Soil Mechanics

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Lecture – 34

Consolidation and Settlement

Students we meet you once again. We had six lectures by me on the topic of stress distribution in soils and before I go ahead with the next topic, let me say a few words about the previous topic for the sake of continuity. Because I shall be following the same format that I followed for the previous lecture, series of lectures rather. Now if you remember in the topic on stress distribution in soils, I had raised a few questions and answered them. Basic questions regarding what is stress distribution, what it means to us, where is it important and then how do we compute stress distribution due to a load applied on a soil. The same format we shall follow for this new topic of consolidation and settlement.

In the previous series of lectures we not only saw the basic theory of elasticity that is fundamental underlying theory that helps us to compute stress distribution. But we also saw its varied forms of applications. We saw how a concentrated load, a strip load, a line load, a uniformly distributed load can all be applied on either a rectangular or circular or an arbitrarily shaped foundation. And how we can compute this settlement at any point in a semi infinite, homogenous, isotropic, linearly elastic medium. We illustrated all the concepts that we studied with the help of a few examples not less than 6 or 7 examples. And at the end of the series of lectures I even posed a couple of question to you. I hope you would have tried to solve those questions or problems and confirm that you are able to get the answers that I had given at the end of those problems. With that I suppose you would have got familiar with the concept of stress distribution.

The stresses that we apply from a structure through a foundation on a soil causes what is know as compression of the soil. This compression is a change in volume that occurs in the soil due to the application of the load. We had assumed that the contact pressure before or rather below the foundation is uniform when we computed the stress distribution in soils using Boussinesq's theory. But in actual practice the contact pressures are not uniform, they not only depend upon the relative rigidity of the foundation and the soil they also depend upon the nature of the soil, clay or soil. Therefore the contact pressure need not be uniform in a general case. This contact pressure which is not uniform in turn may induce compressions which are not uniform.

We need therefore a method to estimate the compression that is likely to arise due these phenomenon of imparting or imposing stresses on soil by the activity of constructing an object. This entire activity of computing the compression is based on a theory or a phenomenon known as consolidation. And the effect of this consolidation phenomenon is compression in the soil which in turn manifest itself as the settlement of the foundation and hence the building.

For example, suppose there is a building and let us say there is a foundation. Let me take a hypothetical single foundation. This foundation is going to impose stresses on the soil due to which the soil is going to compress. Soil compresses and in turn this results in a settlement of the foundation and hence the building. The building as a whole also settles down. Now you can imagine that if the building settles down uniformly perhaps the building will remain intact without undergoing any distress. But imagine the contact pressures not being uniform, the soil not being uniform, the foundation is then likely to undergo non uniform settlement due non uniform compression of the soil.

Imagine this building tilting like this, its not going to be comfortable for the building at all when it tilts like this. When it tilts it may still remain in equilibrium may be momentarily but if the settlement non uniform part or the settlement goes on increasing with time then the building is definitely not going to be in equilibrium. It is going to undergo tremendous distress which will manifest itself in the form of cracking of the building, cracking of its beams and columns and in general disrepair. At this point of time I am sure that your mind has gone to visualizing a very well known building of this type that is the leaning tower of Pisa in Italy. The leaning tower of Pisa is an excellent example of a building or a structure that has undergone non uniform settlement due to non uniform compression of the soil below. The word settlement is related to the displacement, uniform or non uniform that the building will undergo.

So now what we have is a word called consolidation which refers to the phenomenon that is exhibited by the soil when it is subjected to load. That is the cause and as a result of consolidation we have settlement of the building otherwise termed as the displacement of the building and that is called the effect of consolidation, the settlement. So we are actually in effect or so to say in brief we are dealing with a cause and effect. A cause is a phenomenon their effect is a manifestation of a displacement. This displacement may or may not be healthy for the building and its for us now to know how to understand this phenomenon of consolidation, how to estimate this degree of settlement, magnitude of settlement and also to see whether it is healthy for the building whether building will remain in equilibrium without undergoing distress. In other form of looking or facing the same problem is how do we design a building, design its foundation in such a way that during its life time, during its service period it does not undergo and due settlements, unacceptable settlements or display distress due to this phenomenon of consolidation.

Phenomenon of consolidation itself is a characteristic of the soil. In general it is probably possible to contain this phenomenon of consolidation so that the settlements are all within uniform or acceptable limits. But suppose given a certain consolidation phenomenon we should still be able to compute the displacements and design a building and its foundation so that the resulting displacements or the settlements are well within limits. And in short this is precisely what we are going to see in this new series of lectures on consolidation and settlement. The word settling down comfortably in a chair conveys a feeling of comfort but settlement need not always be something comfortable for a building unless the settlement is within permissible limits, it is not at all comfortable and in order to ensure that it is comfortable we are got to have a method to understand the phenomenon of consolidation and a method to compute the settlement.

And that is what we shall be seeing in a series of 6 or 7 lectures on consolidation and settlement. Let us go ahead and take a look at some slides.

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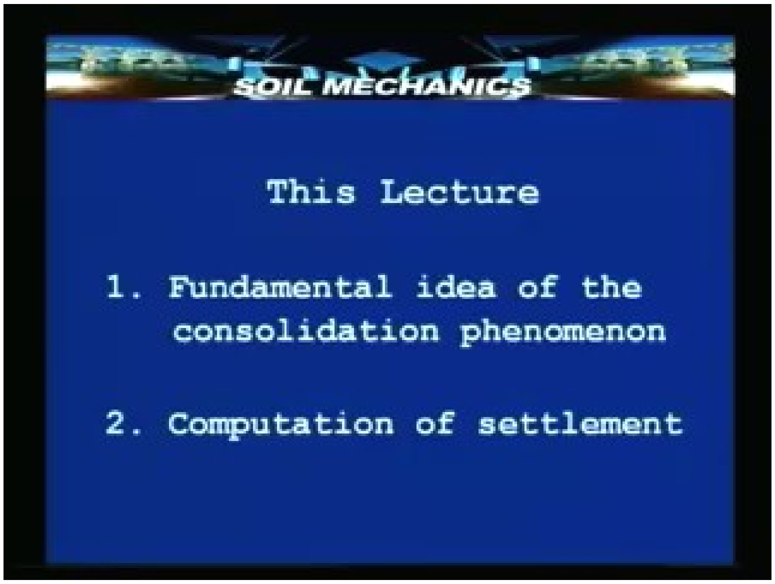

So in this lecture we shall be seeing the fundamentals of the phenomenon of consolidation and we will also be seeing a simple technique for the computation of the resulting settlement due to exhibition of this consolidation phenomenon by a soil. Further as I said the previous series of lectures, we raised a series of question and tried to answer them. In the same way in this series also we shall raise a few questions. Obvious questions are let us take a look. What is consolidation? To some extent I have answered it already. What is settlement also answered to some extent and then we I have listed three more questions. Why is it important? Where is it important? How de we compute settlement? Even without elaborating very much on this you can very easily understand the importance of this consolidation and settlement phenomena.

Today we shall concentrate on these first two items which are shown in yellow color, those which are given below items 3, 4, 5 for example, although you are in a position to understand them intuitively, we shall spend some time on this and try to understand the importance of this phenomenon and how to compute the settlement. I did explain the term consolidation as a phenomenon that is exhibited by a soil when it is subjected to some load. In other words having already seen in the previous set of lectures on stress distribution some thing called stress strain relationship for a material like soil, we can relate ourselves to that phenomenon or that concept in this lecture. After all here also we are applying a load, we are visualizing the possibility of a compression a displacement or change in volume we may say which is nothing but settlement. So this is also in a way, a display of a certain type of stress strain behavior. So if you were to look into more general definition of consolidation you can say that it is a form of stress strain behavior. And what is then settlement? What results as an effect of this cause which is consolidation? The effect is nothing but a form of compression of the soils.

These are two basic questions and these are the rather generalized answers to them. Let us go into some details about what is stress strain behavior, what are the possible stress strain behaviors of a soil and which is the one which is really important from point of your consolidation. Further I have listed here different kinds of stress strain relationships, let us go back for a moment again to stress strain relationships.

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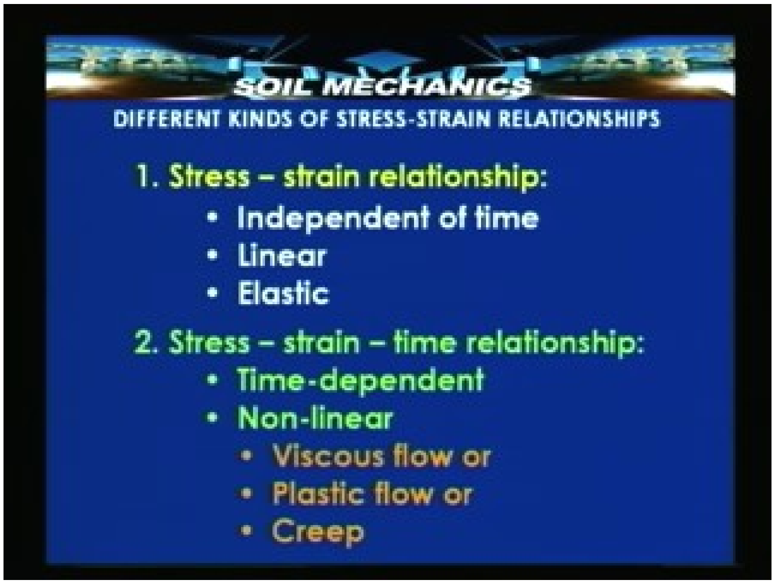

There we saw in the previous set of lectures that the phenomenon which involved elastic theory rather the stress strain and the relationship between the two quantities was assumed as per linear theory of elasticity as sigma equal to e epsilon when we were dealing with stress distribution in soils. And therefore the simpler stress strain relationship for any material is independent of time. It is linear and you may say elastic. But in the present case there is a difference, the stress strain relationship that we are going to see in the present case is not merely a stress strain relationship.

A better way to put this is stress strain time relationship and in this case this relationship is going to be time dependant and that is the reason why I have added the word time in the title. This is time dependant. What is the sense or meaning of this? It is not at all difficult to visualize what the meaning is and why this has been brought in. Imagine applying a load to the building. The building may undergo some settlement today but with a passage of time the settlement may continue and although the building may appear to be safe today, there could be a point of time at which this building is definitely not going to tolerate excessive settlements and is going to display distress.

And therefore this compression of the soil which takes place over the life time of the building could be time dependant. It may not be a single unique independent of time value. So we have to bring in time in this phenomenon of consolidation which we want to understand. Here it is not merely an instantaneous phenomenon where you apply a stress and there is a resulting elastic string. This also is complex in the sense it is not linear, the stress strain relationship is not linear here.

What are the possible relationships then? They are all non-linear, there are different possible relationships, viscous flow that is the soil undergoes displacements in a manner similar to a viscous liquid that moves or imagine a plastic material. It is not difficult to visualize what a plastic material is, you apply a certain stress it will undergo a certain strain which may not be recoverable. Imagine also another form of this non linear behavior that is creep. You might have already been told what creep is in some lecture or the other. You must be already having an idea that creep is nothing but continuously taking place strain under a constant load. And unlike the elastic behavior when the load is applied there is a corresponding instantaneous strain which is recovered when the load is removed.

We have a load and load remaining constant, the strain goes on increasing with time and when you change the load or increase the load the strain increases further and then again goes on changing with time. And all these non linear forms of behavior are described by not simply stress strain relationship but stress strain time relationship. And we are going to see one such form of stress strain time relationship which is relevant to the phenomenon of consolidation. Let us see further. As I said there are several types of stress strain behaviors. Let us take the first one example of elastic stress strain behavior what we have already seen, all these different forms of stress distribution problems that we saw in the last series of lectures.

Let us take non linear stress strain time behavior which I mentioned in the previous slide. It is complex in nature, it is not as simple as stress strain elastic behavior. Although there are several forms of non linear time dependant behavior that is viscous flow, plasticity, creep and so on. There are two non linear phenomena which find tremendous applications in the field of soil mechanics. Of the various applications of the various phenomena two applications are particularly important. One is when the shear stress imposed on a soil due to a structure is less than the shear strength of the soil, meaning soil does not undergo shear failure. But the displacement caused by the stresses or the strains caused by the stresses may be so exorbitant that although the soil does not undergo a stress failure. It undergoes such a large strain that it is equivalent to failure and such a problem is what consolidation is and that is what is going to be the subject matter of a series of lectures.

So consolidation problems come under a case of large displacements and large strains. Another possibility is the shear strength may exceed the strength and there could be failure of the soil. These problems are broadly classified as stability problem, there are variations in this stability of an embankment or a slope for example. Stability of a foundation all these are problems where there is a shear failure, where the shear stress imposed by the foundation exceeds the shear strength of the soil. This class of problems also are of great importance in fact in soil mechanics and we shall be taking a good look at this after we go through this series of lectures on consolidation. The instances of stability problems are many and they are all understandable in a very simple way, by understanding the phenomenon of how shear strength is mobilized in a soil. And that constitutes a totally new area of study and therefore we shall postpone the discussion on stability problems for a future another series of lectures and let us now continue with this consolidation problems.

Now at this point of time it is worth mentioning, I am sure that you already know about the name of Karl terzaghi who is rightly and verily called the father of soil mechanics. Karl terzaghi has classified the problems in soil mechanics into two broad categories almost similar to what we have done here. He uses slightly different free geology. He also classifies the various problems in soil mechanics into problems of displacements and problems of stability. And that is precisely what we have done from a fundamental analysis of stress strain behavior and the first form of these problems that is the consolidation problems we shall be taking up now.

If you take a soil and subjected to a load and subjected to compression. What is the likely behavior of a clay soil, what is the likely behavior of a sandy soil? You need not really imagine this. This has been already studied in much detail, it is known. If you take a small sample of clayey soil let us say in the laboratory and subjected to a load and measure the compression that it undergoes and plot a graph of the compression versus time under a certain load, you will find that the clayey soil goes on showing an increasing compression in terms of percentage until it reaches asymptotically a large but steady value beyond a large duration of time.

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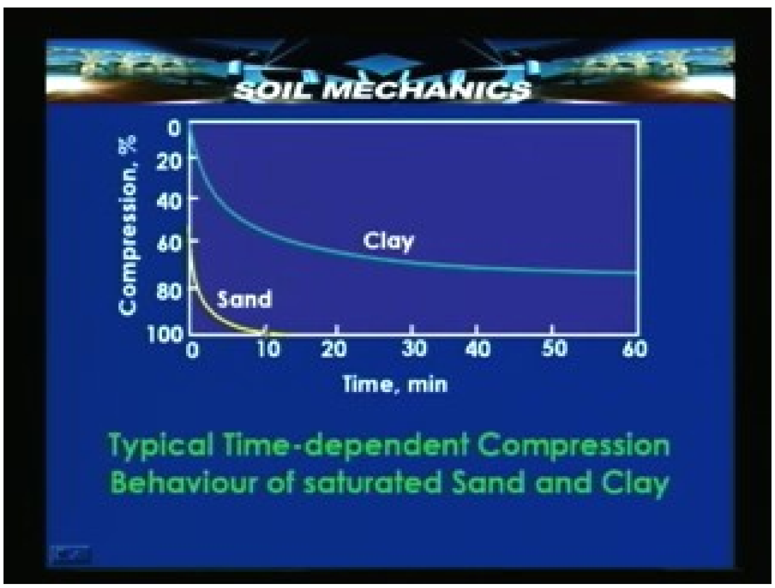

Whereas sand shows a quick increase in temperature within a very short duration of time. What this means is, in clays the compression under load is a time dependant phenomenon, in sands the compression takes place quite fast and so fast that for all practical purposes it can be taken as a time independent problem. Therefore what I am driving at is obvious. Consolidation phenomenon if we want to discuss obviously it relates only to the clayey soils where the compression is time dependent. So this is a typical time dependant compression behavior of saturated sand and clay. I have used the word saturated here, it has got a special significance and it is mainly, only in saturated sands and clays there you find this kind of time dependent behavior. And let us study a little more in detail particularly about the compression of clay with time and that is nothing but the phenomenon of consolidation.

Let us go to fundamentals. The three phase soil model is known to you. I am sure you would have studied about this in the very first lecture or second or third lecture. A typical soil consists of solid grains and voids. You can see here that these are the solid component of the soil and these two together occupy the solids and voids. This combination of solids, any fluid that occupies the voids and any gas that occupies the voids or in other words solids plus the voids together, the total soil is called the skeleton of the soil. The soil skeleton includes the solids, the fluid or the water usually water and gas usually air in its voids. And this three phase model forms the very basis of an illustrating and understanding how time dependant compression takes place in soils.

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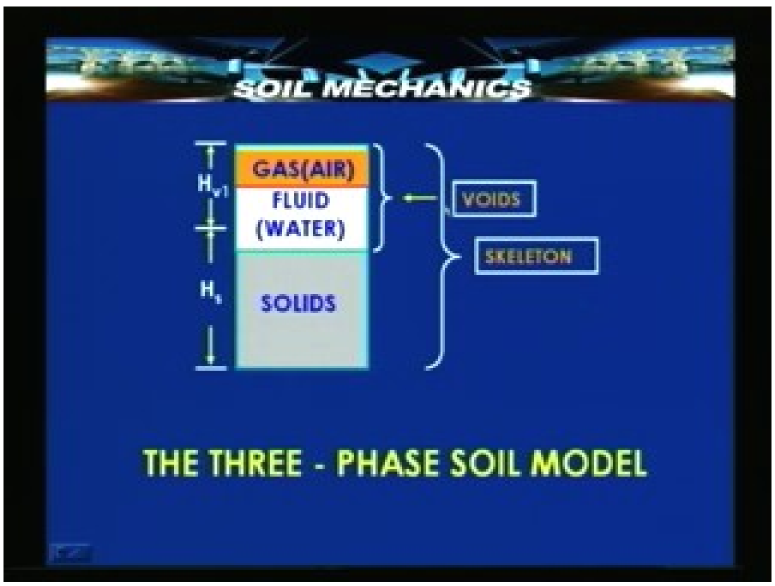

Let us see about compressibility. If you have three phase model like this, what can the compression be due to? Suppose you apply a load here, what can the compression be due to? Let us try to understand this. In actual practice the soil will not have three components distinct from each other. In an actual practice if this is the ground level, there will be solid particles and there will be voids in between. These are the solid particles and these are the void spaces, these red spaces are the void spaces and these void spaces will be occupied by water and air or water or air.

But for convenience of understanding the phenomenon of consolidation we will treat them as three separate phases solids, water and air. And if we do this kind of thing when we apply a load on the soil and suppose the soil is saturated, meaning there is no air and suppose we are considering clay. Then there are a number of things which will simultaneously take place. One is there could be a compression of the solids, there could be a compression of the water phase and also probably air if some air is there if the soil is not fully saturated. If it is fully saturated air will not be there and therefore there is no question of compression of air plus there is another unique phenomenon that takes place. That is when you apply the load, water which is occupying the void tends to move out, tends to get expelled and that is also responsible for readjustment of the particles and compression of the soil.

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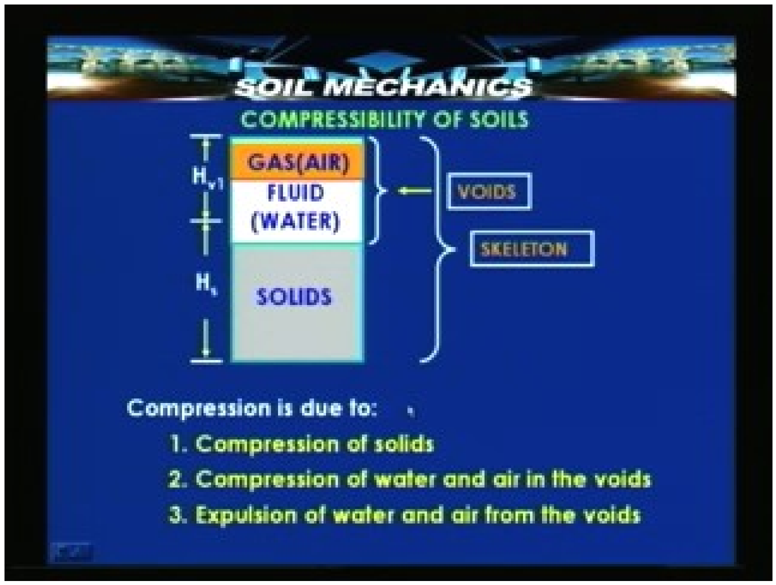

And therefore you can say that the compressibility of soils is primarily due to three possible phenomena. One is the compression of solids themselves because you know any solid body when it is subjected to a load, it will certainly deform, it will certainly undergo some compression. Water and air which are occupying the voids also could be the second contributory factor, the third one is the physical moment of the water or the air from the voids.

Some of these compressions as we seen in a little while ago could be elastic or non elastic. Suppose a load is applied then in a typical soil like this actually speaking although we are talking about consolidation phenomenon in reality both elastic and non elastic components of displacements or moments will be there. The elastic components are taking place instantaneously. It is a non elastic component which is time dependant which is of important to us in understanding the phenomenon of consolidation. Then what happens to the compressions? The elastic part of the compression is primarily due to the compression of the solids and these are going to be very small because the solids are virtually incompressible and we never would like to subject the solid grains of the soils to such excessive loads has to crush them. Because we want safety of our foundation and the structure which is supported. We would therefore never like to subject the solid particles of the soils to such heavy loads as to break them or crush them or make them disintegrate.
Therefore all the loads will be well within limits purely from point of view of safety of

the structure we will have to limit them within certain range. And in that case we can always take the elastic compressions of the solids to be very small and for all practical purposes we can either take the solids as totally incompressible or we can take the elastic compression of the soil to be taking place instantaneously even in fact as we construct the building. And therefore from point of view of consolidation these quick elastic compressions of the solid particles of the soil is not all that important.

Then what is important, it is the non elastic compression which is important. Non elastic compression is going to be due to the other causes, that is of the three causes that we listed. Non elastic compression component is going to be due to the second or the third cause. The second cause was the compression of the water and the air and the third cause was expulsion of water and readjustment of the particles. So readjustment of the particles and reduction in the void space in an inelastic manner is what we are interested in. Suppose we look at this movement and readjustment of the solids. When would they take place? They can possibly take place only if water which is inside is expelled. Why because the water which is inside the void space is also incompressible. So imagine we are applying a load here, we have said already the solids are incompressible or the minor elastic deformations that the solids undergo or negligible or instantaneous. So the next item or the next phase is the water and if the soil is saturated then all the voids are filled with water and water is incompressible. And if water is incompressible, if the solids are also incompressible then how the compression is going to take place?

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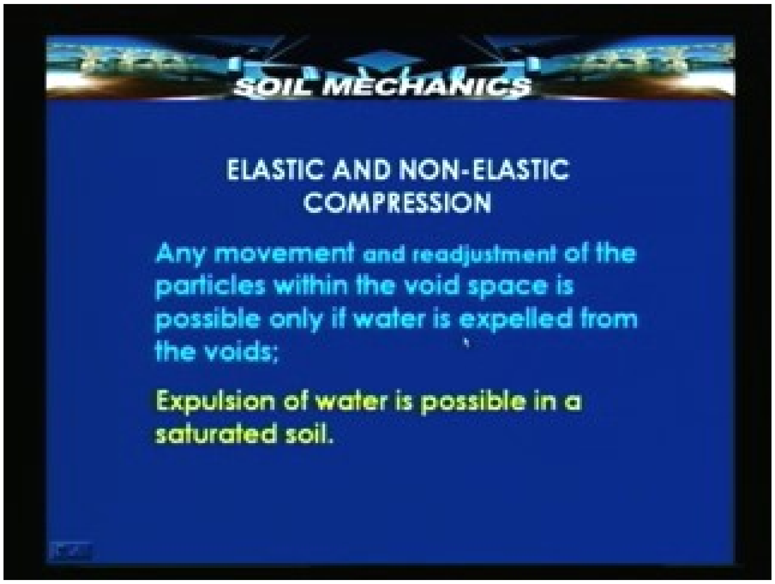

The compression is going to take place because the water will move out of the void space when it is subjected to a load. And therefore as the water moves out the particles get closer, they will reorient and readjust themselves and the soil will become a little more compact or dense. And that is what contributes to the consolidation phenomenon. So any movement and readjustment of the particles within the void space is only possible if water is expelled from the voids. And expulsion of water is not impossible, it is physically possible and in fact unavoidable because water is incompressible and if you apply a load to the porous material like a soil occupied by water, the water has to make way for the solid particles to get together. So what is the most common cause for the consolidation phenomenon of the various possible causes that we saw? The most common cause is under the loads normally encountered in soils, the solids and the water are incompressible, and if the soil is saturated there is no air and no compression of air is also possible. And therefore reason three, that is the expulsion of water from the voids, is the most common reason for the consolidation to occur.

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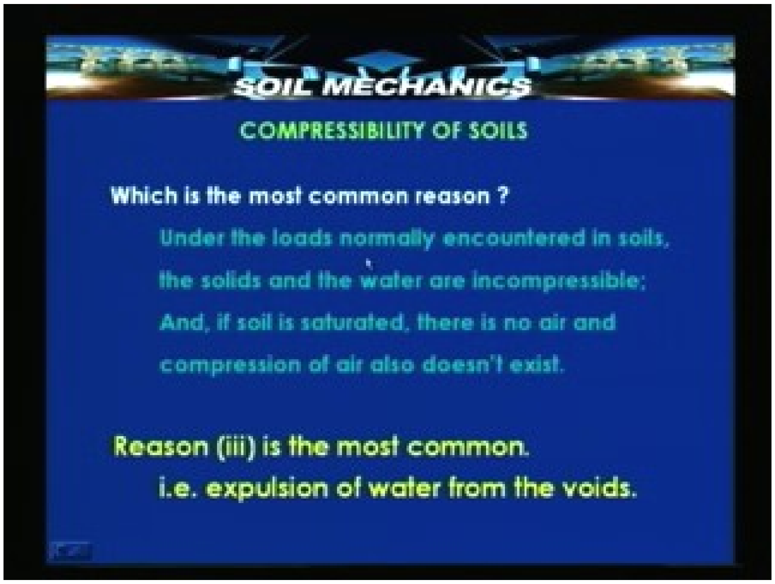

Here the word saturation is very important because if air is there, air will undergo some compression and then only the load will get transferred to the water and when water goes out, the load will eventually get transferred to the solid particles. And therefore the phenomenon of pure compression leading to consolidation and settlement is manifested mainly in saturated soils. Compression of gas or air is important only in partly saturated soils. If the soil is saturated fully, air is ruled out and therefore consolidation is the important for saturated clays. And clays are sedimentary deposits and usually they are saturated and therefore saturated clays are a very common occurrence all over the world, especially in coastal areas. There are a number of different types of clays which are world famous, for example in Bombay region where this lecture is being recorded, we have what is known as marine clay that means clay which has been formed in a marine environment near the coastal region of Bombay.

Where ever there is a coast you will find this form of marine clay. There is a form of clay which is very well known, for example Bangkok Thailand. It is known as Bangkok clay. There is a form of clay which is a very well known as London clay, in fact it is slightly bluish in color and it is called the London blue clay. Like this there are several forms of clays for example mexico, the Mexican clay is also very famous. These are all different varieties of clays, all of them sedimentary, all of them formed under water, all of them are saturated and all of them exhibit time dependant phenomenon. So in short consolidation is an important phenomenon mainly in saturated clayey soils. There is another aspect of these saturated clayey soils undergoing consolidation and settlement. That is an aspect which is important perhaps, very important and that we will be coming to little later in the next lecture. How ever let me make a mention of it in brief. The importance of saturation in a clayey soil is that clayey soil has very low permeability. The permeability of ease is of the order of 10 to the power of minus 6 centimeter per second.

Imagine water being expelled out of a saturated clayey soil by the application of a foundation load. The pores or the voids being so small, the permeability being so small in a clayey soil, water is going to take a long time to move out of the pore spaces of the clayey soil. And that is what makes the compression time dependant and that is the reason why we say consolidation is very important for saturated clayey soils. And that is the reason why I alluded to the likely hood of the settlement being time dependant. There will be perhaps a point of time in the life of a structure, when suddenly the structure may start showing distress. For a long time it would have undergone consolidation but when the settlement reaches a critical magnitude beyond which the structure can hardly stand safely, it starts showing distress. So now all these put together, we need a theory to understand how water gets expelled out of a clayey soil which has a very low permeability and how the solids or the soil as a whole undergoes settlement.

In this context the structure is also important, by structure I mean the arrangement of particles. You must have definitely studied by now that there are several different structures in soils, the single grain structure I am sure that you would have definitely studied it already that there are two varieties of single grain structure, where we have the cubic packing and the hexagonal packing. Cubic packing or packing is a type of packing where the particles are arranged one below the other, hexagonal packing is one in which particles which are assumed to be spherical, occupy the voids between other particles, layers and layers of solid particles which occupy the voids between the surrounding layers.

The structure which is of this nature, which is compact, may not be very critical from point of view of consolidation because much readjustment of particles is not possible. Whereas there are other types of structures like the honey comb structure or the flat platy grain structure or even simply remolded clay which has lost part of its strength where the compressibility could be more and more, could be of a higher order. And it’s for those really where the compressibility is of a higher order that we really need to look into the phenomenon of consolidation in detail and depth. So honey comb structure is incompressible but relative to that spherical single grain structure is less compressible, platy structure is more compressible and remolded soils in general are much more compressible than all these.

And compression of soils is therefore a function of the ability of the particles to shift, move and readjust and realign. And that obviously is going to depend upon the type of structure and will vary from structure to structure. Let us at this point of time make a formal definition that is the gradual process of simultaneous, slow escape of water from voids and gradual compression of soil is what is called consolidation. So there are two gradual, meaning time dependant processes in action, processes in play. One is the gradual process of slow escape of water and simultaneously with this there is a gradual readjustment of particles and compression of soil and this is what consolidation is all about. And another way of putting it is, consolidation is a gradual process involving drainage that is expulsion of water, compression and stress transfer. This is a new word that I have introduced.

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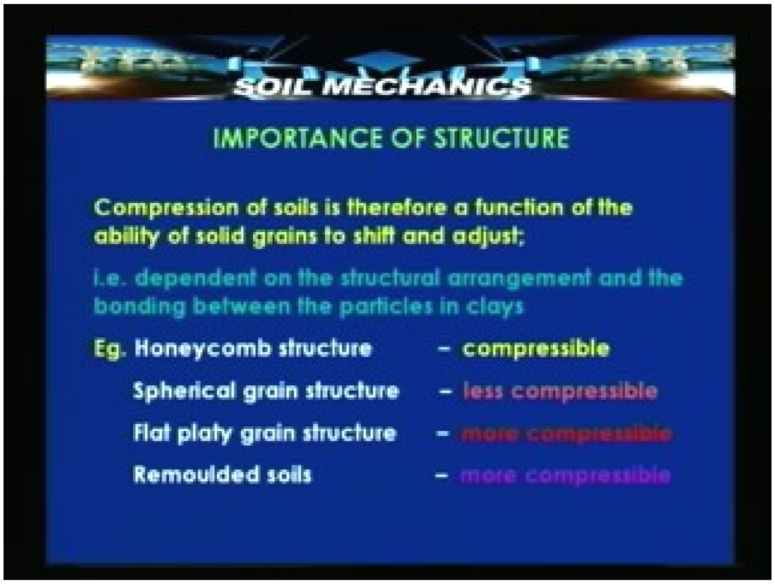

When you apply a load to a saturated clayey soil, ultimately the load has to be taken otherwise the building is not going to stand. Where does this load go? When you apply the load the water being incompressible it start going out of the void spaces. So it is not obviously helping in withstanding the load ultimately. So where does the load go? The load goes to the solid grains ultimately. So the solid grains realign themselves, readjust themselves and ultimately there is a certain form of stress distribution within the group of solid particles and therefore a transfer of the load takes place to the solid particles ultimately. Therefore the consolidation phenomenon is nothing but a phenomenon of gradual expulsion of water and compression of the soil which ultimately leads to the safe transfer of the structural load through a foundation of the solid particles. So you will notice that the two words compression and consolidation obviously do not mean the same.

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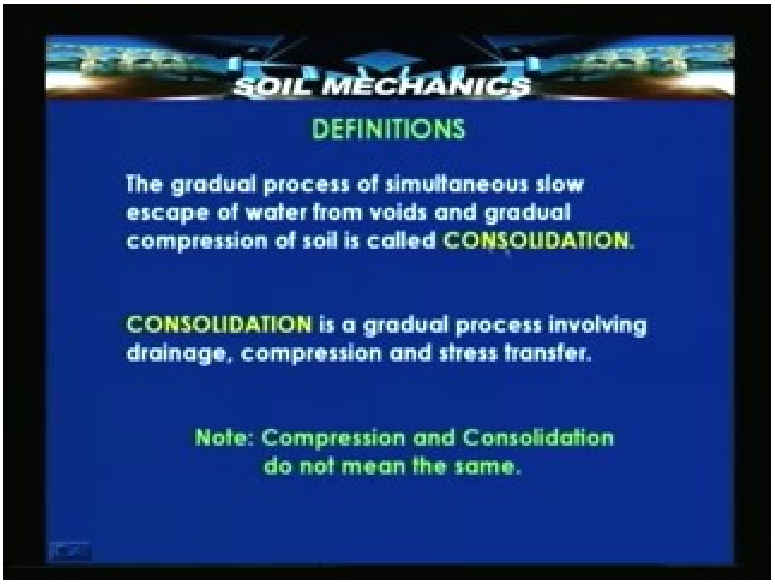

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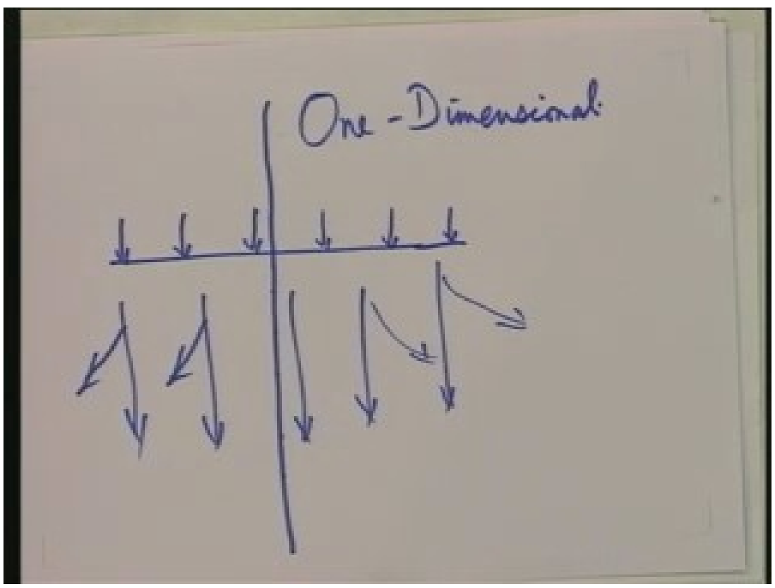

Whereas a compression is a process, consolidation is a phenomenon very broadly we may put it up like that. Now we come to a very important concept and this is what is going to help us to understand the phenomenon of consolidation. You remember that when we were dealing with stress distribution in soils and when we were talking about a uniformly distributed load over a large foundation on the surface of a semi infinite soil medium like this. A large area which is subjected to a load essentially causes a transfer of load in the downward direction but due to Poisson effect it may also effect lateral directions. And for all practical purposes when you have a large loaded area, you can say that the central line or points below the centre undergo or experience maximum stress. And as you go away from these the stresses go on decreasing.

In a similar way when we have a very large area subjected to a uniformly distributed load then for all practical purposes the movement of the water in the saturated clay is essentially in one direction. Or another way of putting it is even if the water gets expelled like this the movement of the solid particles is essentially in one direction that is in the direction of the load. And this is known as one dimensional compression or more often one dimensional consolidation. This considerably simplifies the problem of understanding the phenomenon of consolidation. It is not difficult to visualize that the phenomenon of consolidation is a three dimensional phenomenon. Basically it is a three dimensional phenomenon there is the foundation which is three dimensional. It is experiencing a load and therefore when it transfers the load in three dimensions the soil compression also will take place in three dimensions, it is essentially a three dimensional problem.

But in order to simplify our understanding and make it easy to apply it in practice, to begin with let us assume a simplified model that is one of one dimensional consolidation. What it means as I said just now is when a load is applied over a very large area, by a large although the water may be moving out, oozing out in three dimensions. The compression of soil is essentially in the direction of the load that is in one direction and this is what is known as one dimensional consolidation. And this is what we are going to initially see, we will later on see a special form of three dimensional consolidation which is a very great practical importance. So if I go through this slide quickly the most general case of compression is three dimensional.

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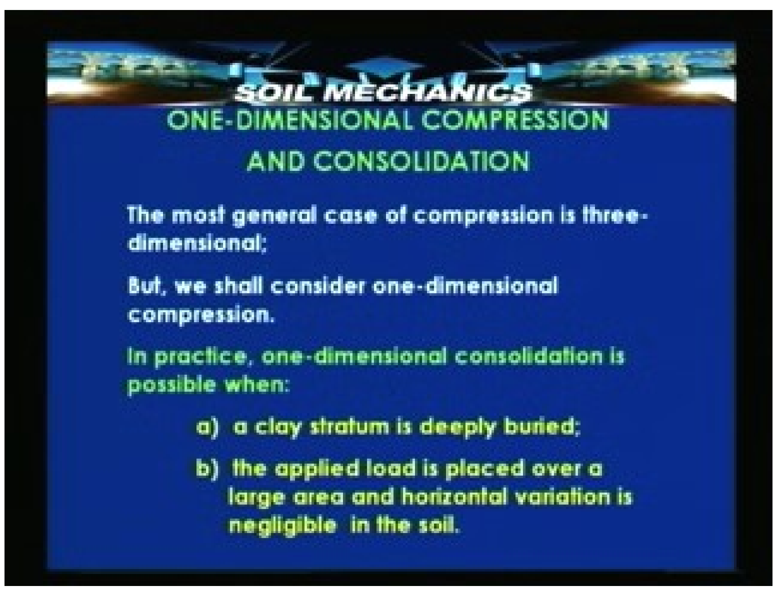

But we shall consider one dimensional compression for the reason which I explained just now; merely it helps to understand the phenomenon of consolidation in a simple way. In practice where is one dimensional consolidation applicable? We cannot have a theory; we cannot have a simplification or idealization which is not acceptable. We cannot have an idealization which is not acceptable in practice. Therefore in practice is this one dimensional consolidation possible and applicable? Yes it is possible as I said some time back, when clay stratum is very deep compared to the lateral dimensions of the loading and the applied load is placed over a very large area and horizontal variations in the soil is negligible. When the soil is more or less uniform in the horizontal direction, when the thickness of the soil layer is very high or when the clay layer itself is lying at a very deep level or when the load is spread over a very large area. These are the three conditions under which one dimensional consolidation is valid.

In general for any compressible clay layer we are interested in knowing two things. One is when you construct a building you have to design this before it is erected, keeping in mind the possible consolidation and settlement effect. Which means we are essentially interested in knowing how much settlement or in other words what is the total settlement that the building is going to undergo over its life time when it is constructed over a given saturated clay soil layer of finite known depth.

Another question that we are interested in is at what rate this settlement is going to take place. Let us say the life span of a structure is 50 or 60 years. We know of course there are many buildings many structures which are even 100 or over years old. But let us talk about a healthy structure which is 50 to 60 years old, even in such a structure even if the settlement that takes place over its life time is not going to be significant. It is important for us to know how at what rate the settlement is going to take place. Is it going to take place over the entire 60 years life span of the building or is it going to take place mostly in the first 10 years or is it going to take place in the next 20 years. This kind of questions arises.

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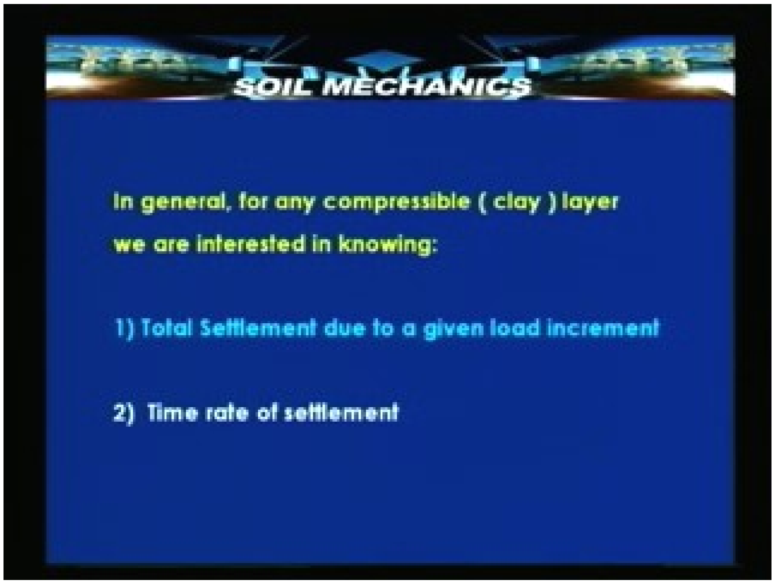

So with respect to consolidation and settlement we need to look for answers for two basic questions. One is what is the total settlement and what is the rate of settlement. We call it the time rate of settlement in the theory of consolidation. It effectively means at what rate or in how much time a certain known settlement takes place. In order to know this we use a simple test. Suppose we want to understand the compression behavior of a soil, we take a small specimen of this and test in the laboratory. The kind of test that we do is known as a consolidation test and it is done in an equipment known as the consolidometer.

This consolidometer which is also called the oedometer looks some what like this. There is a container we shall look at more details of the container in the dimensions a little later in another lecture. There is a small container a soil specimen is kept inside this, below the soil specimen there is a porous stone, porous plate above the soil specimen also there is a porous stone, the whole soil specimen is in a cylindrical or ring like container and outside this ring and inside the main container all the space entire space is filled with water.

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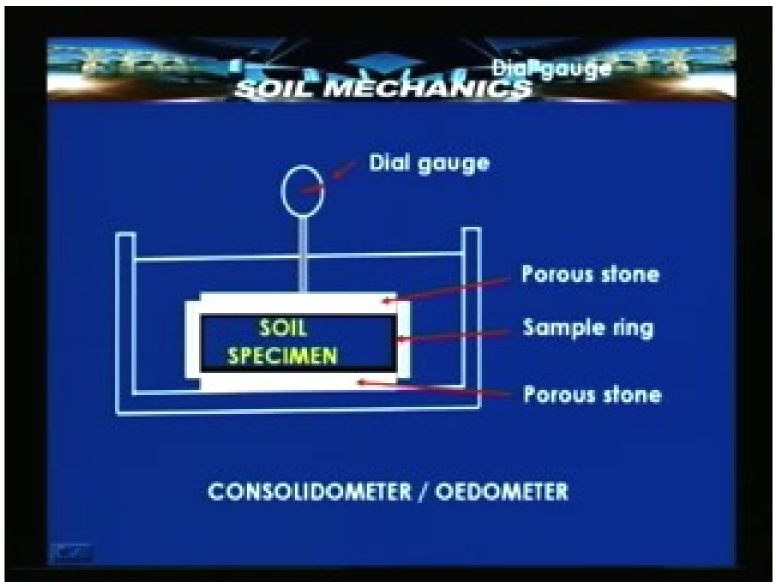

What this means is the soil specimen is fully saturated and when you subject it to a load and measure the deformation with help of a dial gauge then as the soil undergoes compression due to expulsion of water. Water must have a passage for expulsion and these two porous stones help in providing the much needed a passage for the water to get expelled down. So the water can go downwards like this. It can go upwards like this and the expulsion of water in both these directions will lead to a compression of the soils essentially in one dimension and this is by enlarge an experiment which enables us to do in the laboratory level one dimensional consolidation of a soil. Suppose there is a soil layer in the field, we bring a soil sample extract the sample and put it in this and subject it to a load and measure the compression with the help of this dial gauge.

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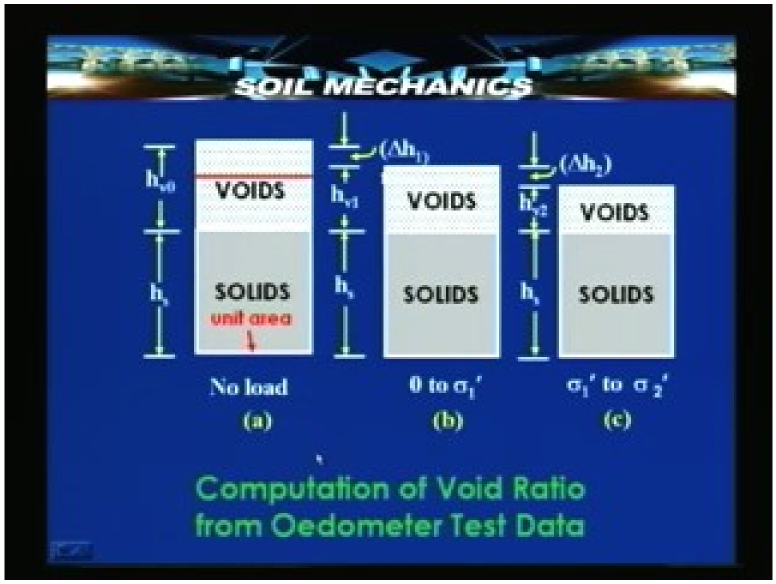

Then we can measure this compression and from the compression we can calculate the change in void ratio. And once we know the change in void ratio we will be able in a position to compute the total change in thickness of the sample and that is nothing but the total settlement of the sample. We shall close here today. So with this in today's lecture we have seen the consolidation phenomenon in very great detail and understood it to be a phenomenon that takes place mainly in saturated clays due to expulsion of water which takes place in all probabilities very slowly because of the low permeability of the soil.

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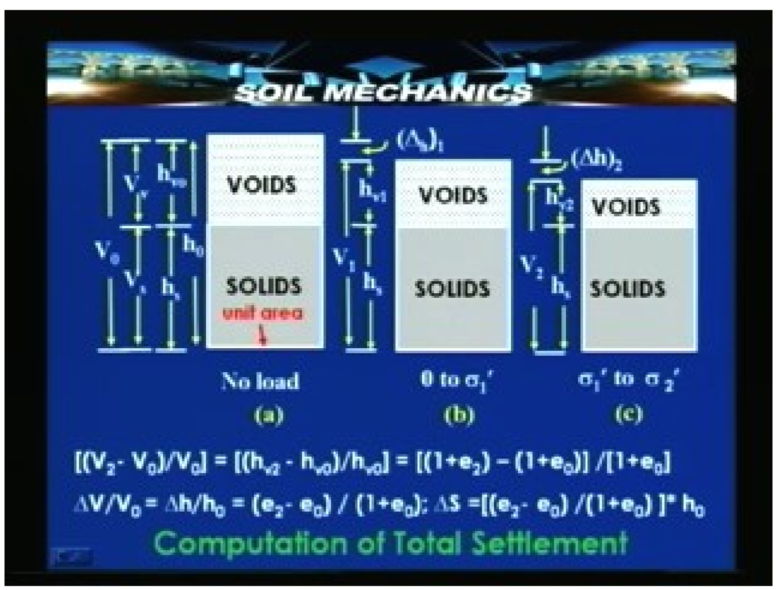

And we have also seen that it is possible to compute the total settlement by doing a simple laboratory experiment called the consolidometer or consolidation experiment. With this we will pass on to the next lecture later on, in which we shall see the details of the oedometer test itself and in detail the compression behavior exhibited by clays and the pressure wide ratio relationships for clays in general, because we saw just now that the settlement depends upon the change in void ratio. Thank you.