Geology and Soil Mechanics
Prof. P. Ghosh
Department of Civil Engineering
Indian Institute of Technology Kanpur
Lecture - 30
Consolidation - B

Welcome back. So, in the last lecture we just talked about the consolidation, fundamental of consolidation in soil and there we have seen and we have discussed what is consolidation and how the consolidation happens in soil right. So, basically consolidation is nothing but the expulsion of water or the drainage of water through the pore I mean from the void space of the soil matrix and causing some deformation or the volume change in the soil matrix or the soil deposit. So, in the last lecture we just talked about or we just discussed about this problem.

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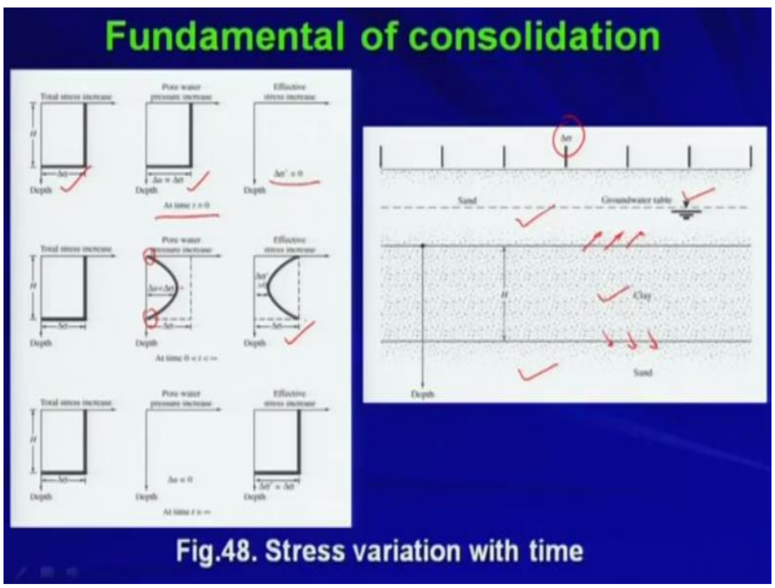

Say suppose you have some sand layer at the top and another sand layer at the bottom and in between you have the clay layer which is getting sandwiched between these 2 sand layers and which is having say depth H. So, because sand you know from the permeability point of view the sand is a good draining material right I mean that means the water will be passing through the sand deposit very easily right.

So, water basically if you apply the stress on this clay deposit basically the water will try to drain out through this interphase of sand and clay right because clay or sand will facilitate the drainage. Now in this problem basically we applied some external increment of stress that is delta sigma so there is some externally applied load or the load intensity is getting applied on top of the sand layer and the ground water table is here so the clay is completely saturated so there is no issue for that so I mean we are not considering any partially saturated or I mean unsaturated soil so clay is completely saturated.

Now what will happen? So, once you apply the load immediately at T equal to 0 we have seen this is my total stress increase because total stress increase will be remaining same because you are not going to change the stress increase during the say process. So, delta sigma will be remaining same. So, therefore your total stress increase will be always same as delta sigma. Whereas you will be having some I mean say balance in the pore water pressure built up as well as the effective stress enhancement right.

So, this at T equal to 0 so your total stress is delta sigma and as we have discussed in the last lecture that the immediately you apply the load the whole load will be taken care of by the water or the pore fluid right because the drainage is not happening and water is incompressible so it will take care of the whole load because it will not transfer anything to the soil solid. So, therefore your pore water pressure will be equal to your stress increase that is delta sigma.

So, delta u is equal to delta sigma. Whereas your effective stress right effective stress delta sigma prime will be zero because the whole load whatever you have applied externally the whole load will be taken care of by the water. So, nothing is getting transferred to the soil solid. So, therefore there is no enhancement or the increase in the effective stress. So, at some time say at say T equal T greater than 0 and less than infinity then slowly what will happen? The water will try to drain out from the clay deposit because it has got some drainage path through the sand layer at the top as well as the bottom as I told you.

So, the water will try to dissipate or try to drain out from the clay deposit. So, therefore at greater time so what will happen the pore water pressure will be gradually decreasing and the same amount of effective stress will be getting enhanced right. So, you can see so you will be getting simply zero pore water pressure at the interphase because that is that location is the closest location or the nearest location to the drainage path right.

So, that is why the pore water pressure immediately pore water pressure will be getting dissipated at those locations right at top as well as the bottom and it will be remaining maximum at the middle because the middle water particle has to move either on towards the top or towards the bottom to drain out from the clay deposit. So, the gradually the pore water pressure will be getting reduced whereas the same amount of effective stress will be getting increased right. So, that is the effective stress diagram.

So, at T greater than 0 less than infinity. Now if T is infinity now you have you have allowed sufficient time to drain out the water then what will happen? The total stress increase will be remaining same as I told you because you are not increasing the externally applied load. So, what will be the pore water pressure because at T equal to infinity the whole whatever water was under pressure so that has gone out so that has drained out okay so your pore water pressure will be completely dissipated and pore water pressure will be simply equal to zero.

So, the now the what will be taking the total stress then. So, whatever stress increment you have given the whole stress will be taken care of by the soil solids that means effective stress will be increased by the same amount. So, your effective stress delta sigma prime is equal to delta sigma. So, this is happening with respect to time.

So, as you vary the time you are getting different phenomena so initially the pore water pressure will be the maximum and slowly it will be decreasing and finally it will be becoming zero whereas you will be getting the reverse strain that is in the effective stress that is effective stress was zero initially and gradually it will be building up and then finally it will be becoming maximum. I hope that you have understood the phenomena right. Now with this concept we can talk more about the consolidation and we will be developing the consolidation equations expressions and the theory okay.

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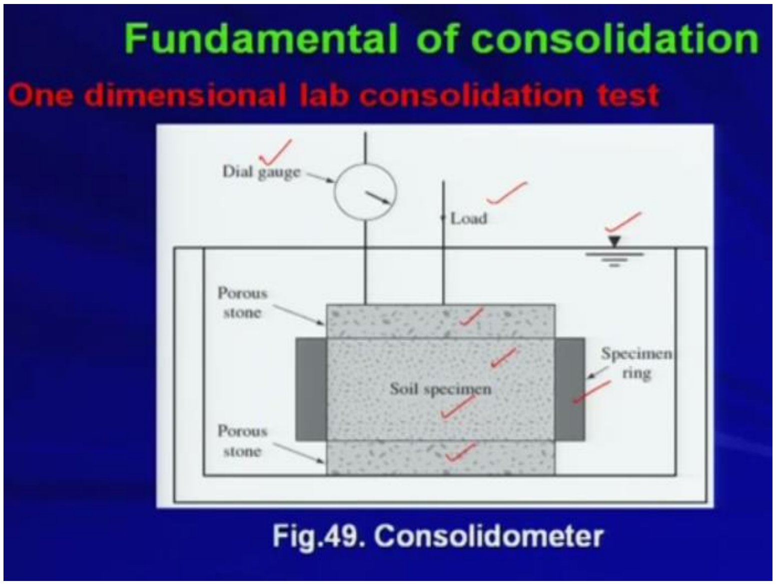

Now one-dimensional lab consolidation test. So, first we will see that how we can perform the laboratory experiment to understand the consolidation phenomena in soil. So, this is typical say laboratory experiment setup that is consolidation meter. So, here what we have you have some right so some metal ring. So, that is some this is the cross section whatever you are seeing on the figure that is the cross section of the test setup.

So, this is the ring okay. It will be happening all round say cylindrical say confinement okay. The soil specimen will be placed inside the ring. On top of the soil specimen you will be putting the porous stone to facilitate the drainage because porous stone will allow the water to come out but it will not allow the soil particles to I mean dislocate from one place to another place right. So, the porous stone will be facilitating the drainage.

So, now what you will do? You will apply some load okay and this whole setup will be completely saturated. That means it will be submerged under water right. So, now you will be applying some load externally applied load on top of this porous stone okay through some mechanism, loading mechanism, and then you will be observing the deformation that is the deformation means because you have the confinement in the lateral direction so the soil will be allowed only to deform in the vertical direction.

So, the volume change whatever you are considering that volume change is nothing but equal to the change in depth of soil specimen because you do not have any change in the diameter. So, diameter is completely confined. The soil specimen will be only deforming in the vertically downward direction right. So, the whatever volume change you are observing the in the soil so that is nothing but equal to the change in height or the depth of the soil specimen, am I right.

So, I hope that you have understood the I mean laboratory experiment concept. So, now in this basically we are applying some load right on top of this and we observing some height deformation or the reduction in height right so delta h. So, these 2 things we are observing and then based on that we will be developing the theory and we can find out that after certain time what should be what will be the deformation or at different stress increment what will be the deformation.

So, this phenomenon is very important right for designing any kind of structure on the clayey deposit or saturated clayey deposit because you want to know say if I apply or if I construct some building right on top of some clay you want to know that how much the how much will be the settlement of the foundation the consolidation settlement rather how much will be the consolidation settlement of the foundation.

That means you are applying some you are constructing some building so that will apply some externally applied load and after say 10 years or 12 years or 20 years depending on the I mean clay deposit you will be getting some deformation and that deformation will be solely responsible for the consolidation settlement right.

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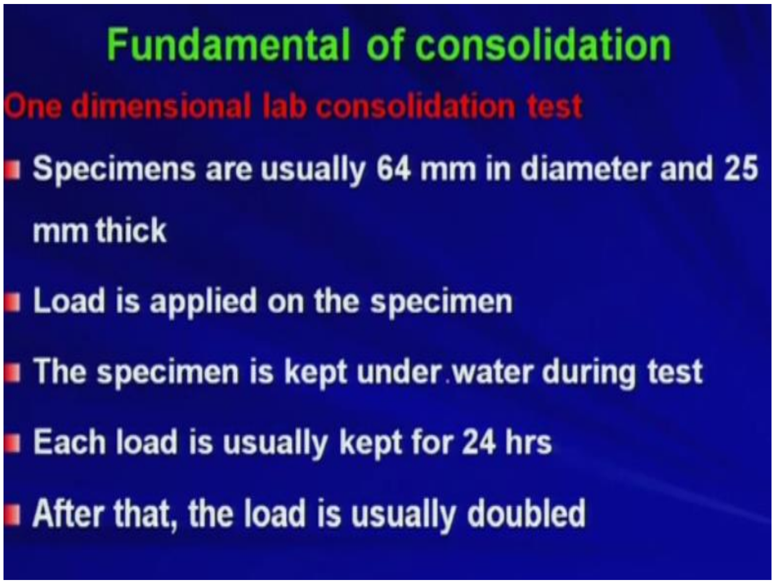

So, now the specimens are usually 64 mm. So, this is these are all standards. So, specimens are usually 64 mm in diameter and 25 mm thick right. Thick means the depth or the height. So, load is applied on the specimen as I told you, externally applied load will be applied. The specimen is kept under water during the test. It will be completely submerged that means you are considering completely saturated condition so whatever water will be coming out from the soil matrix so I mean there will be no change in say air voids or something like that right.

So, whatever volume change you are getting that is due to the expulsion of water. Each load is usually kept for 24 hours. So, this is pretty time consuming experiment. So, you apply the first load and you wait for 24 hours to deform because you have to consider 0 to T equal to 0 to infinity right. So, infinity is so called this is 24 hours almost. So, after that you will be getting complete dissipation of say pore water pressure and whatever enhancement you will be getting that will be happening in the effective stress right.

So, after that the load is usually double. So, that means whatever load you applied initially now you are doubling the load and then you observe the same thing that how much will be the deformation. You wait for another 24 hours and then you see.

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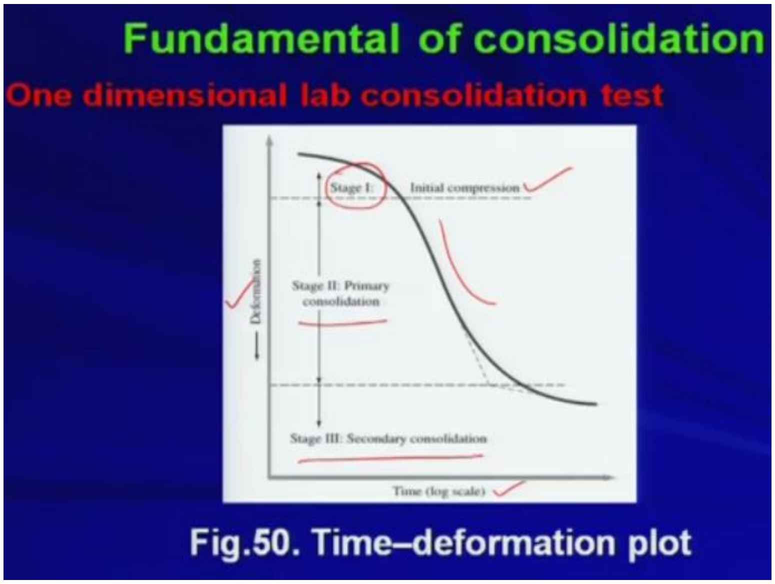

Fig.50. Time–deformation plot

So, now you will be getting a plot like this the this is the time deformation plot. Now you see the deformation is plotted on the y axis and time is plotted on the x axis that is semilog plot okay. In this plot, you are seeing that the you are getting some S curve right some nonlinear curve. So, S type of curve. So, in stage I basically that is nothing but your initial compression. So, you apply the load okay.

After, immediately after that you will be observing some initial deformation or the initial compression right. So, that already we have discussed right. Now in the phase 2 basically this is nothing but your primary consolidation. At that period, basically your water is draining out. At the initial compression, your water will not get enough time to drain out from the soil matrix. Whereas in stage II when the primary consolidation is happening that means you are allowing the water to drain out from the soil matrix.

So, that means the whatever deformation you are getting that is due to the change in void volume okay. In the stage III basically this is you are getting secondary consolidation. Even after T is equal to infinity or 24 hours still you will be getting some amount of settlement though that is not very significant amount but you will be getting still some deformation in the soil matrix because you will be getting some I mean reorientation of the or the plastic orientation of the matrix. So, I mean soil fabrics. So, we will see that.

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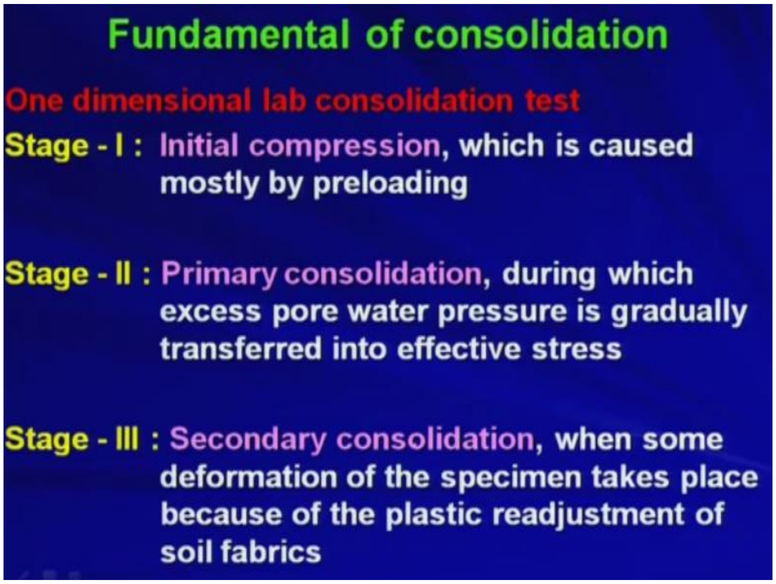

So, stage I initial compression which is caused mostly by preloading. So, immediately you apply the load you will be getting the initial compression. In stage II this is the primary consolidation during which excess pore water pressure is gradually transferred into effective stress as we have discussed so far and in stage III secondary consolidation when some deformation of the specimen takes place because of the plastic readjustment of soil fabrics. So, that means whatever soil fabrics or the soil particle you have though you will be getting some plastic readjustment that means that will not come back again right. So, due to that you will be getting some secondary consolidation.

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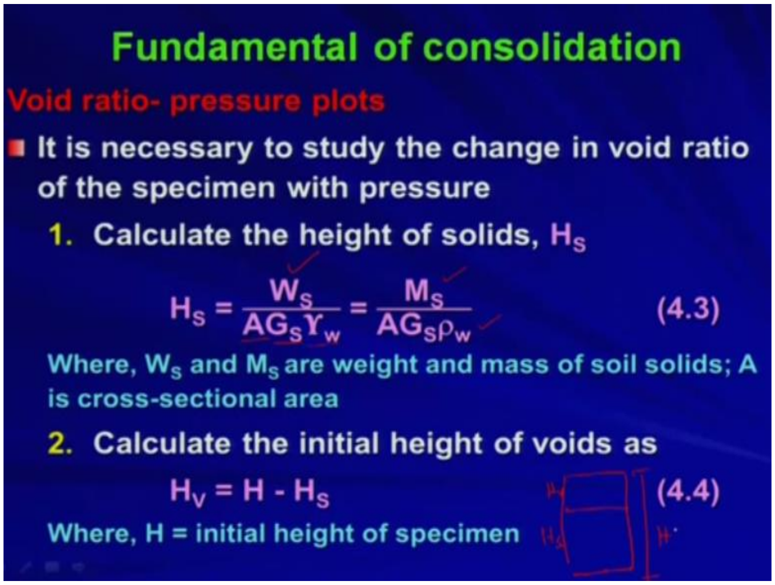

Now we will be seeing some void ratio we will be trying to plot the void ratio versus pressure plot. So, void ratio we are talking about void ratio because the volume change whatever volume change you are observing in the consolidation phenomena that volume change is solely attributed to the void ratio I mean the change in void ratio right because you do not have any change in the volume of soil solids because soil solids is fixed, the volume of soil solids is fixed, so you can only play with the volume of voids.

So, if you play with the volume of voids obviously that will ultimately reflect to the change in void ratio. So, we will just plot the void ratio versus pressure and so that we can see that how the I mean void ratio will be getting reduced with the increase in pressure. So, let us try to first develop or establish the relation and then we will be plotting them. So, it is necessary to study the change in void ratio of the specimen with pressure because it is very important because that will give you that how much change in volume is happening right in the matrix.

So, ultimately you can correlate that thing with the settlement of the soil consolidation settlement and that is very important for designing any kind of structure because you want to know that how much your foundation will settle due to consolidation okay. So, the first one calculate the height of solids that is H s. So, H s is nothing but weight of solid divided by the volume as well as this I mean A is the cross-sectional area G s is the specific gravity of soil solid and gamma w is your unit weight of water.

So, A into H s is nothing but the volume of solid right and G s into gamma w will give you the unit weight of solids. So, W s by A into G s into gamma w will ultimately give us H s okay. So, we can write further M s by A into G s into rho w where M s is the mass of soil solids and A as I told you it is the cross-sectional area okay. So, now in the second stage calculate the initial height of voids as say initial height of voids that means before applying the load what was the volume of I mean height of voids.

So, height of voids is nothing but the volume of voids am I right because as I told you, you have the lateral confinement so if you say some volume is getting changed that change is solely due to the change in the height not in the radial direction because radial direction you do not have any deformation.

It is completely confined through the ring am I right. So, calculate the initial height of voids as H v okay that is the initial height is equal to H that is the initial height of specimen okay minus H s it is as simple as that because H s is nothing but the height of solids and initial height of the specimen say if I have this is my say specimen okay and this is my say height of voids and this is my height of solids and this is the total height initial height of the specimen so H v is nothing but H minus H s okay.

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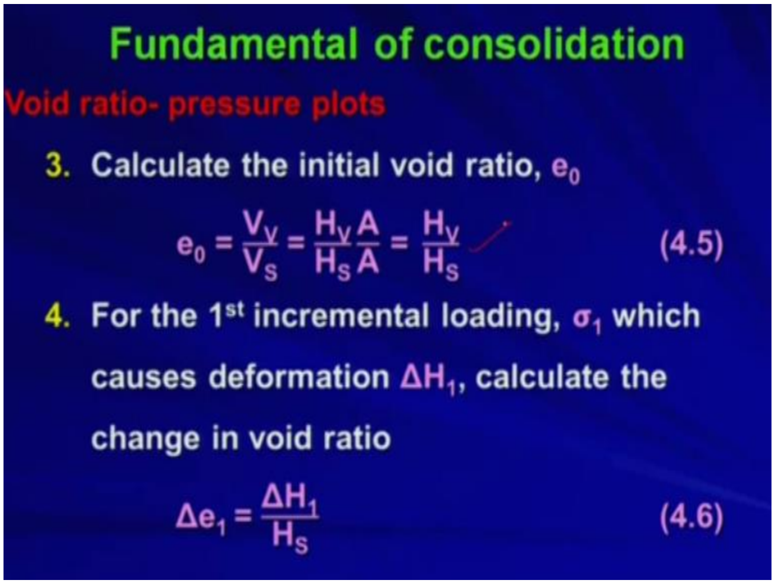

Now in the third step calculate the initial void ratio E not. So, initial void ratio when we are talking about so that is nothing but V v by V s so V s is not going to change. So, when you are considering some soil deposit V s is not going to change. That is the constant part. So, volume of solid you cannot change it okay. You can only play with the volume of voids okay. So, e not is equal to V v by V s. What is V v? V v is the initial volume of voids.

What is that? H v into A. H v we have calculated in the second step right just now. So, H v into A is nothing but the V v whereas H s into A is nothing but V s am I right. So, from this we can get e not is equal to H v by H s okay. So, your volume of voids by volume of solid is nothing but your void ratio. Now it is equal to your height of voids divided by height of solid because you do not have any deformation in the lateral direction or the radial direction.

So, in the fourth step for the first incremental loading sigma 1 which causes deformation delta H1 calculate the change in void ratio. So, that means now you are so this whatever you have calculated so far those are the initial things or the initial parameters. Now you are applying some incremental loading sigma 1 and due to that you are getting some deformation means only in the vertical direction only in the longitudinal direction say that is say delta H 1 say that is only in the height change or the change in height right.

So, delta H 1 you are observing due to the application of externally applied load sigma 1. Therefore, you can calculate the change in void ratio so now what will happen? Once you apply the load so I mean pore water pressure will be I mean the pore fluid will be getting dissipated and ultimately you will be getting some reduction in volume or the change in volume and which is basically due to the change in void ratio. So, the delta e 1 that is nothing but the change in void ratio will be equal to delta H 1 by H s right. So, H s was your volume of solid. So, the change in void ratio is nothing but delta H 1 by H s okay. So, from the definition itself.

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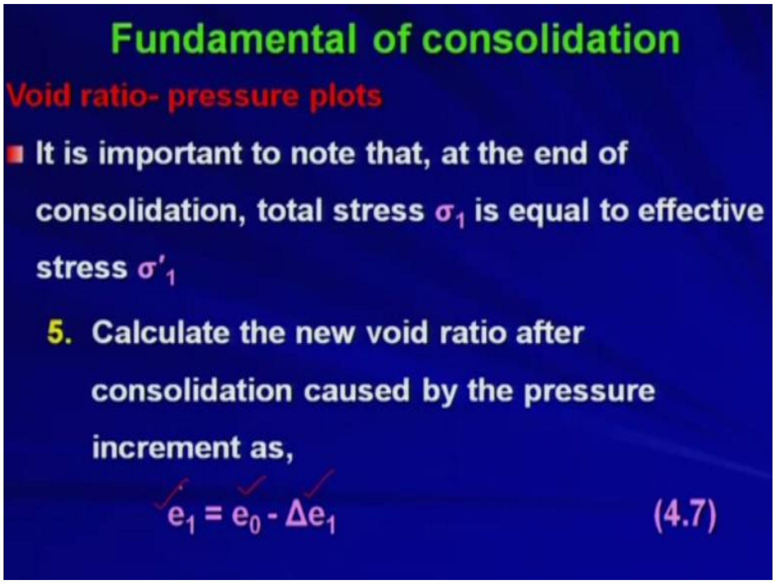

So, it is important to know that at the end of consolidation total stress sigma 1 is equal to the effective stress sigma 1 prime already we have seen right. So, ultimately at T equal to infinity your effective stress must be equal to total stress because you do not have any pore water pressure which is getting built up in the matrix okay because the whole I mean stressed or the pressurized water will be going out or draining out from the soil matrix.

Now in the fifth step calculate the new void ratio after consolidation caused by the pressure increment. So, therefore e not was your initial void ratio and after your application of sigma 1 you have got some change in void ratio delta e 1. So, e not minus delta e 1 is nothing but your changed void ratio or the new void ratio after application of your externally applied load or the load intensity sigma 1 okay.

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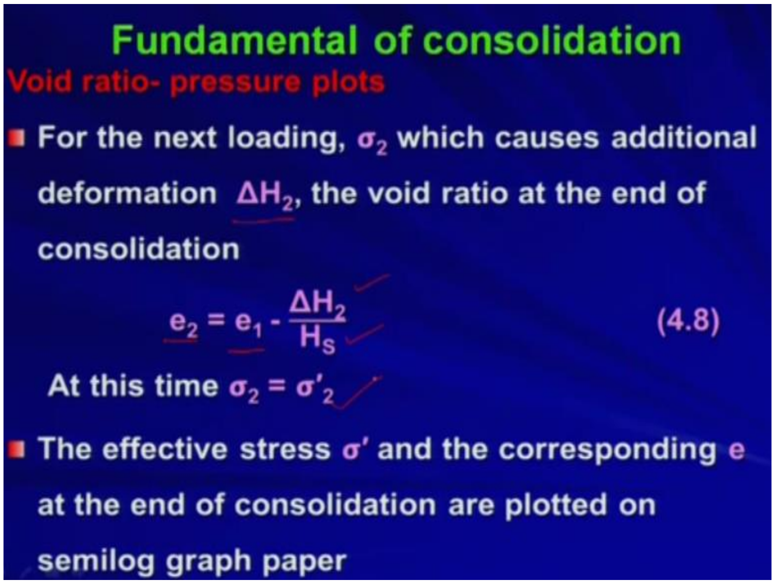

Now for the next loading sigma 2 which causes additional deformation delta H 2 okay. So, what is the thing, initially you have some parameters. Now you have applied sigma 1 and you have observed some deformation or the change in height as delta H 1 and because of that you have got the change in void ratio as delta e 1. Now after that and then you have allowed some T equal to infinity I mean so called say 24 hours or whatever and then you are going for the next increment of load which is say sigma 2 because of that you are observing some change in height is delta H 2.

So, the void ratio at the end of consolidation so every time we are considering end of consolidation means T equal to infinity. That means starting point is 0 T equal to 0 and gradually pore water pressure will be getting dissipated and you will be reaching where your total stress is equal to effective stress. That condition we are considering okay. So, the void ratio at the end of consolidation will be e 2 is nothing but what was the initial void ratio before starting of the second cycle e 1 right. So, e 1 minus delta H 2 by H s. That is nothing but your delta e 2, am I right? So, e 2 is equal to e 1 minus delta H 2 by H s.

Now at this time sigma 2 equal to sigma 2 prime. It is obvious right we are considering at the end of consolidation that means the total stress is getting converted to the effective stress and the pore water pressure is simply equal to 0 because of the draining out of the water. Now the effective stress sigma prime and the corresponding e at the end of consolidation are plotted on semilog graph paper okay. So, what we are getting we are getting the a range of or a bunch of say sigma prime that is the effective stress so we are going on increasing the effective stress.

So, effective stress is nothing but the total stress because at the end of the consolidation we are considering the pore water pressure is 0 so we are increasing the effective stress and because of the increase in the effective stress we are getting some decrease in the void ratio. So, we can we can get a bunch of void ratio values and a bunch of and corresponding a bunch of pressure values or the effective stress values and then you can plot that thing in a semilog plot.

So, I will stop here today. So, in the next lecture we will be continuing this thing. I hope you are enjoying this thing because this chapter is very important and very say fundamental concept is required to understand this thing. So, please be careful when we will be talking about different parameters and when we will be defining different parameters. Try to understand each and every concept okay. So, thank you very much. I will stop here today.