 0 this is your total stress increase right okay. Now pore water pressure increase will be how much? Delta u will be equal to delta sigma as I told you that is the excess pore water pressure will be nothing but the water will take care of the whole load so delta u is nothing but delta sigma. Now what is your effective stress increase?

Effective stress increase is 0 simply 0 so delta sigma prime is 0 because total stress increase is equal to delta sigma so that due to that delta sigma immediately water will take care of the delta sigma that is the I mean stress increase. Therefore, the excess pore water pressure or the pore water pressure will be equal to delta sigma where delta e equal to delta sigma and due to that your effective stress, that means the stress carried by the soil will be equal to 0.

Now at time t greater than 0 but less than infinity that means now gradually the water will be draining out from the clay matrix or the clay deposit right slowly gradually. Then what will happen? Total stress increase will be remaining same. There is no change in the total stress, am I right, because you are not changing the value of delta sigma so delta sigma will be remaining there. So, total stress increase will be remaining same right. Whereas pore water pressure so gradually the pore water pressure will be happening. What will be happening there?

So, within this clay zone so the water particles along this surface they will be draining out because sand is a good drainage material. So, they will be draining out. So, just at the interfaces so these 2 are the interfaces right so at the interfaces you will be having immediately you will be having pore water pressure is 0 but at the middle of the layer you will be having the I mean higher pore water pressure.

So, that therefore you will be getting some curve like that so this is the pore water pressure increase okay so that means gradually initially the pore water pressure was delta sigma. Now gradually the pore water pressure is getting reduced and the same amount of stress is getting increased in the effective stress. So, you see that this is your effective stress profile am I right. So, at t equal to infinite that means the all water in the from the clay layer has been draining out drained out okay.

So, now in that situation total stress increase will be remaining same because you are not changing the stress increment. Pore water pressure will be simply 0. So, that means the water is not taking care of any pore any pressure. The whole load whole additional load is carried by the soil solid now okay. So, now effective stress increase is delta sigma prime is equal to delta sigma. So, basically you see initially it was 0 effective stress then gradually the effective stress is going on increasing and finally you have got the effective stress is equal to the total stress because your pore water pressure is becoming 0. That means the no extra load is carried by the water body. The whole load is carried by the soil body now okay.

So, I will stop here today. So, in the next class we will be continuing this consolidation theory and we will be looking at or we will be trying to understand the concept of consolidation because it is very important and based on this consolidation there are so many I mean aspects of geotechnical structure is lying so I mean you will see that one by one we will be discussing because this is very important. If you do not consider this consolidation phenomena then you will be in serious trouble when you will be designing some geotechnical structure. So, thank you very much.