Geotechnical Engineering I

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Lecture-25
Compression Characteristics of Soils-I

We have discussed a lot about the soil characteristics and we have devised different types of strategies to understand how the origin of soil occurs, how soils redeposited and how they are classified based on their redeposition and the transportation agency. Later on we talked about some indices, which characterize the soil mass, and they were at our limits that in short was the interaction of the soil with water.

And we wanted to study what really happens when soils come in contact with water. From there on we moved to discuss about the compaction characteristics of soils. And this is the first time and we talked about how the microstructure or the pore structure changes because of the external impact of the loads or the stresses. Then we talked about the seepage characteristics and then we try to understand based on the coefficient of permeability, how the science can be characterized.

I am sure you must be realizing that all these discussions which we had done until now are valid for characterization of the soil mass. Subsequently we talked about the stress, which develops because of the external loading in the soil mass. And this is where the compressibility comes in picture. That means when the soil mass is exposed to external loading, how it responds, and this could be a sort of an engineering behavior.

So, I am sure the common thread between all these discussions which we had until now is to understand the response of the soil mass to the external stimuli or to the floods or to the pressures which are being exerted on them. So, in today's lecture, I will be discussing about the compressibility characteristics of the soil mass. And what I have written over here is this is compressibility and consolidation.

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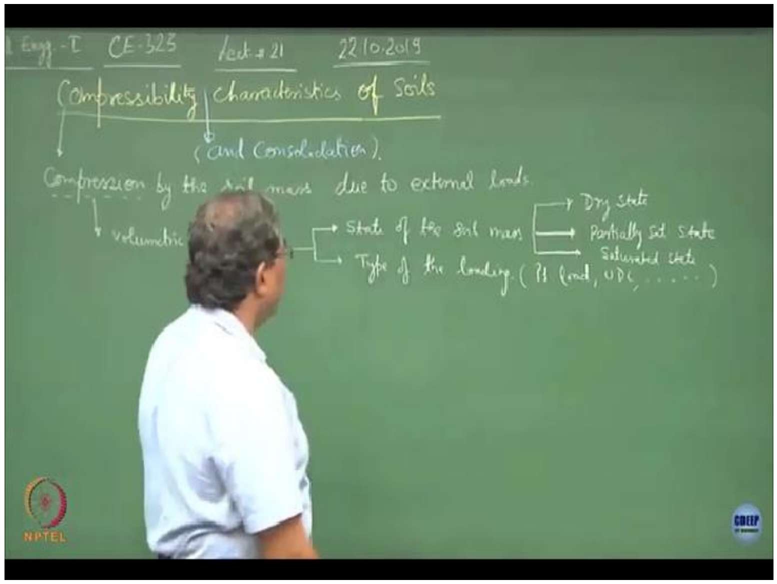

Because once we have understood the compressibility characteristics of the soils, we will move on to discuss about the consumption characteristics of the soils. As the name suggests, the compressibility is the compression undergone by the soil mass and this is mostly because of the external loading. In the previous lecture we have talked about how these stresses can be computed in the soil mass because of the external loading.

Now if I consider the compression of the soil mass this is normally we talk about or we are interested in the volumetric compression. Now volumetric compression of the soil mass would depend upon the state of the soil mass and the type of loading which acts on it, we have already studied the type of the loadings, this could be the point load, this could be the uniformly distributed load, this could be different types of loadings which we have talked about in the previous lecture.

So, as far as the state of the soil mass is concerned, normally we deal with a dry state, it could be a partially saturated state or it could be a completely saturated state. So, when we define the compression characteristics of the soil mass, it becomes important for us to understand soil is in what state dry state, partially saturated state or desaturated state. Now, suppose if I consider a surface.

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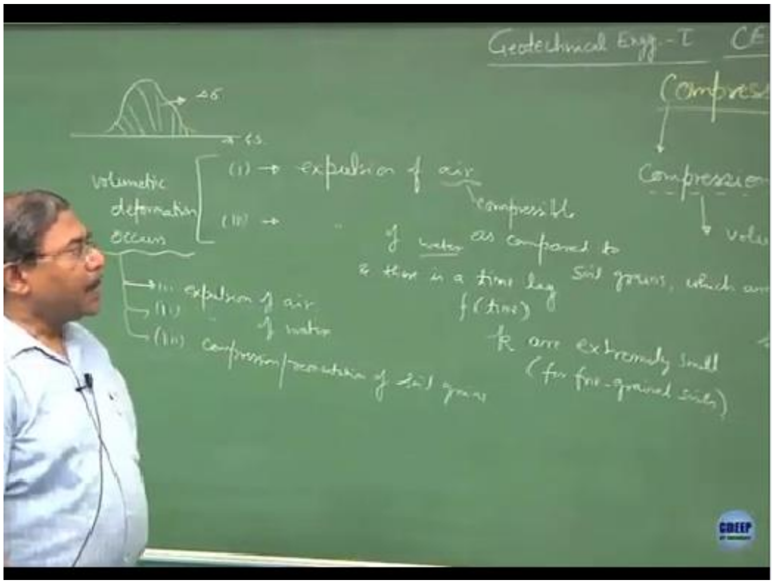

This is the ground surface, let us say and there is some loading, which is coming on the top of this. So, normally we say that this is delta sigma. Now, delta sigma is the one because of the construction of this facility over here. Now, if the soil mass happens to be dry. What is going to happen the compression is going to be due to the expansion of air, why because air is compressible okay, as compared to the soil grains which are incompressible.

And so is water also, if I am dealing with the dry soil and if I note that dry soil system the air will being compressible will go out but the soil grains which are compressible (()) (07:23) however when I change the scenario I will be talking about the third case directly that is when you have been saturated state of the soil, this is because of the expansion of water the volumetric deformation is going to occur okay.

Because water is compressible and it takes time to move out of the coarse. And there is a timeline that means, this process of exploration of water from the soil pore is going to be a function of time. And this is mostly because of the fact that hydraulic conductivities of the geomaterials are extremely small particularly for the fine grained soils alright. So, the situation is like this that the moment you load the system of soil mass from outside in the form of delta sigma the amount of somewhere may expel out.

And there could be a compression, the major contribution of the compression is going to come because of this process and hence we say that volumetric deformation of the soil mass is going to take place because of either the expulsion of air, expulsion of water or the third one could be the compression of or reorientation of soil grains alright. So these are 3 responsible factors. Now, when I was talking about the particular nature of the soil I had this small model.

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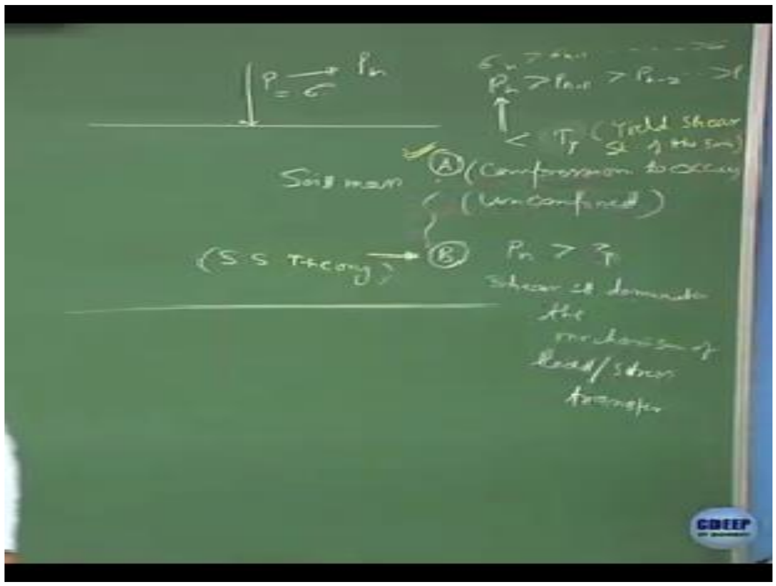

That supposed with loading P which delegates to sigma and I had talked about 2 situations suppose this is a soil mass and the lateral pipes are unconfined alright. So, this is the unconfined soil mass. If I keep on increasing the intensity of the load say from P to P n where P n is greater than P n – 1 is greater than P n - 2 is greater than P. What is going to happen, if I do not have a confinement the tendency of the particles would be to first you know the whole soil mass will get compressed.

And then because there is no confinement the tendency of the soil to flow. So if I restrict P n to certain limit that P n itself is less than the yield strength of the soil, now we do not write sigma y over here, we will be writing the shear stress. So suppose if I say the shear stress y alright, in this case only the compression is going to take place. Why because the shear strength of the soil is higher as compared to the stressor which are getting delegated into it.

And hence there is no you know, slippage. There is no rolling over. There is no reorientation, the particles and hence this is a pure case of the compression. This is what actually we are going to study today A part. However if reverse is true and if I say P n creates a stress which is greater than the yield strength of the soil this becomes a shear strength analysis. So, shear strength dominates the mechanism of no transfer, hope this part is clear to you.

So, part number B we are going to do in the second course. This will be dealt with under shear strength theory, not today, however the part 1 A will carry on the discussion on A that means we are restricting to a situation where the state of stress in the soil mass because of the external loading is not going to exceed the yield shear strength or light and hence the compression only is going to govern the process is this part okay.

Oh this is the P that means a load and if you compute the stressors along with this will be sigma n greater than sigma n – 1 to sigma. So, these are the stressors, these are the loads, below this is the yield strength of the soil yield shear strength of the soil alright. So, coming back to the issue, see what we have done until now is we have defined the compressibility in such a manner that this is a fundamental characteristics of the soils as engineering property.

And it basically tells you about the response of the soil mass to the external loading, a follow up of this would be the consolation process, which will be discussing in the subsequent lecture. So, this is how actually the compression has to be defined. Now, what I intend to do in today's discussion is, I will be talking about how to quantify the compressibility characteristics of the soils. So, the question is how would you obtain the compressibility of the soils. So, that is the determination of compressibility characteristics of the soil mass.

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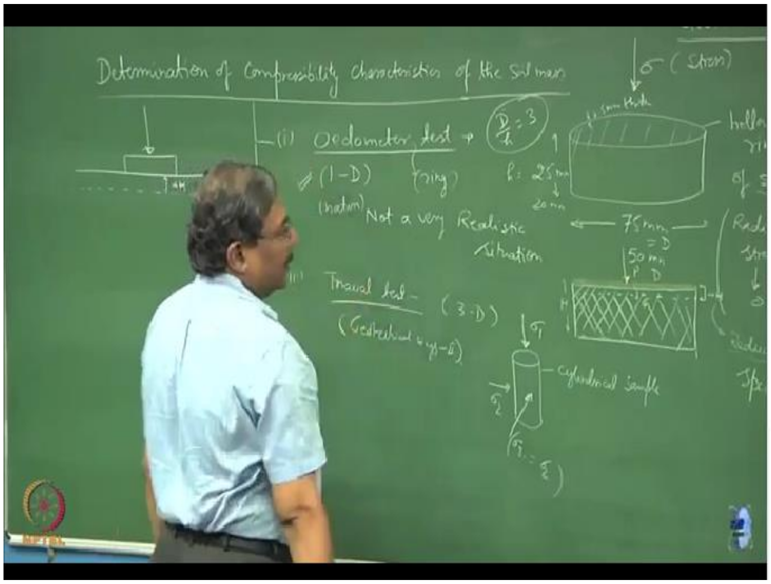

There are 2 ways. The first method is which is known as Oedometer test. We call it as Oedometer test, find out what is the meaning of the word Oedo. So, this is the hollow ring of stainless steel, normally 75 mm in diameter and 25 mm in height and made up of you know about 0.5 mm thick metal. Now, this is the odometer ring Oed is basically a sort of happiness. So, the name is a interesting name , this is what is known as a Oedometer ring alright.

So, this is a stiff stainless steel hollow ring of dimensions 75 mm and 25 mm, sometimes people use 50 mm diameter and the moment it becomes 50, this will become 20 mm. So, these are the standard things. So, one is by conducting the odometer test and filling the soil sample in this ring and then applying a normal stress alright. So, sigma is the stress which is applied on the soil sample which is contained in a hollow ring, which is made up of steel.

Now steel gives enough stiffness and hence the radial strains in this sample 10 to 0, let me there is no deformation of the steel ring. So, when you apply the load on the soil mass there is no radial deformation taking place in the system. So, this becomes a opposite case where we had talked about the unconfined, this becomes a confined boundary and then confined boundary is there you know this is what gets stimulated with the odometer ring when I load it.

The only possibility is that the soil grains are going to get compressed. There is not going to be a shear failure. There is not going to be any rolling and there is slippage along the plates of the fine grain materials. No, unfortunately, this is not a very realistic situation. Because most of the situations with prevail in the nature or in practice are 3 dimensional, I hope you can realize that this is a one dimensional loading and one dimensional deformation of the sample.

So, that means, if I keep my sample like this, so this is a sample to begin with, the moment I have loaded it and normally rather than having a point load what we do is we distribute this load on the surface. So, this is how the P load is acting which gives a sigma stress. Now, this is not a very realistic situation. So, in order to create a realistic situation, what we can do is we can obtain the compressibility characteristics by doing a triaxial testing.

So, this is 3 dimensional in nature. What we do is, we to take a cylindrical sample. So, this is the cylindrical sample you must have noticed here, what we call this as the diameter D and this is the height of the sample h. So, we maintain D by h ratio as 3 alright. This is what the typical situation is and I hope you can realize that why D by h is kept as 3 because in the previous lecture when we are talking about the stress which is getting induced into the soil mass you know, when your dimension of the loaded area is 3 times the height of the sample all the stress balls which are going to get confined into the sample would be 99% you got this.

So, geometrically we forced the all the pressure balls to remain confined in the system. And hence I can assume that the loading is uniform on the sample from top to bottom clear. That is the reason. So, when we do triaxial testing, we apply let us say sigma 1 over here, sigma 2 over here and then sigma 3 over here. Normally, we maintain sigma 3 = sigma 2. So this also becomes a biaxial testing, but is not 3 dimension.

When we are talking about the triaxial test for obtaining the shear strength characteristics of the soil mass. So let us again remain confined to Oedometer test, which is 1 dimensional in nature. Okay, and as I discussed when you apply this stress over here, so the deform sample would look like this. This is the deform sample. And I can say that there is a deformation of let us say, delta H and delta H is the reduction in height of the specimen, specimen of the soil (()) (23:11) again we are trying to find out how the compression characteristic look like.

Now delta H will be compression also. So, rather than writing reduction in better scientific language, this can be replaced with the compression. What is the significance of this. If you have a soil mass sorry, if you have a soil mass and suppose if I lay a foundation on the top of this alright, so this much of these compression of the soil we are going to observe due to extra loading provided the soil is same.

So, this soil is same as what you have in the nature, you have taken out some sample over here filled in the ring either I can reload the sample or I can take rings, which I can insert into the soil mass, I can take them out and this is how we collect the undisturbed sample and that sample can be inserted into the loading frame and I can load it and I can get that deformation right. So, this becomes the Oedometer testing, which is what we are going to discuss in today's class.

So, let me discuss a bit about the 1 dimensional Oedometer tests or the consolidation test we call it, there are 2 methods of ring analysis.

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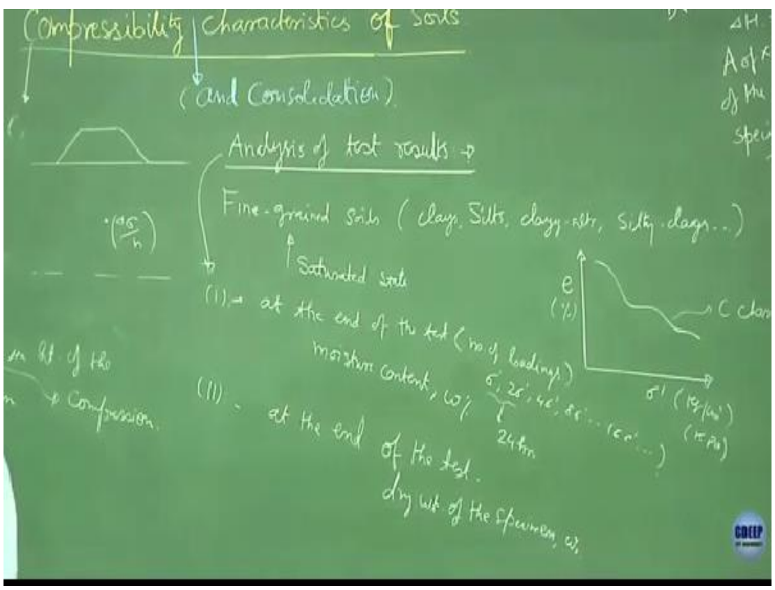

Particularly when we are working with fine grain materials like either clays or you might be having silts or you might be having clay silts or silty case so on. Normally we do not talk about the compressibility characteristics of the coarse grain materials because as I said, the grains are incompressible and then they look point in talking about the compressibility of the dry soils particularly granular material.

So, when we talk about the fine grain soils, in order to simplify things, what we do is we saturate them.

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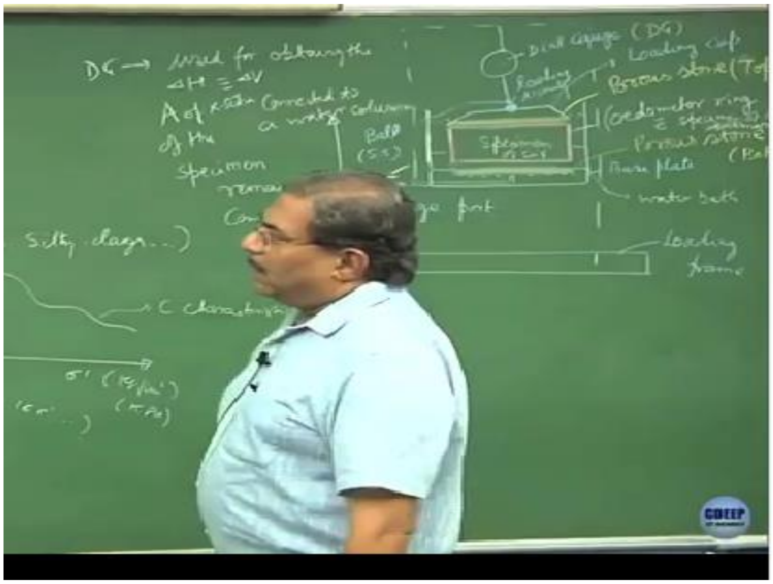

How saturation has done, this ring which is containing the specimen of soil. Normally this is placed in a on a pad in such a manner that this pad has a groove in it alright. So this is what is known as base plate and this base plate is collected with a drainage tube or the drainage, we call this as a drainage port. And this drainage port can be connected to a water column fine, what we do is in order to to spread the load which is coming on the sample we put it on porous stones.

So, we placed porous stones in this groove. This is the porous stones and when similar porous stones is kept on the top of the specimen, which is contained in the ring. So, if I show you the ring like this in which the specimen is contained. So this is the Oedometer reading with a specimen of the soil mass, we will put a porous stones at the top also. So, this is porous stones number 2 or we can say top and bottom alright, on the top of this porous stones come say loading pad is made up of steel and there is a groove in which I can keep a ball.

So, this is the loading cap and this is the ball which is made up of stainless steel and this is connected to entire thing is connected to a load frame. So, this is the loading pattern or sorry loading assembly, we can call it, so this is the machine or the loading frame I can read how much load I have applied or I can devise a system by which I can apply a certain known amount of the load on the plate. I also attached a dial gauge over here and this dial gauge gives us the deformation undergone by the specimen when it is loaded.

So, dial gauge is DG is used for obtaining the delta H alright. So, dial gauge gives you the readings that after you applied this stress on the sample or the load, how much the deformation, the specimen is going on. That is delta H and I hope you can realize that area of cross section remains constant of this specimen remains constant and hence delta H is also equivalent to delta V the volume.

Now choice is mine. If I want to do a study on a dry sample, I can do it you can prepare the sample you can take dry soil you can pack it in the Oedometer ring and you can apply stresses and you can obtain delta H. I can vary the moisture content of the fine grain materials and I can fix them in the Oedometer ring and I can study the compressibility characteristics. Normally, when we deal with the fine grain soils, as I was saying to make life easy, we saturated we make sure that the sample remains saturated always.

So, when we do this test, we open the wall and we allow water to remain always filled up in a container which is a bath. So, this becomes the water bath and this remains flooded with in fact, the water bath should be up to the higher limits of the specimen. So, the water can be maintained up to here. So, sample remains or the specimen remains submerged in water all the time and hence they are ensuring that we are obtaining the saturated state deformation characteristics, compressibility characteristics of fine grain soils in particular.

You should do this test to understand things better or maybe see some videos where these type of demonstrations have been done. So, as far as the analysis of test is concerned, basically what I want to do is I want to obtain a relationship between the wide ratio and sigma prime. So, sigma prime is in kg per centimeter square, sometimes we also write it in kPa, wide ratio is going to be in percentage and whatever relationship I get, this becomes the compressibility characteristics okay.

There are 2 methods of doing this test. The first one is where at the end of the test. So, when I say at the end of the test is understood that the objective or the target effective stress level has been exposed to the sample. Normally, effective stress is exposed on the sample in steps. So, when we say at the end of the test that means, number of loadings which are normally double. So suppose we start with sigma prime 2 time sigma prime, 4 times sigma prime, 8 time sigma prime, 16 times sigma prime and so on.

And between the each loading, incremental loading, we wait for 24 hours for the dial gauge readings to stabilize. In other words, we give 24 hours of waiting time for the specimen to undergo the maximum possible deformation alright or the compression. So, we can find out how much sigma prime is required that must load you have to apply because sigma is the area of cross section multiplied by sigma prime will be the loading.

So, normally you take first load 2 times second loading and so on, so at the end of the test that because the number of loadings have been achieved, you find out the moisture content, how does it is done, suppose if I am a designer and I want to design less than embankment, which is going to be coming on the ground surface. So, remember what we have done is we have obtained these stresses coming at this point because of external loading. So, that is delta sigma.

So, this becomes my design stress okay. So, this design stress I am going to expose onto the specimen to get this response and hence, I know what is the total magnitude of delta sigma which I have to apply on the specimen. I can make it small cycles, number of cycles or number of steps So, I can apply delta sigma by n and follow this pattern of 2 times of the loading which is a standard procedure and complete the test.

So, once the test is over, you remove this specimen containing sorry you remove the ring containing the specimen and wait and find out its moisture content. So, suppose this moisture content is W. In the second procedure, what we do is at the end of the test take out the ring containing the specimen and dry it up and find out the dry weight of the specimen which is W s. So, these are 2 methods fine.

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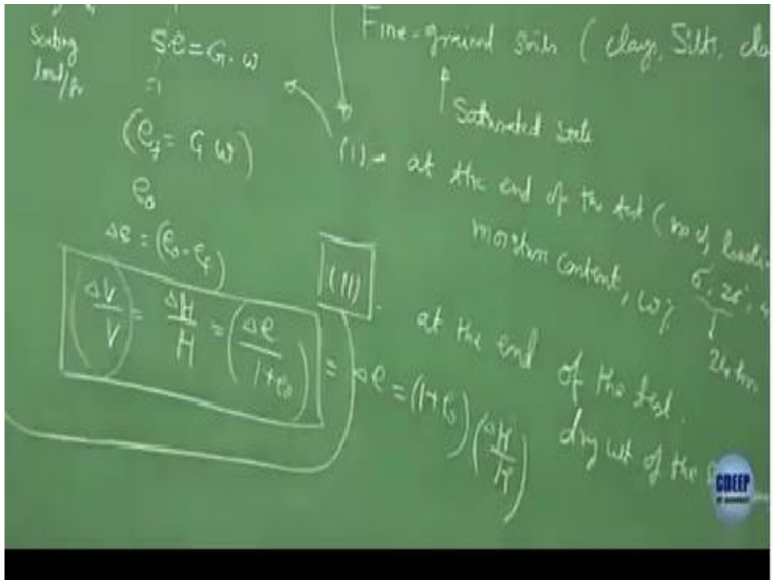

So, in the first method, when we are dealing with moisture content if a specific gravity is known multiplied by moisture content, this will give me s into e. So I am making sure that the specimen demand saturated all the time by doing this arrangement of water bath and water bath remains filled up with water specimen remain saturated. So s is 1 that means the wide ratio are G into w. If I know the initial wide ratio e 0 this is the final one after the test.

So, if I say that delta e is e 0 - e f clear. And making sure that I am doing 1 dimensional analysis, if you remember here, area of cross section is constant. So, I can say that delta V upon V, the volumetric strains, which the sample or the specimen has undergone are equal to delta H upon H, where H is the initial height. So, suppose if I replace this by capital H and delta H is the change in either the sample, this will be equal to delta e over 1 + e 0.

This is a relationship which can be utilized. So, here what I have done, I have got the final wide ratios, I know the initial wide ratios, delta H can be obtained at every change of stress. So, if I try to recomplete or complete this graph, I know the initial wide ratio which is known at a very small stress, we call this as the seating load or the seating pressure. This is just to maintain the contact between the sample and the top plate, you know, complete.

Because if you do not allow any seating load, there will be initial disruption in the readings. So, this is a point from where we are starting the compression process. So, suppose if you take the first increment of the load sigma 1 prime y prime, because the sample is saturated and submerged, clear. So, you have to reduce the pore water pressures and compute the sigma 1 prime. But I am sure you must be realizing when we are doing the Oedometer test.

And we have put porous stones at top and bottom we are ensuring that the pore water pressure does not remain contained in the specimen and gets dissipated. So, basically you turns out to eb 0 and hence sigma prime is same as sigma. So, this is how the relationship would look like. Okay. So, this is the function which I have created from e value, now how would you get e from this relationship. So, delta e will be equal to 1 + e 0 into delta H upon H, e 0 is known change in height of the specimen which can be obtained directly from the dial gauge reading.

And I know the initial height of the sample I can compute delta e and from there I can back computer starting from this point to this point I can fix the relationship. So, once I have e was a sigma prime relationship, I will tell you how to do analysis further. The second method is at the end of the test you find out the dry weight of the specimen which is W s. So, if I know the W s.

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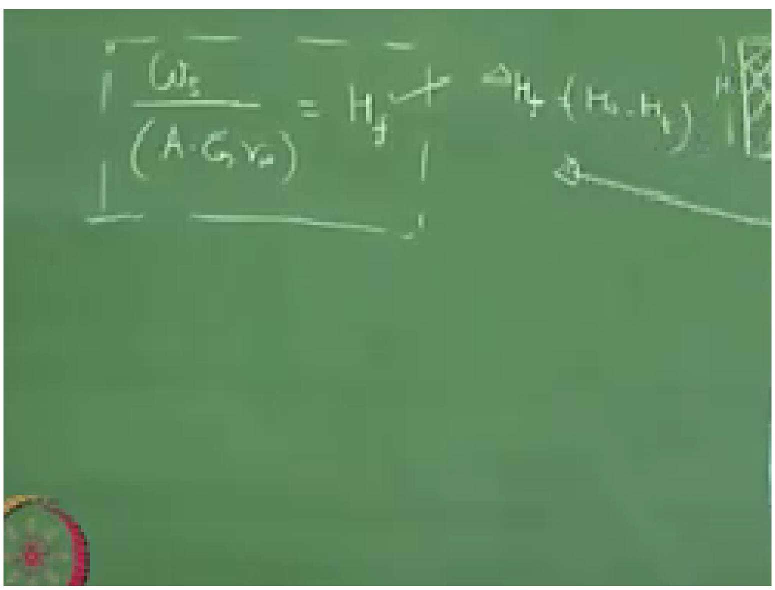

So, if I know W s this thing divided by area of cross section multiplied by G into gamma w. What this value will be sorry, very good. So, this will be the H final is this correct. Nice why because once the test is over, you have taken out the whole thing you can subtract the weight of the ring from the total dried weight of the specimen, you get W s of the specimen W s, this is the area of cross section and G into gamma W is the density clear. So, weight upon density is multiply by area cross section will be the height term.

So, H f I have obtained, I hope you can realize we have fixed this dial gauge to get the change in the H value. And what I am getting from here is final H f. So, at each incremental loading, I know the value of H also. So, this can also be utilized to compute the wide ratio by using this relationship, choice is yours whatever you find easy can be utilized. So, nothing is changing except for W s, the weight is corresponding to the final space. So, H f is fixed.

So, in most of the situation, what we do is after getting the final point view back traverse to be initially. So H f, once you obtain delta H f will be equal to x 0 - x f clear. No delta V upon V is the volumetric strain which is same as the vertical strain the sample or the strength of sample, which is equal to change wide ratios upon 1 + e 0. If you remember when we were talking about the3 phase system of the soil, we had used 1 + e 0 term as especially volume okay.

So it is a sort of a normalization of the change in a wide ratio undergone by the system because of the compression for a specific volume of 1 + e 0, so, this is how you normalize the things. So 1 + e 0 is a normalization parameter, which is known as a specific volume. So, implicitly what we are not plotting on these scales is I hope you can understand the time, because each step is a function of time.

So this time we assume to be 24 hours and we make sure that the dial gauge readings have subsided. Normally the practices, you keep on observing 3 to 4 dial gauge readings and once they are constant we can go for the incremental loading or unloading. So if 3 dial gauge readings are constant, we assume that the sample has accumulated clear, done. Any questions, these tests look very simple, but you will be surprised to know that till date, the profession depends upon these tests to get the correlation between what is happening in the field once you have taken a sample out from down below and testing it in the laboratory.

There is no other way to do the analysis of what has caused the failure of the geotechnical structures, foundations, embankments, any structure which are making out of it. Now I would like to interpret this graph further, because this is the crux of the things. So, what we have done is by conducting these experiments, we have got a relationship between wide ratio and applied stress. So, let us do the analysis of this relationships and see what all can be dissipated from here. So, typically we get a relationship like this, what I have shown there.

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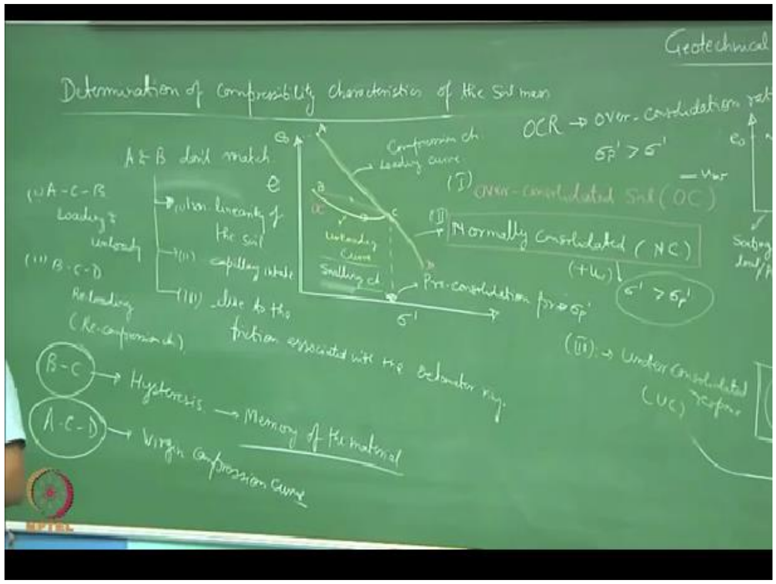

If I plot e verses sigma prime. This is the initial compression curve alright, at this point which is corresponding to a certain sigma prime value, if I stopped loading the sample and if I unload it reverse process, see what we have been doing here is we have been doubling of the stresses. So, this is the loading process and suppose if I start removing the load from 16 to 8, 8 to 4, 4 to, 2 to 2, 2 to sigma, so, this will be unloading clear.

So, at this point, if I unload the sample this is all the response looks like. So, this is the loading curve and this one is the unloading curve or unloading response, this point is defined as pre consolidation pressure and we defined this as sigma p prime. This has a lot of interesting, you know, knowledge in built into it. We will discuss about this, this is also known as competition curve and this is known as swelling curve.

This is compression or compression characteristics you may say these are the swelling characteristics. Now one interesting thing to observe here is this is how we started the test with e 0 value. What you observe is that point A and point B will not match A and B do not coincide.

What is the reason. The first reason is because the soil sample is nonlinear because truly speaking e upon sigma prime is nothing but a sort of a stress strain curve, is it not.

You must have notice that if I normalize it with a e 0 value this becomes e upon e 0 or I can do even delta e upon e 0, which is a strain versus stress. So, this is first of all, because of the non linearity of the soil number 2 regain of yes, correct. So, what you have done from A to C you have squeezed out water from the soil sample by applying the external load and water being incompressible as moved out of the specimen.

Now C to B is a sort of a unloading behavior little bit of water can be sucked by the sample yes. So, that is also valid. That is you know what we call it as a capillary intake and which is less than the water which has been expelled out because the uptake capacity of the soil in compacted form is less. The most important thing is why A and B do not match because of the friction. So, this is a friction which is offered by the ring alright.

Due to the friction associated with the Oedometer ring which is not allowing B to coincide with A is a in elastic material fine. So, this is known as unloading curve or swelling characteristics also. Now suppose, if I reload the sample from point B onwards, what is going to happen is, this is how the reloading would be, so B to C to D, A - C - B is loading and unloading, B- C - D is I would say reloading or sometimes people also call this as a recompression.

Now one interesting thing here to see is, if I reload the sample from B it passes through point C and goes up to D. I am sure you will realize that B - C has formed a hysteresis. And hysteresis is associated with the memory of the material. So from this point onwards I respect soils for having memory. So, this point will get clarified very soon. Soil behaves as if nothing has happened to it and if you look at A- C - D this becomes a continuous curve.

So, A to C to D remains a virgin compression curve as if nothing happened to it, alright. So, for all practical purposes, I can assume this to be something like this okay. So, this happens to be passed all sorts of torture which you are given to the sample goes into the memory and it maintains it. Now, this concept is used quite a lot, when we talk about the shear strength theory of the soils. It was interpretation of C to B to C.

So, unloading and reloading cycle alright, why we are called with a virgin compression curve as if nothing has happened to this from this point onwards. So, pre construction pressure is the point clear or the pressure above which the sample is going to behave as normally consolidated. We call it as NC response, from this point onwards you will realize that the material vanishes and the state of stress in the material guides the entire mechanics of the material.

So, we do not bother whether this is clay or this another soil as far as the pre construction pressure is concerned that becomes the basic characteristics of the soil mass which is going to help us in designing the systems from C point onwards when you did loading sorry unloading this creates the OC behavior of the side which is known as this is the OC behavior we call it as over consolidated soil alright.

So, by definition, if I define the term OCR which is over consolidation ratio clear if the signal is greater than sigma prime you know at this point what has happened the material has already experienced the very high effective pressure as compared to unloading part clear. So these type of soils are over concentrated. They will show less settlements, less deformation, less compressibility.

However, if your sigma prime happens to be greater than sigma p prime this is the case of the normally consolidate soils where the deformation, the settlements and the consolidation is going to be much more fine. So, what I have done is by utilizing the concept of the pre consolidation pressure I have characterized the soils and as an engineer technologist, I will be more interested in utilizing the soil mass where it is exposed to the stresses rather than anything else.

So, this is the best possible engineering characterization of the soils based on the history of stresses the system has on been exposed to, there is the third category which is known as. So, this is the first one over consolidated response normally consolidate response and the third one is you know which is known as under consolidated, we call it as UC. In this case, the present pressure is higher than the previously exposed pressure to the system, sigma p prime.

And hence, this is NC material. Later on we link these 3 things with the pore water pressures. So, in OC materials normally the pore water pressure is always negative. Why, because you rightly said they have a tendency to suck water. So, he has the tendency of the material becomes to suck as much as water it can uptake or it can suck. So, this becomes a situation where the negative pore water pressures prevail in the soil sample.

In NC normally, we have positive pore water pressures. So, suppose if I give you 2 situations, the soils which are formed in the Himalayan region and the soils which are getting formed in the Sundarban delta, which you discuss in the beginning of the lecture. So you mean in the case of the deltas everyday fresh load of sediments is coming and is getting dumped into the ocean beds clear. So, that means the present pressure is always higher than the past pressure.

So, this becomes a normally consolidated material, however up stream in the Himalayan region was happening the soil is getting eroded day by day clear. So, the present pressure is always less than the past clear. So, this is a situation of OC material. So, the sides which are in the Himalayan regions are over consolidated as compared to the ones which are in the Bay of Bengal clear. So, as you understood that from a simple test how much information we have deciphered about the material.

And that 2 in 1 dimensional compression situation, under consolidated is the one where you know the past pressure is equal to the present pressure is something in between. So, this is what is known as under consolidate response So, these 1, 2 are normally used in defining the state of the material and how to utilize this as a construction material.