Foundation Engineering
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Module - 03
Lecture - 01

Hello viewers, I am Doctor Mahendra Singh working as Associate Professor in Department of Civil Engineering at IIT Roorkee. I am going to talk about the course Foundation Engineering, let me start with the introduction.

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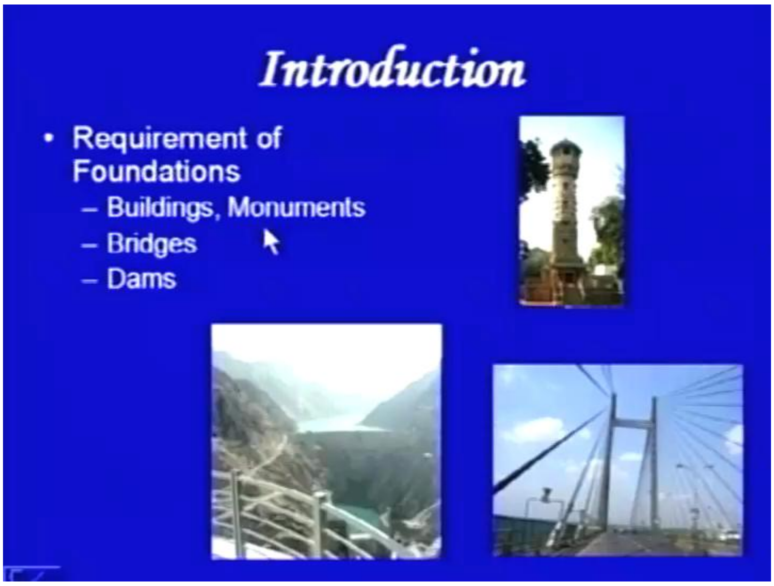

What is the requirement of foundation, in civil engineering we have number of the types of structures, it maybe a building, it maybe two storeyed building maybe a three storeyed building or it may be a old monument, it maybe a bridge or a dam. All of these structures they apply, they have some loads associated with them and all those loads have to be transferred to the ground.

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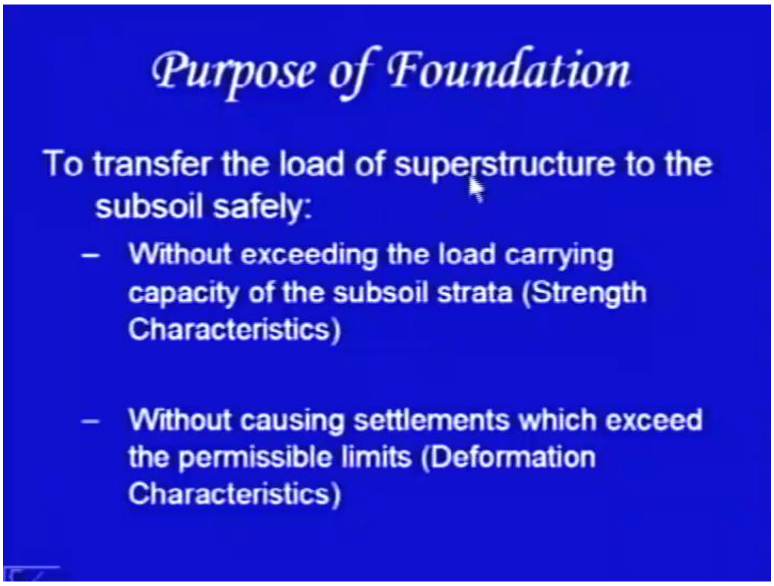

And the purpose of the foundation is that to transfer this load of superstructure, when we say superstructure it means the structure which you can see. And the purpose of the foundation is to transfer this load from the superstructure to the subsoil, subsoil means the ground which is under the foundation and purposes is to transfer this load safely, when we say safely it means, it should not exceed the load should not exceed the load carrying capacity of the subsoil strata, this is termed as strength characteristic.

And also at the same time there is a second requirement, which we would like to confirm and that is, it should not cause settlements which exceed the permissible limits. Let us, now come to what are the aims and objectives of this particular course.

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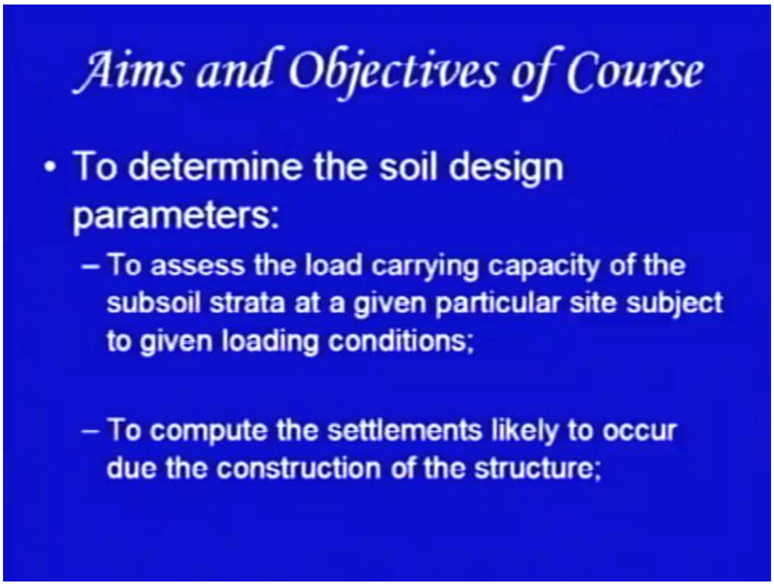

I define it, that we are going to determine the soil design parameters, what we mean by that is, we will be assessing the load carrying capacity of the subsoil strata at a particular site, subject to given loading conditions. What I mean by that is, that there will be a particular site and that particular site will be having certain characteristics and for those characteristics, we have to find out what is the load carrying capacity.

Second thing which we are interested in is, we should be able to determine or to compute the settlements which are likely to occur due to construction of the structure, because as I told you the it is an essential requirement that the settlement should not cause settlement should not be more than the permissible limits, so we should be able to find out the settlements using the soil design parameters.

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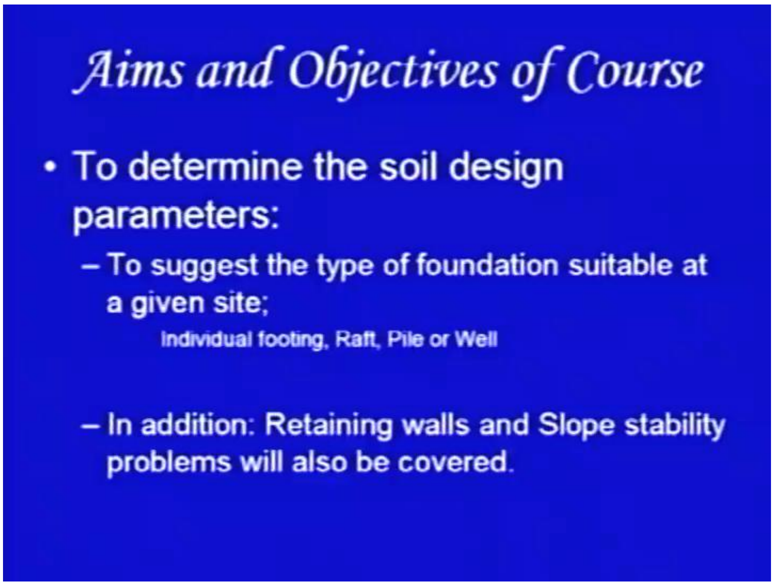

Thirdly, the aim of this course is a by doing the analysis, we should be able to suggest, what is the kind of the foundation, what is the type of the foundation which should be provided for that given site and for that given particular type of loading. It may be an individual footing, it may be a raft, it maybe pile, it maybe a well foundation, for example if the loads are very heavy, they have to be carried down to very greater depths, then piles maybe provided, if it is a shallow foundation then individual footing can be provided.

In addition, in this course we are also going to discuss about the retaining walls, how to analyze the retaining walls how to design them and also I shall be discussing the slope stability problems. Let me now come to what is the prerequisite, what I accept the students those who are using this course, what they are supposed to know in advance.

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We expect that you have all ready undergone a course on basics soil mechanics, this will include solid water air relationships means you should know all about those threee phase diagrams. I shall be discussing little bit in not in detail in brief, but all those relationships about the unit weights, about the about the void ratio etcetera, you should know. Secondly you should also know about the classification of soils, we will be touching it in the next chapter.

But, in detail you should know about the classifications and we shall be using the indian classification, then also you should know about soil structure and clay minerals, and then soil compaction. If the soil is compacted how the properties are going to change, what are the expected changes in there characteristics that you should know, also effective stress concept, this is a concept which is used when the water is present in the soil mass, the total stress is there and the concept of effective stress is there you should know about that.

And also capillarity and permeability, these are the phenomenon which you are supposed to know, next is the seepage through soils, these things also are the prerequisite, then compressibility and consolidation of soils, for the clay soils consolidation is very, very important because long term soil settlements are there. So, you should have known all those theories behind the consolidation. And lastly and not the, it is the last, but not the least and very important the shear strength of soil.

The soils have some shear strength subject to some normal pressure, normal stress they have certain shear strength and we expect that you know about the shear strength of clay soils, shear strength of sandy soils and what is the effect if it is saturated, if it is dry, if it is under water and so on. Now, let me talk about the course content which we intend to cover in this particular course.

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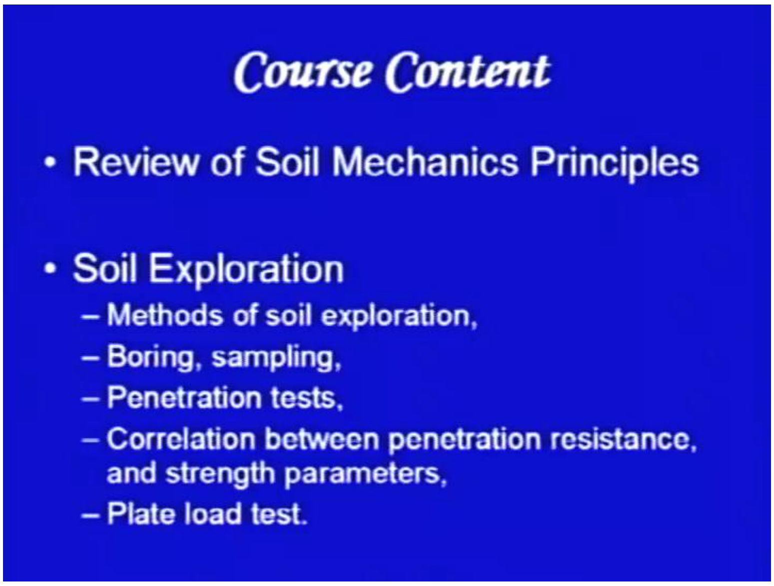

As I told you, we expect you to know about the soil mechanics principles, but I will be refreshing some of those memories, some important things I will be taking and I will be discussing them again. Then I will move on to the actual content of this particular course, the chapter the next which I will be taking is the soil exploration, here we shall talk about the methods of soil exploration.

Soil exploration means you go the site and that particular site then you find out, at that field what is the condition of the soil subsoil strata, what are the types of the soils available there, and this will be doing using boring, so I will be discussing about the boring methods, how to sample them. And then you will be discussing about the penetration tests, these are very important tests which are carried out in the field , penetration tests specifically for a cohesionless soils, these are very, very important.

And then we will discuss what correlation, there are certain correlation between the penetration resistance and the strength parameters, you get certain values out of this penetration test and how to correlate them with the design parameters which we need.

And then I will move onto the plate load test, this is a very important test which is carried out in the field, it needs a, it uses a plate which is loaded and we find try to find out the bearing capacity of the ground at the site itself. Then I will move onto the next chapter which is earth pressure and retaining structures.

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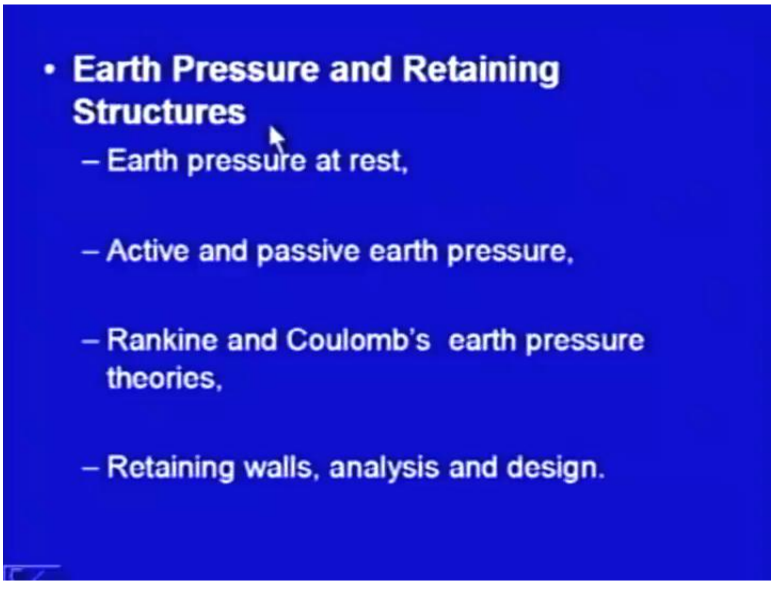

The earth pressure theories are very useful in designing the retaining structures like retaining walls, so we shall be considering them in detail, I shall start with earth pressure at rest, then I shall be discussing active and passive earth pressure. Then there are certain theories, Rankine theory and Coulomb's earth pressure theories, we shall discuss those theories in detail. And then finally, I shall be taking up the design, the analysis of the retaining walls, after that I am going, I will be moving onto the foundations.

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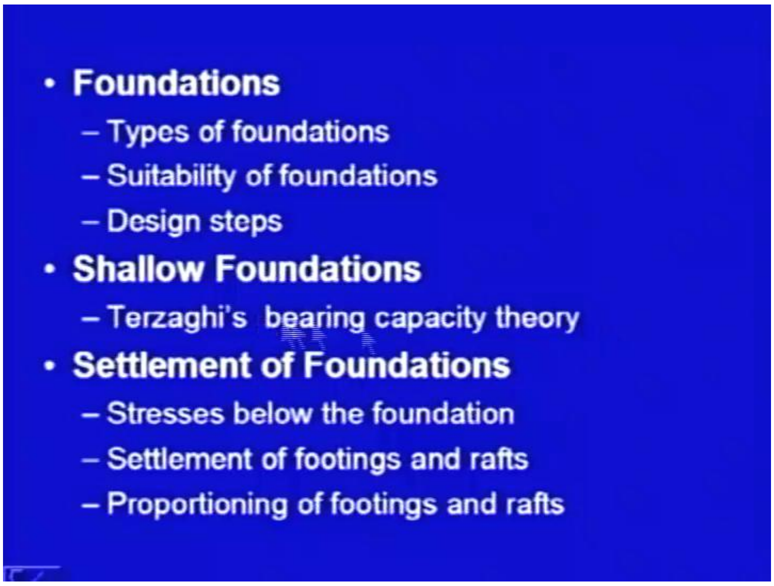

First, we shall discuss what are the different types of foundations, then what are the suitability at particular site for a particular condition, what kind of the foundation is suitable. And then the design steps, what actually we mean by the design of foundations as far as geotechnical engineering is concerned. Please note, we are not going to discuss the structural design, we are only going to discuss about the soil parameters, which will be used in the design of the structure, design of the foundation.

Then we shall be taking up the shallow foundations in detail, and here we will be discussing Terzaghi's bearing capacity theory in detail, though there are several other theories also I will just mention them, but Terzaghi's bearing capacity theory, this is the most important and most widely use theory, we shall be discussing in detail. Then I shall be talking about the settlement of foundations, how to calculate settlements because settlements are very, very important the ground should be strong enough to support that load.

In addition it is the requirement that no particular point, no particular point in the space or no particular point of the corner of the building or whatsoever the structure maybe it should go excessive settlement, so wish we wish, we shall be a going in detail how to calculate the settlement of foundations For that purpose, we shall need the stresses how the distribution of the stresses takes place below the foundations. Then we shall discuss in detail how to calculate the settlement of footings and rafts.

And then proportioning of means, once all these things are available then for a particular type of the loading, how to proportion the footing, how to proportion the rafts this we will be discussing. After that shallow foundations, we will move onto pile foundations.

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Pile foundations are the foundations which are given, when the load carrying capacity of the subsoil strata is not that good and we have to transfer the load deeper into the ground, so shallow foundations are not sufficient, we have to give piles they are little bit costly and the loads can be transferred deeper, where the strong strata the competent stratum is available. Here we shall discuss, we shall with the types and methods of the pile foundations.

Then how to estimate the pile capacity from the soil design parameters from the test which we have all ready done in the field or in the laboratory, then how to calculate the bearing capacity and settlement of group of piles. And finally, how to solve the design problem, proportioning means we are basically trying to we were, we are trying to design, we are designing the actual pile foundation, then we will move onto well foundations.

These are another deep foundations which are used for very heavy structures for example bridges. So, we shall discuss there methods of construction and then how to compute bearing capacity, settlement lateral stability of the well foundation, then we will move onto the stability of slopes.

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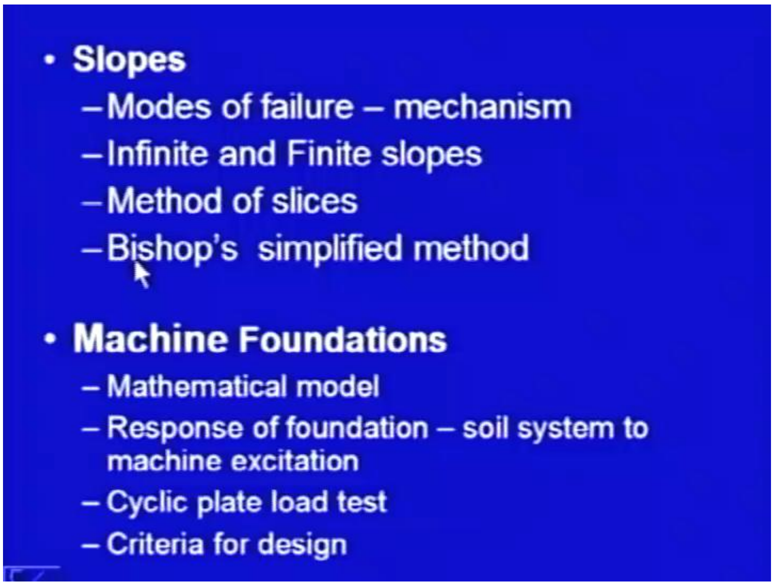

Slopes are very, very important in the hilly regions, there maybe a manmade slopes, there maybe natural slopes, there stability is a great concern. So, we shall be discussing about the modes of failure, what is the mechanism, how the failure takes place. And then infinite and finite slopes, where infinite slopes are there when like hills are there, natural slopes are there and finite slopes are there, which are generally manmade.

Then we shall discuss particular methods, how to raise how to stay, how to analyze the infinite and finite slopes, and for finite slopes. I will be discussing the methods of slices, there are number of methods available and we shall be concentrating on a very simple Bishop's simplified method. Then we will move onto machine foundations. In machine foundations we shall be discussing the mathematical model, then the response of foundation soil system to machine excitation.

Then the cyclic plate load test which is quite useful in designing the machine foundations and then what are the criteria for design. So, friends this was the entire syllabus which I am going to cover and here are some of the textbooks which I recommend.

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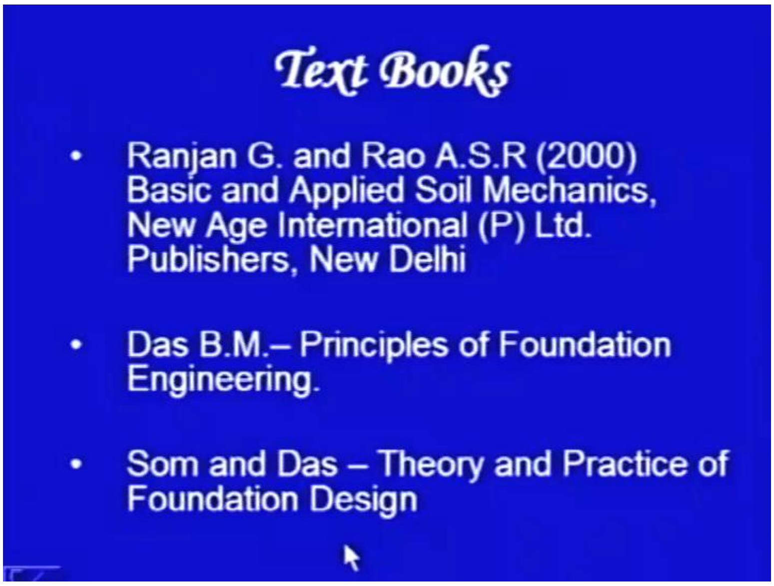

Most of the material is taken from Ranjan and Rao, basic and applied soil mechanics. And then some matter has been taken from the from the book by Das principles of foundation engineering, another book by Som and Das theory and practice of foundation design.

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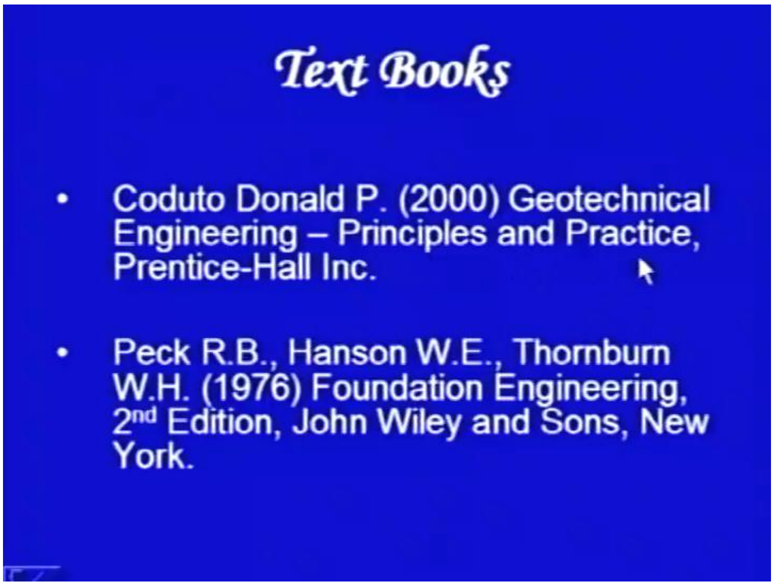

Then another book is Coduto Donald P geotechnical engineering principles and practice, And finally, there is a very classic book which I refer that the student should go through this Peck Hanson and Thornburn foundation engineering. Now, let us start the actual syllabus and as I told you initially, I am going to discuss I am going to refresh the general principles of soil mechanics and here I am starting with the classification of soils.

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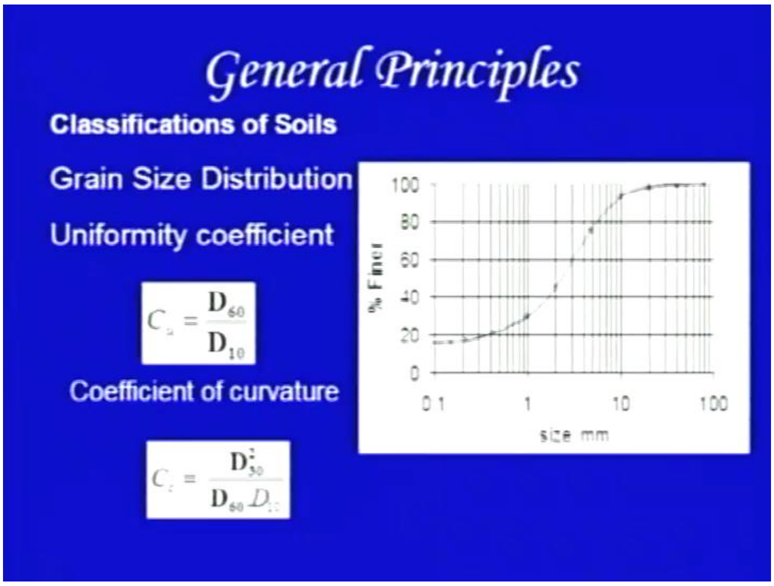

When we say classification, classification means we try to divide the individual into certain groups and those groups should have properties should have those properties which are similar in all the individuals belonging to that group. So, classification of soils means we divide the soils into the groups and those groups of soils we will be having same engineering properties, same strength characteristics similar deformational characteristics.

And in classification we start with the grain size distribution, which is done using sieve analysis and the analysis is represented in grain size distribution curve as shown here, on the x axis we have the size of the particle and on y axis it is the percentage finer by weight. When I say 40 percent means it is the size 40 percent is finer than that. So, a curve is plotted between percent finer and size and from this, then these two parameters one is called as uniformity coefficient and second one is called as coefficient of curvature, these two parameters are computed.

Coefficient of uniformity is given as D 60 by D 10, D 60 means corresponding to 60 percent finer corresponding to this percent finer, this is the particular size. So, this particular size corresponding to that value such that 60 percent is finer than this. And D

10, D 10 is another size, so 10 percent is here, so corresponding to it, corresponding to 10 we have take that particular size.

So, Cu is taken as D 60 by D 10, D 10 coefficient of curvature it gives the idea about the curvature of the curve and this is given as D 30 square divided by D 60 and D 10, so these two parameters are computed and based on that, then the classification is done for the for the cohesionless soils. For cohesive soils, we have to conduct the Atterberg's limit test, liquid limit, plastic limit.

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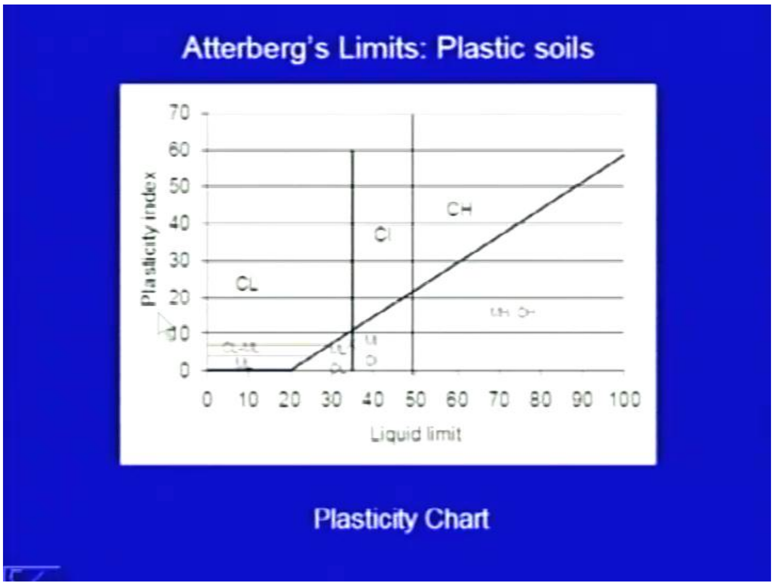

Here on x axis this is the liquid limit, on y axis here it is the plasticity index, plasticity index means liquid imitation minus plastic limit. And then on this chart we plot the point, the position of the point, suppose the point is somewhere here, then it will be clay with low plasticity, the limits the limits of different clays for different classification is like this. Here it is 0 this is 35, this is 50, so clay if it is in this range, it will be clay of low plasticity.

If the if the point is somewhere here it is the clay of intermediate plasticity, it is the clay here with high plasticity. this is the line which demarcates the M H soils, M I soil from C I and C S soil. So, based on this plasticity chart the cohesive soil has to be classified.

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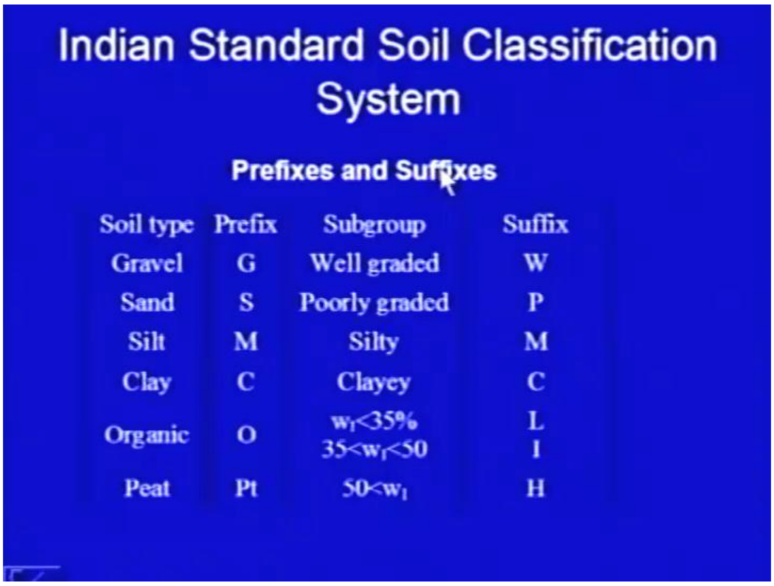

Now, once those parameters are available, then we use the classification system, here we have given the prefixes and the suffixes, these are the broad categories of the soil types, gravel and gravel will be represented by G, sand will be represented by S, silt is represented by M, clay is represented by C, organic soil is represented by O and peat by P t. Then we have the suffixes also, well graded that is represented by W, poorly graded is represented by P, silty by M, clayey is C then low intermediate high and these values they represent the limit of the liquid limit, from this symbol chart and using the classification chart, then the soils can be classified.

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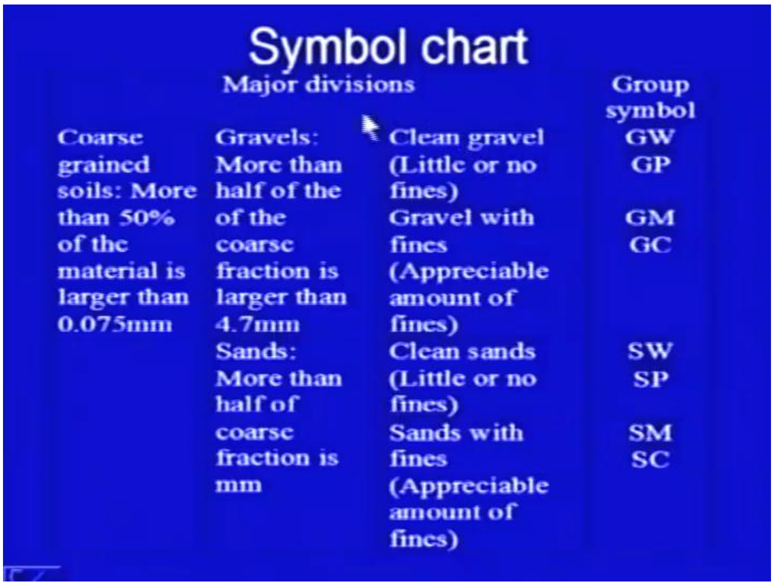

For example coarse grained soils, the coarse grained soils will be soils which are having more than 50 percent of the material larger than 0.075 millimeter, so this has to be decided based on the sieve analysis. And here under coarse grained soils, there can be gravels, clean gravel, G W well graded gravel, then G P poorly graded gravel. Gravel with fines G M, G M means it is gravel with non-plastic fines, G C gravel with plastic fines.

So, same way, sands then sands well graded sand, poorly graded sand, sand with non-plastic fines, sand with plastic fines and so on, this is the second part of this same table.

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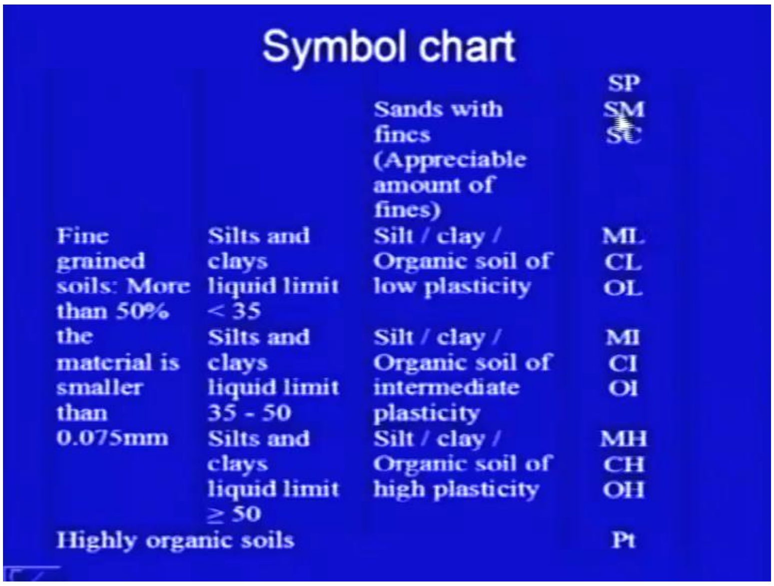

Here, poorly graded sand, sand with non-plastic fines, sand with plastic fines, and then fine grained soils, those soils which are having more than 50 percent of the material is less than 0.075 millimeter. They have silts and clays ML CL OL MI CI OI MH CH OH, M stands for silt, L again as I told you it stands for the range of the liquid limit, C stands for clay L means lower, lower means less than 35, I means it is intermediate range of the liquid limit 35 to 50 and H means high range of the liquid limit that means, more than 50.

So, using this symbol chart one can classify the soils as per the Indian standard system. Now, next thing which I told you was that you should know about the weight volume relationship of the soil.

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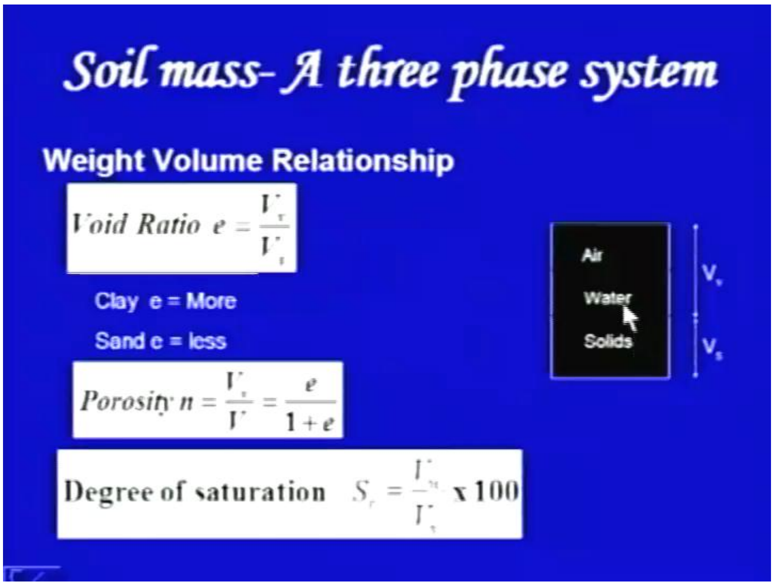

A soil mass can be treated as a three phase system, which will be having air, which will be having water as well as solids all these three are there. It is not something like that that the air is at the top and then the water is there and then solids are there, they are all intermingled with each other. Every soil mass will have certain amount of air, it will have certain amount of water, it will have certain amount of solids.

So, the volume, in terms of volumes air plus water that is called as total voids. Vv, Vv stands for volume of voids and then volume of solids that is represented by Vs. The term void ratio defines the volume of voids and volume of solids, in clay you will observe that void ratio is generally more, in case of the sands void ratio is less. The other way to define the volume of voids is through porosity, the term porosity is defined as n is equal to V v, V is the volume of voids divided by V, V is the total volume of the soil mass.

So, it is little bit different from void ratio, where void ratio was Vv upon Vs and here V is nothing, but Vs plus Vv, so the porosity n will be equal to e upon 1 plus e. The another term is degree of saturation, which gives the idea as to how much volume, how much proportion of the total voids are filled up with water, so as r is defined are volume of water which is present, divided by total volume of voids, air and they are represented as percentage, the other expressions are first is unit weight.

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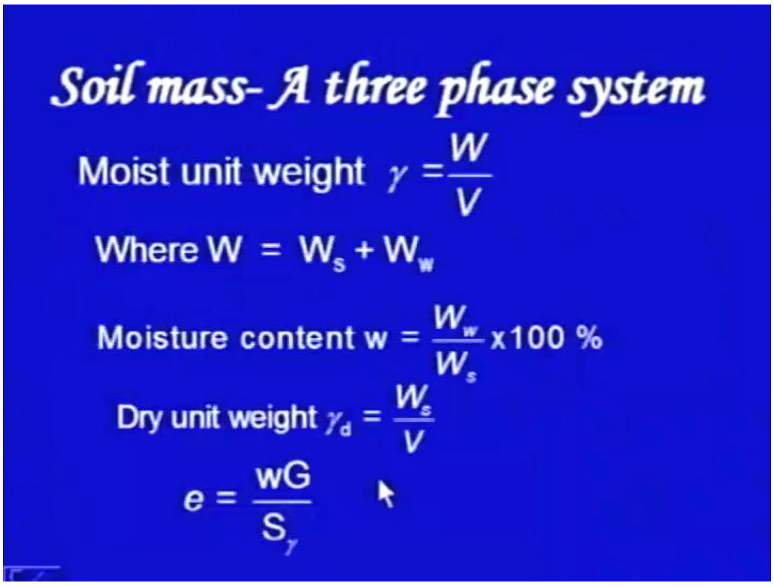

It is moist unit weight or you can say the bulk unit weight gamma, that is equal to total weigh of the mass divided by total volume, the units will be kilo Newton, here it will be meter cube. So, the units of gamma will be kilo Newton per meter cube, here weight means total weight it includes the weight of the solids and also weight of water, which is present in the soil mass. The moisture content W is defined as weight of water which is present in the soil mass divided by weight of solids and again in general it is represented as percentage.

The dry unit weight gamma d is defined as dry weight of the sample divided by total volume V, you can note down starting from here if you dry the sample, if you have a sample at normal at a natural moisture content and you dry it the volume is not going to change, volume is going to remain same. So, the water is dried it becomes W s, W s the weight of solids dry unit weight is defined as W s upon V.

The void ratio e can be obtained in terms of the moisture content which is available, specific gravity G and degree of saturation S r. So, e is w G upon S r this is one of the expression which we will be using number of times, the other expressions are…

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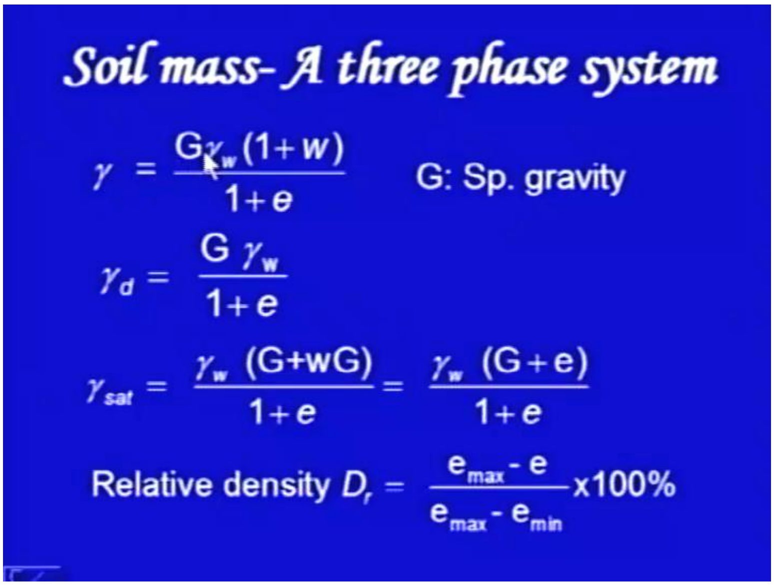

Gamma equal to G gamma w into 1 plus W divided by 1 plus e, so probably this is one of the most important equation using which you can derive many other equations. Here G is specific gravity, W is moisture content and e is the void ratio, gamma is the unit weight. And if you want to know the dry unit weight, so gamma d will become G into gamma w, here this W becomes 0 in case it is dried, so G into gamma w upon 1 plus e.

If the soil mass is completely saturated all the voids are filled with water then saturated unit weight, gamma sat is defined as gamma w into you take G here inside this bracket, so G plus W into G upon 1 plus e. And since it is completely saturated e equal to wG upon Sr, Sr is equal to 1 and from there you get this expression, gamma saturated is equal to gamma w into G plus e divided by 1 plus e.

Now, for sandy soils a very important term is there which is called as relative density Dr, this is defined as e max minus e divided by e maxi minus e minimum, e max means the maximum value of void ratio which the soil mass can attain, so it will be the loosest state e is the natural void ratio and here it is the again the maximum void ratio; that means, the loosest state minus e minimum. e minimum stands for when it is compacted, it is quite dense the maximum density will be here.

So, this ratio e max minus e upon e max minus e minimum represented as percentage will be termed as relative density. And there is this empirical table available.

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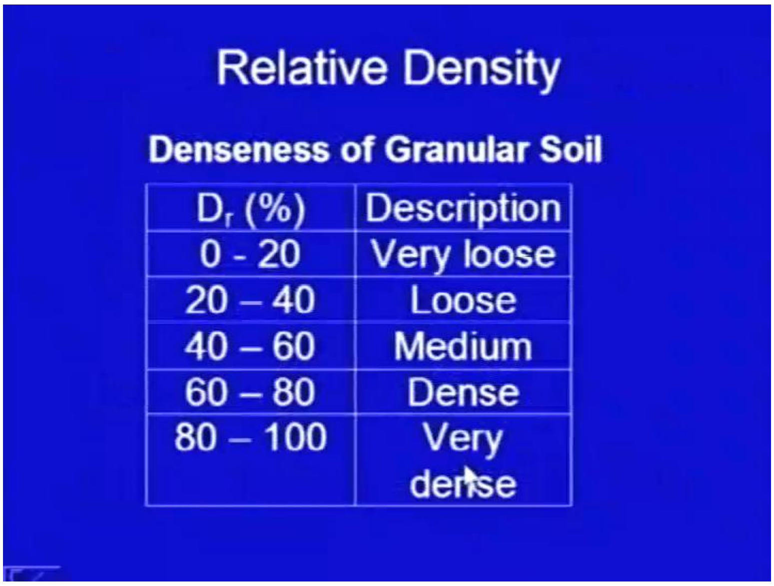

D_r (%)	Description
0 - 20	Very loose
20 – 40	Loose
40 – 60	Medium
60 – 80	Dense
80 – 100	Very dense

Using this empirical table one can define the compactness of the granular soil or the denseness of the soil, If the Dr value relative density is less than 20 it is termed to be very loose, if it is between 20 and 40 it is termed to be as loose soil. Between 40 and 60 it will be medium, 60 to 80 dense and if it is more than 80 then the soil is called to be very dense. We have discussed the physical properties of the soils and now let us have discussion on the engineering properties.

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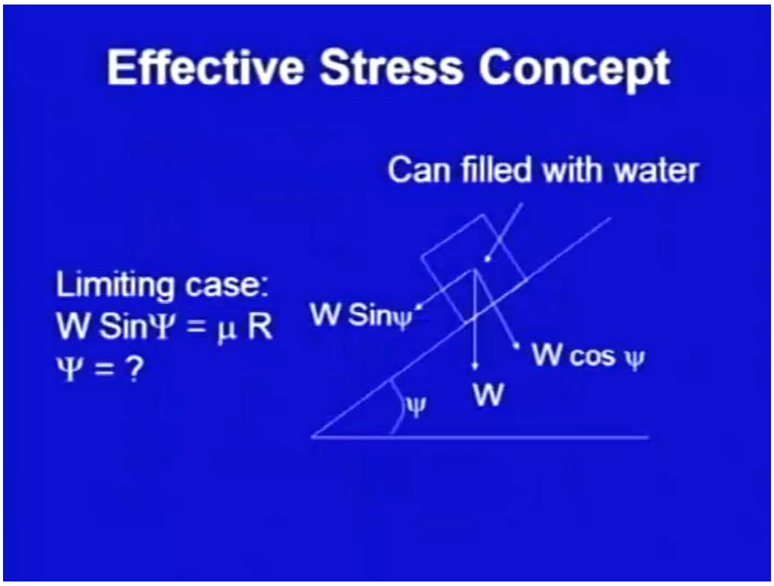

Here I am discussing a very important concept, which is called as effective stress concept, Before I really go technically to this concept, let me recall the problems which you might have solved in you intermediate or high school classes. Let us say this is an inclined surface, surface is rough having a coefficient of friction mu is the coefficient. And a can is placed on this surface, the can is filled with water and this surface is inclined at an angle psi with the horizontal.

Now, what we are doing is, we are gradually increasing this psi value means, we are gradually tilting this inclined surface more and more, the question is can you find out the maximum value of psi or in technical terms can you get the limiting value of the angle at which this particular body remains in equilibrium. So, how we are going to solve it, what we are going to do the weight, we will know the weight, we know the weight of the can it is filled with water.

So, the weight is acting in vertical direction its one component of this force will be acting normal to the surface, another component will be acting parallel to the surface. This normal component it is going to give the reaction R, which we have studied in your high school intermediate. And from that R the limiting value of the frictional force mu R is going to develop in the direction opposite to the sliding direction, and this component W sin psi, this is trying to destabilize this body.

So, when the limiting case is raised, when the equilibrium is raised, when this psi value has raised its maximum value at that particular point this frictional force which is developing here at the interface that will be equal to R into mu and R will be equal to W cos psi. So, mu into R that will be the frictional force and W sin psi that will be the sliding force you can equates these two expressions, these two values and from there you can find out limiting value of psi.

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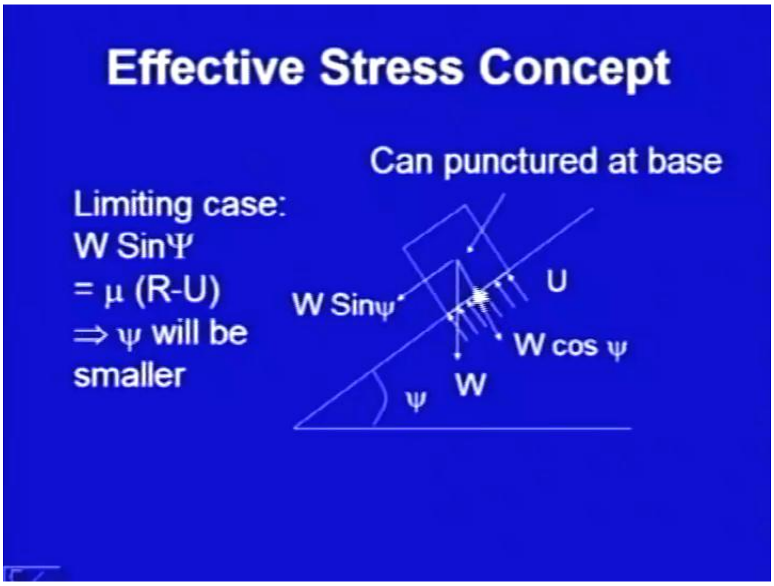

Now, let us do one thing, let this base of this particular can is punctured, so I am assuming that still the can is filled with water, weight remains the same, water starts seeping through this hole at the base and it starts seeping out in the outward direction. The net resultant is that water will be exerting a pressure on the base and let us say that we are able to calculate this force, which is being exerted by water in the opposite direction and let us say this is U.

Now, what happens to the equilibrium condition, now, in this case this component was this component of the force of the weight was W cos psi, U is acting against it, so the net resultant net R which you will be getting will be R minus U. So, now if you consider the equilibrium of this body, destabilizing force is W sin psi and stabilizing force, the resisting force, the frictional force which is developing here at the interface will be equal to mu times R minus U.

And, now again you can find out the value of psi, the maximum value of psi for which this particular system will be in equilibrium, and in this case this psi will be lower it will be smaller than what we obtained last time. So, this gives you the idea that when the water is there, it exerts pressure and because of that poor water pressure, the strength the frictional force reduces, now let me come to the effective stress concept.

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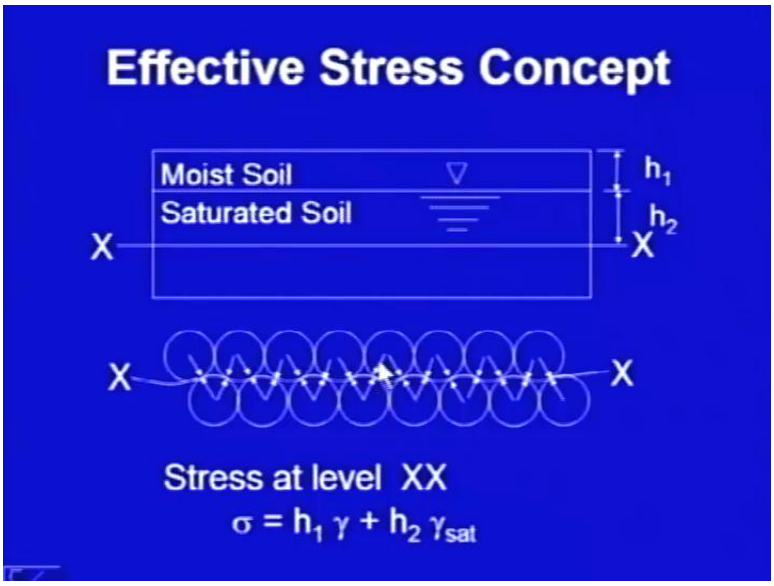

I am considering here, it is a soil mass and here at the top the soil mass is moist, somewhere here the water table is there, so this is completely submerged and I am taking a section X X at this particular depth. The first layer is having thickness h 1, the second layer this one is having a thickness of h two. Let me see microscopically at section X X, there will be millions of soil particles along this section X X, I am hypothetically representing all those particles by these spheres, they will not be actually spheres, they will be rounded particles.

All these particles are in contact with each other and let us say this is the section X X. These particles will be touching each with each other and here, where they touch with touch each other they will be exerting intergranular force. So, at this point, at this point, at this point the intergranular forces will be acting, so the stresses in the soil mass will be transferred through this intergranular, stress intergranular forces.

The total stress at section X X you know this will be equal to h 1 into gamma, gamma is the unit weight of first layer, plus h 2 into gamma saturated this will be the stress at this particular level total stress.

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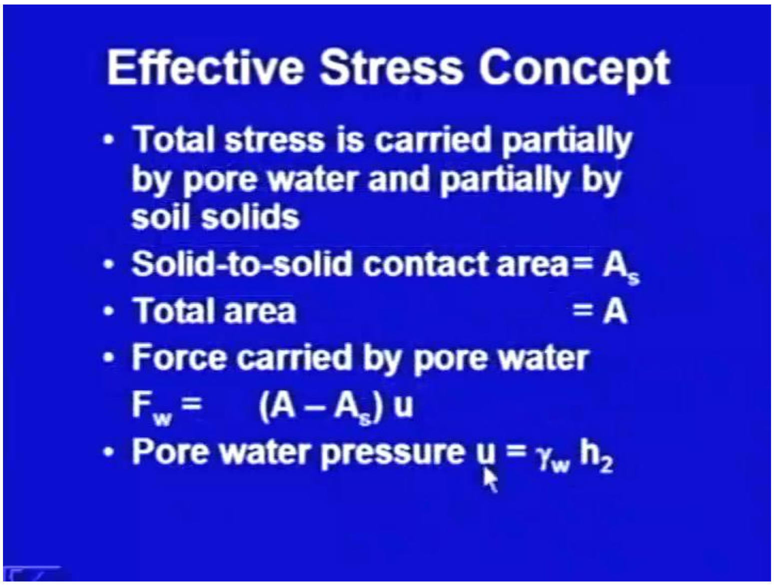

Now, this total stress will be carried partially by the soil solids as I told you and partially some pressure will be born by pore water, let us say the solid to solid contact area is As, total cross sectional area is A and u is the pore water pressure. Then the component of the force which is being born by poor water will be equal to A minus As that is the area for which water pressure is acting into u, so A minus As into u, this will be the force which is being born by pore water, where u will be equal to gamma w into h 2.

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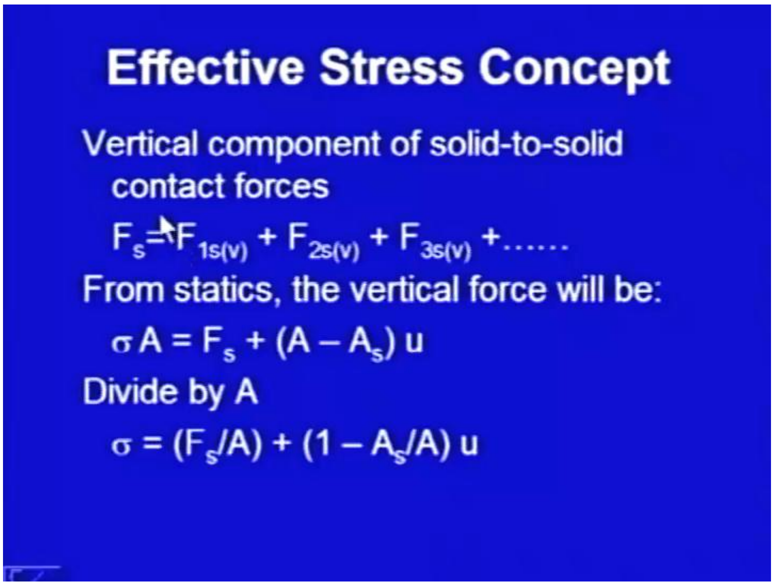

Now, we can find out the vertical components of all those forces which I discussed, there are forces from grain to grain the forces are acting. Let us say those forces are F 1 s F 2 s F 3 s and. So, on if you know their angles, we can find out there vertical components, so vertical components are F 1 s v F 2 s v F 3 s v. So, total vertical component of solid to solid contact forces F s will be equal to F 1 s v plus F 2 s v plus, so on.

Now, from the statics you know that total vertical force will be equal to this is the stress total stress into area that will be equal to the force which is being born by solids plus force which is being born by the pore water. So, sigma into A sigma, sigma is the total stress which I calculated earlier, A is the total cross sectional area from statics this equation should be satisfied. Now, if I divide this equation by A, then I get this expression sigma equal to F s upon A plus 1 minus As upon A into u, now, this component F s upon A.

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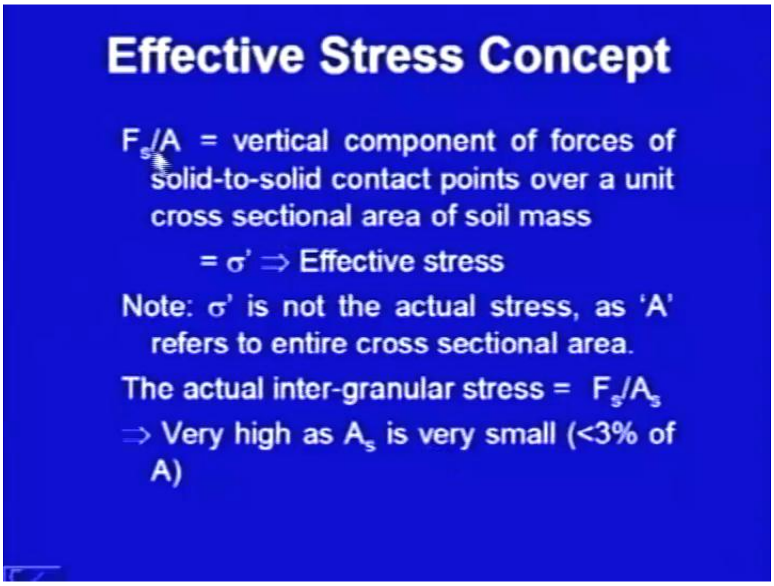

Fs is the vertical component of solid to solid contact forces this divided by A, A is the total area this particular component, this particular Fs upon A, this term is called as sigma dash which we call as effective stress. Please note here that A is the total area, it is not the contact area, so this sigma dash is equal to Fs upon A. The actual intergranular stress, if you, if you are interested in finding the out the actual intergranular stress that should be equal to the Fs divided by the actual contact area as.

So, this value will be very, very large because you know the contact area solid to solid contact area is very, very small, in normal cases it cannot be more than generally its not more than 3 percent its less than 3 percent, so this As as compared to A is very small. So, actual intergranular stress is very, very large where this is a hypothetical term, hypothetical expression sigma dash is equal to effective stress that is Fs upon A.

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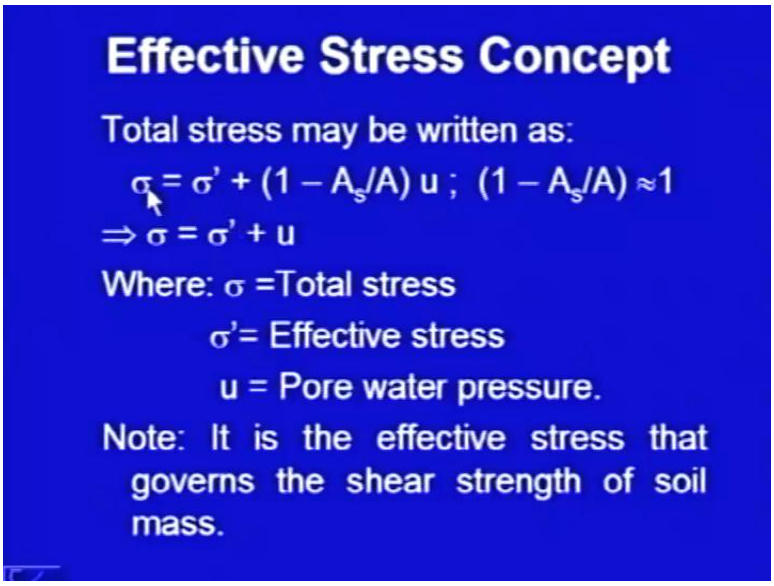

So, now the total stress can be written as sigma as equal to sigma dash plus 1 minus As upon A into U, as I told you this term is very, very small not less than not more than 3 percent. So, this term 1 minus As upon A is roughly 1 and finally, we can write down this approximate expression, sigma is sigma dash plus u, this particular equation is called as effective stress concept. What it tells is that the total stress, here sigma is the total stress, that is equal to sigma dash is effective stress and u is pore water pressure.

So, it gives us the you can find out the effective stress sigma dash, if sigma is available, if sigma has to be found out and sigma dash is available we can calculate sigma and you can note down here, that when you go for the design problems, it is the effective stress and not the total stress that governs the shear strength of the soil mass. So, this effective stress is very, very important and you have to remember this expression, now sigma equal to sigma dash plus u.

So, I have discussed the first concept that was the effective stress concept, now I am coming to the next very important phenomenon in the soil mass, specially for clays it is for clays consolidation.

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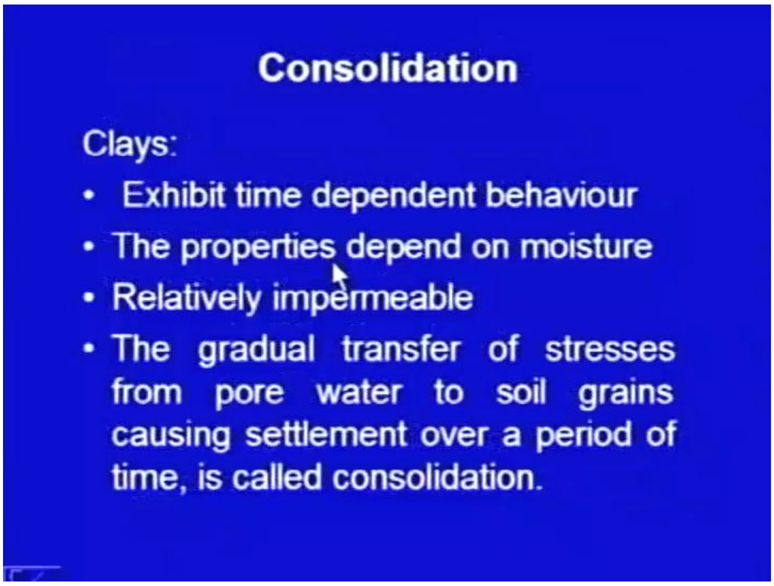

The clay soils, they exhibit time dependent behavior what we mean by this, that if you construct a building on a clay soil and if you construct a building on a sandy soil, the settlements in case of the clay soils will be time dependent they will be increasing with time. Whereas in case of the sandy soils, it occurs almost a within the time in which the building is constructed. Secondly the properties depend on the moisture content, so water is very, very important the moisture is very, very important as far as clays are concerned.

Third point about this, soils are that they are relatively impermeable, so if you apply load on the soil mass, which is having predominantly clay soil then water will not squeeze out very easily it will take time, they are not permeable and this will create problem this is the reason, why they are time they show the time dependent behavior. And here this is one of the definitions, there are several definitions to this term consolidation, this is the concept.

The gradual transfer of stresses from pore water to soil grains causing settlement over a period of period of time is called consolidation, so let me explain it this way, that a building is constructed over a clay stratum. So, a load is going to be applied, load is applied on the clay stratum and clay let us say it is completely saturated with water, it is impermeable, so what is going to happen is initially that entire load is born by the pore water which is present in this soil mass.

Gradually, the consolidation occurs and that load is transferred to the soil grains, let me try to explain it technically.

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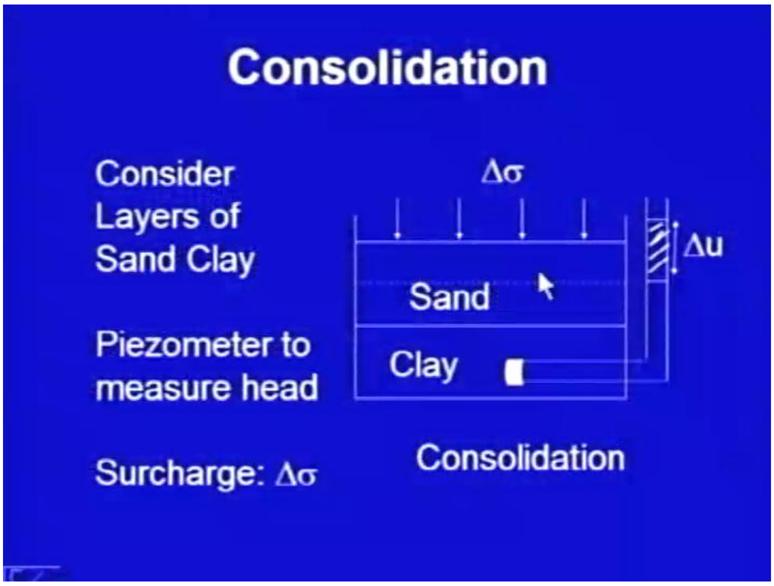

Here it is a site you can say, which is having a sandy layer, which is a underlain by a clay layer and we are able to put a piezometer here, let us assume that and here somewhere here the water table is there. Now, a surcharge is placed over here, surcharge means some weight maybe a building is constructed at this place. What is going to happen is when you put the surcharge, the weight will be transferred to sand the weight will be transferred to this particular clay layer.

In the clay layer, though it is completely saturated, initially the water will be bearing that particular that load and because of that the pressure in the water will be increasing.

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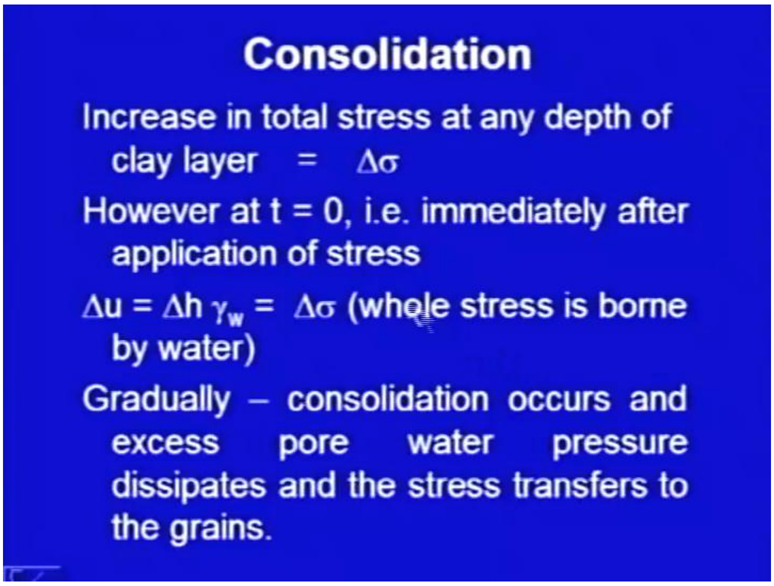

So, increase in total stress at any depth of this clay layer will be delta sigma, this is the total increase, just in the beginning theoretically at time t is equal to 0. immediately after the application of the stress. The increase in pore water pressure, excess pore water pressure will be equal to the total stress, which has been applied at the top, gradually the consolidation will occur this excess pore water pressure will dissipate and the stresses will transfer to the soil grains.

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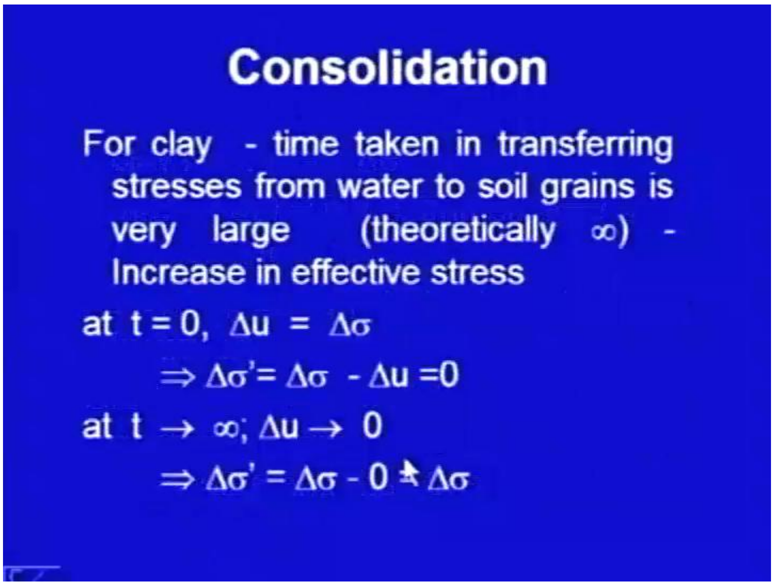

Theoretically, the time taken in transferring these stresses, from water to soil grains is very large, theoretically it is infinity, so at time t is equal to 0, the increase in the pore water pressure, excess pore water pressure is equal to total increase in the total stress. That means effective stress the incremental effective stress, just now I have discussed the effective stress concept. Total stress is equal to effective stress plus pore water pressure and the effective stress is equal to total stress minus pore water pressure.

So, here we are taking the incremental values, so incremental effective stress will be equal to incremental total stress minus incremental pore water pressure, so at time t is equal to 0 just after the application of the surcharge, this effective stress increase in effective stress will be 0. As t approaches a very large value, the entire pore water pressure dissipates, it becomes almost 0 and then this term becomes 0. And delta sigma dash that is the incremental effective stress will be delta sigma minus 0 equal to delta sigma, so effective stresses will be increasing to the extent of the applied surcharge stress.

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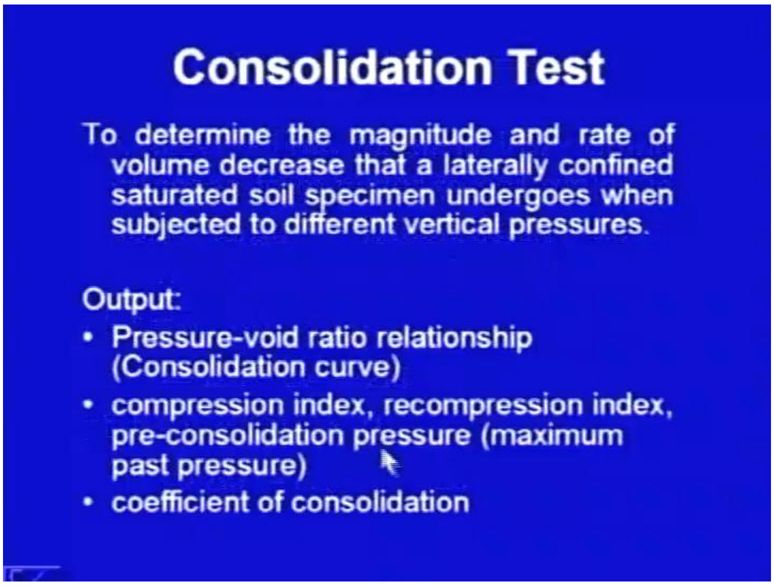

Now, this phenomenon, we use it in the design of the buildings and there are certain tests consolidation test is used for this purpose and the purpose of the consolidation test is to determine the magnitude and rate of volume decrease, that a laterally confined saturated soil specimen undergoes, when subjected to different vertical pressures. So, what we are going to do in this test is that we will be taking a soil specimen, we will be subjecting that soil specimen to various vertical pressures.

Those vertical pressures will be maintained for sufficiently long durations of time, so that settlement the consolidation is complete and we will note down, what is the settlement or what is the consolidation corresponding to different pressure values and from that, we will be getting the output. The output of this consolidation test is pressure void ratio relationship, some sometimes called as consolidation curve.

Then you will also get some other indices compression index, recompression index, pre-consolidation pressure, pre-consolidation pressure means the maximum past pressure. You know in the geological history there are changes in the loading and in the past, the soil mass might have been subjected to pressure, which is existing the present pressure. So, you can find out the pre-consolidation pressure and also you can find out the coefficient of consolidation. Let me discuss some details, discuss some something about the consolidation test apparatus.

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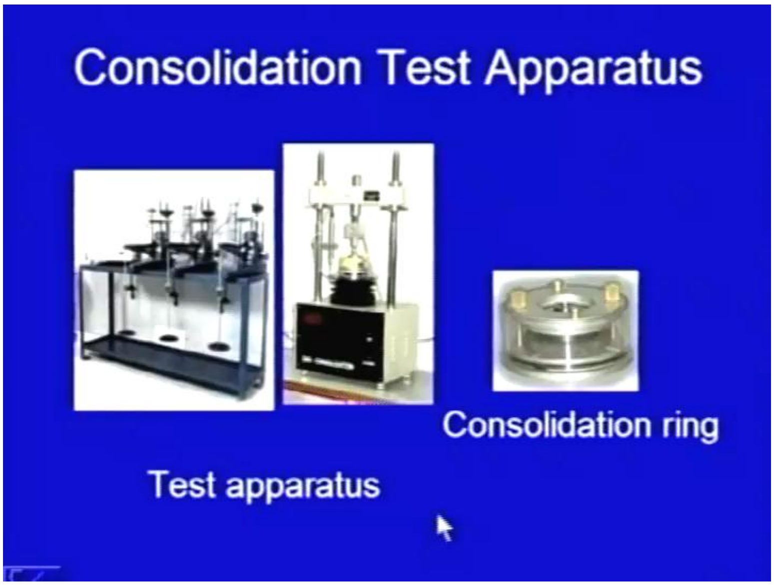

Here are the two photographs I have given this is the apparatus and here this is the consolidation range, this is the most important part you can say, In this ring it is a circular ring with certain height, let us say height is h, diameter is d and the in the ring that particular specimen or soil is placed and from the top, now this consolidation range is placed in the apparatus somewhere here, somewhere here. And then a load is applied on that, a predefined pressure is applied as I discussed earlier and that pressure is maintained for a long duration.

In this particular apparatus, you can see here this is a lever arm and using this lever arm and this dead weigh the pressure in applied on this specimen, so that pressure is a the deformations. The settlement of this clay of the specimen is monitored through the LVDT or dial gauges, these are the steps.

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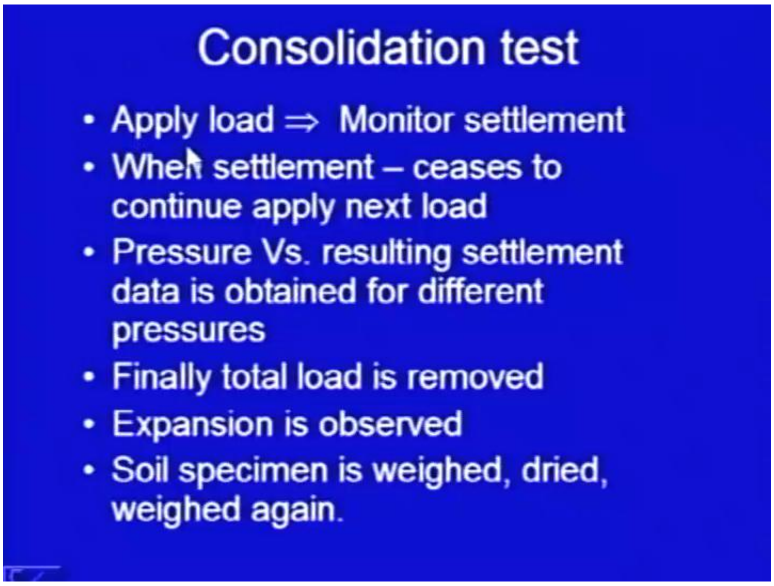

After putting the specimen in the apparatus, apply the load monitor the settlement, when settlements there will be initially the settlements will be increasing very fast, but with time the change in the rate of change of settlement will decrease. So, when rate of change of settlement almost ceases to almost 0 or when the settlement is complete then we apply the next pressure. From this pressure versus resulting settlement data is obtained for different pressure values.

Finally, the load is removed you can also check, whether there is some expansion after the removal of the of the pressure, now the soil specimen is taken out it is weighed in saturated condition, then it is dried and then weighed again. So, friends we started with introduction, we discussed the classifications of soil masses, then we discussed the physical properties, different expressions for the physical properties, different phenomenon then we discussed the effective stress concept.

Then we started discussing the consolidation, we have completed the what consolidation phenomenon is, we are now completing the consolidation test. And in the next class I am going to discuss how to use the outcome of these test results to find out the settlement of the clayey soils.