Geology and Soil Mechanics
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Lecture - 57
Tutorial on Consolidation - a

Hello everyone. So, welcome to our sixth lecture on tutorial section of Geology and Soil Mechanics.

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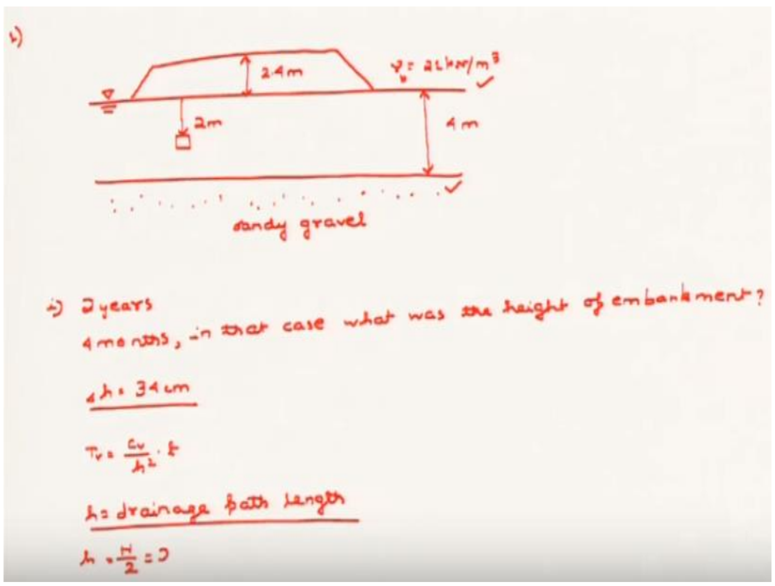

So, we are discussing here a problem on consolidation which basically stated that there was an embankment of height 4 m, height 2.4 m below a clay layer of 4 m. So, the figure was this height was given as 4 m this embankment height was given as 2.4 m the gamma of embankment was given was 21 kN/m cube. Basically, this is the gamma b or the bulk gamma.

The water table was at the top of the clay layer and below it this clay layer was a sandy gravel layer. Now it was said that a that basically sample was extruded from a from 2 m below the water table that means at the mid height of the clay layer and a consolidation test was carried out whose results were plotted and we founded out that what was the compression index the coefficient of consolidation and also the settlement.

Now it was also asked in the question that the settlement was actually concluded after 2 years but it was asked that the settlement is to be concluded in 4 months. In that case what was the height of embankment? So, in that case we found out that the total settlement height of the, the total settlement height was 34 cm for a clay layer of thickness of 4 m.

Now if the settlement height was 34 cm then we said that in this case from the equation of the total time that is T v is equal to C v into h square into t where h is basically the drainage path length. So, in this case the drainage path length is to be halved because the drainage is both in the bottom as well as in the top direction. So, the drainage of clay layer is both in both directions so h is actually equivalent to H by 2 or equivalent to 2 m because the height of the clay layer by 2 so equivalent to 2 m.

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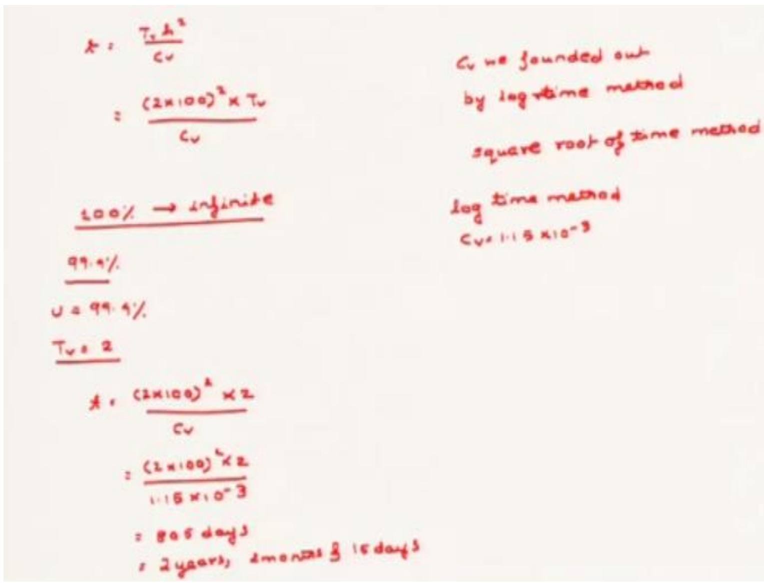

So, we said that t is equal to T v into h square by C v which is equivalent to 2 into 100 square into T v by C v. Now we also said in the previous lecture that 100% of the settlement is reached in infinite time that means it takes a very long time to reach the 100% of settlement. So theoretically it is theoretically it is suggested that at 99.4% generally the 100% of settlement is reached.

So, if the U or the degree of consolidation is actually equivalent to 99.4% then you can find out from formula that T v is equivalent to 2. So, putting that value in the previous expression we get 2 into 100 square into 2 by C v. Now C v we founded out by log root by log time method. There is another method that basically is called square root of time method and from log time method we founded out that the coefficient of C v is the coefficient of consolidation or basically C v is equivalent to 1.15 into 10 to the power - 3.

Now you can also adopt the square root of time method if you think that that is more suitable and in this case, we came to the conclusion that the total time required for the clay layer to reach a settlement of 34 cm is actually equivalent to 805 days which is equivalent to 2 years 2 months and 15 days. Now practically you can see that this is a very long time that is required for the settlement of 34 cm to reach. So, in that case you can reduce the height of the embankment in order to achieve the settlement in 4 months.

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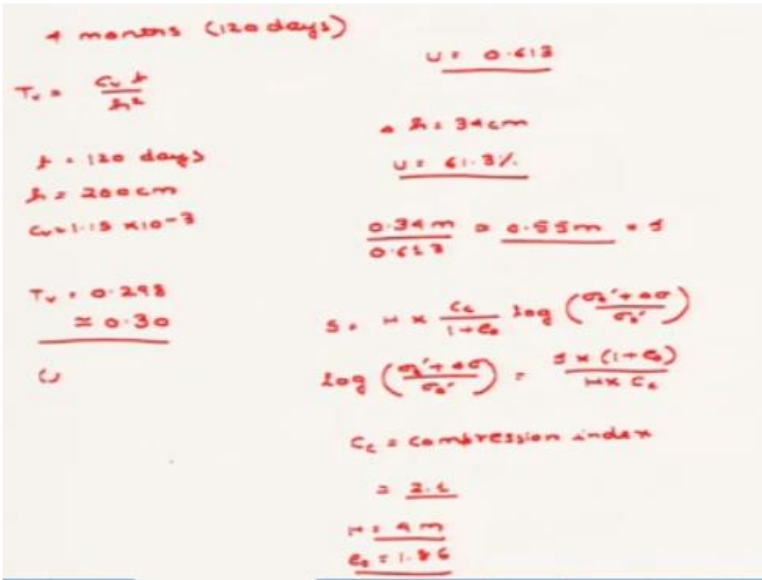

So, in order to achieve the settlement in 4 months or let us say 120 days what I said was that we just recalculated T v. So, in this case T v is equal to C v into t by h square and you already know that t is equivalent to 120 days. We also know that h is 200 cm and C v is 1.15 into 10 to the power - 3 because it is the same clay layer. So, from there we calculated T v equivalent to 0.298 or equivalent to 0.30.

Now from T v we can actually calculate the degree of consolidation. So, because there is a formula between T v and U so from T v if you back calculate the degree of consolidation it comes out to be 0.613. So, delta h equal to 34 cm would actually now correspond to 61.3% of the total consolidation settlement. Now 61.3% of the consolidation settlement would be obtained under a surcharge of under a heavier surcharge.

So, in this case basically it will be equivalent to 0.34 m divide by 0.613 because 61.3% correspond to 34 cm. So, the total settlement will correspond to 55 m. So now this is the 55 m is the total settlement. The settlement of 34 cm corresponds to 61.3% of the settlement S that will be obtained under heavier structure so in this case the settlement would be equivalent to 54 m the road settlement would be equivalent to 55 cm.

So now moving back to the previous formula for the settlement we know that H into C c by 1 + e 0 into log sigma 0 dash + del sigma by sigma 0 dash. This is what is the formula for settlement if you ignore the preconsolidation settlement. If you ignore that the settlement is totally equivalent to the virgin consolidation curve. So, in that case log of sigma 0 dash + del sigma by sigma 0 dash would be equivalent to S into 1 + e 0 by H into C c.

Now already founded out this value of the compression index of the C c from our previous from our pervious lecture the value of the compression index was found out to be equivalent to 2.1. H as we all know it is 4 m because the total thickness of the clay layer is 4 m and e 0 that also we said in the previous lecture was found out to be equivalent to 1.86 and now you already know the total settlement is 0.55 m corresponding to a 61.3% settlement corresponding to a 61.3% consolidation for a settlement of 34 cm.

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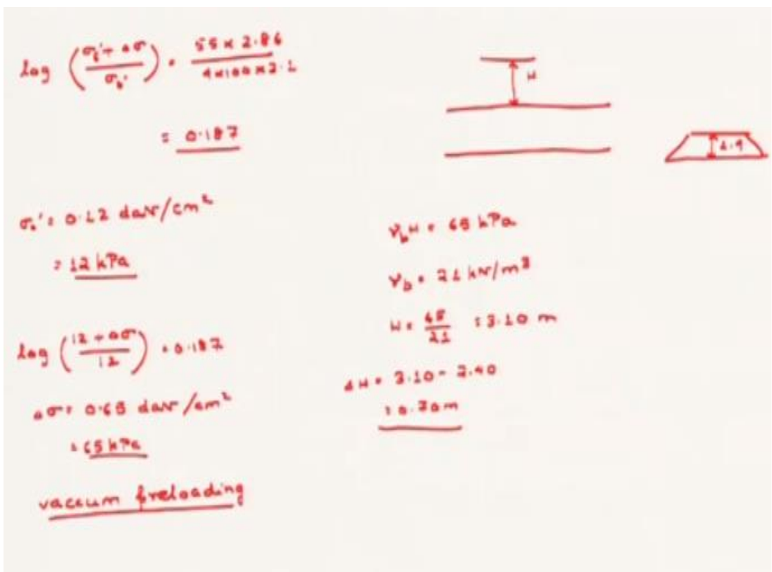

So just plug the values and you will get log of sigma 0 dash + del sigma by sigma 0 dash as 55 into 2.86 divide by 4 into 100 into 2.1. This is equivalent to 0.187. So, from here you already know what is the value of sigma 0 dash is because sigma 0 dash is basically the stress at the mid height of the clay layer. So, the stress at the mid height of the clay layer corresponds to a value of 0.1 0.50 0.12 da newton per centimeter square or basically 12 kPa.

That is what is the stress at the mid height of the clay layer is. Now if it is if the stress at the mid height of the clay layer is 12 kPa then log of 12 + del sigma by 12 corresponds to 0.187. So, from there del sigma comes out to be 0.65 daN/cm square or 65 kPa. So, this is the extra stress that is imparted on the clay layer. So that means if this is the clay layer if the height of the embankment is H then gamma which is the density of the embankment which is gamma b into H must be equivalent to 65 kPa.

Now as we all know that gamma b is already equivalent to 21 kN/m cube. So, H is 65 by 21 which is equivalent to 3.10 m. The surcharge that is del H will be equivalent to 3.10 - 2.40 equal to 0.70 m because 2.4 is the previous height of the embankment. The previous height of the embankment is 2.0. This is already said here. So, this is the extra surcharge that is to be needed in order to achieve a settlement of 34 cm within 4 months.

So, you can see from this example that how it is possible to quickly stabilize an embankment if you add a surcharge. So often this is done with vacuum and this type of technique is termed as a vacuum preloading. In certain cases, you will see that in certain cases in the field you will see that basically you have to achieve a settlement you have to achieve a desired settlement within a very short period of time.

In that case you need an extra surcharge and this surcharge is calculated and the surcharge that is needed in order to achieve the required settlement is calculated in the same fashion as it is shown in this example. So, in this case basically preconsolidation generally the points of preconsolidation or basically applying a surcharge in order to achieve the desired consolidation is programmed. In this case a surcharge of 70 cm if you keep it for a period of 4 months and then remove it would accelerate the settlement and it would achieve the desired settlement of let us say 34 cm within the required time.

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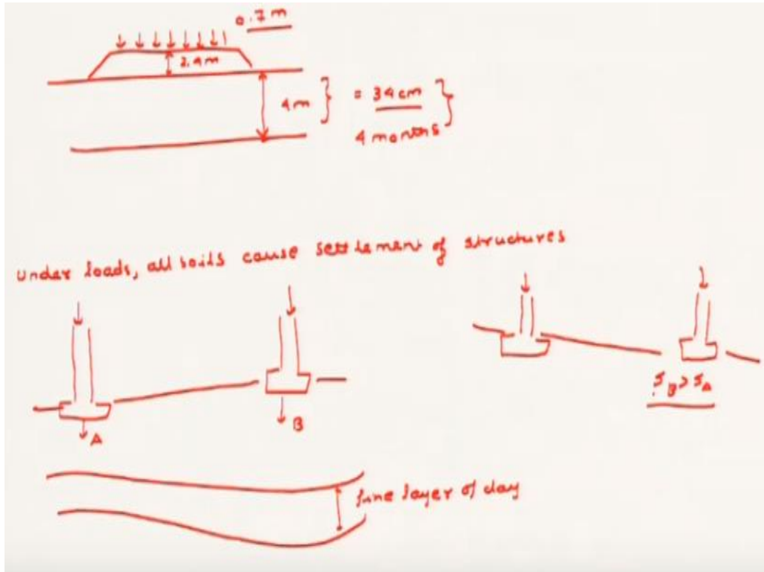

So, no need to wait for the period of 2 years 2 months and 15 days rather you add an extra surcharge rather on this clay layer of 4 meter and on this embankment of height 2.4 m you add an extra surcharge of 0.7 m and accelerate this settlement to 34 cm within the period of 4 months. After that you can remove this 0.7 m you can remove this 0.7 m and since the total settlement that is achievable under this type of surcharge under this type of embankment is actually 34 cm.

So, this surcharge will be so this settlement will be attained within 4 months rather than waiting for 2 years or 2 years 2 months and 15 days. So, this is the way in which a ground improvement technique is done. Now as we know that under all soils almost under loads almost all soils will cause settlement of structures. Now one of the most important thing that you have to see while performing a consolidation settlement is that whether the settlement is within the desired limit or not.

Now different codes have specified different values for the for the settlement within the desirable limit and if the settlement is within the tolerable limit then only you can design that structure otherwise not. So, structures and one of the most important fact is also that there is not only a single type of settlement like a consolidation settlement there is also a part called differential settlement.

That means different parts of the structure may settle differently under loads. So, let us say that this is a column and there is another column here. Now if this part of the soil due to some due to some very fine layer of clay may settle differently than this part of the structure then the settlement at B would be greater than A. In that case the structure may settle differently under the same load.

Basically, the load imparted on the structure is same. So, settlement of B is greater than settlement of A. In this case a differential settlement is introduced. Now a differential settlement is very dangerous compared to the general consolidation settlement. It may induce cracks in the structure because the 2 parts of the structure settle differently and it is a it is very crucial when basically you are designing a structure.

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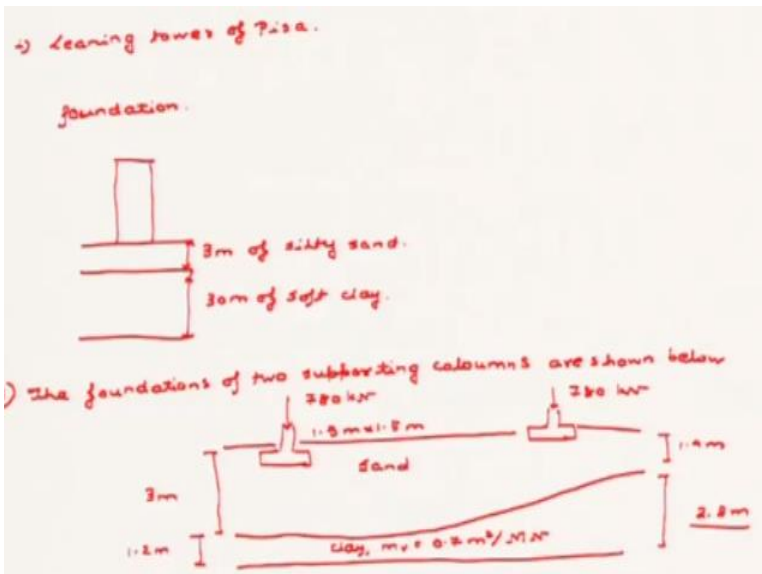

An example a very good example of the different settlement is as you all know is Leaning tower of Pisa. Now in this case when the when the end at the end of the 1178 when the structure was completed the tower began settling differently. The foundation in that case let us say this is the structure then this is 3 m of silty sand and this was the clay layer that was 30 m of soft clay. Now this 30 m of soft clay was the only reason why basically it caused the differential settlement.

Now we are not going to discuss in details about the case study here but we are going to carry out an exactly a same different type of problem on a differential settlement in order to make you make you aware of the about how a different settlement is detrimental for the cause of a structure. So, let us say our second problem is basically on a foundation or the same type of column load that I showed you.

The foundations of 2 supporting columns are shown below. Just like the same type of thing that I showed you just earlier. So, a load of 780 kN the load is same in both the column and this is of width 1.5 m the foundations are also same. Both the foundations are of width 1.5 m into 1.5 m. This is a layer of sand. Now as you see as I have said in the previous problem also that the clay layer may not be uniform just below.

The clay layer may be different below one foundation and maybe different below the other foundation. That is one of the major reasons why the soil investigation is to be carried out very accurately. Otherwise the differential settlement may affect the structure very much. So, this is the clay layer which has an m v of 0.7 m square or mega newton. Now this height is given as 1.4 m while this height is given 3 m. This height is again given as 1.2 m. This side is obviously 2.8 m. Now this is due to an extensive soil investigation that this type of profile is obtained.

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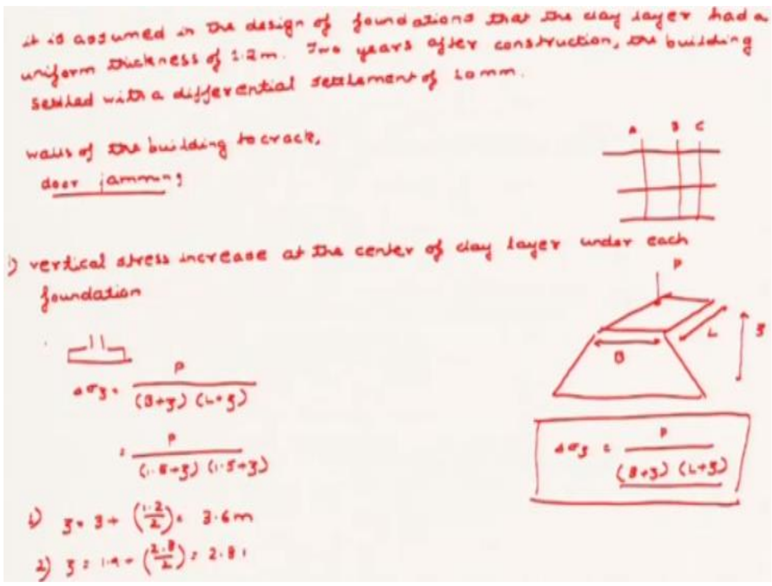

So, it is assumed in the design of foundations that the clay layer at a uniform thickness of 1.2 m. So, this is the reason because you see that the extensive soil investigation was only carried out below one of the foundations. So, if below one of the foundations when extensive soil investigation is carried out and below the other one if the extensive soil investigation is not carried out in this case you will assume the clay layer is actually uniform.

For this case, actually what is done is that you have carry out or you have to perform different bore holes or in order to get the soil profile you have to dig at different points within the profile. So, let us say a point A, point B, a point C. In these cases, you will know that whether the layer below whether different layers below are actually of uniform thickness or not. In this case basically it was one of the faulty constructions because in this case the clay layer was assumed to be uniform of thickness of 1.2 m.

So that is why what happened was that 2 years after construction the building settled with a differential settlement of 10 mm. It is obvious from the soil profile that the that there would be a different settlement because the clay layer is thicker here more while the clay layer is thicker here less. So, this different settlement now caused walls of the building to crack and door jamming and other things because the settlement here in below the second column was more.

So obviously this column had a this one settled more. So that is why all those things this cracking and all those phenomenon’s came up. So that is why I said that differential settlement is very detrimental to the structures. So, you have to perform a very proper soil investigation is order to know that whether there will be a differential settlement or not. Different codes have also specified different measurements for different settlement.

So, there is only a particular limit to the different settlement that you can actually approve in the field. So, in this case what you have to do is that we have to first find out that what is the vertical stress increase at the center of clay layer under each foundation. That means the stress increase just at the mid height of this layer and just at the mid height of this layer. You have to find out that what is the stress increase below each layer.

So now a general formula that we will take here will be discussed in the next subsequent lectures that is the effect of stress that is (()) (22:30) method. So, under let me discuss a little let me discuss just a little bit of it here. So basically, if there is a rectangular if there is a rectangular footing let us say in 3 dimensions with a breadth of B and a length of L in that case the extra stress that is imparted to the soil at a depth z is equivalent to due to a load P is actually equivalent to P by B plus z into L plus z if you consider it to be if you consider the distribution to be at 45 degree.

That is if you consider the distribution to be at equivalent in both the directions. So, this is a general formula that you take help of that we will take help here. In general case, you are not actually you are not able to find out that what is the delta sigma z. In all the previous problems that we have discussed actually we have either said about delta sigma z or just an extra load was imparted on the soil layer.

But in this case, it is a footing and generally you are asked to find out that what is the extra stress increase below a footing. So, this is a general formula. If it is a rectangular footing or a square footing this is a general formula about how you can find out that what is the extra stress that is imparted due to the load that is coming on the footing at a certain depth below. So, in this case we will take up this formula that delta sigma z is equal to P where P is the load B is the width of the footing and L is the length of the footing.

Now obviously B and L are here equivalent because we have said that the footing is of length and width it is a square footing of length and width 1.5 m into 1.5 m. So, P by 1.5 + z into 1.5 + z. Now let us look that what is the mid height of the clay layer is at. Now for the first footing the z is actually 3 + 1.2 by 2 so equivalent to 3.6 m. While for the second footing it is z is equivalent to 1.4 + 2.8 by 2 so equivalent to 2.8 m.

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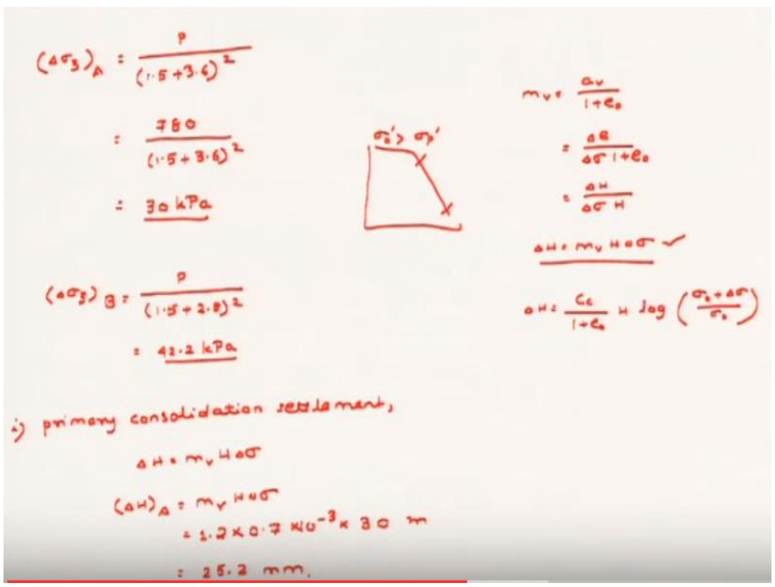

So, delta sigma z for footing number let us now name this as footing A and B so for footing A it is equivalent to P by 1.5 plus now z for first footing is 3.6 so 1.5 + 3.6 square. Now P 780 kN so 1.5 + 3.6 square equivalent to 30 kPa. So, this is the extra stress that is imparted in the clay layer due to the load on the footing and B 1.5 + 2.8 square 42.2 kPa. So, these are the 2 these are the 2 stresses the increment of stress at the clay layer just at the mid height of the clay layer for the footing A and B.

Now for more accurate for more accurate as I have said previously also that if you want to consider a more accurate distribution of the stress or the settlement what you have to do is that you have to divide this clay layer. You have to divide this clay layer into number of segments as you wish. You can divide this into 2 segments you can divide this into 4 segments whatever you want. In that case the stress calculation as well as the settlement calculation would be more accurate.

Now just a simple formula for calculation of the primary consolidation settlement because in this case we will not consider any secondary effects or in this case we will consider only the virgin consolidation curve and we will not consider any preconsolidation settlement. So, no over consolidated soil is present here. Just a normally consolidated soil is to be is present here so no over consolidation settlement calculations are done here.

Now as I have said that settlement calculations can be done in 2 ways. Either using the m v formula m v is equal to a v by 1 + e 0 is equivalent to delta e by delta sigma into 1 + e 0 and this delta e by delta sigma is equivalent to delta e delta H by H so delta H is actually equivalent to m v into H into delta sigma. Either by this way or you can go by delta H is equal to C c by 1 + e 0 into H into log of sigma 0 + del sigma by sigma 0.

Any one of them if your settlement is within the virgin consolidation curve or basically if your settlement is here in this virgin consolidation curve after the preconsolidation pressure after sigma P dash or sigma 0 dash is greater than sigma P dash in that case you can use any one of this above formula to calculate the settlement. So here we are going to adopt the method of m v or the coefficient of volume compressibility method.

So, delta H is equal to m v into H into delta sigma because m v is already given to us in the question m v is 0.7 m square per mega newton. So, m v is given to us in the question. So, for delta H for footing A will be equivalent to m v into H into delta sigma so 1.2 into 0.7 into 10 to the power - 3 into 30. The stress increase is 30 and the left thickness is 1.2 so that is why H is 1.2 m v we have already said it is 0.7 m square per mega newton. So, in order to convert into appropriate units, we have considered 0.7 into 10 to power - 3. So, 25.2 mm. This is the settlement under the footing A.

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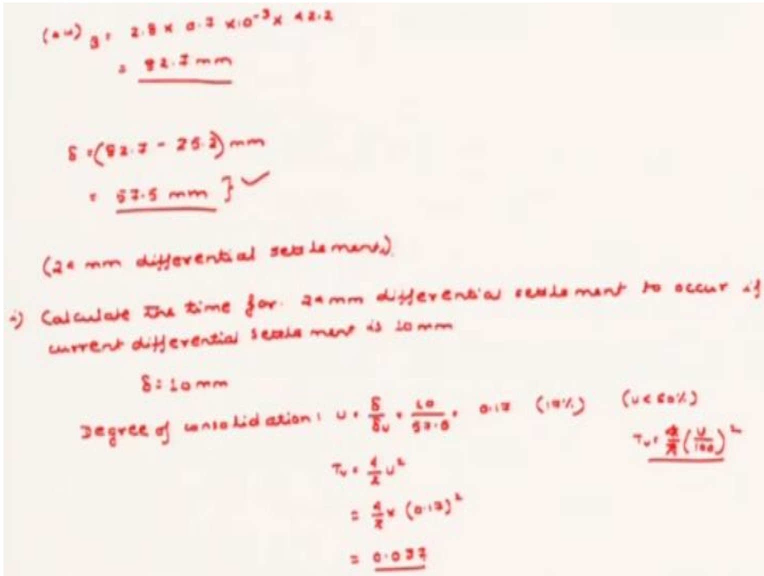

Similarly, you can find out using the coefficient of volume compressibility settlement under the footing B. In this case the clay layer is of thickness 2.8 m. So, 2.8 into 0.7 into 10 to the power -3 into 42.2 because that is the extra stress that comes due to the load on the footing B. So, in this case it comes out to be 82.7 mm. Now just consider that if you have considered the clay layer to be free from thickness then your settlement would have been 25.2 mm throughout but now as I have said also previously that your settlement below footing B is more.

So, in this case the settlement below footing B has come out to be 82.7 mm and if you considered it to be uniform then your settlement was 25.2 because that is what is the settlement under footing A. So, this comes out to be equivalent to 57.5 mm. So, an extra settlement of 57.5 mm occurs under footing B. Now generally the code prefers a differential settlement of 24 mm.

So, if you consider the 24 if you consider the 24mm differential settlement or 10 mm 24 mm differential settlement. So, this is obviously greater than 24 mm differential settlement. So, you cannot actually you cannot construct a building like this I mean you cannot construct a building of the clay layer just with a differential settlement of 57.5 mm.

So, the next question that comes here is that calculate the time for 24 mm differential settlement to occur if current differential settlement is 10 mm because they have asked to find out the 24 mm differential settlement because that is the limit within which you should within which you should restrict your different settlement. So, at present the different settlement is ongoing in the structure because this is the ultimate different settlement that you have found out 57.5 because as you know these formulas are basically to find out the ultimate settlement.

So obviously this different settlement is the ultimate different settlement. Now since you are asked to find out the now in the ongoing process basically the different settlement is right now 10 mm and you are asked to find out the different settlement for 24 mm. So, let us first find out just like the previous problem as we have said that you have to find out the extra load that is imparted to find out a settlement that is to be caused within the 4 months.

Here also similarly you have founded out the degree of consolidation in that case so here also similarly we will find out the what is the degree of consolidation at present going on in the soil. So, in the soil the present degree of consolidation can be given by delta by delta ultimate. Delta is the present different settlement delta ultimate is the final different settlement. This is equivalent to 10 by 57.5.

So is equivalent to 0.17. So, at present 17% of the total different settlement is going on. So now T v is equal to 4 by pi into U square because you all know this 17% because you all know that for U less than 60% the formula for T v is pi by 4 into U by 100 square. That is the same thing that we are applying here. So, if you just rearrange the numerators and denominators you will come across T v is equal to 4 by pi into U square sorry 4 by pi into U by 100 square. So, this is equivalent to 4 by pi into 0.17 square because 17% is the differential settlement so 0.037. So, your T v comes out to be 0.037.

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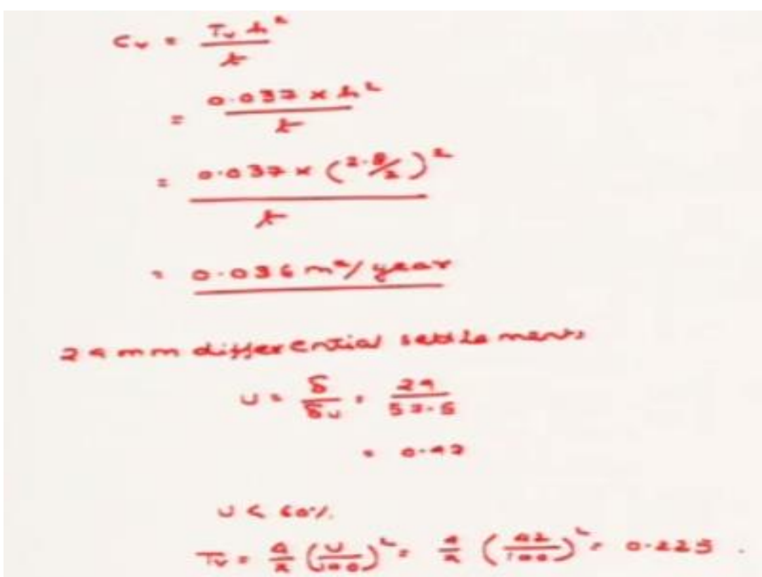

Now from T v we will calculate the coefficient of consolidation. So, T v into h square by t the formula for coefficient of degree of consolidation. So, T v as we all k now we have founded out to be 0.037 into h square by t. Now let us look at the soil profile before we find out the h square. Now below this is a gravel layer. So obviously like the previous case since the top is covered with sand and below since there is a gravel so like just before the previous case this is also a double range problem.

So, the height will be halved. So, 0.037 into 2.8 by 2 square by t because 2.8 is because you have to consider the clay layer below the footing B. So, this comes out to be 0.036meter square per year. So, this is the coefficient of consolidation that you have found out. Now you are asked to find out the 24mm different settlement. You considered the you have considered the h just below under footing B because as I have said previously also that you have already considered the clay layer to be a 1.2 m thickness.

So, all questions or all calculations regarding 1.2 mm 1.2 m thickness are accurate. But because of this extra 2.8 m that came all your calculation are now out of bounds because all your calculations are now wrong because this extra 2.8 m has caused a different settlement of 57.5 mm. So that is why that is the extra layer that you have to consider when calculating all these coefficients of consolidations because the coefficient of consolidation during that period only you have to consider.

The 10 mm already has been the 10 mm can be achieved in both the layers the 10 mm can be the 10mm different settlement is due to the excessive settlement under footing B but not under footing A. So that is why we considered a 2.8 m rather than considering 1.2 m. Now for 24 mm different settlement now again I have to find out what is the degree of consolidation for 24 mm different settlement. So again, delta by delta U so 24 and your ultimate is 57.5 mm so it comes out to be 0.42 or 42%. Now since U is again less than 60% so again your T v comes out to be 4 by pi into U by 100 square so which comes out to be 4 by pi into 42 by 100 square so which comes out to be 0.225.

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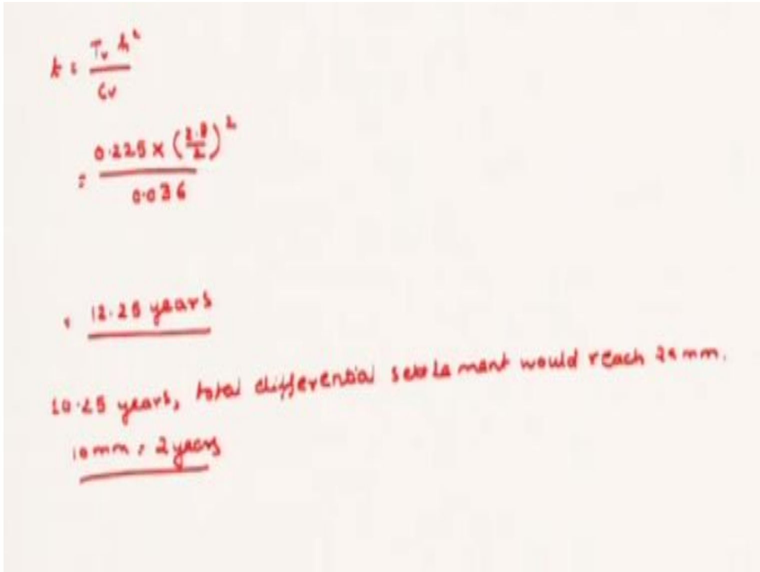

Now just rearranging this formula we have found out what is the coefficient of consolidation C v for settlement for basically a differential settlement of 10 mm or 10 mm which is the present ongoing different settlement. Now considering the different settlement of greater than 10 mm or 24 mm T v into h square by C v the time required to know the at what time the differential settlement occur.

So, T v as I founded out is 0.036 m square per year so 0.036 T v is obviously 0.225 so 0.225 and h is again 2.8 by 2 because I have said that all the calculations that you have to consider is due to that extra 2.8 m layer below footing B because that is the only layer that is considering the different settlement. So, 12.25 years. So, 12.25 years or 12.25 years your building is actually within the permissible differential settlement limit but after 12.25 years your building will not be within the permissible differential settlement limit.

So, the extra in the coming 10.25 years your total different settlement would reach 24 mm if you consider that if you consider if you calculate if you calculate you will see that this 10mm considering the coefficient of consolidation C v if you calculate this 10 mm you will see that this in 10 mm has actually been achieved in 2 years. This 10mm different settlement is actually achieved in 2 years. So that is why it is said that in the extra 10.25 years the total different settlement will reach 24 mm.

So, you can see that how a different settlement is actually very detrimental to a structure. Now we will consider just another problem before going on to the next chapter. This also is not exactly on different settlement I would say rather this is about how if you have an uneven soil profile you have to calculate the settlement at different points in the soil profile. So that is why I have said from the beginning that in order to know the settlement is very important to a structure as you will know from all the Indian Standard Codes if you consider an Indian Standard Code you will know that the settlement is very detrimental to the structure.

Above shear strength means above testing of footing for the whether the soil can hold its strength or not. The next important factor that you have to consider is whether the structure would allow a settlement within permissible limit or not. That is why an extensive soil investigation is always required by constructing different holes and the soil profile in order to know the exact profile of the soil. A soil profile is not uniform beware as you see in problems rather it is very different than you see in problems.

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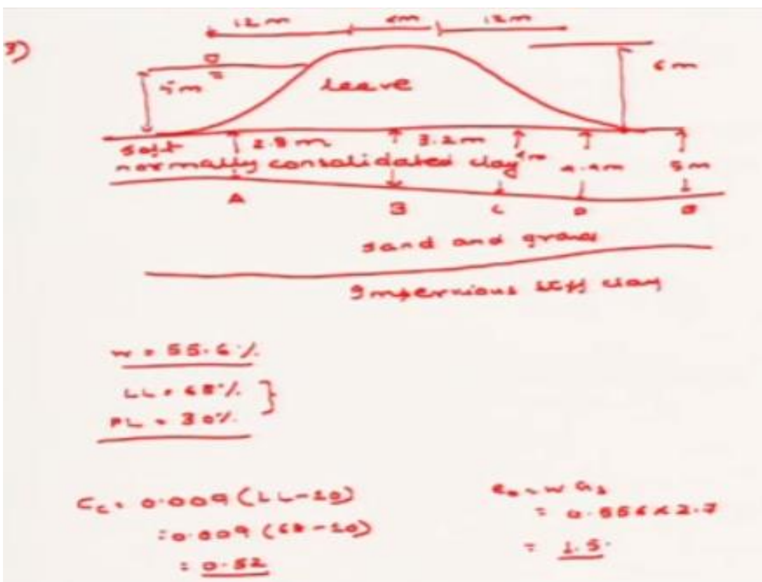

So, in a third problem illustrating the effects about how it would be is described here. So, this is a leave and here is a normally consolidation clay layer. Now since it is a normally consolidated clay so obviously the effect of preconsolidation now we will not consider we will only consider the virgin consolidation curve so that means you can approach both by the coefficient of volume compressibility method as well as by the coefficient of compression index method in order to calculate the settlement.

Now you see here that the soil profile again is not uniform. So, the different depths so generally how in actual life how it is done is that let us say you construct a bore well here so you find out that the soft normally consolidated clay has a height of 2.8 m. In the next case, you consider it at here when you construct a bore well and you find out that is 3.2 m. So, this is at point A this is point B.

At here you construct another and this is 4 m this is C then there is a 4.4 m this is D and this is 5 m this is E. Now what you do is that you have this soil profiles so you have the complete soil profiles at let us say at point A point B point C point D point E. You just join these points because you know what is the depth of normally consolidated clay at each of these points and join these points and you get an approximate soil profile.

Then there is a layer of sand and gravel and there is a impervious stiff clay. Now see in all the previous problem that you have discussed we considered that the load that is imparted on the structure is actually constant only the soil profile is varying. In this case however you see that the leave itself is uneven that means the load that is imparted on the soil due to the structure is non-uniform.

So, in this case let us consider that this height length is 12 m this length is 4 m and this length is 12 m. That means it is symmetric about the center. The water table is at a height of 5 m from the depth of normally consolidated clay and this total height is 6 m. So now you can see that the soil data is extremely limited. Now it is given that whatever the soil data now another important problem is that the soil data that is given here it is not always possible to calculate this consolidation and all these data.

So, if you are given to evaluate the compression index and coefficient of consolidation very fast in that case basically you have to take help of different formulas that we also did in the previous problems like liquid limit, plastic limit all those cases and we can generally evaluate the compression index or the coefficient of compression from all these cases. So, in this case the soil data is entirely limited and it is given that that w or the water content of the soil is 55.6%.

Obviously, this is of the clay layer because the clay layer is the only layer that will settle under the consolidation. The liquid limit is 68% and the plastic limit is 30%. Now what we will do is that first you have to know that how to find out the compression index. Obviously, the compression index can be founded out from 0.009 into LL - 10 for this clay layer and it is equivalent to 0.009 and L is given as 68 - 10 this is equivalent to 0.52.

So, this part for consolidation has been known. Now you can also find out e 0 because e 0 is equal to w into G s and it is already given that this entire layer is below the water table. So, w you know is obviously 0.556 and G s is given as 2.7. So, this comes out to be 1.5. So, e 0 you also found out. H is obviously varying at different depths. The question here is that how do you find out the vertical stress distribution because as I have said that the structure that the load that is imparted on the soil is non-uniform and the structure itself is not uniform. It is symmetric alright but it is not uniform throughout.

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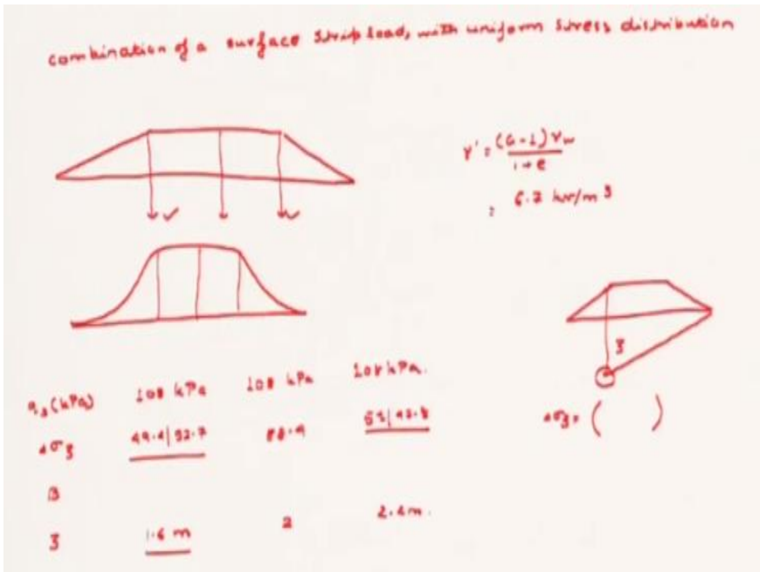

So, you can use a combination of a surface strip load with uniform stress distribution. That is how you generally approach the problem. So, in that case basically what you do is that you consider it to be like this rather than considering it to be a leave of like this you consider it to be of like this and you find out the stress at this point at this point due to the layer. Now as I have said here only gamma into h are the 2 combinations that is going to be considered here.

So, if you consider a uniform surface strip load then in that case you can find out the q s that is generated at each point. So, let us first we will consider only this point and this point because all the other points we already know since we already know the soil profile the soil profile is given to you so we will consider only at this point. What is the at this point what is the depth. So primarily your q s at his point would be equivalent to 108 kPa if you find it out from gamma.

Now obviously you have to find out the gamma dash or the profile so gamma dash will be equivalent to G - 1 into gamma w by 1 + e. So, this is equivalent to 6.7 kN/m cube. At the center of the embankment it will be equivalent to 108 kPa and here also it will be equivalent to 108 kPa. Now delta sigma z that is the stress imparted due to the additional part will be equivalent to 49.4 and 52.7.

Now how did I find out this number? Now these numbers you will we will come across in later part where basically we will discuss the distribution of stress on soils. In that case we will say that if there is an embankment like this then depending on the position of the point where you want to find out the stress let us say if this point is z there are either there are charts available or you can use formulas like the previous formula that I used in case of a rectangle this formula like the previous formula that I used in case of a rectangle in this case.

You can also find out the stress below an embankment the delta sigma z from a formula. So, in this case I am not discussing the details of the formula but I am just showing you an example about how you can find out. So, the stress on the either side of the embankment will be different and that is what it is written that 49.4 and 52.7 at this point 88.4 at the midpoint and 51 and 47.8 at the end point. Now width and z is given as 1.6 m 2 m and 2.2 m.

Now obviously these points are as I have said at this point 2, 1,3. Now these are all remember this z's are always the half the half width because the actual because you have to find out the settlement at the mid height. So that is why I took z as 1.6 m. So, 1.6 m because is at this point 3.2, 4 in between the leave, and 4.4 at the end. So, this is 2.2 m.

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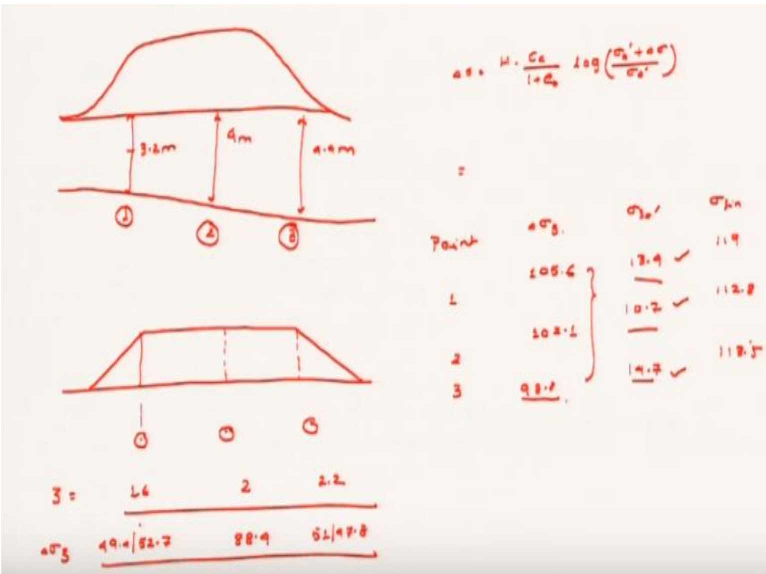

So,

a little soil profile if you consider it is like this actually so at this point the height is 3.2 m mid height it is 4 m and at this point it is 4.4 m. So, this is how the soil profile looks like and I have approximated it to be like this with this side this side and this point. I am finding out the stresses at this point this point and this point. So here the height is 1.6, 2, and 2.2. So, you know that the extra stress that is imparted here is 49.4 and 52.7 and I have ignored the formula here. Let us assume for the time being that this data is actually given to you.

This is 88.4 and this is 51 and 47.8. This is delta sigma z and this is the z. Now if this 3 things are known to you then how do you calculate the settlements. So, the settlement so basically if the settlement is so as I have said that the soil is normally consolidated so obviously the only settlement that you will come across is H into C c by 1 + e 0 into log of sigma 0 dash + del sigma by sigma 0 dash.

Now H is varying because H for the for the for the leftmost case is 3.2 m for the middle it is 4 m and for the end is 4.4 m. So, let us form a table so point 1, 2, 3; 1 point is the leftmost point, 2 is the middle point, 3 is the rightmost point. So, in that case delta sigma z is given to you as 49.4 + 52.7 which is equivalent to 105.6, 102.1, and 98.8. So, these are the delta sigma z that are given to you right now and sigma z 0 dash is 13.4, 10.7, and 14.7.

Now this you can easily find out because you know that what is the height of the what is the height of the clay layer at this point and basically multiply it by gamma so let us say that your gamma is 6.7 and you just multiply 6.7 with 3.2 so the at mid height of the clay layer so that means 6.7 with 1.6 and you will get 13.4. Similarly, with 2 and similarly with 2.2. So, once you multiply all these things then the final then the sigma final will be equivalent to or sigma 0 + delta sigma will be equivalent to 119, 112.8, and 113.5.

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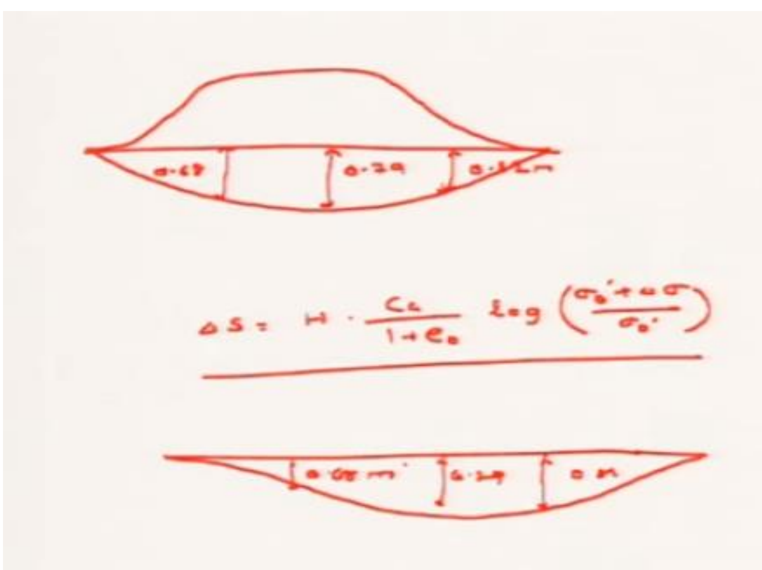

Now just plug these values and you will see that a settlement profile like this is obtained. This one is 0.68, this one is 0.79, and this one is 0.8 81 let us say. So, you see that the settlement profile here is again non-uniform in nature. Now this is let me tell you that this is a demonstrative problem because there are many parts of this problem that are still not discussed. So, like the how to find out the stress below how to find out the stress below an embankment. That is why I have ignored all the calculations here.

I just showed you that how basically if there is a non-uniform soil profile how basically you find out the how basically you can see or you can visualize the settlement below a non-uniform structure. So, in this case the non-uniform structure is the leave and in this case, you can see that this is the settlement profile. So initially let us move back to the problem that there was a soft normally consolidated clay and there were 3 there was a soil there was a extensive soil investigation that was carried out but datas were not available.

So, we just considered only the water content and liquid limit and plastic limit that can be easily obtained from the fields were discussed. So, in this case we founded out what is the value of C c what is the value of e 0 and then we moved to the part where basically the how to consider the vertical stress distribution. So, in this case we said that or I said that the leave is to be divided is to be considered to be an embankment with different heights with embankment with a uniform surcharge considering a uniform surcharge with uniform stress distribution and then you find divide the embankment with 3 sections and find out the stress below each of these sections.

So, in this case when you found out the stress below each of these sections then delta sigma z came out to be 105.6, 102.1, 98.8 respectively for the 3 cases and delta sigma z 0 is nothing but actually the stress at the mid height of the clay layer. Now since the 3 depths are different so that is why it was multiplied with gamma z gamma dash or the submerged unit weight to obtain the different depths and the sigma final was obtained accordingly just by adding these 2 numbers.

Considering those facts we have considering those facts now I am considering the settlement equation since it is a normally consolidated settlement equation H into C c by 1 + e 0 into log of sigma 0 dash + del sigma by sigma 0 dash we just plotted that how the settlement profile would look like and we saw that the settlement profile somewhat looks like this where this one was found out to be 0.81 this one was found out to be 0.79 and this one was found out to be 0.68 that is settlement profile is non-uniform and in this case also you have to see that what is the permissible differential settlement for the earth structure so what is the permissible differential settlement for the earth structure that you can permit.

Remember that in considering all these cases I have only considered 3 points but you can consider you can consider points more than 3. In fact, you can consider even all these 5 points that are 2.8, 3.2, 4, 4.4, 5.5 there is no problem regarding this but 2.8 and all these things are actually far out of the leave rather than 3.2, 4, and 4.4 are the only 3 point that are within the leave. So that is why we considered only these 3 points. So, we will stop the consolidation problem here today and in the next class we will discuss about the shear strength of soils which will be the last tutorial section. Thank you.