Foundation Engineering
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Module - 03
Lecture - 02

Hello viewers, welcome back to the course on Foundation Engineering. Last time we were discussing about the consolidation, we had discussed the fundamentals, then I had started discussing about the consolidation test apparatus.

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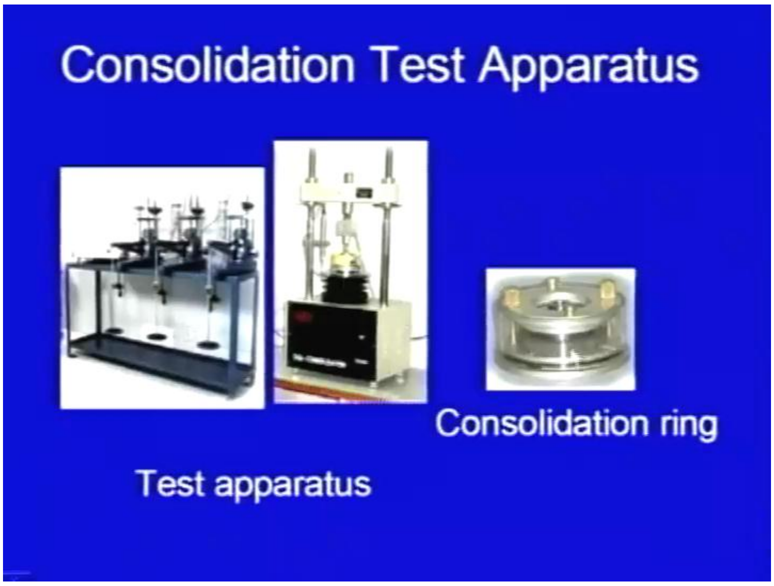

Here these are the machines, which I discussed this is the consolidation ring and we discussed how to do the test.

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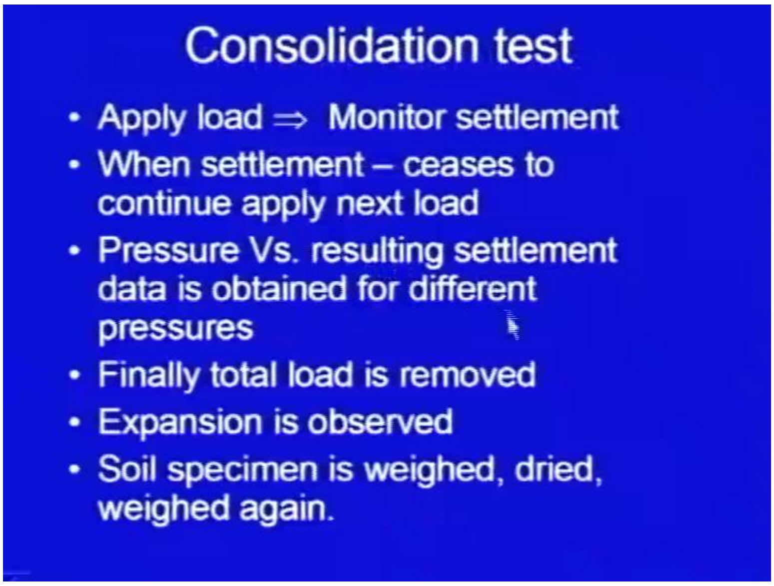

The different steps, in this test also we had discussed last time, means for example you apply the load and then take the readings, ultimately what we do is we apply different pressures and corresponding to those pressures, then we find out the settlements.

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Today, let us go to the computations here I am discussing only one method, there are more than one method available in the books you might have studied. Let me take an example, suppose we have conducted a test these are the initial readings, which we take weight of the ring, suppose it is 90.5 grams, then diameter of the ring, height of the ring;

so these dimensions are available I can find out the area of the ring and I can find out the volume also.

When I do the consolidation test these are the different pressure values, vertical pressure values which have been applied first one is 0 means there is no pressure, then 25 kPa, 50 kPa, 100 and so on. And each pressure is maintained for sufficiently long duration, so that complete settlement is there and in general we keep every loading for 24 hours, so corresponding to 0 this is the first dial gauge reading. Corresponding to 25 this one second reading, second reading it indicates the final reading corresponding to 25, so when the pressure is 50 this reading 16.10 this is the final reading.

So, what you can do is you can find out corresponding to any pressure value for example, corresponding to 50 you can find out what is the settlement, settlement will be the first reading minus this third reading, corresponding to 100 the settlement will be first reading minus corresponding reading from this table. Now, once this complete test is over we had applied the pressure up to maximum value, this was the final reading after that we take off the sample and then we take it is weight, so ring plus wet soil after the test let us say it is 275.7 gram.

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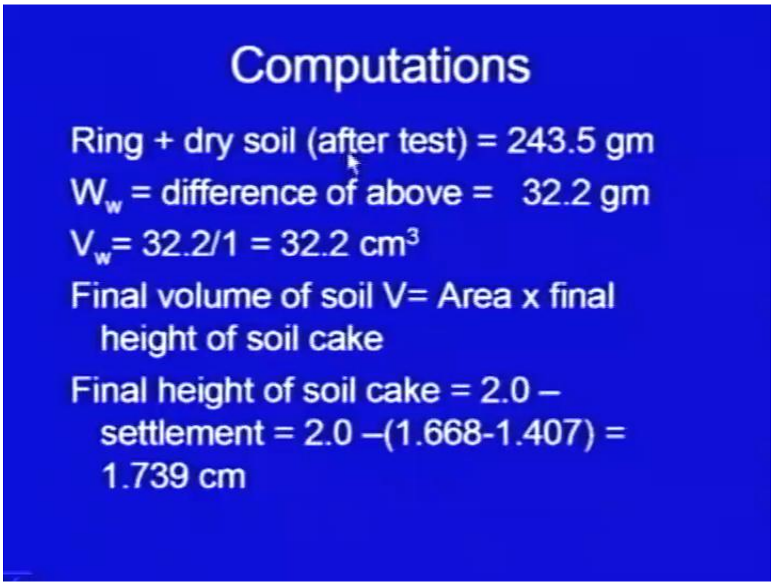

Then we keep it for one drying 24 hours are given to sample for being dry and then, ring plus dry soil let us say this is the weight. So, from the above two values you can find out what is the weight of water in the sample, that will be first reading minus the second reading and once weight of water is available you can calculate the volume of water. Now, you calculate final volume of the soil cake that is equal to area of the ring into final height of the soil and the final height of the soil cake, as I told you will be the initial height was 2 centimeter and minus the final settlement.

And that was this was the first reading it is in centimeters minus 1.407 this is second reading, this value gives you the settlement; so initial height was 2 centimeter to minus this gives you the final height of the soil cake.

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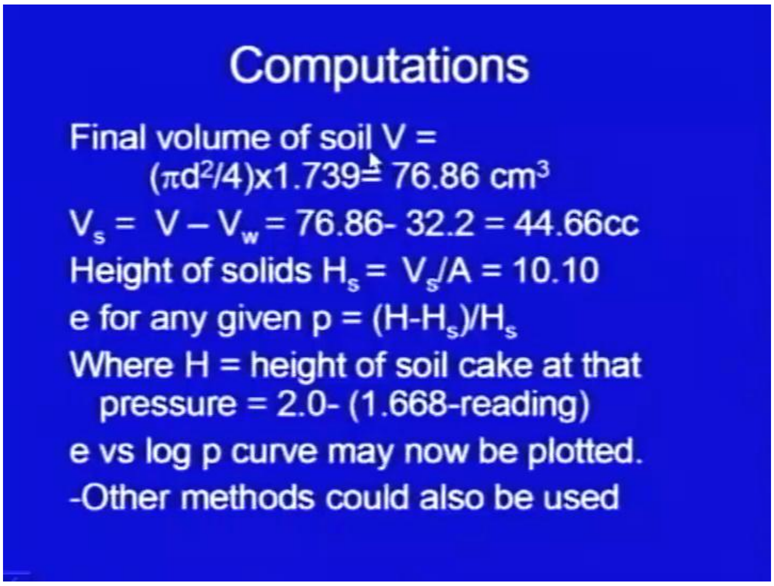

Now, you can find out the final volume of soil this is the area, area of the ring into height and that gives you final volume of soil 76.86, final volume of total soil mass is available we had already calculated the volume of water. So, you can now find out volume of solids, so that will be volume of the soil mass minus volume of water 76.86 minus 32.2 and 44.66, this is the volume of solids. You already know the definition of height of solids, height of solids will be now volume of solids and divided by area of the ring and it comes out to be 10.10 millimeter.

Now, you can calculate void ratio at any given pressure p that will be H minus H s upon H s, H is the height of the soil cake at that particular pressure and that will be initial height minus, this is the first reading and minus the reading corresponding to that particular pressure p. So, H minus H s divided by H s this gives you e for the particular pressure void ratio for that particular pressure, so e versus log p curve may be plotted.

You can get different, for different p values now you can get the void ratio and you can then plot the e versus log p curve, I have discussed only one method there are several other procedures also which you can use, now this is the output of this test.

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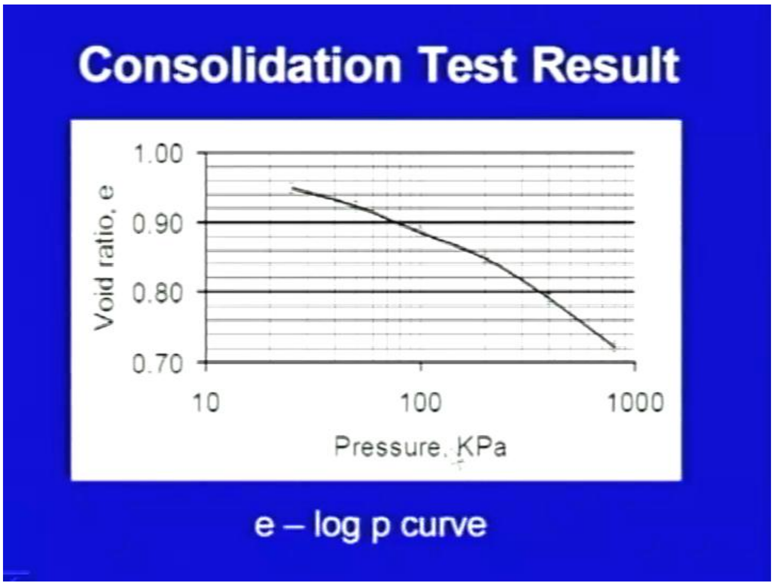

Here on the x axis it is the pressure, remember it is effective pressure, means total minus in the field when you use it you have to use the effective stress here. So, it is the effective pressure and on y axis we have the void ratio and this is the way the variation of e has occurring with pressure p, so this is the output, one of the outputs of this particular test.

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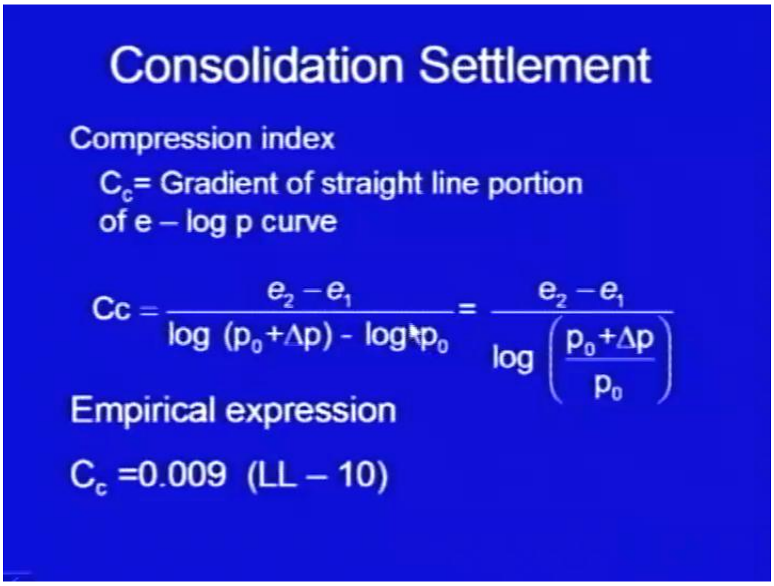

Now, let us go to the parameters which we can compute from this test, one of them is compression index we shall be using compression index to calculate the settlements and it is defined as the gradient of the straight line portion. You take the straight line portion at the higher pressure values and then, find out its gradient from the previous curve which I just discussed.

So, the compression index will be on y axis you have e values, so difference of e values and on x axis we have pressure values on log scale, so log of p 0 plus delta p, this is the incremental value of the pressure minus log of p 0. So, finally, you get C c equal to e 2 minus e 1 divided by log p 0 plus delta p upon p 0, please remember again all these values are effective values, effective pressure values, so this is the way you can calculate the compression index.

If this test is not available you can use some other data also and you can find out the approximate values of the compression index, one expression I have given here there are several other expressions you can see the references. So, this is C c is equal to 0.009 times liquid limit in percentage minus 10, so this gives you one approximate value of C c if you do not have the settlement, the consolidation test data. Let us now go to how we have to use these values in the field.

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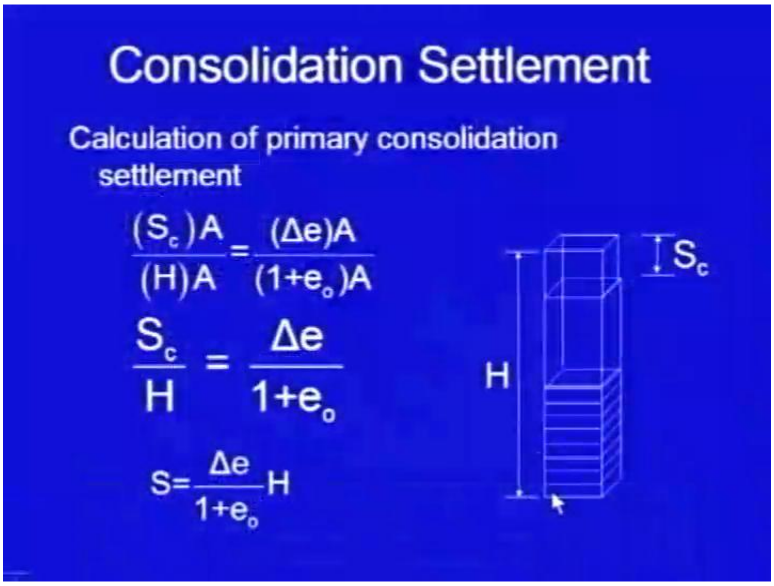

Here, I have shown the soil mass of depth H and some let us say a building is constructed over here and because of that load there is settlement, one can get these expressions, this

S c into A divided by this total height into A is the area will be equal to delta e, e is void ratio into A divided by 1 plus e 0 into A. So, one can obtain this expression S c upon H is equal to delta e upon 1 plus e 0, finally you can have S c will be equal to delta e upon 1 plus e 0 into H.

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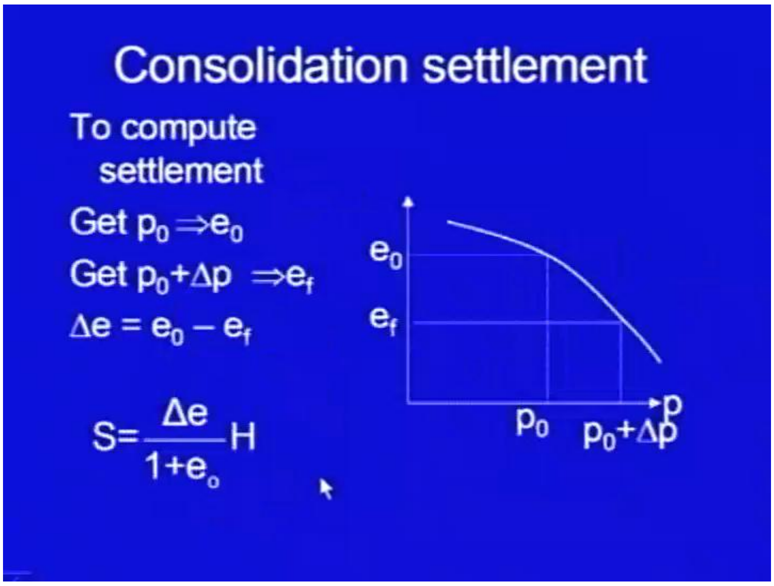

How to use this expression in the field to compute the settlement, what we do is we get the effective pressure at that particular depth, where we want to calculate the settlement. And corresponding value of e 0 we read from e versus log p curve, this is again the same curve y axis is e and x axis is on log scale is pressure, so corresponding to p 0 you can find out what is the void ratio e 0, this is the initial void ratio.

Then, let us say delta p is the incremental pressure at that particular location, because of construction of the building or any other load and you will be able to calculate it, so p 0 plus delta p gives you the final or the second the incremental value of the pressure. So, p 0 plus delta p is somewhere here, I get corresponding to this curve you can get e final; and once e final and e 0 are available, the settlement is given as S is equal to delta e upon 1 plus e 0 it is the same equation, which I discussed just few minutes ago. And H, H is the thickness of the layer for which we are calculating the settlement.

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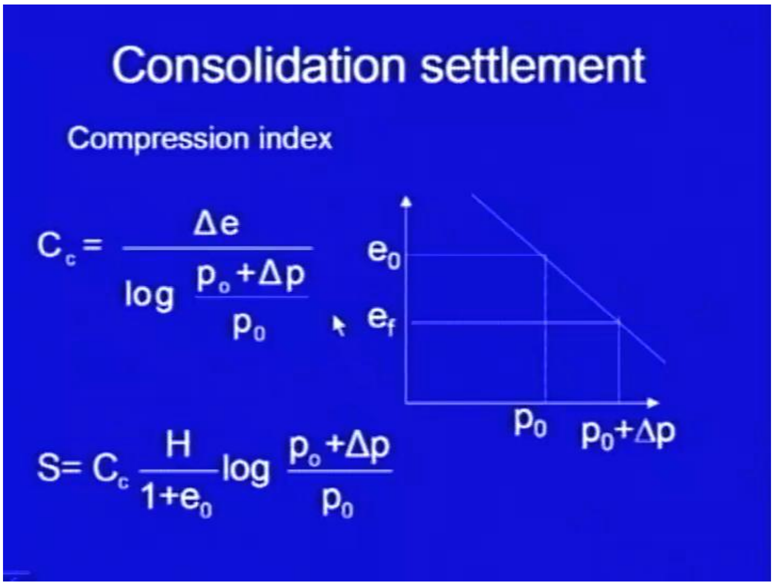

If you are using the compression index as per the definition of the compression index C c is delta e upon log of p 0 plus delta p upon p 0, it is the gradient of the straight line portion. We combining this equation and the previous equation of the settlement I can get this expression for the settlement S is equal to compression index multiplied by thickness of the, layer for which you are calculating settlement divided by 1 plus e naught it has the initial void ratio this one.

And then, log of p 0, p 0 is the initial effective pressure when there was no building and the settlement was only because of the soil, delta p is the incremental pressure, because of the surcharge or the building. And p 0 plus delta p upon p 0 log on this multiply by this and you can get the settlement of the particular layer.

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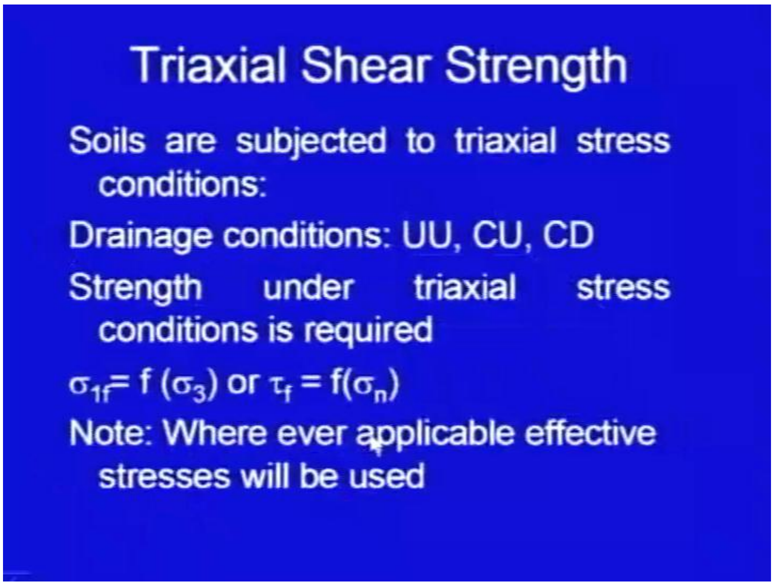

We have discussed the consolidation test, now the second most important thing which I would like to just go through briefly is the triaxial, shear strength or simply the shear strength of soils. Whenever you talk of the varying capacity of the soils or whenever you talk of the slope stability analysis, any kind of the analysis in soil engineering when you do we always talk in terms of the shear strength of soils.

We assume that the soils are feeling big in shear, one of the test which is used is triaxial shear strength test, there are different drainage conditions which you have studied earlier in your previous course, this is unconsolidated un drained test, consolidated un drained test and consolidated drained test. And for doing the analysis in the field, whether it is a bearing capacity computation or the slope stability analysis, you will need the strength under triaxial stress, under all these drainage conditions.

In nutshell we need in terms of, if I talk in terms of major principles stress and minor principles stress, then major principles stress at failure corresponding to given confining pressure either we will need this. Or we may also need in terms of the shear stress at failure as a function of normal stress at the failure surface and again please note wherever applicable, we have to use the effective stresses.

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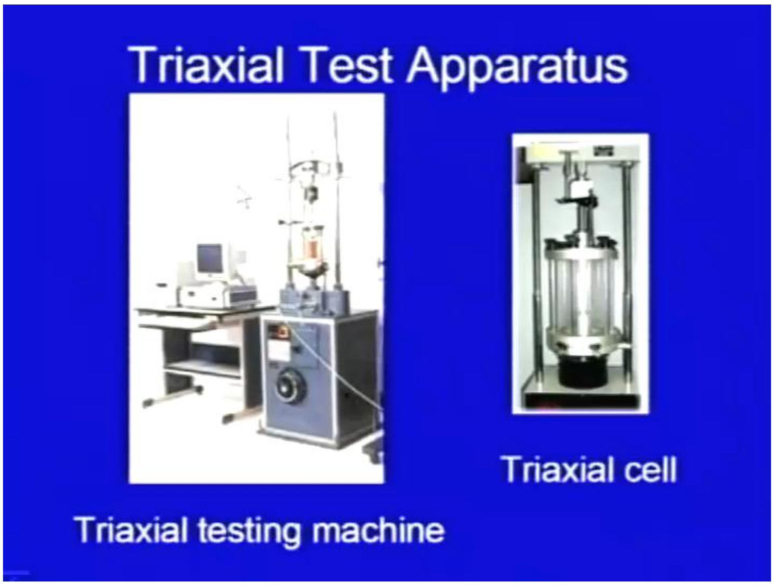

Here are some pictures of the triaxial test apparatus, this is the triaxial testing machine it is having a loading frame and most important part is here it is shown here triaxial cell, in this cell the specimen will be placed here and using water all round pressure sigma 3 will be applied and then, the load will be applied. So, corresponding to different sigma 3 you can go on increasing the deviatoric stress from the top up and you can continue up to the failure occurs.

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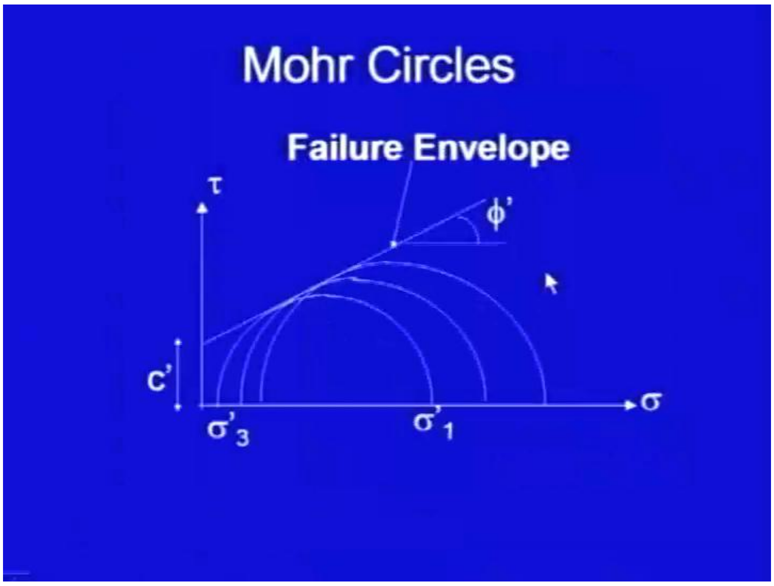

The results of the triaxial test will be available in terms of the confining pressure and corresponding deviatoric stress from which you will be able to calculate the major principles stress. Now, if you conduct test on different confining pressure values and plot them on Mohr circles, you know Mohr circles it is a sigma axis and here it is tau axis, on sigma axis you can put sigma 3 here and sigma 1 here and then, take this as the diameter and draw the circle.

So, next higher sigma 3 this is the Mohr circle the second Mohr circle, for next higher sigma three this is the Mohr circle, if you draw a common tangent to them this particular curve which may be a straight line also, it defines the failure condition of the soil. And here it is a straight line, I have taken it as a straight line which is having intercept C dash and phi dash, C dash here and angle phi dash here.

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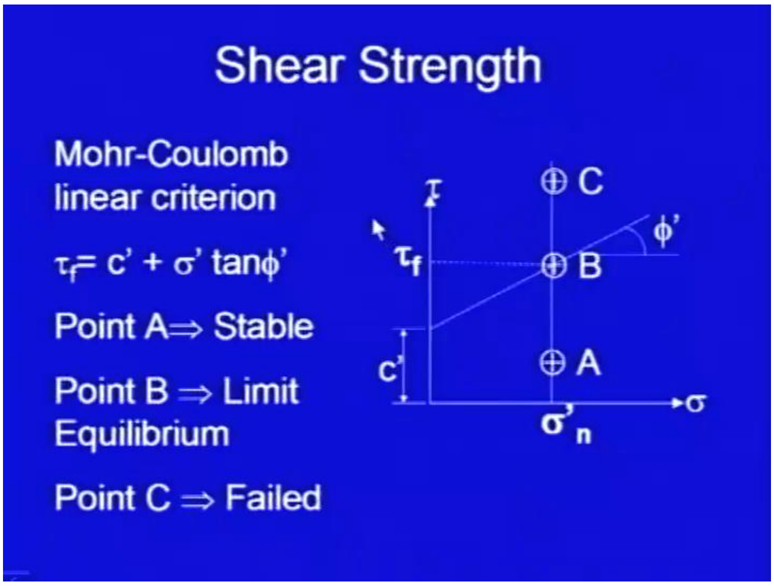

Let us talk about this failure envelope, the most widely used expression for this failure envelope is Mohr-Coulomb failure criterion, this is a linear equation. Mohr-Coulomb equation uses two parameters, C and phi or C dash and phi dash, wherever it is applicable. The equation is given as the failure, the equation of the failure envelope is given as tau f, here it is y axis has shear stress, tau f is equal to c dash plus sigma dash tan phi.

Tau f is the shear stress at failure, C is cohesion and phi is angle of internal friction or angle of shearing resistance, sigma is the normal stress. Let me explain what this failure envelope mean, let us have three points A, B and C they are representing three different stress straights, when I say stress is straight on this space tau sigma space means, there is a given sigma n value some normal stress value; and this is having some shear stress, this is the point A and the y coordinate represents the shear stress.

Another point I have to B which is on the failure envelope and shear stress here is exactly equal to the shear strength tau f I have taken it from this equation. Third point I have taken arbitrarily, here sigma n is maximum and it correspondingly some tau value will be there. What do these points on this particular space mean what do they represent, now look at the point A here corresponding to this normal stress sigma n the shear stress is this value, this value is less than tau f, so point A will be stable.

If there is a point, if there is a plane which is having this stress sigma n and this much shear stress, then this point this plane will be stable, so point A represents a stable stress of state. Come to point B here I have taken the y coordinate of this point is tau f which is just equal to the strength shear strength at that particular normal stress. So, this particular condition we will be calling as limit equilibrium condition what does it mean, it means the plane is just at the verge of failure come to the point C, here the shear stress is quite large compared to the strength.

So, it is not possible if there is a condition in the field were the shear stress has exceeded the shear strength which should have failed, so this means it is all ready failed. So, this particular equation, this particular curve, this particular line represents a failure condition, if you have a stress of state for a particular point in the field, we have plot it here. If the point is below this line all those points will be stable, if it is above they are not possible they might have already failed and if the point is here, then it is just at the verge of failure.

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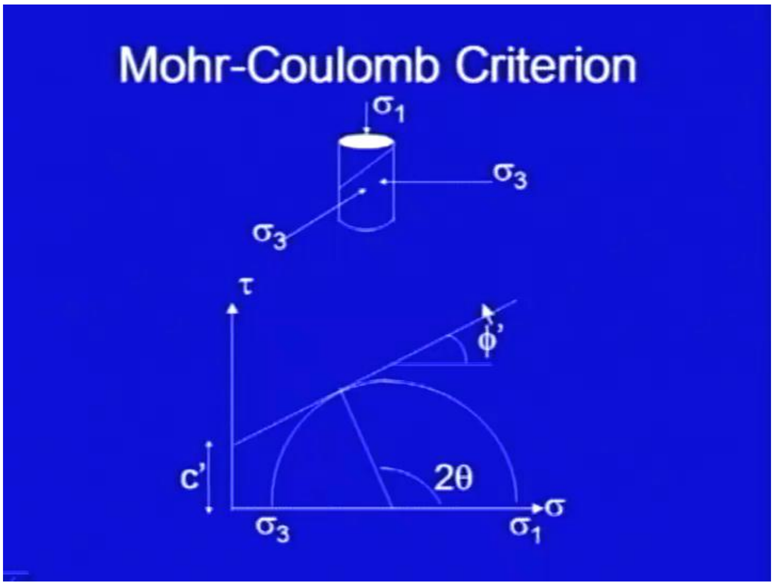

Let me go little bit more in detail about the Mohr-Coulomb criterion, I have shown here a soil specimen sigma 3 is all round pressure and considering it now in 2 d only, so sigma 3 is acting in this direction, sigma 1 is acting on this direction. And let me take a plane which is inclined at theta degree with the horizontal, theta it is making an angle theta with the plane on which sigma 1 is acting.

If you recall the Mohr circle theory, if I draw the Mohr circle for this condition, so sigma 3 is here this is the circle which is representing the stress of state, so this point represents sigma 1. So, this point will represent the plane on which sigma 1 is acting, so horizontal plane from this point if I move anti-clock wise by angle 2 theta, I will be reaching this particular point. And this point represents this stress of state for this plane which has inclined at an angle theta with the plane on which sigma 1 is acting.

So, the condition for failure is this is the failure envelope and the failure envelope touches this circle, so when the circle touches it, it is the limit equilibrium case. So, the sample is just at the verge of failure, so at angle 2 theta here this point represents just limit equilibrium condition.

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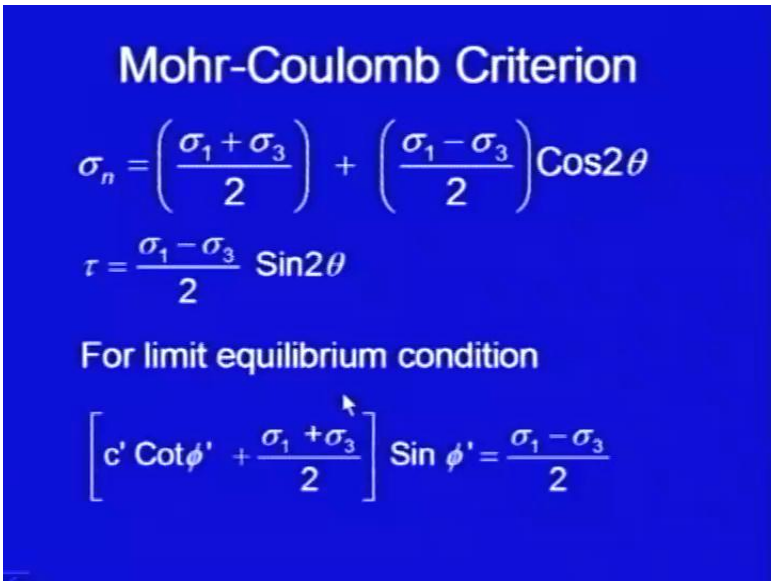

From your mechanic principles you can find out the normal stress which is acting on that plane which is inclined at an angel theta. Sigma n will be equal to sigma 1 plus sigma 3 by 2 plus sigma 1 minus sigma 3 by 2 into cos 2 theta, you can also calculate the shear stress which is acting on that plane. And for limiting condition this shear of stress should be equal to the shear strength from the previous diagram.

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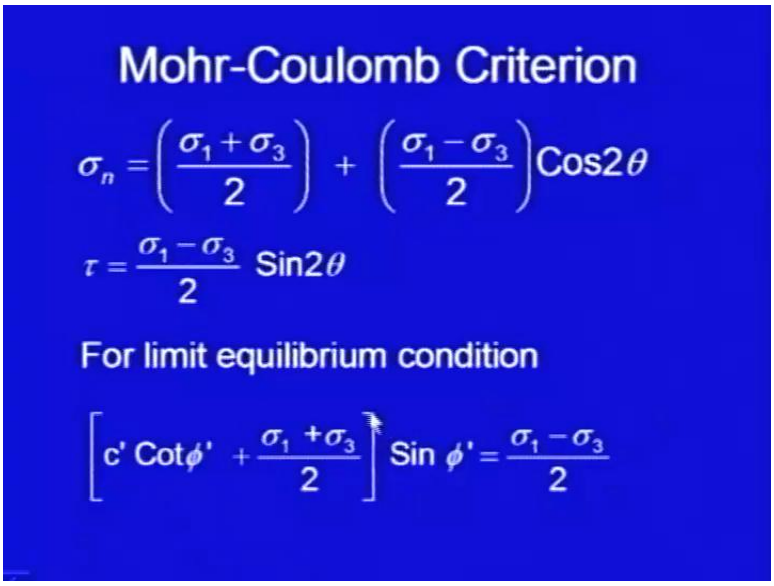

And you will be getting this expression this is the condition for failure from that diagram c dash cot phi plus sigma 1 plus sigma 3 by 2 sin of phi dash is equal to sigma1 minus sigma 3 by 2.

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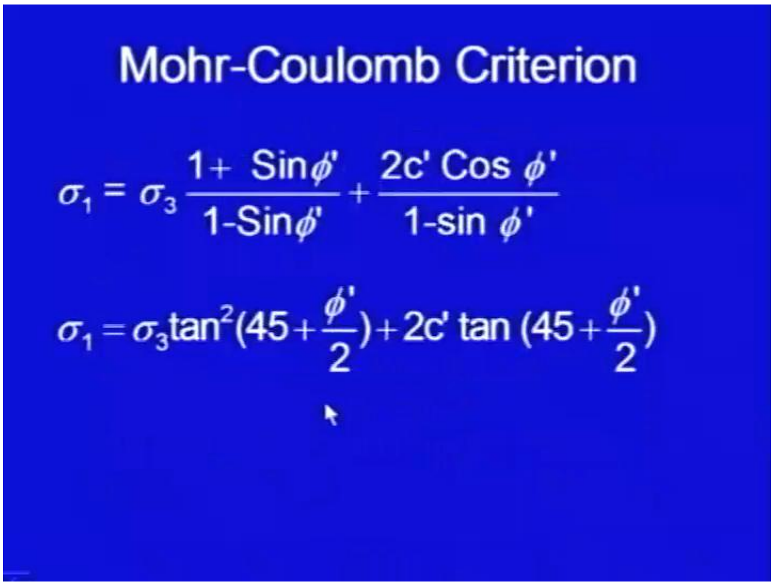

And finally, you are going to get this equation sigma 1 equal to sigma 3 1 plus sin phi upon 1 minus sin phi plus 2 c cos phi upon 1 minus sin phi, or you can write it in this form sigma 1 equal to sigma 3 tan square 45 plus phi by 2 plus 2 c tan 45 plus phi by 2. So, the same equation which we plotted in terms of the shear strength tau equal to c plus sigma tan phi, we can also represent the same equation in terms of major and minor principle stresses. Now, these parameters c dash and phi dash are very important parameters you will need them in the analysis, how to get them.

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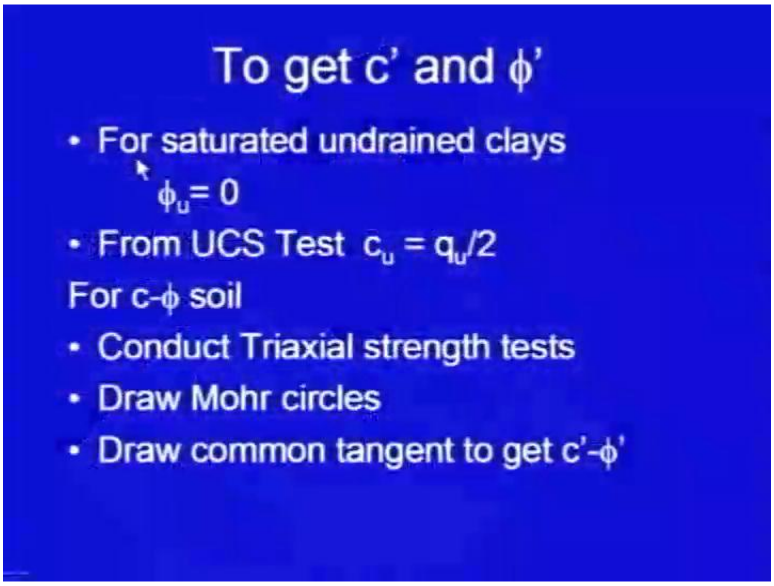

If the soil is undrained clay and it is saturated, normally in analysis we can take phi u to be equal to 0 and from unconfined compression test, the parameter c you can be taken equal to UCS, UCS is uni axial Unconfined Compressive Strength divided by 2. So, C u directly you can take equal to UCS by 2, if it is a c phi soil then we have to conduct the triaxial strength test as I discussed, then you can draw the Mohr circles. And then, you can draw common tangent to all the Mohr circles and c dash you can get as the intercept on the y axis and phi dash as the gradient of their the failure envelope.

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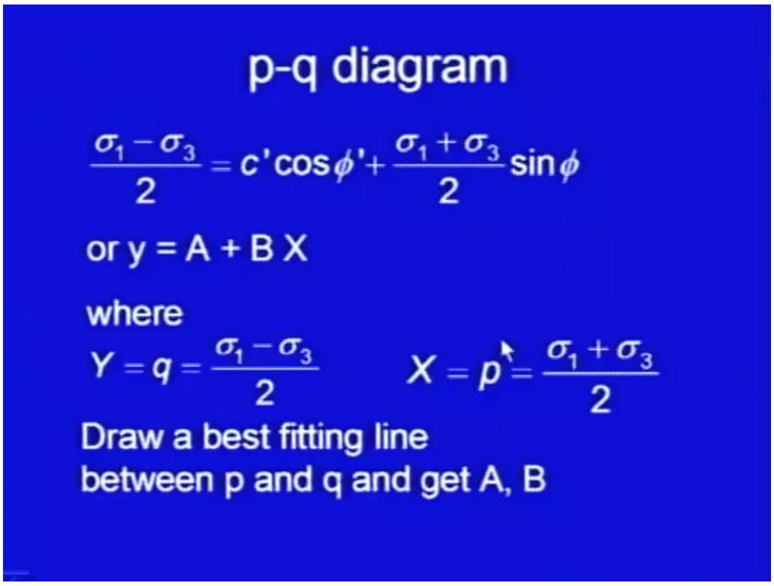

The another way to find out c dash and phi dash it is a very convenient method rather than putting a common tangent to the Mohr circles. It is a convenient way and mathematically more stronger. You can represent the Mohr-Coulomb equation in this form sigma 1 minus sigma 3 by 2 equal to c dash cos of phi dash plus sigma 1 plus sigma 3 by 2 sin of phi dash.

Or this is y, I can write it y is equal to A plus B X this is A and B times X, here y is equal to sigma 1 minus sigma 3 by 2 and X is equal to sigma 1 plus sigma 3 by 2, this two values we will be calling them p and q. You can now draw you can get these values p q values for different tests, you have the test data different sigma three values, for different sigma three values you have different sigma one values you can get p q values.

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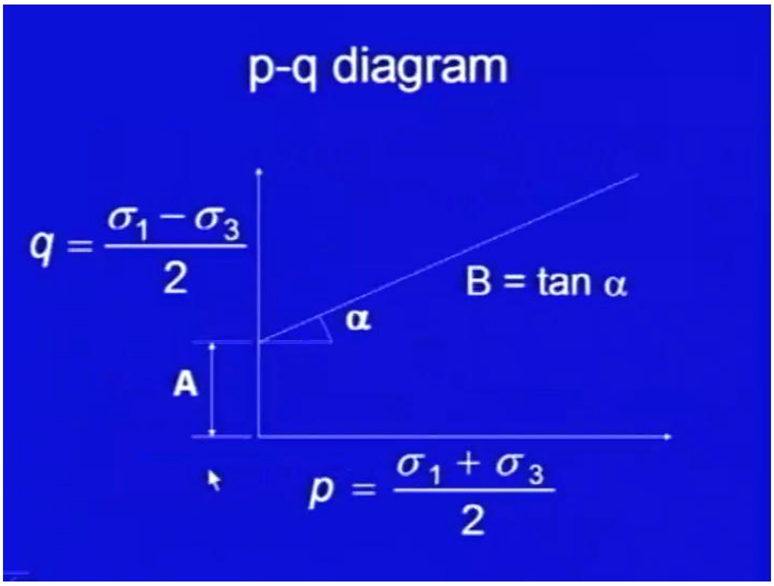

And then, you can draw a best fitting line here on x axis I am plotting p, on y axis it is q and then this is the best fitting line you can find out it is gradient alpha and it is intercept.

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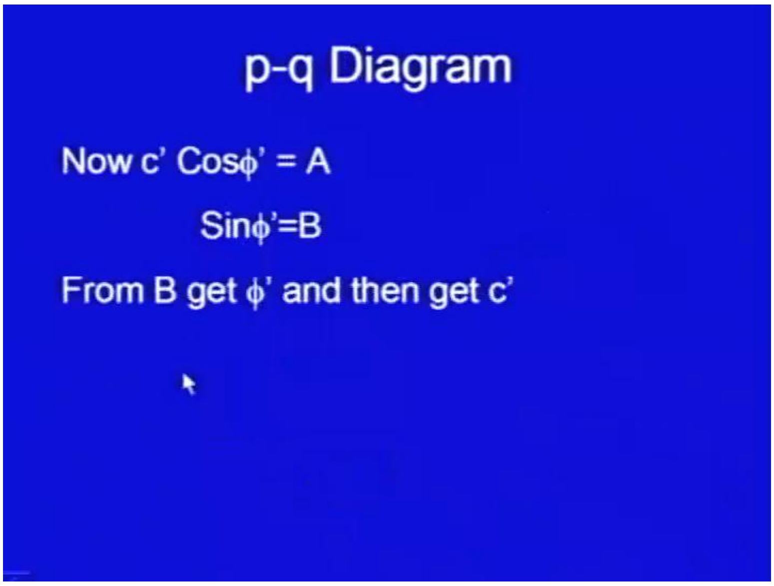

And then, you can correlate these two the exact value of A will be equal to c dash cos phi and B equal to sin phi dash, from B you can get phi dash and then, from first equation then you can get c dash. So, it a better way and mathematically a simpler we are getting c dash and phi dash.

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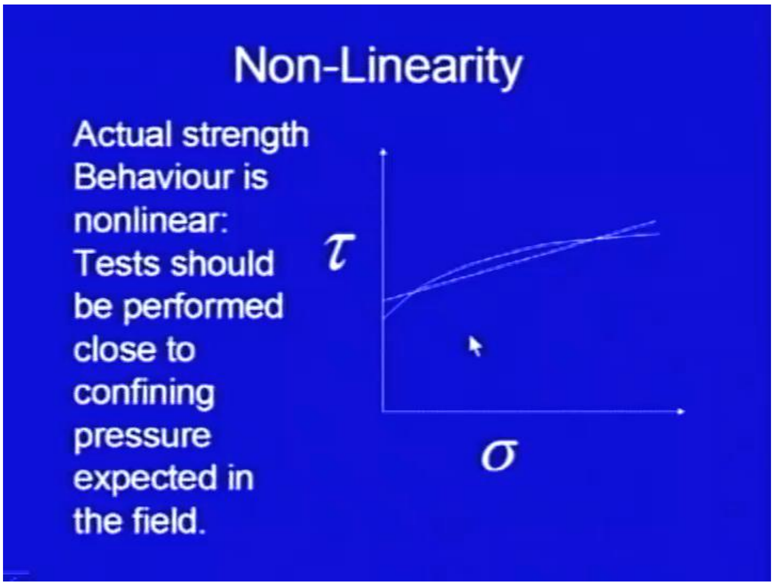

Here I have like to put one note, please remember the failure envelope we had taken was a straight line, so actually it is a non-linear curve and it is advised that the test should be performed at those confining pressure values which are near to the field values. So, if you are conducting test in this range you will be getting this straight line, if you are conducting test in this range you will be getting this straight line. So, you should get the tests at those confining pressure values which are closed to the field values.

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Friends with this I come to the conclusion of the chapter number 1, in this chapter we started with the soil classifications I discussed about different classifications. Then we had discussed about the physical properties, what are the different expressions though you know them, I had just brief them. Then I discussed I touched the engineering properties in brief, the very important concept effective stress concept has been discussed wherever applicable we will use this concept.

Please remember, wherever you want to find out the strength you have to use the effective shear strength parameters, you have to use effective normal stress. Then we have discussed about the consolidation of the clays, it is a time dependent phenomenon and wherever the clays are there you should expect to get time dependent settlements, so we have discussed this also.

And finally, I have discussed the shear strength of the soil of soils we have use the Mohr-Coulomb linear failure criterion, we have discussed how to do the triaxial strength test and how to compute the shear strength parameters; so with this I conclude the chapter 1.

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In the last chapter we have briefed, we have refreshed our memories about the basis of the soil mechanics principles, so we have discussed classifications, physical properties and engineering properties.

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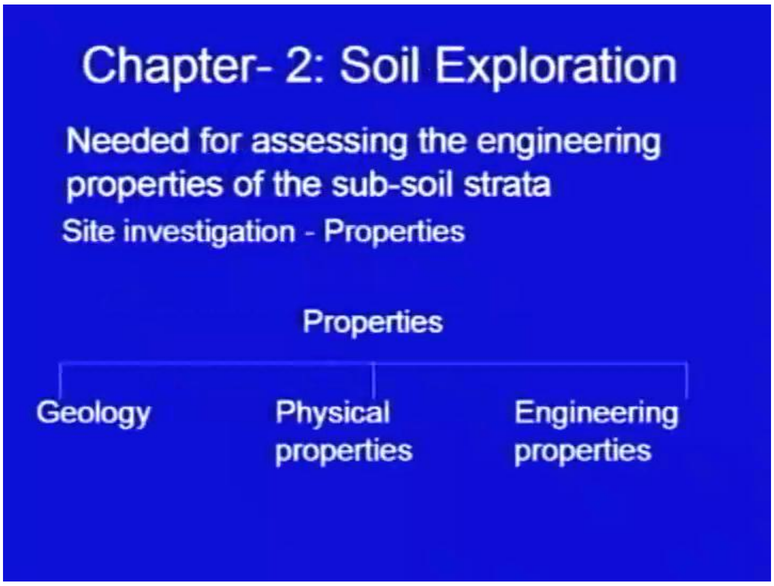

And friends, let us now go to the next chapter of this particular course and this chapter is about the soil exploration. Why we need exploration, whenever you have to construct a structure, you have to design the foundation, you have to find out what is the load carrying capacity of this strata of the sub-soil strata. And for that purpose you need to assess the engineering properties of the sub-soil strata, the ground how would kind of the ground is there, what kind of the load it is going to take, so for that you need the properties of that particular ground.

The purpose of this particular course is to give you an idea how to do this, how to get the properties, what are the different tests. The properties which we need can be divided into these categories number 1 is geology, then physical properties and engineering properties geological properties, you can get the geological maps and this is the first thing, in fact one should do you should get the geology of that particular place.

This comes under desk study you can get the maps and you can study the maps and you can have the idea about the geology, these two properties physical properties and engineering properties we shall be discussing in this particular chapter. When you plan a an exploration, the preliminary studies have to be carried out first.

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It includes as I told you the geological study, then you can have a reconnaissance of the site you have to go to the site, then look at the local topography, look at the existing building codes. Also sometimes it is very helpful to interact with the local people and find out what kind of the strata, what kind of the problems they are encountering as far as the soil engineering is concern.

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Also look into the local technologies sometimes very useful things are available, what is the natural drainage pattern at that particular site, whether it was a pond, whether it was a lake many a times you will be having a site which in pre-history period, there might have been some pond there, there might have been some lake or something like that there may be filled up soil. So, get the idea from the people there, then also inspect the existing excavation, try to find out a some exposures are available, some cuttings are available, some earth fills are available.

Then you can see those sections and you can have the idea about the sub-soil strata and also you look at the buildings if there are cracks in the buildings, because of some foundation problems, if there are excessive settlements they also speak off some problems. So, they also speak about the sub-soil strata all these things you should get when you visit the site, so visiting the site helps us in a big way you get lot of information from that.

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The bores are advanced and this is this investigation is done through bore holes.

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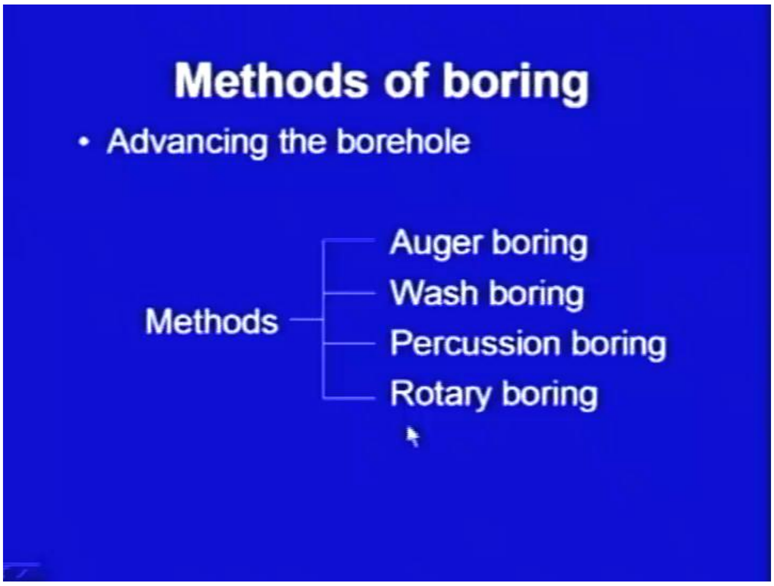

There are several methods of advancing the bore holes, first method is auger boring, wash boring, then percussion boring and rotary boring.

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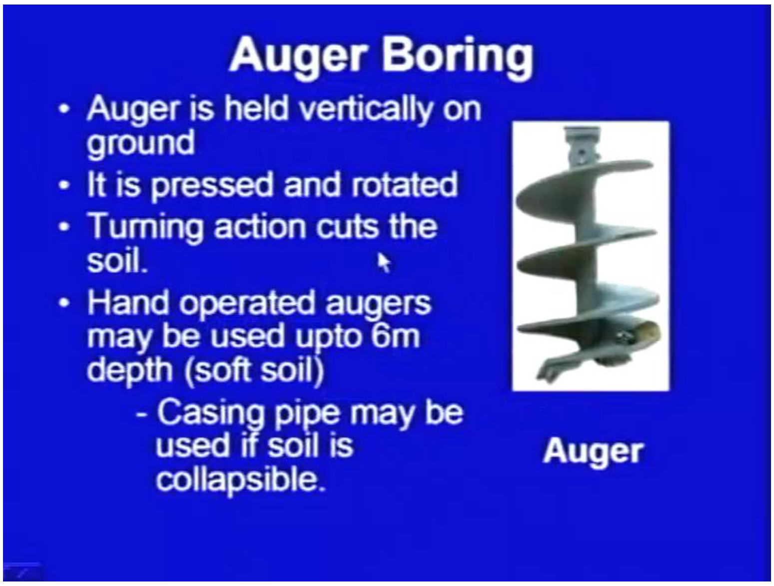

Let me in brief discuss all these methods, in first one the auger boring this is a picture of the auger, this auger is held vertically on the ground and it is pressed and rotated, here it is the cutting edge the turning action cuts the soil and that soil is excavated out. So, these augers hand operated augers can be used for shallow depth, for greater depths you have to use the machines, so this is the first one.

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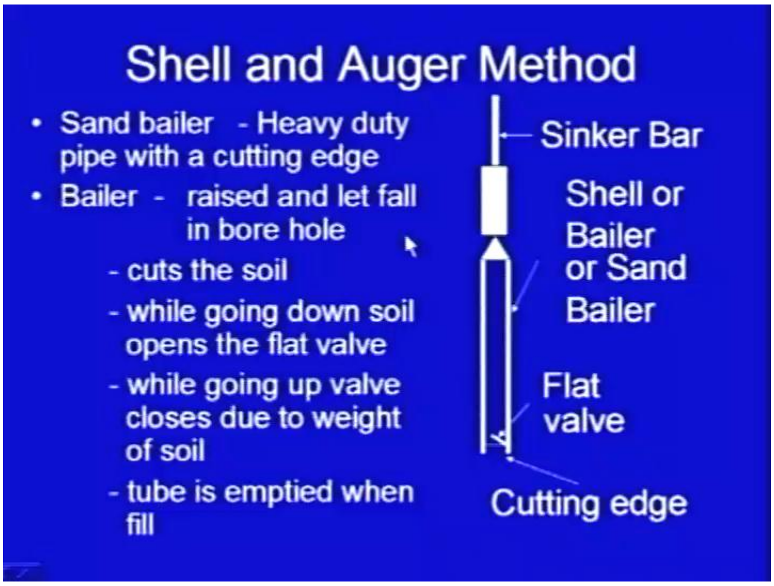

Then shell and auger method is there, this consists of a sand bailer it is a heavy duty pipe, this is a very heavy duty pipe here and at the bottom it has cutting edge, so this bailer is raised and that fall, when it falls it will cut the soil and when it goes down the soil will enter into this pipe there is a valve here, this valve opens. So, when soil enters in the pipe the valve will open and when this pipe goes up, when the sand bailer goes up this valve will close, so after number of repeated cycles this particular this pipe will be filled up with soil and then, it can be taken out.

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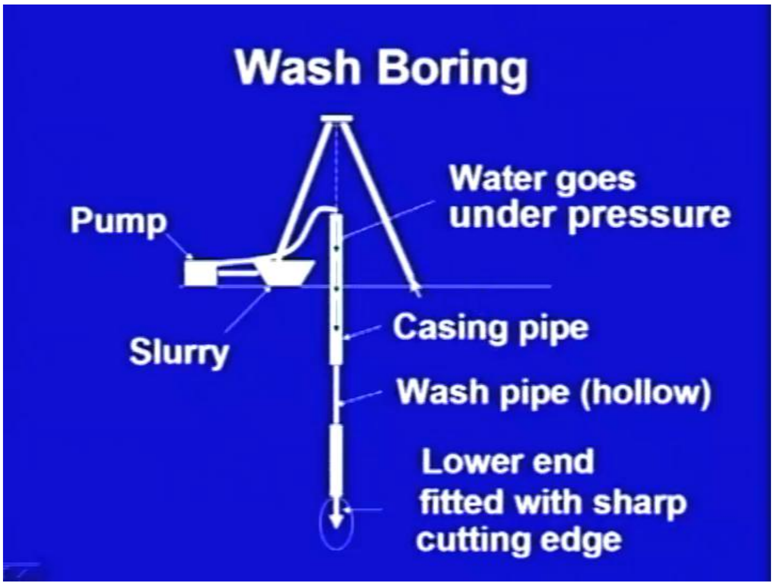

Wash boring technique is used this is a tripod having some pulley arrangement, here is a pump using pump, water is forced through this casing pipe and at the lower end, the end is fitted with sharp cutting edge, so water is there and cutting edge is there.

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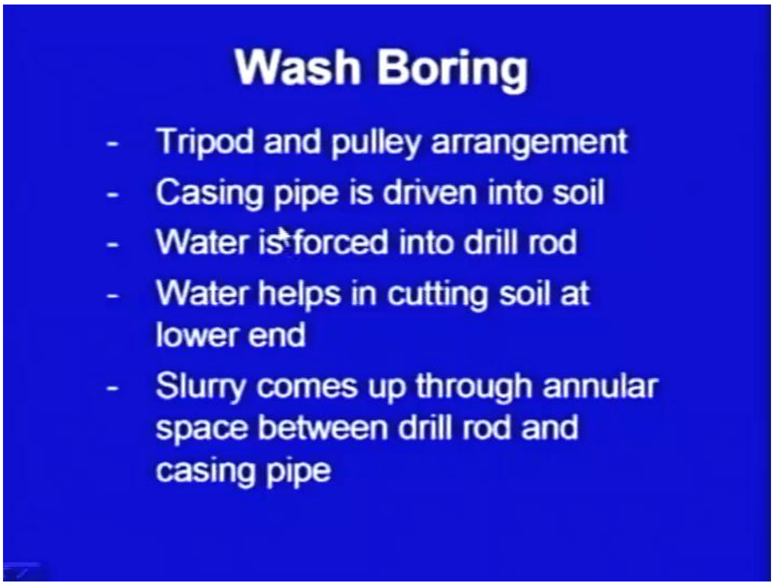

And these are the steps, the casing pipe is driven into the soil, then water is forced into the drill rod water will help in cutting the soil and then, slurry will come up through the annular space between the drill rod and casing pipe.

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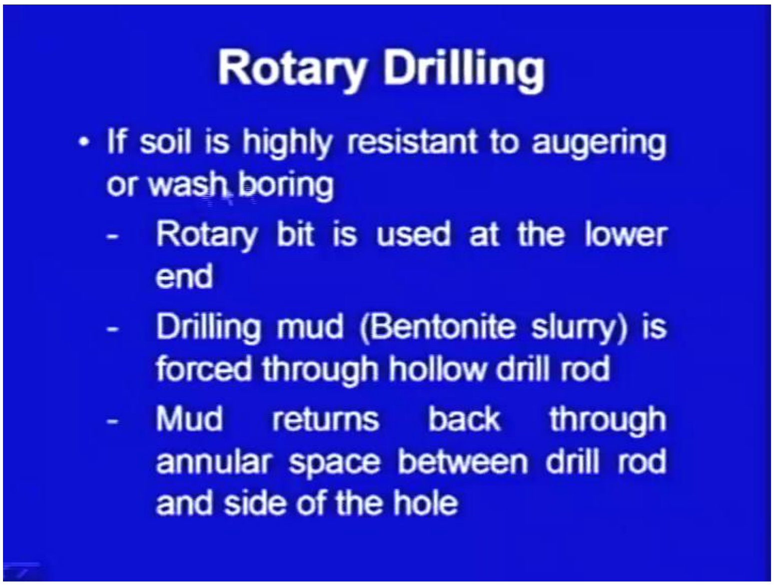

If the soil is very tough it is highly resistant to augering or wash boring, then rotary bit can be used at the lower end and drilling mud, bentonite slurry is forced through the hollow drill rod, then mud returns back through the annular space between the drill rod and side of the hole.

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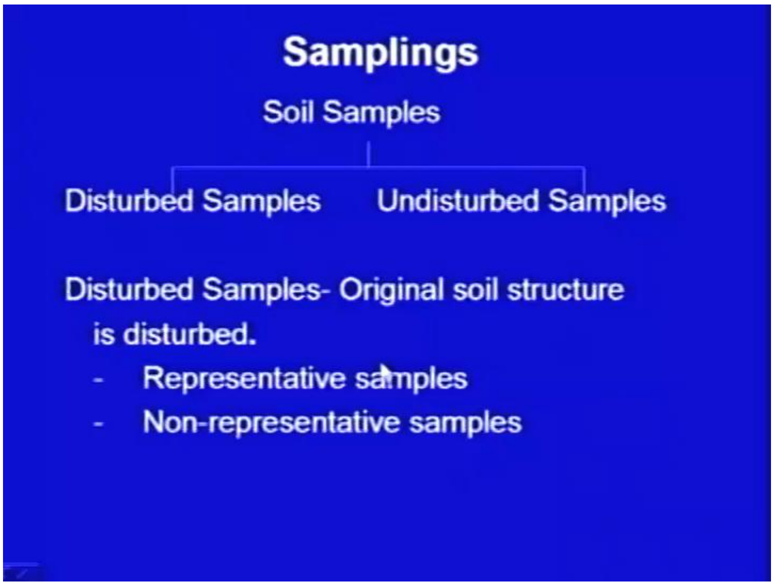

Coming to the sampling, the purpose of the investigation is to take the samples we take the samples from the field and those samples are then tested in the laboratory. The soil samples can be divided into two categories disturbed samples and undisturbed samples, in case of the disturbed samples the original soil structure is disturbed. So, we can have two categories under these representative samples and non-representative sample.

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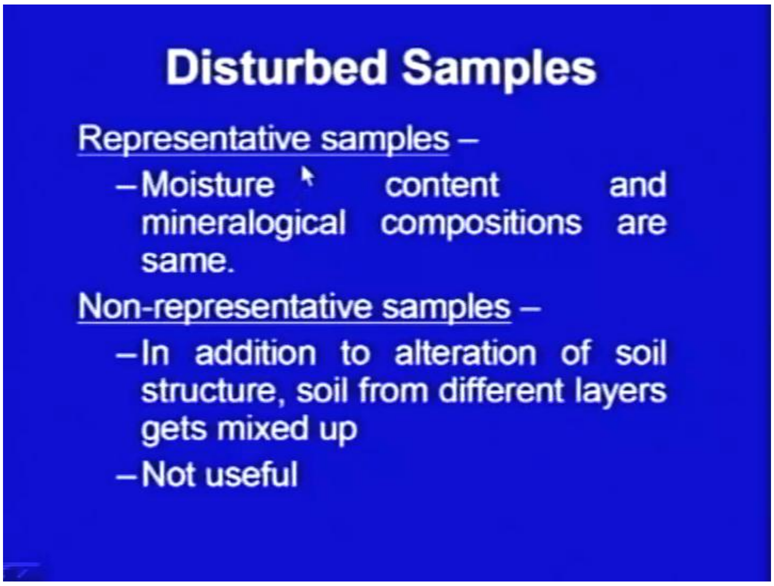

Representative sample is defined as that sample in which moisture content and mineralogical compositions are same in non-representative sample is defined as that sample in which in addition to alteration of soil structure, soil form different layers also gets mixed up. So, as far as our purpose is concern for foundation engineering, this non-representative samples are basically of no use, we use the representative samples for some of the tests.

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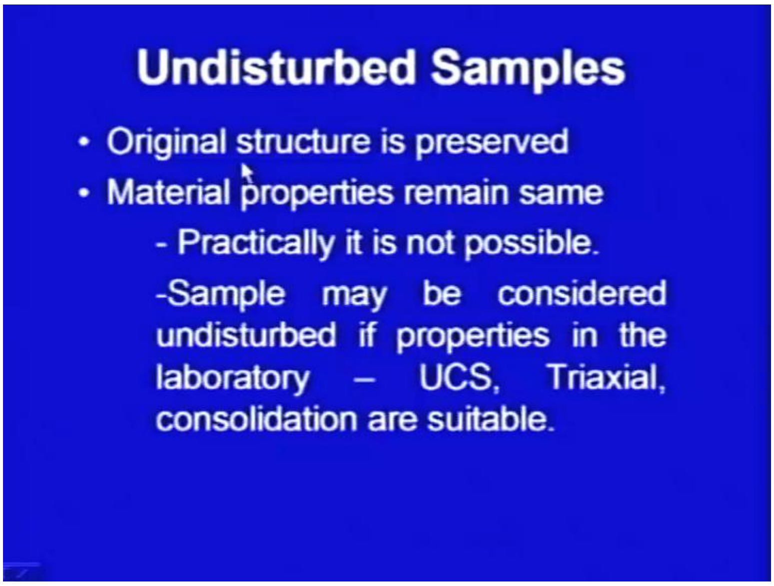

Undisturbed samples is that sample in which original structure of the soil is preserved, the material properties remain constant it remains the same. So, practically it is not possible to take any sample which is undisturbed, whenever you take a sample from there from the field, some disturbance is bound to occur. So, we defined the undisturbed sample in this way, those samples that the samples may be considered undisturbed.

If property is in the laboratory, for example unconfined compressive strength, triaxial strength and consolidation test data they are suitable for the design purpose. So, we will be considering them to be undisturbed samples, but keep in mind some disturbance always occurs there.

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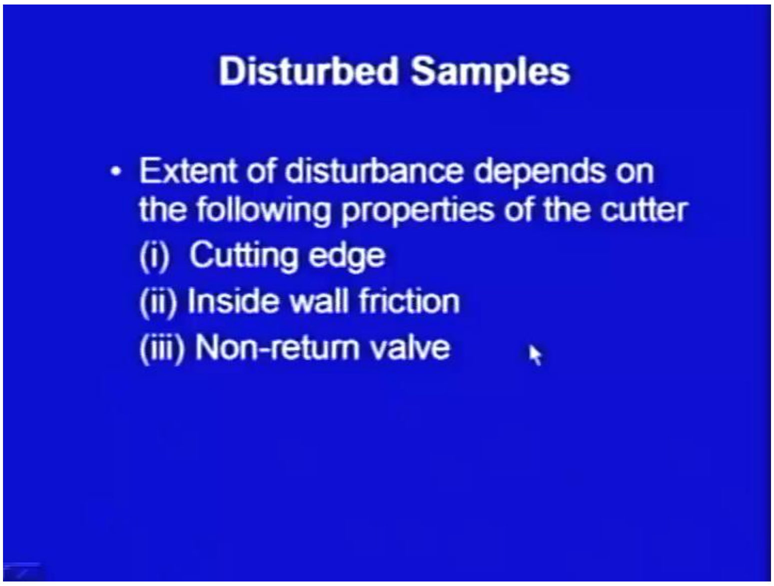

And this disturbance depends on several parameters, the extent of disturbance depends on the following properties of the cutter, the cutting edge inside wall friction and what is the non-return value.

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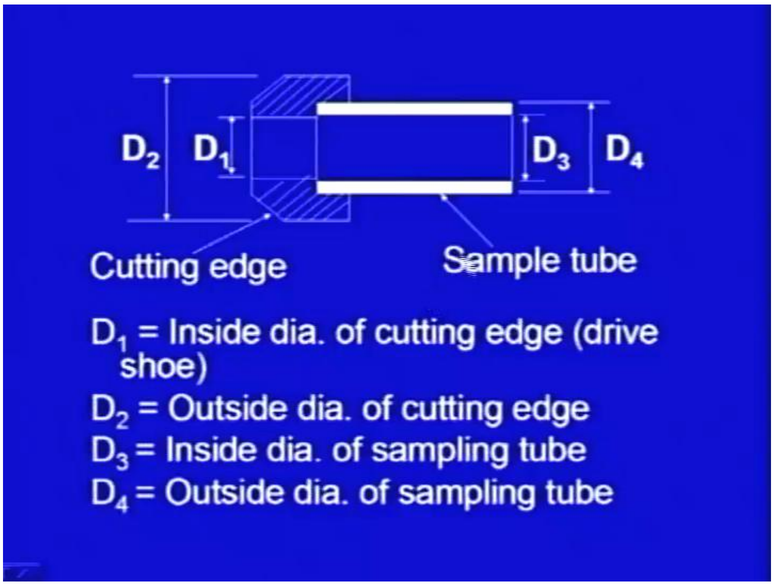

Here I have shown a sampler this is a cutting edge here, this is the sampling tube, D 1 is the inside diameter of the cutting edge, so sample will enter, the soil sample will enter from here towards this sample tube. D 2 this is the outside dia of the cutting edge, so this particular cutting edge this enters the soil first and soil specimen, the soil sample will be collected at this place. D 3 is the inside dia of the sampling tube and D 4 is the outside dia of the sampling tube.

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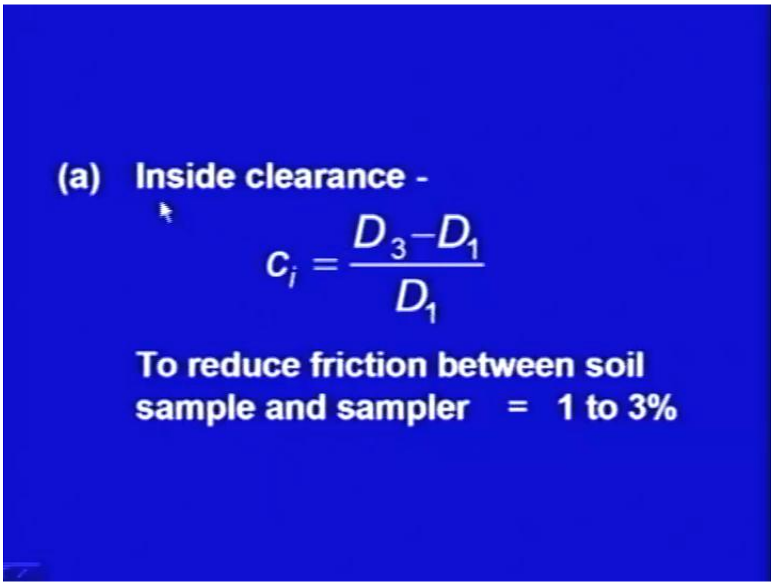

For practical purposes some terms are defined, the first term is inside clearance this is defined as D 3 minus D 1 upon D 1. D 3 as I told you was this inside dia meter of the sample tube and D 1 is inside dia of the cutting edge. So, this value is used to define to explain the friction between the soil sample and the sampler, and for practical purposes to have good results this value should be between 1 to 3 percent.

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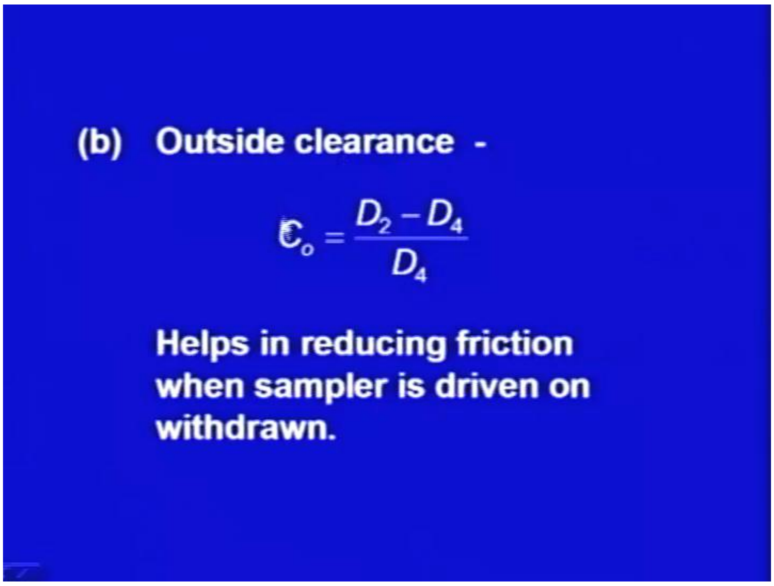

Another term is defined as outside clearance C o, it is defined as D 2 minus D 4 upon D 4, this outside clearance helps in reducing the friction when sampler is driven on or it is withdrawn, this is D 2 diameter and this D 4 diameter. So, this gives you the difference this ratio defines how much friction is there when the sample is been taken or it is been withdrawn.

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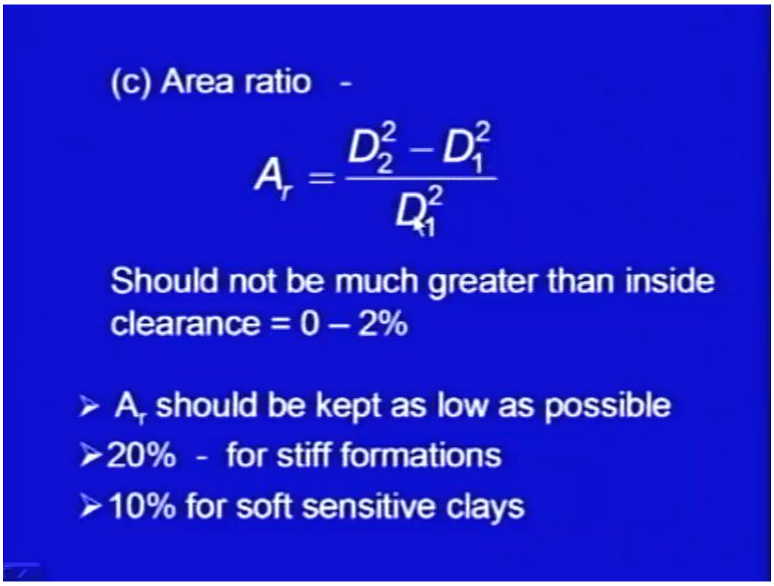

The another term is area ratio D 2 square minus D 1 square upon D 1 square and this should not be much greater than inside clearance, may be it is difference should be 0 to 2 percent. This value should be kept as low as possible for stiff formations around 20 percent and for soft sensitive clays not more than 10 percent.

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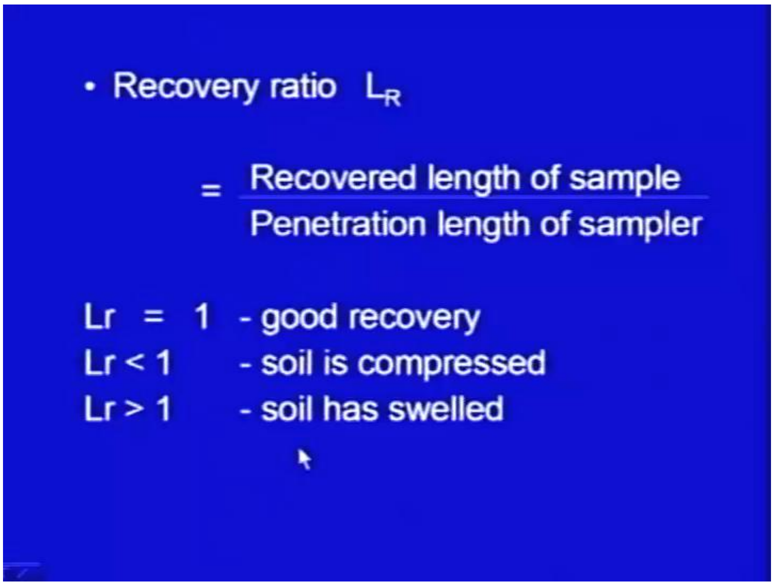

There is another term recovery ratio, it is defined as recovered length of the sample divided by penetration length of the sampler, so if the recovered length is equal to the penetration length, then it is a good recovery. If recovered length is less than penetration length, that means the soil has compressed and the reverse can also occur, if recovered length is more than penetration length, that means soil has swelled.

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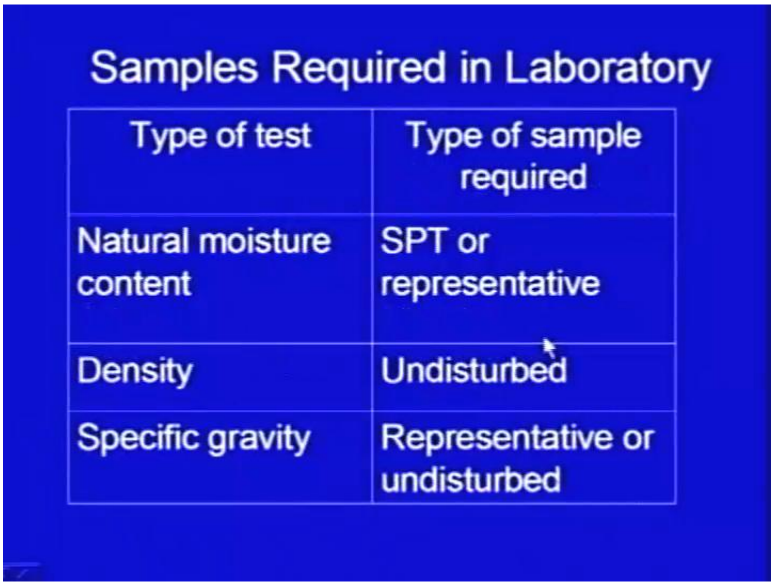

Now, here are some of the samples and listing the type of the test and what is the type of the sample required for that particular test, for computing natural moisture content you can use a sample from the standard penetration test, this we will be defining later on what is SPT. So, SPT sample or representative sample could be used, if we want to get density then the sample should be undisturbed sample, if you want to get specific gravity then a representative sample or undisturbed sample is required.

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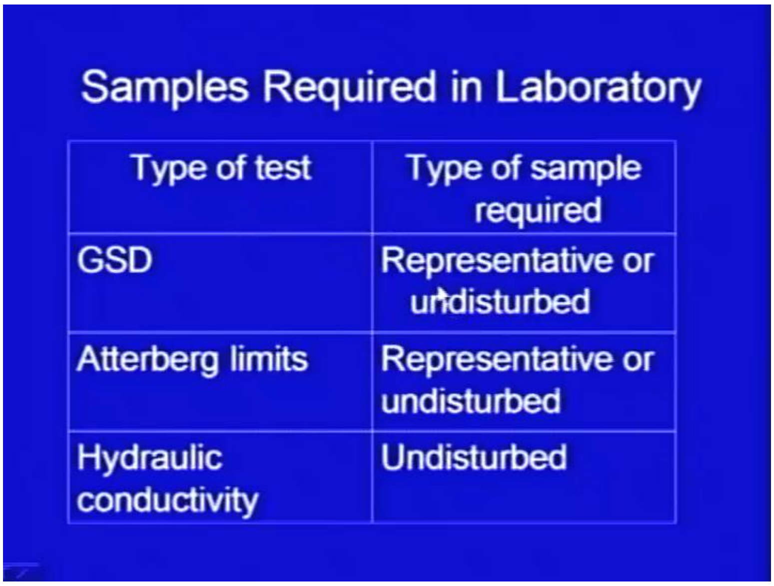

Samples Required in Laboratory

Type of test	Type of sample required
GSD	Representative or undisturbed
Atterberg limits	Representative or undisturbed
Hydraulic conductivity	Undisturbed

For getting grain size distribution curve, we should have a representative sample or undisturbed sample, for getting the atterberg limits, liquid limit, plastic limit we should have representative or undisturbed sample. For getting hydraulic conductivity we should have undisturbed sample.

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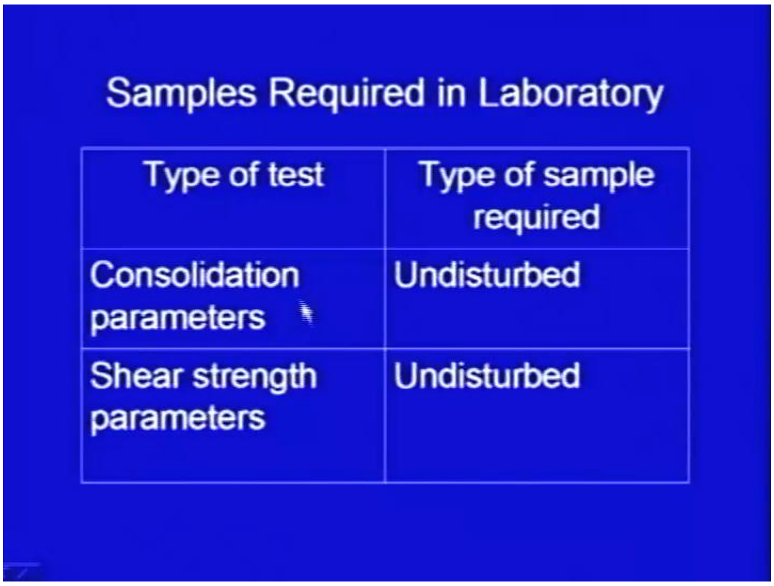

Samples Required in Laboratory

Type of test	Type of sample required
Consolidation parameters	Undisturbed
Shear strength parameters	Undisturbed

For consolidation parameters again undisturbed sample is required and shear strength parameters, because shear strength will vary with the disturbance again undisturbed sample is required.

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Now, let me talk about what should be the depth of exploration, this is the thing which you have to decide when you go, when you plan for the detailed investigation, one basic thing which we have to keep in mind is this is called as significant depth of exploration. That depth which is likely to undergo settlement, means we should know about the strata below the foundation which is causing the settlement and it should be a function of the type of the structure, it will depend on the size, shape of the forting.

And also the way the loaded area, the disposition of the loaded area is taken intensity of loading, soil profile, soil properties and all these things this will be depending.

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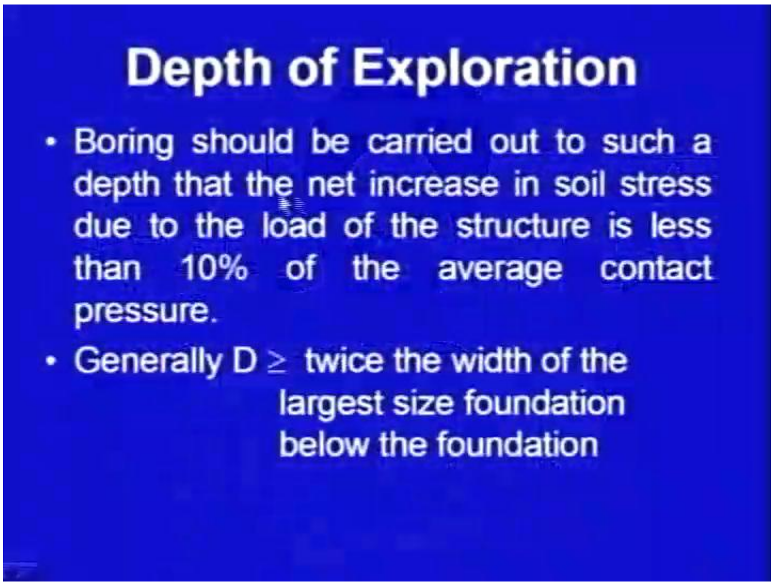

As a rule the boring should be carried out suit to such a depth that the net increase in soil stress due to the load of the structure is less than 10 percent of the average contact pressure, this particular statement we use as a thumb rule. What does, what it means is that various, let us say some contact pressure and as you go deeper and deeper the pressure the incremental pressure, increase in pressure, because of the foundation goes on decreasing.

So, roughly if you go up to that depth where are the increment in pressure is of the order of 10 percent, we assume that that much depth is going to contribute towards the settlement of the structure, so we must go up to that depth. And roughly the depth of exploration is taken as twice the width of largest size foundation below the foundation level. So, what it means is if there is a structure and width is let us say 5 meter, then you should take the exploration at least up to 2 times 5 that is 10 meter depth.

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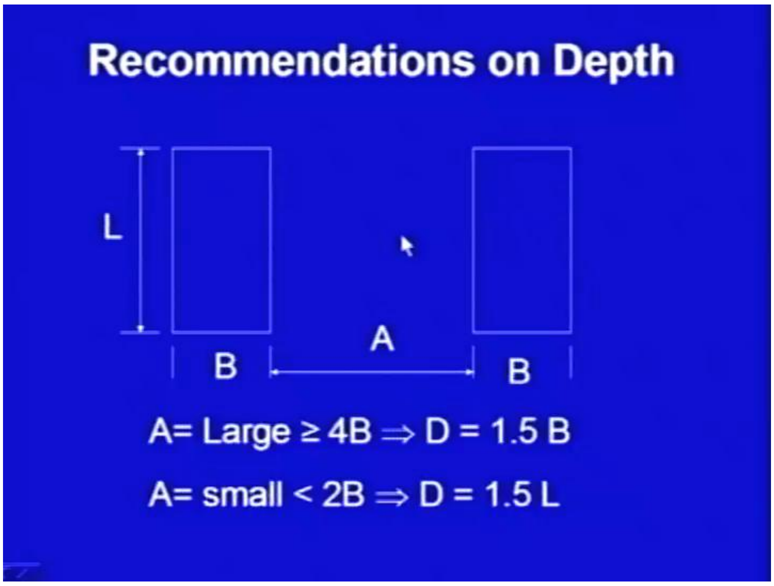

There are some other recommendations on depth, these are two buildings or the loaded areas, I am showing their plans here A is the clear spacing between these two buildings. If A is very large then B you can take 1.5 B, sometimes we take it 1.5 B to 2 B just now I discussed that you should take it up to 2 B, there is a as such no hard and fast rules, so it is 1.5 to 2 times B is the depth of exploration which you should take.

So, here A is very large, this clear spacing is very large that means, they are not these buildings are not interfering with each other, so you can treat them individually and you can go up to 1.5 B to 2 B. But, if A is a small, if A is small if they are closed to each other, then they are going to interfere with each other, then you have to have the exploration up to more depth, so it is recommended that at least 1.5 times the larger dimension L you should go.

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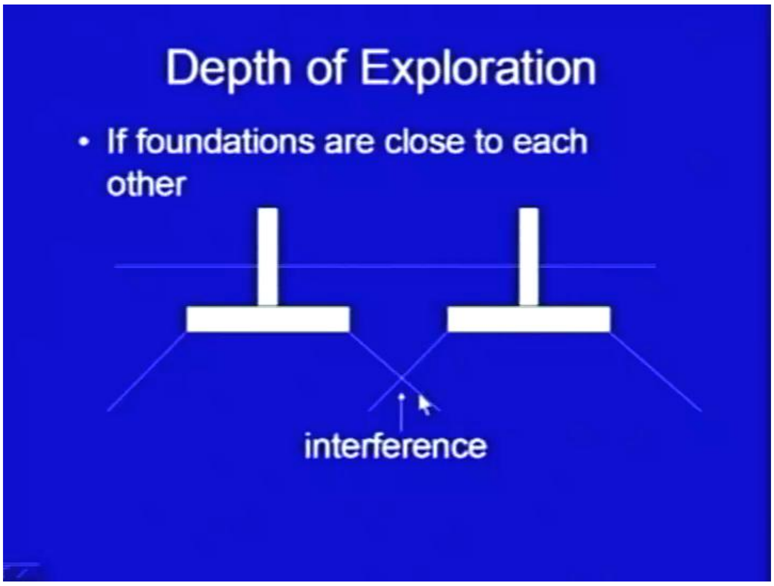

Here we have shown these two foundations, if they are closed to each other this is the stress of deviation, the stress is being dispersed in this way, so somewhere here the interference is start, so in this case you should have much more data available up to much more depth.

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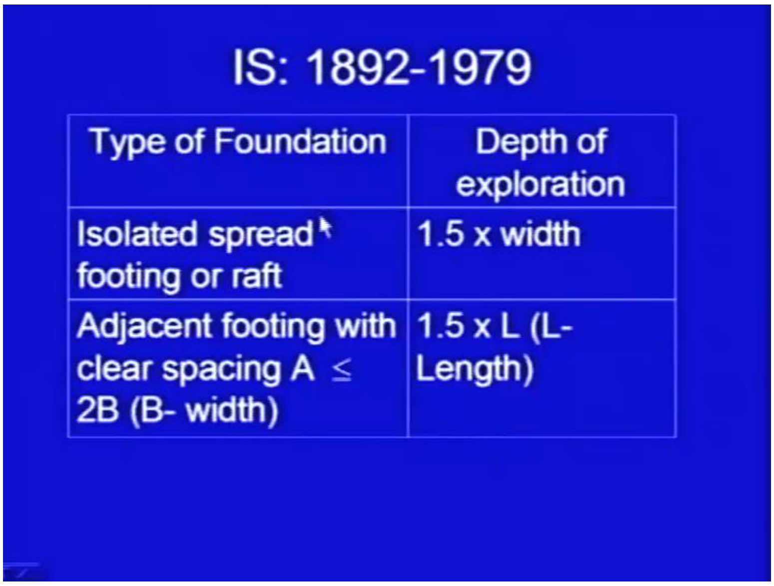

Now, these are the recommendations by the code, if isolated spread footing or raft is being used, the code specifies that the depth of exploration should be at least 1.5 times width. If there are adjacent footing with clear spacing A as I just discussed and if A is less than 2 B, then the depth of exploration should be 1.5 times L, L is the larger dimension of the building.

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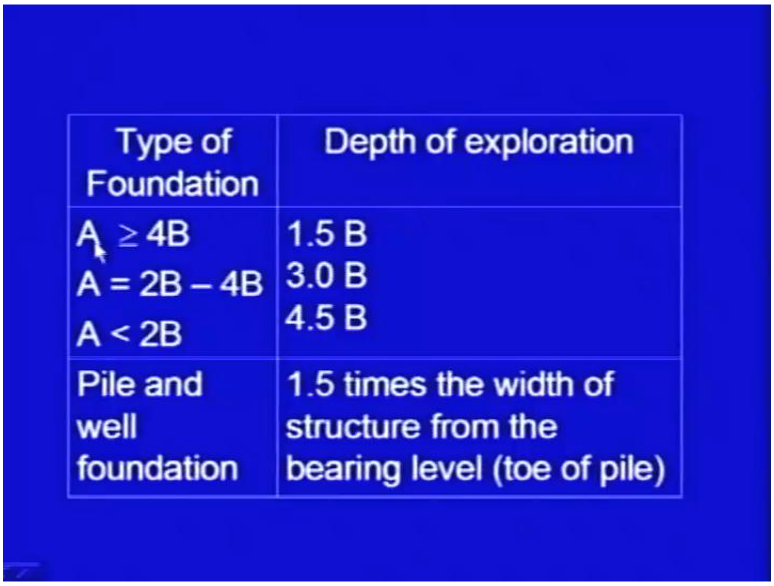

If the clear spacing is more than 4 B minimum depth of exploration is 1.5 B, if it is between 2 B and four B the minimum depth of exploration is 3 B, if A is less than 2 B the depth of exploration is 4.5 B. Again please remember these are only the guidelines, you have to take the decisions as per the requirement at that particular site as per the your preliminary investigations, what kind of the strata are available, based on that you have to take the decisions.

So, next one is pile and well foundation for this 1.5 times the width of the structure from the bearing level, bearing level means toe of the pile. From the toe of the pile you have to go 1.5 times deeper times the width of the structure, you have to go that much deep below the bearing level.

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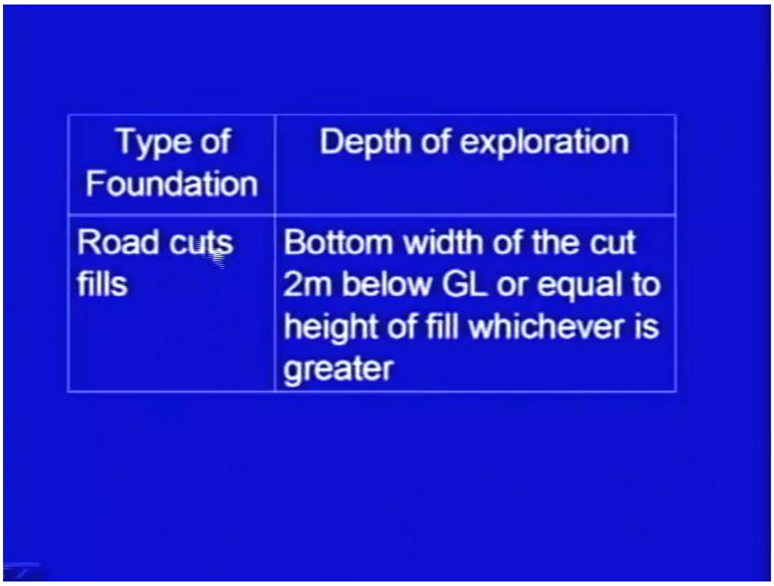

If they are road cuts and fills, then bottom width of the cut 2 meter below the ground level or equal to height of the fill whichever is greater that should be taken as the depth of the exploration. So, this was the discussion about the exploration depth and as I told you these are only the guidelines and there is no specific answer, there is no fixed answer the decision will depend from site to site and it will vary from site to site.

The ground water observations are also very important for foundation engineering problems, what happens is that the, when the water table is high the sub-soil strata become saturated.

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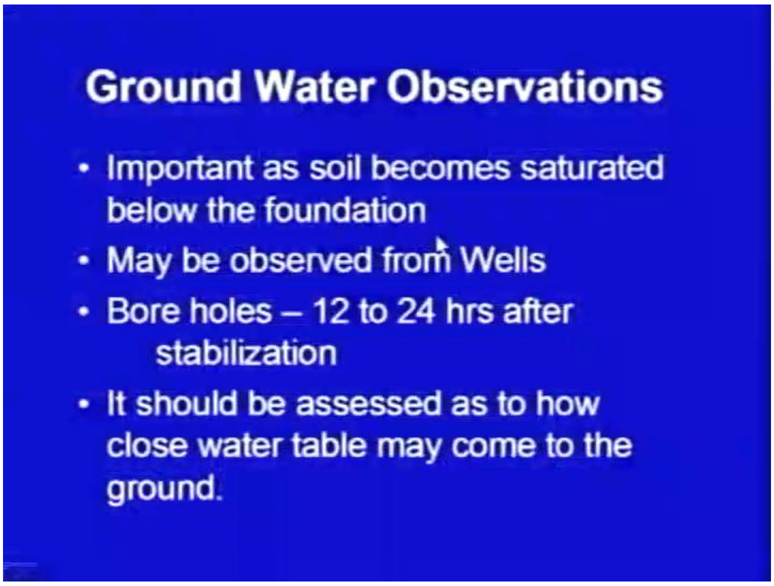

And it may enhance the settlements, secondly it may also reduce the shear strength, so this is one of the objective of the soil exploration program, that we should know what is the kind of the water table depth, how much water table depth is there you can get it from the wells. Or you can also get it from the bore holes which are advanced during the exploration program and for that at least 12 to 24 hours time should be given for water table to stabilize.

After the water table stabilizes, then the water table depth should be lesser and it should be assessed as how close this water table may come to the ground or it may come closer to the foundation, so that is the thing which we should assess from the soil exploration, field exploration program.

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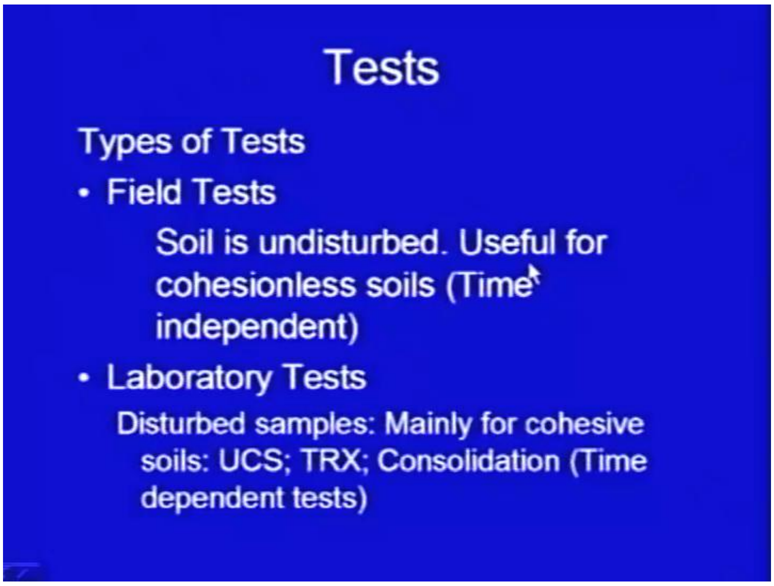

Now, once we have decided our, we have planned the investigations let me come to the tests, what are the different tests and how they are conducted, types of tests. I divide them into two categories broadly two categories, one is the field test and second one are the laboratory tests, the field tests they are more useful in case of the cohesionless soils. Because, in case of cohesionless soils it is very difficult or rather impossible to get a sample which is having least amount of disturbance as we want, so we have no other alternative.

Then to test the cohesionless soils, for example sands in the field itself, whereas the laboratory test will be useful for the cohesive soils, because in case cohesive soils the disturbance is not that large, you can get the representative samples. And those samples then can be tested in the laboratory, the tests are for example, unconfined compression test, triaxial test and consolidation test.

The consolidation test it is a time dependent test and it can be conveniently conducted on the laboratories test, in the laboratory in the field it may not be feasible, so these are the two main categories of the tests field test and laboratory test. Let me come to the field test, first the different test which we are going to discuss in this category of the penetration tests.

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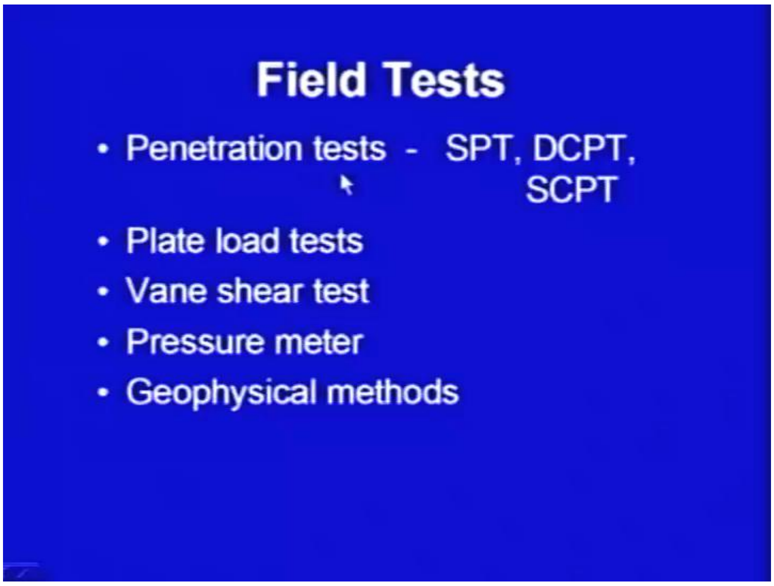

Here will be discussing standard penetration test, dynamic cone penetration test, static cone penetration test, then plate load test, vane shear test, pressure meter test and then, geophysical methods.

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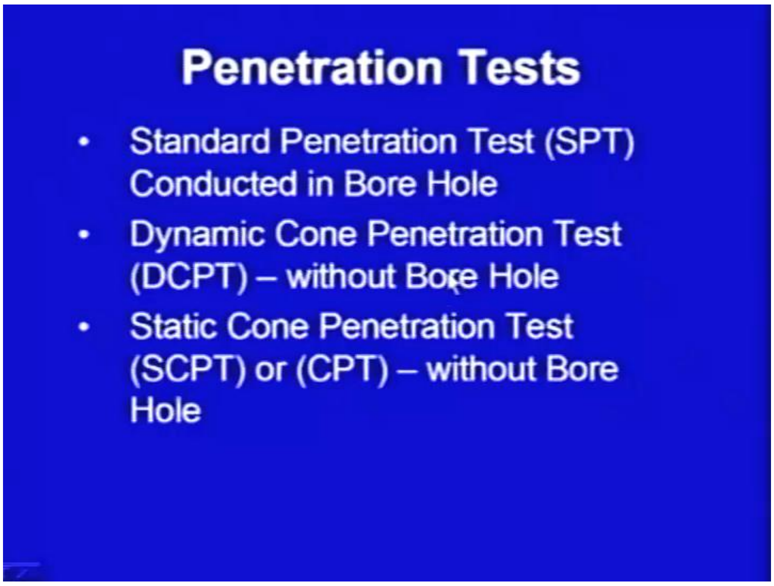

The penetration tests under this category we will be discussing Standard Penetration Test, SPT is the short form and this test is conducted in bore hole, a bore hold is needed for this test and we take the sample also. So, you can get the sample of the soil and you get field test values results the Dynamic Cone Penetration test DCPT radius conducted without bore hole, you cannot take the samples the sample is not soil, sample is not available in this case, but the penetration values are available.

Static Cone Penetration test SCPT or simply called as CPT Cone Penetration Test, it is also done without bore hole, so here also the soil sample is not available. So, friends today we have started the soil exploration which is a very important part of the foundation engineering, we have discussed about the methods of borings; we have discussed about how to plan the depth, what are the different tests.

And in the next lecture I am going to discuss in detail the penetration test, I will be starting with the standard penetration test next time.

Thank you.