Geology and Soil Mechanics
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Lecture – 36 & 37
Consolidation - F

Welcome back. So, in the last lecture we took a couple of problems on consolidation of soil deposit and today we will be taking another couple of problems on the consolidation part. So, let us see what is the problem today.

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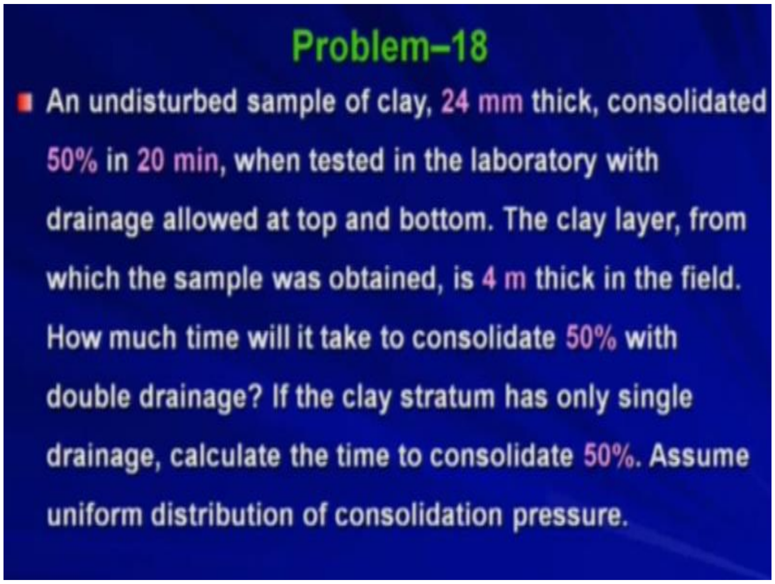

The problem 18. So, the problem says that an undisturbed sample of clay 24 mm thick, consolidated 50% in 20 minute, when tested in the laboratory with drainage allowed at top and bottom. The clay layer from which the sample was obtained is 4 m thick in the field. How much time will it take to consolidate 50% with double drainage? If the clay stratum has only single drainage, calculate the time to consolidate 50%. Assume uniform distribution of consolidation pressure.

So, the problem is you have the clay deposit okay in the field which is 4 m thick okay and now you are taking some sample or you are collecting some sample in from that particular deposit and then you are testing that thing in the laboratory. So, in the laboratory the thickness of the sample is 24 mm. That means basically you are trying I mean from this problem will be understanding the phenomena that whatever you are observing in the laboratory how you can extrapolate or how you can use or apply to the field condition, to the real field condition okay.

So, basically you have the soil sample, laboratory soil sample of 24 mm thick okay and it takes 20 minutes to consolidate 50%. That means the degree of consolidation say 50% at 20 minutes okay. So, now we are going to find out that if the soil sample whatever has been tested in the laboratory is taking 20 minutes to consolidate 50% then how much time it will take in the real field okay I mean for consolidating the or the degree of consolidation 50% right.

So, the same thing we will be applying and drainage is allowed at top and bottom in the laboratory scale and drainage is allowed that is I mean that is top and bottom means as we know from our earlier discussion that when you have the drainage condition or the drainage is allowed from top as well as the bottom.

Basically, you are calling that sample or that thing that situation is double drainage system okay and in the field also you are trying to find out the time required for double drainage system and then later on another problem another I mean statement is said that basically I mean he is asking that if you allow or if you have the single drainage system that means I mean water or the draining of water is only allowed from top or bottom right any one of these surface surfaces okay. So, if it is allowed then how much time it will be required okay. So, let us solve this problem.

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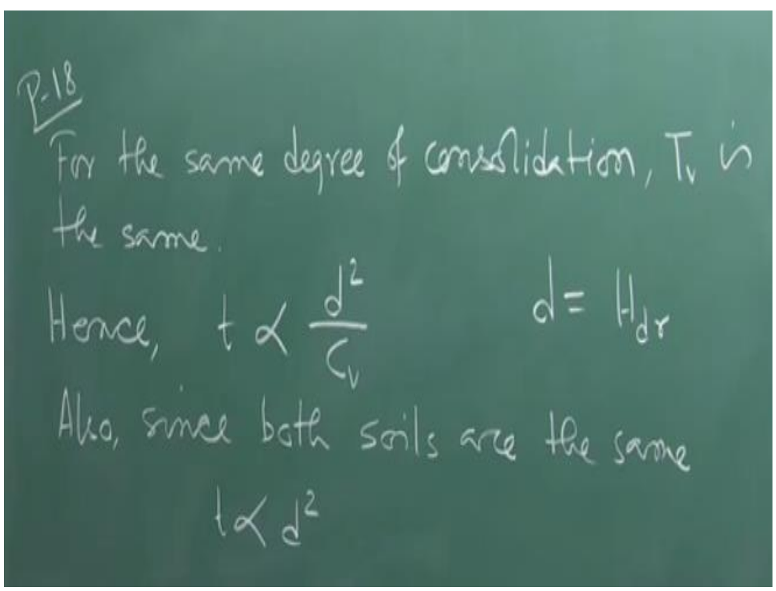

So, for the same degree of consolidation, so for the same degree of consolidation, that means if your degree of consolidation is same that is capital U if it is same then what we can conclude from that. Your time factor that is T v is the same right. So, already we have seen that T v is completely dependent on the degree of consolidation okay. So, if you have degree of consolidation 0 to 60 percent then you have one expression for T v if you have the degree of consolidation U is greater than 60% then you have different expression for T v.

Anyway, so T v is the same if your degree of consolidation is same for both the samples. Both the samples mean in field in real field as well as in the laboratory right. So, you are talking about only 50% degree of consolidation. So, T v must be same for both the situations okay. So, also so therefore we can write t the time required for 50% consolidation is directly proportion to d square by C v agreed?

If you recall the expression for your C v right so basically it was I mean if your T v is same right time factor is same then I can write the time required is directly proportional to d square by C v from our earlier discussion okay. Then also since both soils are the same both soils means in the laboratory as well as in the field both soils are same because in the field whatever soil is there from there actually you are collecting the soil sample to test it in the laboratory.

So, both the soil samples are same. If both the soil samples are same then it is not very illogical to assume the same amount of degree of I mean coefficient of permeability and same amount of other parameters like your m v and all okay. So, if they are also same because the soil is same if they are also same then I can think of C v is same for both the soil samples right. So, if C v is same then I can write t is directly proportional to d square.

I mean I can so d what is d? d maybe the new term I mean not the new actually it is something like your H dr. So, I am writing d in place of H dr. It is just matter of say different usage of the notations anyway. So, d is nothing but your H dr right. Please I mean try to understand. So, instead of writing H dr I am writing d anyway. So, the t is directly proportional to d square, d square means that is the it is dependent on the drainage path right.

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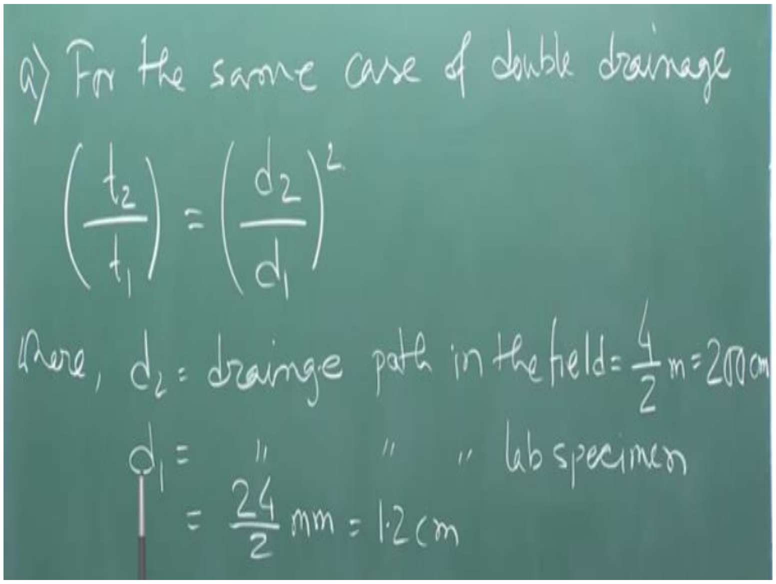

So, now for the first statement that means how much time it takes in the field at that time for the same case of double drainage that is t 2 by t 1 is equal to d 2 by d 1 whole square where d 2 is equal to drainage path in the field will be how much will you please tell me from the problem what will be the drainage path in the field. So, if I say d 2 is the drainage path in the field then what should be the numerical value of d 2, I mean from the problem. The problem says that the thickness of the deposit in the field is 4 m.

So, if you are talking about double drainage system then your d 2 must be 4 divided by 2 m right. Already we have discussed this thing earlier. So, 4 divided by 2 m so that comes as 200 say cm agreed okay. Then d 1 that is the drainage path in lab specimen will be how much? d 1 will be so 24 mm is the thickness of the lab specimen. So, if 24 mm is the thickness of the total specimen then for the double drainage system d 1 that is the drainage path in the lab specimen will be 24 divided by 2 that means 24 divided by 2 mm that is nothing but 1.2 cm okay.

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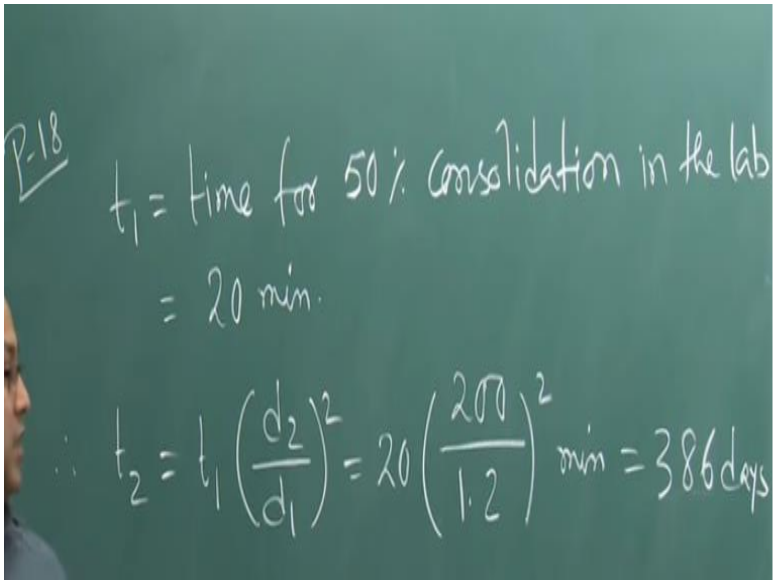

Well now t 1 that is your time required for 50% consolidation in the lab. So, what is the value of that? 20 minutes right, so it is given in the problem. That is given as 20 minutes okay. So, our objective is to find out t 2 that is the time required for 50% consolidation in the field. So, therefore I can write t 2 is equal to t 1 d 2 by d 1 square is equal to 20 into 200 divided by 1.2 whole square minute. That comes as 386 days.

So, if you convert the minute in days so basically it will be coming as 386 days. So, now you can really appreciate or really understand the material whatever you have tested in the laboratory that took only 20 minutes to consolidate for 50% consolidation right. So, the degree of consolidation was 50%. So, for getting 50% consolidation you have you took 20 minutes in the laboratory specimen right.

Same thing if you want to achieve that means 50% consolidation if you want to achieve in the field you need 386 days that means more than a year right more than a year you need to get 50% consolidation in the field. So, now you can think of I mean you can understand that it is not a matter of say few minutes or few second or few days. It could be more than a year right so that you can see from this to get only 50% consolidation.

Now if you think of or if you want 90% consolidation or say 95% consolidation then you have to give more time right. So, this is the situation I mean so that means you will be getting primary consolidation say 50% primary consolidation after 386 days. So, if you go for say 90% consolidation you will I mean it will be required I mean even more time right. So, more than 386 days.

So, I mean you have to wait till that period to get the total I mean say total primary consolidation say 90% primary consolidation or say 95% primary consolidation or whatever. So, that means the consolidation phenomena is not a very I mean say short duration say phenomena. So, you need to wait for a longer period to get the primary consolidation. Forget about the secondary consolidation. So, primary consolidation itself will take this much of time okay.

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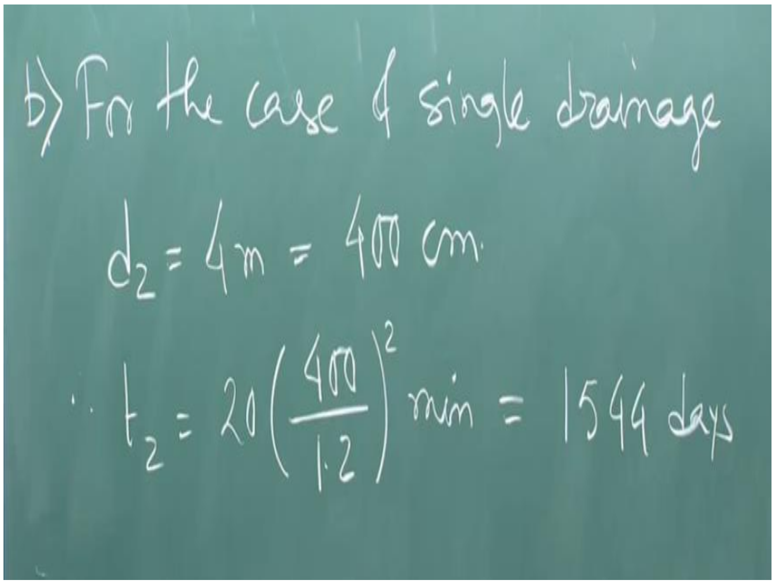

So, now we will go for the second part. In the second part, it says that so you had the double drainage system so that is why you are taking 386 days okay in the field to get 50% consolidation. Now the second part is saying that if the clay stratum has only single drainage that means the water is draining out either from the top surface or from the bottom surface because of some kind of impermeable layer situated at the top or as well as the bottom okay.

So, if that situation arises then what should be the time required for 50% consolidation. So, let us see how much time will be more to get 50% consolidation okay for single drainage system. So, for the case of single drainage your d 2 because it the problem says that if the clay stratum has only single drainage right. It does not say that your laboratory specimen is also having the single drainage system.

So, that means in the laboratory you are allowing double drainage system. You are allowing double drainage system to get 50% consolidation. Now you are trying to apply that result to get the 50% consolidation in the field with single drainage system. So, that means in the laboratory you have double drainage but you want to apply that thing for the field where you have single drainage system.

So, if that is true so your d 2 will be simply 4 meter. That is nothing but 400 centimeter. So, your t 2 will be required as 20 into 400 by 1.2 minute it comes as 1544 days. Now you can think of okay almost I mean 5 times okay almost 5 times more time you need to get 50% consolidation in the field with single drainage system. So, that means if you allow more amount of drainage okay so that that actually tells you something okay.

So, if you allow more amount of drainage basically your consolidation phenomena will be more faster. That you can see from this. So, in case of double drainage system you need 386 days whereas in case of single drainage system you need 1544 days. Now what does it tell you? It tells you that if you have more amount of drainage from the soil matrix basically your consolidation phenomena or consolidation say condition will be faster, rate of consolidation will be faster right. So, from this actually people or geotechnical engineers they design some kind of drainage system so to facilitate the drainage so it could be stone column it could be sand column something like that to allow or to I mean employ more amount of drainage in the soil stratum so that I mean water will be expelling out or draining out very quick or very fast so that your this time for consolidation will be coming down because you cannot afford 1544 days to get the primary consolidation of degree 50% right.

That means you have to wait till that period and then you can go for the construction. So, that is not possible so that is why what people do people put some or people put some artificial drainage system like stone column sand column so those are the things are beyond the scope of this course anyway so those things you can employ to get or to facilitate or to accelerate the drainage and ultimately your consolidation rate will be faster and you will be getting reduction in the consolidation time okay. So, we will take the second problem. What we have that is the problem 19.

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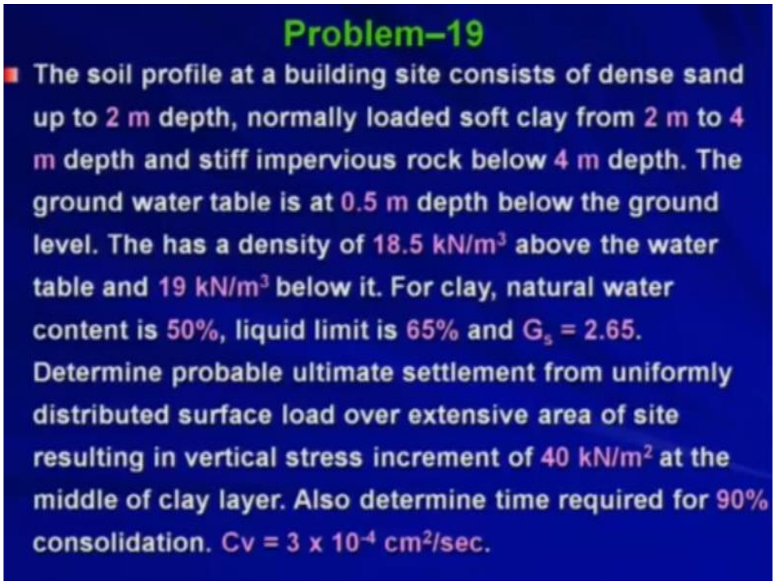

It says the soil profile at a building site consists of dense sand up to 2 m depth, normally loaded soft clay from 2 m to 4 m depth and stiff impervious rock below 4 m thick. The ground water table is at 0.5 m depth below the ground level. The soil has a density of 18.5 kN/m cube above the water table and 19 kN/m cube below it. For clay, natural water content is 50%, liquid limit is 65%, and specific gravity G s equal to 2.65. Determine probable ultimate settlement from uniformly distributed surface load over extensive area of site resulting in vertical stress increment of 40 kN/m square at the middle of clay layer.

Also determine time required for 90% consolidation if C v is equal to 3 into 10 to the power of minus 4 cm square/sec. So, the problem says that you have a real stratum. So, the top layer of the stratum is say sand that is from 0 to 2 m depth. From 2 to 4 m depth you have the actual clay deposit which will be consolidating and then below the clay deposit you have the impervious rock that means drainage is not allowed for I mean through that phase okay well.

You have the properties of the soil like your density above the water table I mean this unit weight basically and then unit weight below it all those things are given and natural water content, liquid limit, specific gravity those are also given and basically you are talking about the consolidation due to the increment of the load as 40 kN/m square at the middle of the clay layer okay. This is something like that I mean if you consider the whole clay layer if you calculate the settlement at the middle of the clay layer so that will give you the average settlement of the whole deposit okay.

So, that is basically I mean I mean people are interested to get that average settlement anyway so that is why the middle of the clay layer is very important so at that location we will be trying to find out the settlement and C v is also given. So, with these parameters we are going to find out that what I need to find out the probable ultimate settlement at the middle of the clay layer and then also we will determine the time required for 90% consolidation okay. So, let us try to find out.

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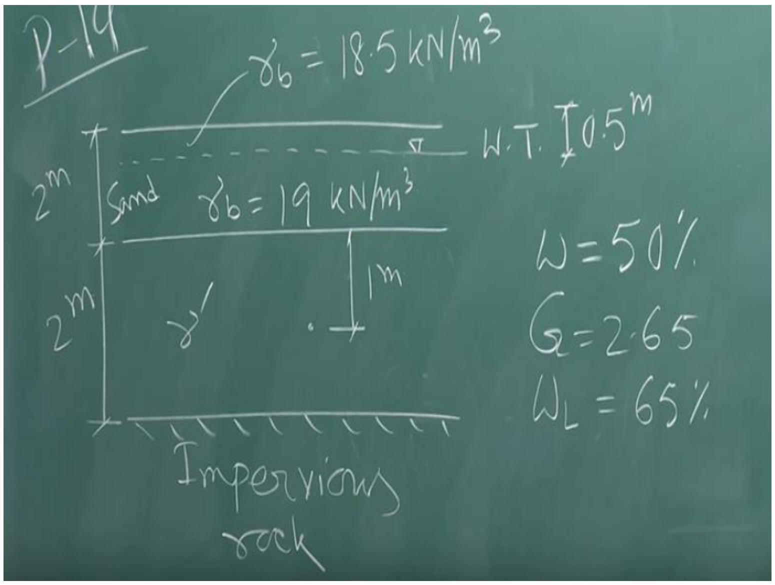

So, problem 19. So, let us draw the clay layer first I mean the soil deposit first. It is given that water content is 50%, specific gravity is 2.65, and liquid limit is 65% okay. These are the things are given. So, this is the deposit. This is the top layer is sand. You have the impervious rock okay impervious rock. Top layer is dense sand and this is your clay okay. Now you need to find out the average settlement at the middle of the clay layer okay and you need to find out the time required for 90% degree of consolidation okay.

So, these 2 things are required. Now basically by seeing this problem, this is a real-life problem right. By seeing this problem what you can tell or what you can think of. See sand layer that will not consolidate because you know if you apply the extra load or additional load on sand immediately water will be draining out and there will not be any kind of consolidation okay. Now the consolidation is only possible in the clay deposit am I right.

So, consolidation is only possible in the clay deposit. Now if you see this deposit the water will be draining out only through this top phase because only sand will facilitate the drainage whereas through the bottom surface you cannot have the drainage because that is completely consisting of impervious rock so water I mean drainage is not allowed through that phase. So, that means the problem is single drainage system okay. Now we need to calculate the different unit weights at different locations because this water table is situated at 0.5 m below the ground level okay.

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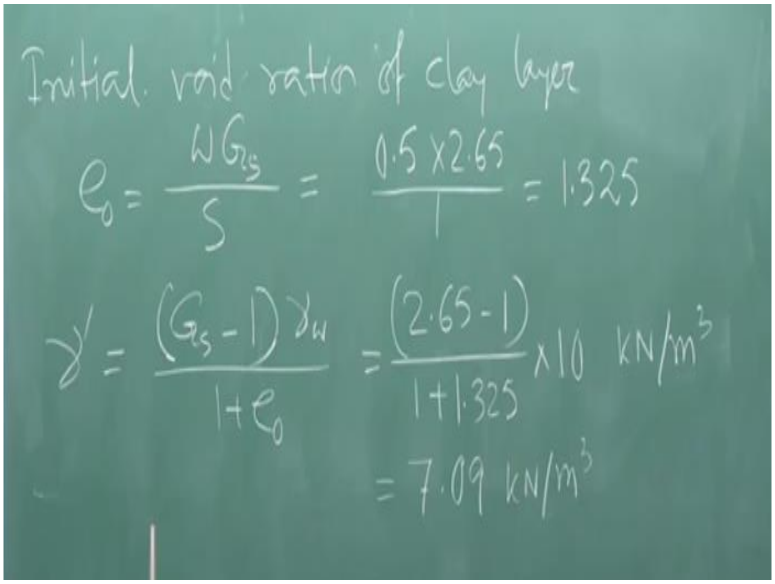

So, now first thing what we will do that is the initial void ratio of clay layer e not is equal to I mean how we can express this. If you recall the definitions of this e void ratio in terms of water content, specific gravity, degree of saturation all those things you can write W into G s into S where W is the water content, G s is the specific gravity, and S is the degree of saturation. Now what is the magnitude or what is the value of degree of saturation for this particular deposit, clay deposit, degree of saturation is simply 1 right. It is completely saturated.

So, degree of saturation is 1. So, I can put the value of water content and specific gravity and degree of saturation so that gives me the initial void ratio of this clay deposit or the clay layer is 1.325 okay. Now we are trying to find out gamma submerged okay.

So, we are trying to find out gamma submerged that can be obtained from this expression you know this expression or you can establish this expression from the basic definition right so which gives me 2.65 minus 1 divided by 1 plus 1.325 into gamma w is 10 kN/m cube so that comes as 7.09 kN/m cube okay. So, 7.09 kN/m cube is the submerged unit weight for this clay deposit okay. So, now basically if you want to find out the effective, I will keep this figure so I will rub this part. For your future reference, I am keeping this figure okay.

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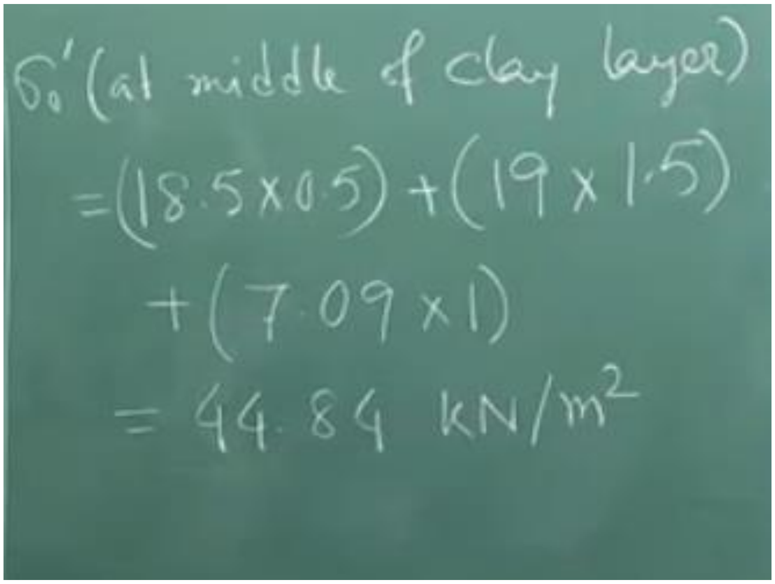

So, basically sigma not prime that is the effective stress at the middle of the clay layer, so at middle of clay layer okay. How we can find out the effective stress at the middle of clay layer that is sigma not prime that is nothing but equal to 18.5 into 0.5. Now what is 18.5? 18.5 is the unit weight, it is given in the problem, it is the unit weight above the water table okay. So, 18.5 so above the water table what is the depth of the soil deposit that is nothing but 0.5 m.

So, 18.5 into 0.5 plus 19 into 1.5. So, what is 19, 19 is the bulk unit weight below the water table okay fine. So, that is nothing but the unit weight below the water table that is given right that is given in the problem right. The unit weight is given in the problem that is nothing but 19 into 1.5. So, that is again your say for example this is this should be your gamma submerged anyway because below the water table you have so it should be your gamma submerged so nothing but your bulk unit weight below the water table okay.

So, that is 19 into 1.5 so 1.5 is this much of depth is 1.5 Am I right okay plus gamma submerged for the clay deposit or sand deposit is over. So, the effective stress is getting generated because of the sand deposit so this much is effective stress will be getting generated because of the sand layer on top of the clay layer. Now coming to the clay layer. So, what is the depth of clay layer at the middle of the clay layer. It is simply 1 meter. So, 7.09 that is the submerged unit weight just now we have calculated into 1.

So, if you calculate this it comes as 44.84 kN/m square. So, this is the effective stress okay at middle of the clay layer and that is there. That is already there. So, this much because of this much of pressure soil has been consolidated or whatever has happened that has happened. Now you are applying 40 kN/m square some additional stress additional vertical stress at the middle of the clay layer. That means your delta sigma prime is 40 kN/m square and sigma not prime is 44.84 kN/m square.

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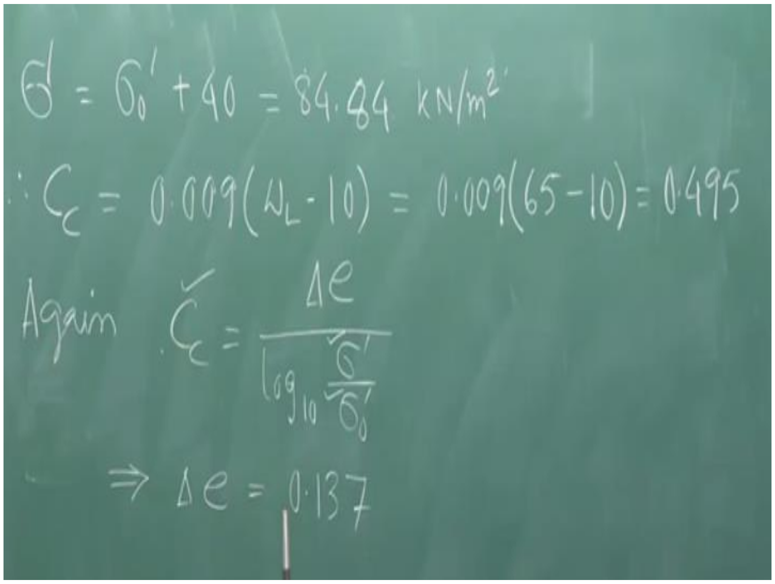

So, therefore your modified effective stress after this additional stress of 40 kN/m square will be so your sigma prime that is the modified effective stress at the middle of clay layer will be sigma not prime plus 40 is equal to 84.84 kN/m square okay so that is your sigma prime. That is the enhancement of the effective stress after some after application of additional stress of 40 kN/m square.

So, now we can calculate C c. How we can calculate C c? Because if we know the liquid limit we can calculate C c. We have already seen this expression earlier right 0.009 into W L that is the liquid limit minus 10. So, that gives me 0.009 65 - 10 is equal to 0.495. So, C c we have got it. Now once we have got C c we know from the expression of C c is equal to delta e that is the change in void ratio divided by log sigma prime by sigma not prime right. In this expression, I know C c.

I know sigma prime that means the modified effective stress due to the additional stress application and this is my initial effective stress. So, these things are known to me. So, I can find out the change in void ratio. So, from this I can find out delta e, if I put all the values I will get delta e equal to 0.137 right. So, this is my change in void ratio.

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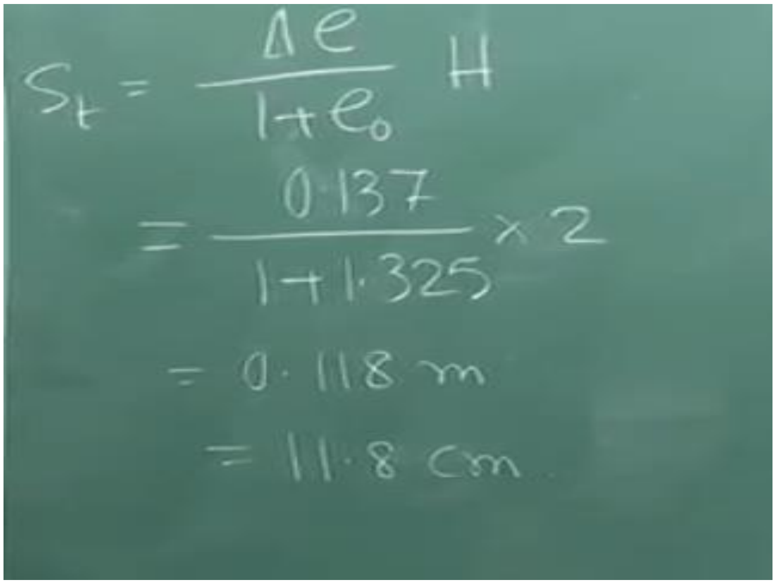

Now if I want to calculate the settlement at the middle of the clay deposit or the clay layer so basically S t that is the ultimate average settlement at the middle of the clay layer will be simply delta e by 1 plus e not into H. What is H? H is nothing but your thickness of the deposit okay. So, that gives me so delta e what is the value of delta e just now we have calculated 0.137 1 plus e not 1.325 and what is your H the thickness of the stratum that is nothing but 2 m right so multiplied by 2 will give me 0.118 m which is nothing but 11.8 cm. So, that means you will be getting 11.8 cm as your ultimate settlement.

That means when your primary consolidation is over at that time you will be getting the settlement at the middle of the clay layer will be equal to 11.8 cm. So, I mean you can think of 11.8 cm is a huge amount right. So, that means if you do not consider this settlement or if you do not anticipate this settlement rather before designing any geotechnical structure so basically you may get some crack or may get some failure due to this much of settlement in the structure okay. So, now we will go for the second part.

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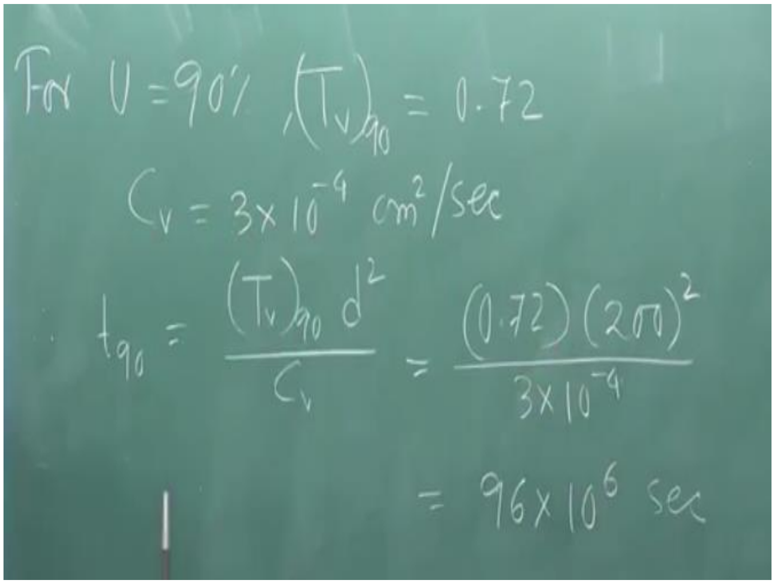

Second part basically for U equal to 90%, 90% consolidation, your T v 90 is equal to 0.72. So, I am not writing the expression, you can find out, you can calculate okay. Your T v is equal to 0.72 and your C v is given as 3 into 10 to the power minus 4-centimeter square per second okay. So, from this I can get t 90 that means the time required for 90% consolidation is equal to t 90 is equal to T v 90 by C v into d square.

So, d is same whatever we have seen in the last problem, so d is H dr right. So, this is the expression, already you have derived or you have seen when we discussed about the theory right. So, in this problem what is your T v 90? That is 0.72. Now what is d? So, this is a single drainage system. Please try to understand, this is the single drainage system because drainage of water is not allowed through this phase, through the bottom phase.

Water is only draining out through the top phase because the top layer is sand layer. So, this is the single drainage system. So, your d will be the total thickness of the deposit or the clay deposit. That is nothing but 2 m, that is nothing but 200 cm say divided by C v is 3 into 10 to the power minus 4 which gives me 96 into 10 to the power 6 second which will be coming as approximately 1111.11 days which will be approximately okay.

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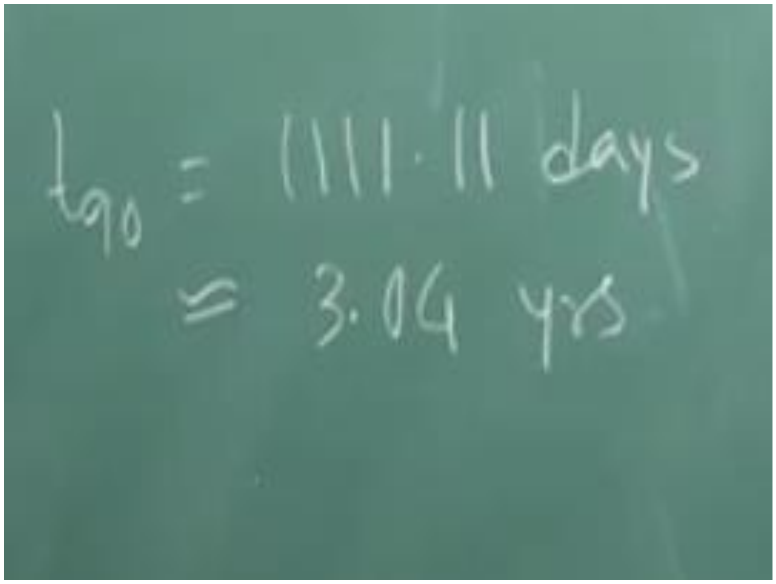

So, this will be equal to this will be equal to 1111.11 days which will be approximately equal to 3.04 years. So, now you just see that for 90 for getting 90% degree of consolidation the 90% primary consolidation you need to wait almost 3 years okay and then only you will be getting only 90% consolidation okay. So, I mean this is a quite huge time right as far as any project is concerned.

So, if you are going to construct any structure on this kind of say deposit basically I mean if that structure is giving me 40 kN/m square additional pressure at the middle of the clay layer so basically that will cause the consolidation and that consolidation will take almost 3 years for 90% degree of consolidation. So, if you want to accelerate this process then basically you have to facilitate the drainage. Otherwise you do not have any other control right. You cannot control the soil.

Whatever deposit you have whatever God has given the deposit you cannot change the deposit unless until you do some modifications like excavating the whole soil, filling up the different soil, something like that. Those things are different but with the same deposit if you want to construct anything on this kind of deposit basically you need to accelerate the drainage I mean rate that means if you have more and more drainage basically your rate of consolidation will be faster right. So, for that people do some artificial drainage system inside the soil deposit so that the draining out of water will be much more faster and because of that you will be getting reduction in the consolidation process.

So, I will stop here today. So, in the next lecture we will be starting the new chapter that is shear strength of soil that is another very important chapter because that chapter will give you the insight about the soil strength how I mean if you apply some load in the soil and how the soil will resist that load because something like that suppose if I give you some load to carry then basically your internal say mechanism will try to resist that much of load right.

So, that internal mechanism is known as the shear strength of the soil. So, from the next class onward we will be starting that new chapter and I will be quite sure that you will be also interested to know the phenomena of shear strength in soil. Thank you very much.