Advanced Foundation Engineering
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Lecture - 5
Shallow Foundation: Introduction

Hello. Today, I will start my second module, that is, on shallow foundation. Before I start on the shallow foundation, I will discuss about two other geophysical explorations, that is, the part of our previous module that is, soil exploration. First, I will finish that part, then I will start this shallow foundation section.

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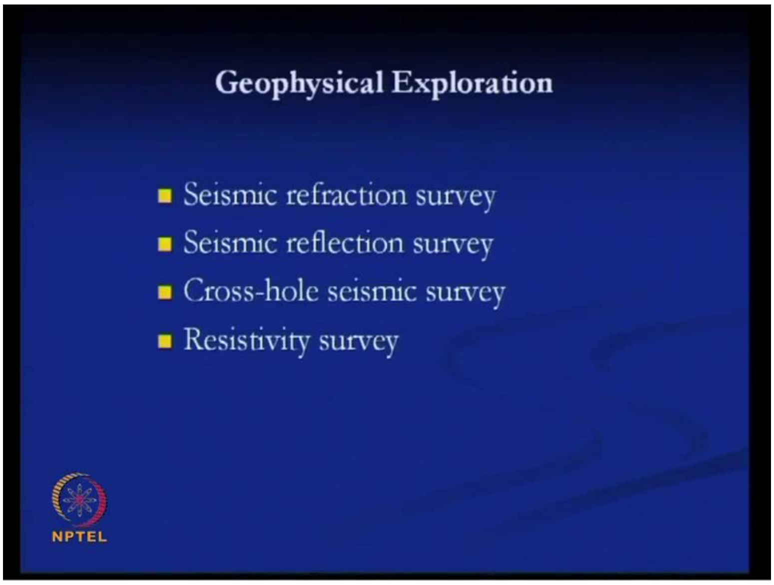

In the last lecture, I have discussed about the geophysical exploration; and I have discussed about the seismic refraction survey and seismic reflection survey. Now today, I will discuss about the two other geophysical exploration methods that is cross-hole seismic survey, and then resistivity survey.

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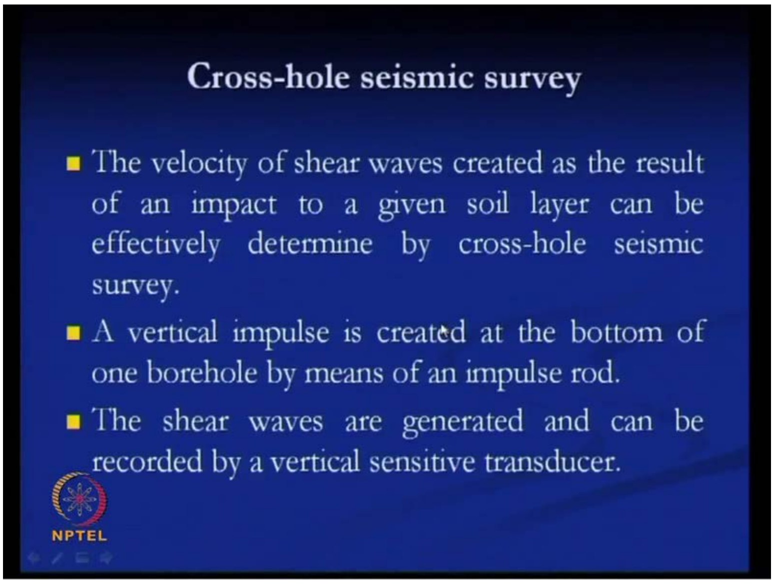

In the last class, I have discussed that we can use the seismic refraction survey to determine the velocity of the seismic wave that is passing through different soil layers; and we can determine the thickness of the soil layer. But the condition is that in the seismic refraction survey that velocity of each layer should increase as we go in the higher depth. So if there is any layer, which is not following this pattern; that means, the velocity of a particular layer, which is not greater than the velocity of the particular shear of seismic wave within that layer; that means that layer velocity is less than the velocity of the above layers.

Then it will be very difficult to determine the properties for that particular layer, because then we cannot determine this property if that condition that means, the velocity of the wave in the layer will increase if we go in the higher depth. So, for this limitation, if any particular layer is present, whose velocity is not greater than the velocity of the previous layer, then we will go for the seismic cross-hole survey.

Now, in this seismic cross-hole survey, the velocity of the shear wave created as the result of an impact to a given soil layer that can be determined by seismic cross-hole survey.

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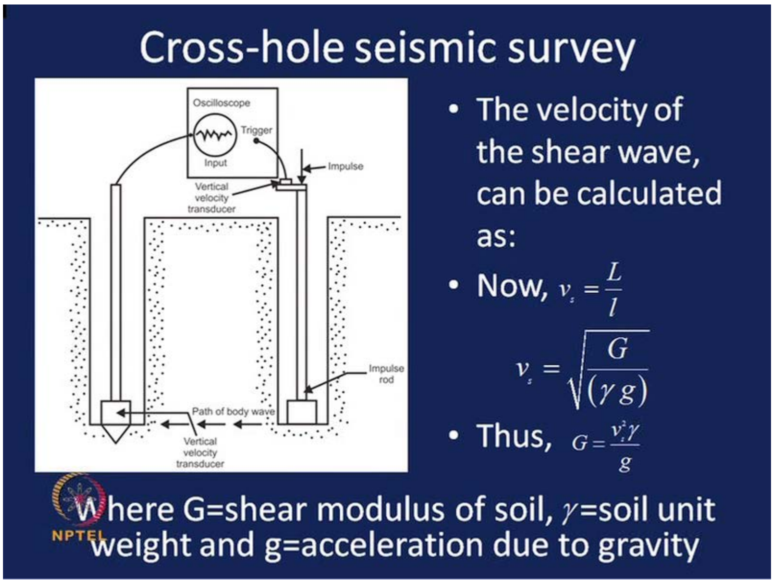

Now, suppose in this particular seismic cross-hole survey, we need the boreholes, at least two boreholes, where this depth of the boreholes - we can determine based on the position, where we want to determine the soil properties or the velocity of the shear wave; that means, we have to go for that depth and then we can place these two boreholes here; we can place this vertical transducer by which we can measure this wave. And, this is another borehole, where we can create the shear wave. So, this vertical impulse is created at the bottom of the one borehole by means of an impulse load. So, here by this impulse rod or impulse load, we can create a vertical impulse for a particular borehole; that means, this will generate a shear wave.

Once we go for this impulse, the shear waves (Refer Slide Time: 04:12) are generated and can be recorded by vertical sensitive transducer; that means, here (Refer Slide Time: 04:21) two boreholes are there. So, here we can by using the impulse rod, we can create one vertical impulse wave and that will generate the shear wave. And, in another borehole, which is at a distance say L; from this point to this point, this distance is L, where we can place a vertical velocity transducer, which can measure or record this shear wave. So, here first, we create one shear wave by using a vertical impulse and this transducer can record the shear wave. So, the time… This is the total system. So, the time required to travel this shear wave from this point to this point - that we can record.

Suppose if the distance between (Refer Slide Time: 05:13) this point or this vertical impulse point, where the shear wave is generated and this point, where the wave is recorded, then this distance is say L. So, if we can measure the time required to travel the wave from this source point to this receiver point, then we can determine the velocity of this shear wave by using this expression; that means, the velocity of the shear wave will be L by t. So, in this way, we can determine the shear wave velocity for any layer or within the soil; that means, after that required depth, we have to… The depth of borehole will be that particular depth. And, here at the bottom of this borehole, we have to place this transducer; and, by the use of this impulse rod, we can create shear wave. So, at any point, we can determine the shear wave velocity within that particular layer.

Here (Refer Slide Time: 06:21) no such condition is there; that means the shear wave… that means here directly we can measure the velocity. So, once we get this shear wave velocity, then by using this expression… This is the shear wave velocity expression, that is, G divided by gamma by g, where G is the shear modulus of the soil; gamma is the soil unit weight; and, g is the acceleration due to gravity. Once we know this unit weight of the soil and G value and we know this velocity, by using this expression, we can determine the shear modulus of that soil layer. So, by using this expression, we know this velocity that we can calculate from this length and time if we know this length and time; and, this is the unit weight of the soil; and, g is the acceleration due to gravity. So, we can determine the shear modulus of the soil. So, in this wave, we can determine the shear modulus of any soil layer at any particular depth from the ground surface by using this technique.

Next one is the resistivity survey. First one is this cross-hole seismic survey. We can determine the shear modulus of the soil and the velocity of the shear wave within that particular layer. Now, next one that another geophysical survey, where we can use the electrical resistivity in this expression; this electrical resistivity is a rho, will be RA divided by L; where, I is the electrical resistance of a particular material; and then, A is the cross section area of that material; and, L is the length of the material. So, if we know this R, A, L, then we can determine the electrical resistivity of that particular material. With this technique or this principle, we can use here also to get the properties of the soil or the thickness of the soil.

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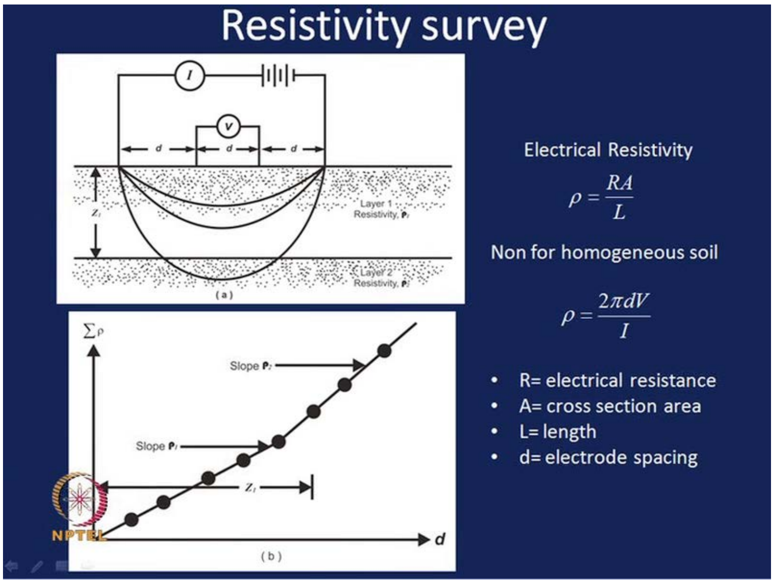

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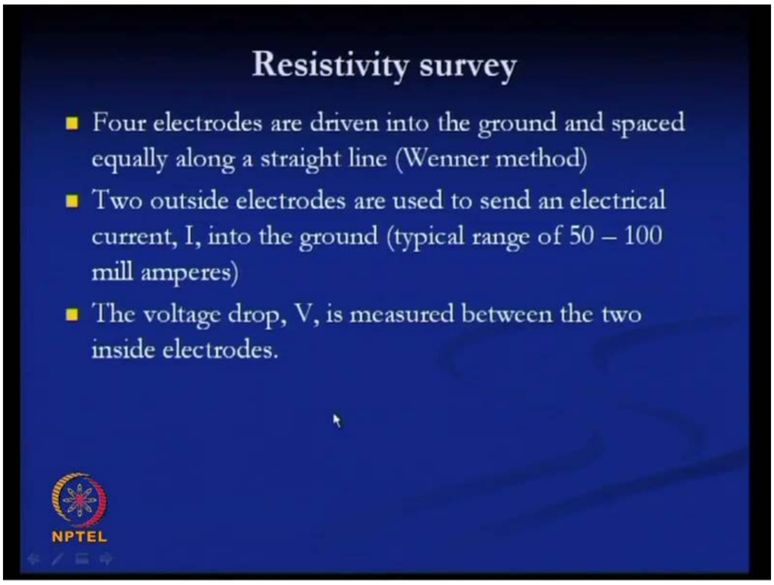

Now, this resistivity surveys - how we can conduct the survey? These four electrodes are driven into the ground and spaced equally along a straight line. This arrangement is called Wenner method. Here these (Refer Slide Time: 09:00) are the four electrodes; this is 1, 2, 3 and 4. These four electrodes are driven into the soil layer in a straight line with equal space. Suppose this equal space… that means, this d is the distance between the electrodes. Here we can write this is the electrode spacing or the spacing between the two electrodes. So, we have four electrodes we can driven in the soil. And then, the (Refer slide Time: 09:32) two outside electrodes are used to send an electrical current I into the ground; typical range of this current - 50 to 100 milli amperes. So, by using this (Refer Slide Time: 09:43) outside two electrodes, the current I is passing through this ground. So, this current is passing through the ground.

And, the corresponding voltage drop V (Refer Slide Time: 10:00) is measured between the two inside electrodes. Now, after passing the current through this (Refer Slide Time: 10:08) soil layer, then the corresponding voltage drop V is measured by using these two inside electrodes. So now, we know what is the value of I, the current that is passing through the soil layer by using the outside two electrodes; and, the corresponding voltage drop is measured by two inside electrodes. Now, this d is the spacing between the electrodes So, if we know these properties, then we can measure, for a homogeneous soil, this resistivity value rho will be 2 pi d V by I. So, here we can measure the electrical resistivity of a homogeneous soil.

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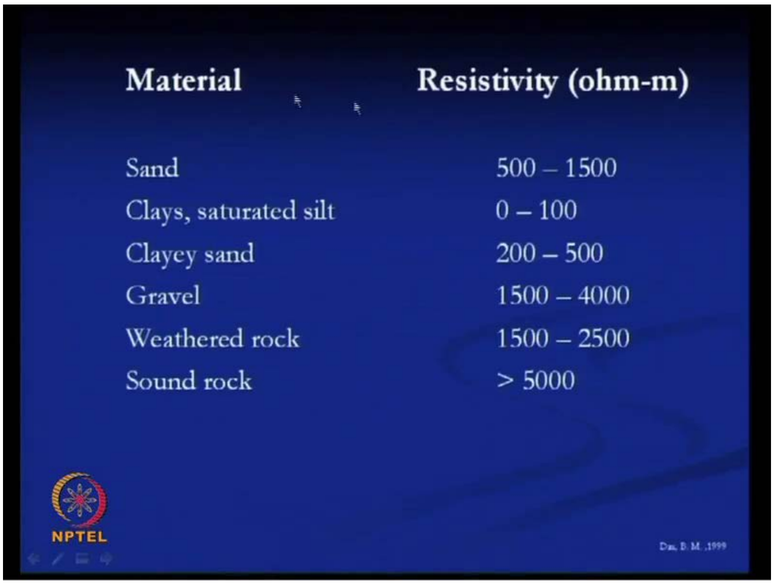

Now, if we use this chart, these are the different soil materials or different soil has its own resistivity range. If we know the range of the resistivity of that particular soil material, then we can identify which type of soil it is. For the sand, this resistivity range is 500 to 1500 ohm meter; and, for clay or saturated silt, this range is 0 to 100; for clayey sand, this range is 200 to 500; for gravel, this range is 1500 to 4000; for weathered rock, this range is 1500 to 2500; and, for sound rock, this value is greater than 5000. So, if we know the range, from this resistivity survey, we can measure the resistivity for the homogeneous soil layer. Then we can determine or we can identify that, what type of soil it is.

Now, this is (Refer Slide Time: 12:05) for homogeneous soil. But for most of the cases, this soil is not homogeneous. So, in that case, how we will determine the thickness of each soil layer and the resistivity of this each soil layer? We can explain in this way that, for that particular case, if the soil is not homogeneous, then we can change this spacing between the electrodes. This is this is the d. So, we can change this d value, because we will still place these four electrodes in a straight line, but these are equal space. But we can change the spacing here. So, if we change the spacing for these different points, then we can determine the resistivity for that particular spacing. So, once we get the resistivity for that particular spacing, then we can plot this diagram, where this is the distance of the electrode; this x-axis represents the distance between the electrodes or spacing between the electrodes; and, this y-axis is the summation of the resistivity. So, we can plot. So, once we get the resistivity for this particular spacing, then we can sum all the resistivity that we are calculating; then, we will plot this graph. So, once this is the value for a particular d, then corresponding summation of the resistivity you can plot here. So, ultimately, we will get this type of plot.

From here (Refer Slide Time: 13:48) we can see from this plot that there is a junction for… or change of slope of this plot or this line. So, this change of slope, this particular point indicates a corresponding distance d; that indicates the thickness of the first layer. So, if this is the first layer, whose resistivity is say rho 1 and this is the second layer, whose resistivity is rho 2; then this point where this slope is changing for this particular graph, the corresponding d value - that will give the thickness of the first layer. And, the slope of each straight portion - that slope will give the resistivity for each layer. So, for different d, we can plot this graph corresponding the slope of each layer; or, each straight portion will give the resistivity of each layer. So, this slope will give the resistivity of the first layer; then, this slope will give the resistivity of the second layer. And, the point, where these two slopes… or the slope is changing, then corresponding d will give the thickness of the first layer. So, these are the four different seismic geophysical expressions. Here this is (Refer Slide Time: 15:33) the table.

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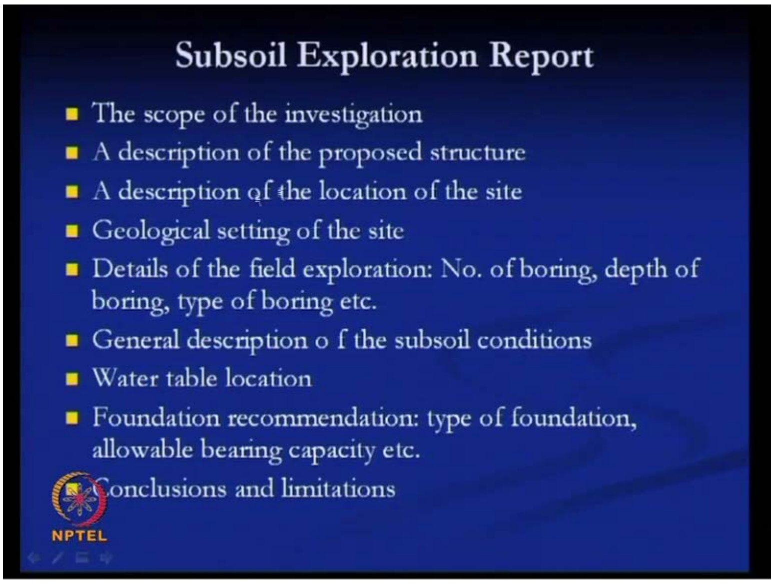

We have done the all the possible methods by which we can determine the soil properties: the thickness of the soil layer and the depth of that soil layer, where we have formed the ground surface; then, the location of the ground water table from the soil. And, we have done the laboratory test also to determine that the samples are those we have collected from the field; that we can test in the laboratory to get the different properties. As I have already discussed that, the shear strength parameters or properties and the consolidation properties - those are the most important engineering properties, because for any design of foundation, this shear strength and the settlement, which is related to the consolidation of the soil, are the most two important (( )) criteria of the design. So, shear strength parameter of the soil are the most two important (( )) of the design. So, shear strength parameters have been C 5; and, the consolidation property, which is related to the permeability of the soil - these properties are the most important engineering properties of the soil. As I have mentioned that, to determine these important engineering properties, we have to always collect the undisturbed sample to determine these properties, because these properties are very important.

And, other engineering properties also we can determine; where, some cases we can use the representative although the undisturbed; but representative soil sample - I have discussed, where we have to use those representative soil sample; under what condition, what type of laboratory test, would determine what type of material properties of the soil or engineering properties of the soil. So, those things we have discussed. Now, once we get all the properties, then we have done the soil exploration (( )) and then how we will prepare the report? What are the components of a soil exploration report? That part is that this soil exploration report - this is… The (Refer Slide Time: 17:41) first we have to write the scope of the investigations. What is the scope of the investigation for a particular site? Then, this description of the proposed structure. So, what will be the type of structures, will be constructed on that particular site? That description should also be incorporated in the report.

Then, the (Refer Slide Time: 18:03) description of the location of the site – where the site is located? So, that description also we have to give. Then, the geological setting of the site beyond the geological condition of that site; then, details of the field exploration. So, what will be the detail of the field exploration that we have to include in the report? That means the number of boring or the borehole, the depth of the boring, and the type of boring – which type of boring we will use; and, the number of borehole; and, the location of the boreholes, where we will place the borehole. Then in the map, we have to indicate the position of these boreholes in the depth of boreholes.

Then, the general description of the subsoil condition - once we get this (Refer Slide Time: 18:49) data; what is the general description of the subsoil condition. And then, the location of the water table - that we have to also include in the report; then, foundation recommendation - the type of foundation; what type of foundation? Either we will go for the shallow foundation or we will go for the deep foundation. If it is a shallow foundation, what type of foundation, either it is mat foundation or isolated footing? So, those things all will go for the combine footing. Those things we have to recommend here in the report. And then, the allowable bearing capacity of the soil - this is very important that what is the allowable bearing capacity; that means the load carrying capacity of the soil; that is, that of how much load will be allowed in that particular soil? So, two criteria… These basic two conditions that is, the bearing capacity condition and the settlement condition. So, this allowable bearing capacity - what is the allowable bearing capacity? Those things I will discuss in the next module.

Then, the conclusion and the (Refer Slide Time: 19:47) limitation - what are the limitation of these exploration process? And, what is the conclusion? Then, those things we will look. So, this is the complete report components that we have to include in our report.

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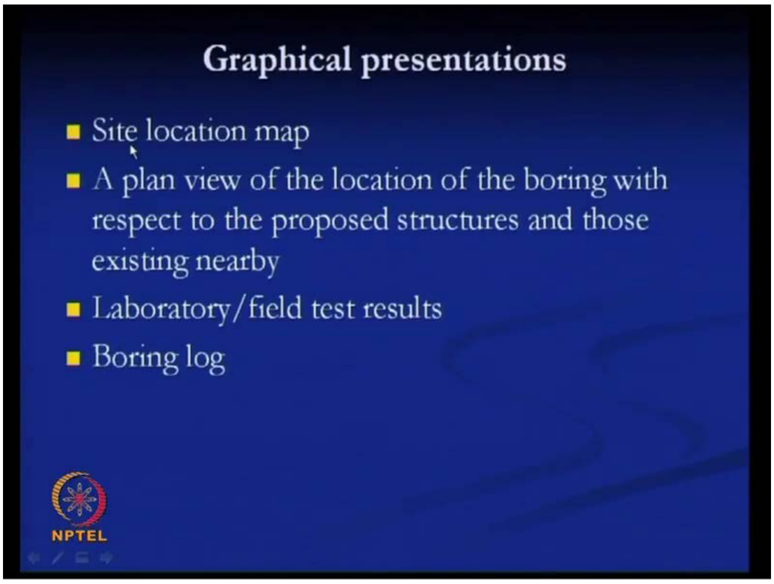

Then, the graphical representation - these are the… Then, with this report, we have to produce some graphical representation also; what are the different components. And, this is the site location map; that means, site map - we have to include in the report. Then, the plan view of the location of the boring with respect to the proposed structures and those existing nearby – where the proposed structure plan; and then, the corresponding boring location we have to show; and then the existing structure - if there is any existing structure also, then the position of this existing structure also have to be mention in that report. Then, the laboratory and field test results - that we have to report. And then, the boring log - now, this boring log is also important.

Boring log means – suppose this is a particular boring log, where we have to indicate the depth wise starting from the ground surface. So, what are the different types of soil? What is the classification of the soil if there is N value and if SPT we are conducting? We have noticed the N value at different waves. What is the description of the soil type? Suppose this is the bore log example 1. This is the description of N of the strata; then, the R L - the reduced level of that particular strata; then, the legend; then, the depth of this particular soil; then, the samples, where this representative or undisturbed… R means the representative and U is the undisturbed; N is the S P T value; q u is the load carrying capacity or ultimate load carrying capacity of the soil; remarks over the position of the water table. Those things we have to mention in that borehole.

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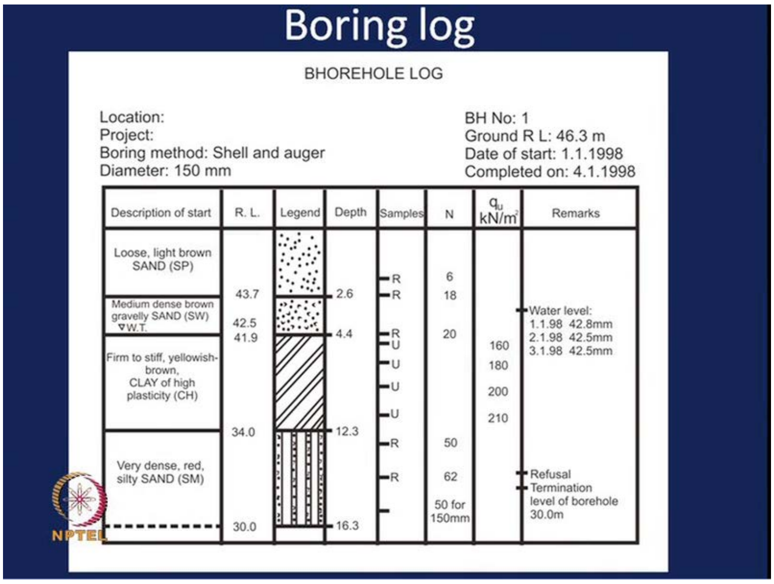

Particular to this borehole, this is the loose light brown sand; the classification is s p; that means this sand with fully gridded. And, this is R L position of this particular layer, is 43.7 meter. Then, this is the legend; the depth is 2.6 meter below the ground surface.

Here (Refer Slide Time: 22:17) with the soil sample, that is, collective; that is, representative. And, the N value for this level is 18 and 16. And, this is the ultimate load carrying capacity. This is 160 kilo Newton per meter square. And then, what is the position of the water table? Then, what is the diffuser of this N value, is observed. Then, all these things we have to mention in that particular borehole. So, this is the different soil strata description basically we are presenting in this form. So, again, U is the undisturbed; and R is the representative soil. So, this is the borehole. So, these all components we have to include in a soil report. So, once this report is finalized, then we have to submit this report in the design office, so that the proper foundation can be designed.

Now, the next part that I will start is the shallow foundation (Refer Slide Time: 23:24). Up to this, we have done the soil exploration part. Now, we know the different components of the engineering properties of the soil; then, the different soil strata thickness; then, the location of the water table; what is the allowable bearing capacity or the load bearing capacity of the soil. So, roughly, these things we know. Now, based on that, we will design our foundation. So, now for the design of foundation, either what type of foundation we will choose; either we go for the shallow foundation or the deep foundation. Then, those things we will discuss here. Once we get this soil exploration report, then based on that, we will go for this design part.

Now, another thing here in the soil exploration part - this plate load test is also another field test that is conducted in the field to get the load carrying capacity of the soil. But this plate load test description - I will cover in this shallow foundation part in this module 2.

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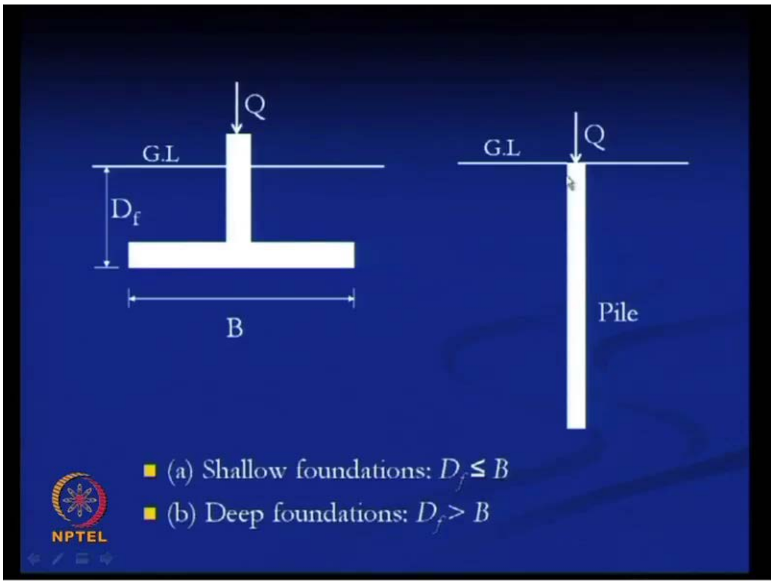

Shallow foundation means… What is the shallow foundation? This is typically two different types of foundation: one is this, is the shallow foundation; and, this is the pile or the deep foundation. Now, the definition of the shallow foundation is, suppose this is the width of the foundation B and D f is the depth of the foundation. In the shallow foundation is, if D f is less than equal to B - width of the foundation, then this is called the shallow foundation. If D f is greater than the B, then this is called the deep foundation. In few cases, if D f is also equal to 3 to 4 B, then it is also called as shallow foundation. Now, these are the different components; this is the width and the shallow foundations; this is the pile foundation; this is the deep foundation. Here this load is transferred to this pile for a hard strata; or, this can give the… The resistance is coming by the frictional resistance and the bearing resistance.

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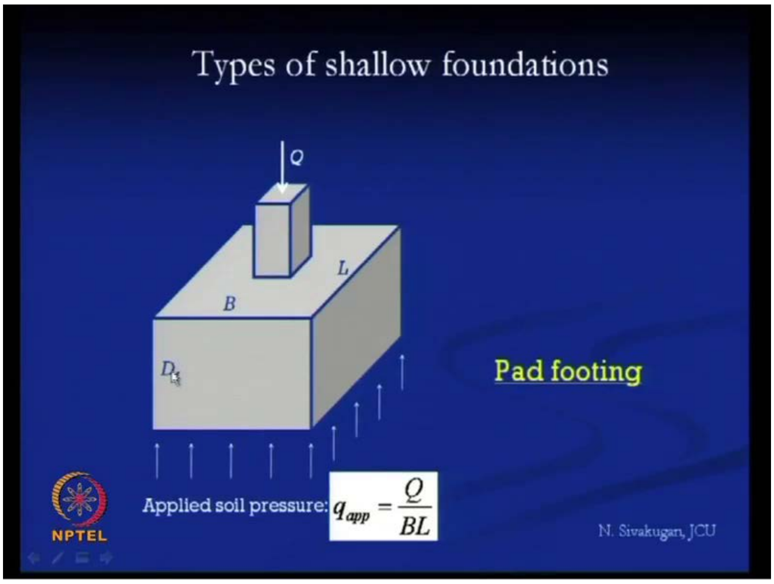

Now, these are the type of shallow foundations. This is the column and this is the particular foundation, where B is the width of the foundation; L is the length of the foundation; and, D f is the depth of the foundation. This is the applied soil pressure, which is basically Q by B into L. Now, if it is the rectangular footing, then this is B L; if it is a square footing, then B will be equal to L; then, this value will be Q divided by B square. So, this is the pad footing or the spread footing, where either rectangular or square.

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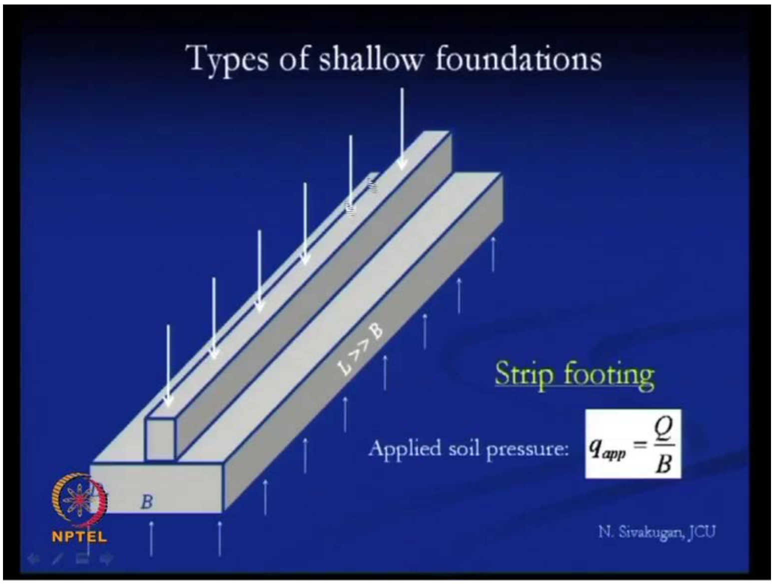

The next one is the strip footing, where the length of this footing is much greater than the width of the footing. This is the particular wall, which load is acting here Q; and, this is the depth of the foundation - B; and then, applied soil pressure – we can write here Q by B. Here this is… If the load is kilo Newton, then B is meter; then, this Q will be kilo Newton per meter. But in this previous (Refer Slide Time: 27:11) case, if load is kilo Newton and this B, L is in meter, then this will be kilo Newton per meter square. So, this is the strip footing, where L is much greater than the B.

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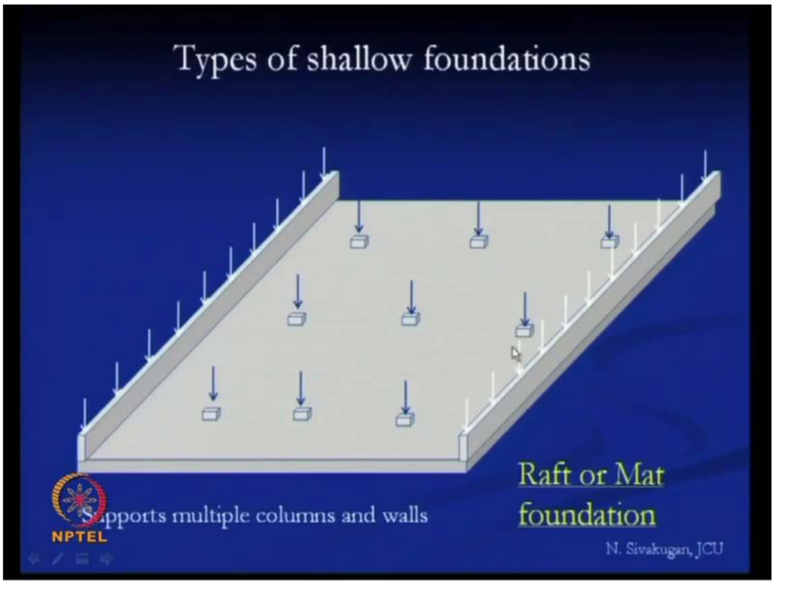

The next one is another type of shallow foundation, which is raft or mat foundation; where, this is the isolated…; this is the column; or this is multiple column and this is the wall of the structure. So, all this combined thing is called the mat foundation or the raft foundation; where, this is the column position; and, this is the total foundation system. This is where these multiple columns and wall system. So, this type of shallow foundation is called raft or mat foundation.

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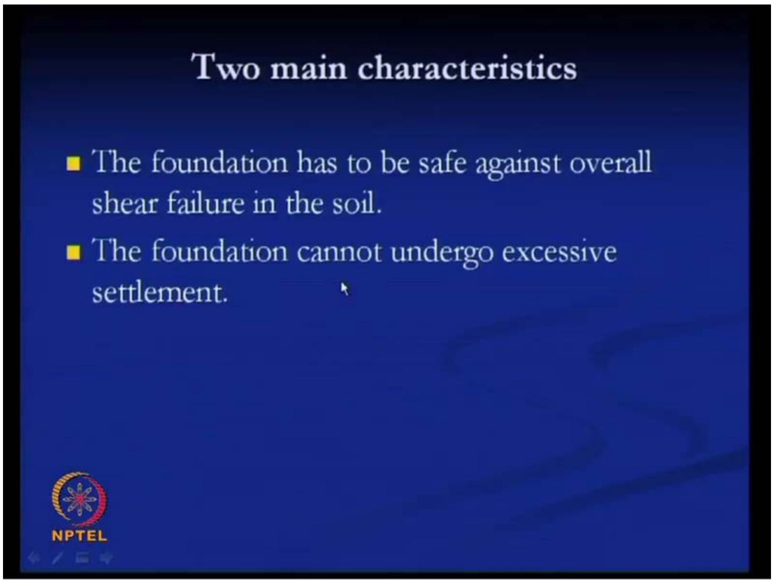

Now, when we design particular foundation, then these are the two main characteristics; or, we you can say these are the two design criteria that we have to always follow. Then the foundation has to be safe against overall shear failure in the soil; and, the foundation cannot undergo excessive settlement. So, that means this first criterion is the bearing capacity of the criteria; that means, the load carrying capacity of the soil. So, this is the first criteria that, this soil should not fail against shear due to the applied loading. And, second one - the foundation cannot undergo excessive settlement. So, this is the settlement criterion. So, these both criteria we have to follow. And this the minimum… From here this load carrying capacity character will get one load; that is the load carrying capacity of the soil; that means the load that can take this. If we go for the safe load, then we have to apply the factor of safety. So, here we will get one load.

And, from this (Refer Slide Time: 29:19) settlement criteria, we will get another load or limiting load. So, the minimum one we have to provide as the allowable bearing capacity of the soil. We will discuss these things - what is the allowable bearing capacity? How to calculate the load from this settlement criterion and this bearing capacity criterion? Those things I will discuss in this section.

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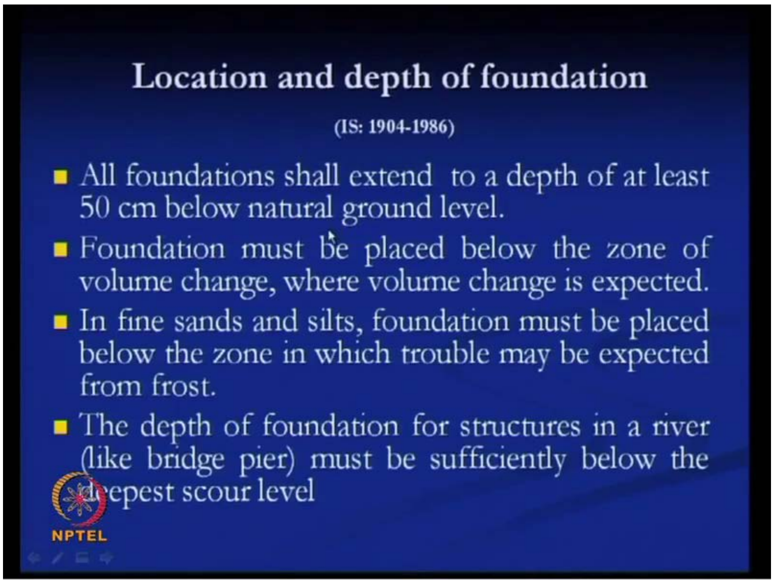

Before we go for the design part, we should know where we will place our foundation, then with the depth, and the location of the foundation before we start the design process. This IS: 1904 and 1986 - this IS code has given some recommendation, so that when you design these things, you have to follow these recommendations, where we will place our foundation; that means the location at depth of the foundation. First, one condition is all foundations shall extend to a depth of at least 50 centimeter or 500 millimeter below natural ground level; that means the minimum depth of the foundation is 500 millimeter. So, we have to go for the minimum 500 millimeter depth below the ground level. That is the first condition, where all foundation should go up to 500 millimeter.

Then, foundation (Refer Slide Time: 30:52) must be placed below the zone of volume change, where volume change is expected. Now, if the type of soil is such that there is the volume change can occur and we know the extent of this volume change, so that the depth of foundation should be below that zone of the volume change. So, in case of fine sand and silts, foundation must be placed below the zone in which trouble may be expected from frost. So, if this soil is fine sand and silt, then foundation must be placed below the zone, which trouble may be expected from the frost. You have to provide the foundation below this zone. And the depth of foundation for structure in a river like this bridge pier must be sufficiently below the deepest scour level. So, for the river structure, first, we have to calculate the deepest scour level; and then, the foundation should be placed below that deepest scour level or sufficiently below that deepest scour level in case of river structure.

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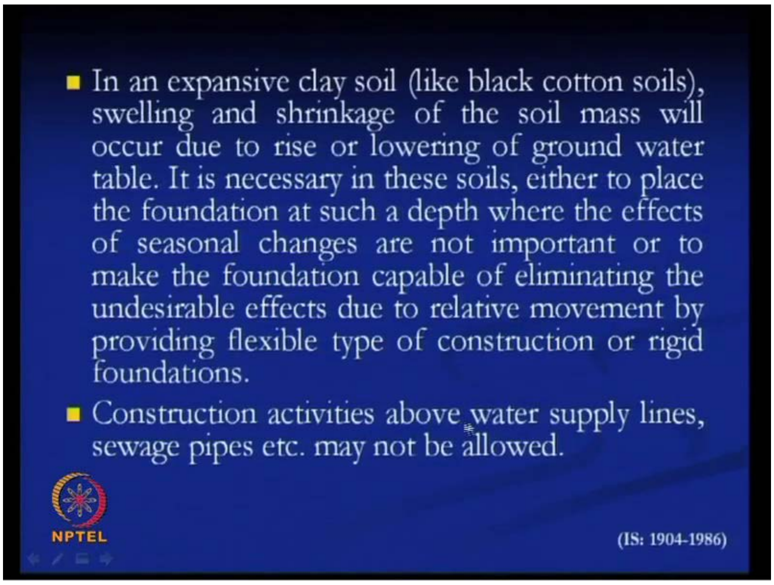

Now, next one - if it is expansive clay like the black cotton soil, where that the swelling and shrinkage - these both will occur due to the rise, and lowering of the ground water table; that means, this expansive soil then the shrinkage. So, soil may shrink or soil may expand or swell. So, due to the rise and lowering of the ground water table, then in such case and such soil, it is necessary that either you can place the foundation in such a depth, where these seasonal changes are not important; that means these changes for the expansive soil due to shrinkage and swelling. These are seasonal changes. When the water table will rise, the soil will swell; if water table is due to the lowering of the water table, the soil will shrink.

So, this is seasonal change. So, we have to place foundations such a depth that this seasonal change are not an important factor in that case; or, we make the foundation capable to eliminate such effects; that means either we place the foundation at a particular depth, where this effects are not so significant; or, we can design our foundation; or, we can make the foundation capable to eliminate such undesirable effect due to the relative movement. By that we can provide the flexible type of construction or we can provide a very rigid type of foundation. So, to eliminate these type of effects either we can provide a flexible type of construction or we can provide a rigid foundation.

Now, construction (Refer Slide Time: 33:59) activities above water supply lines, then sewage pipes, etcetera, may not be allowed. So, we cannot construct the foundation above the water supply line or any sewage pipes. So, these are not allowable. So, these are the conditions. So, based on that, we can decide where we will place our foundation. So, we can particularly identify the depth. So, here we locate if this type of situation is… Any of these condition arises, then by this condition, we can decide where we will place the foundation.

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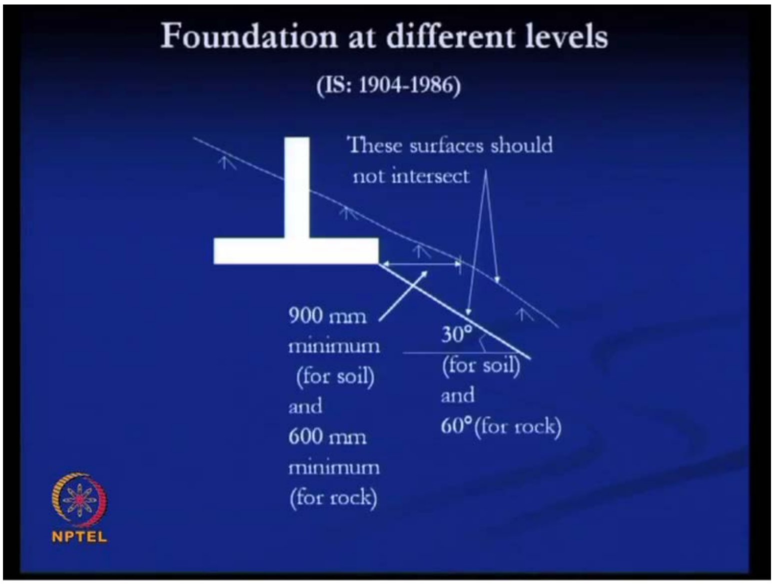

Now, if this is foundation at different levels; suppose if the foundation is mainly sloppy ground, then also this IS code - IS: 1904 to 1986 - it recommends different conditions. So, we have to also satisfy those conditions if this it is a sloppy ground. Suppose this is the foundation; this is the sloppy ground, where we can place the foundation. One condition is that from the edge of this foundation - this is the edge of the foundation to the… If we draw one particular line, which intersects this edge of this slope, this distance minimum distance - we have to provide 900 millimeter for soil. So, from this edge of the foundation to this slope surface, this minimum distance that we have to provide is 900 millimeter for soil and 600 millimeter for rock. So, we have to place the foundation such that this foundation edge is located at least 900 millimeter from this slope edge. So, this is one condition if it is a sloppy ground.

Another condition (Refer Slide Time: 36:12) that if we draw one line, which is passing through this bottom edge of the foundation; and, that line is passing making a 30 degree angle with horizontal (( )) that means this line if we draw, this is 30 degree for the soil and 60 degree for the rock - this angle. Then, the condition is these two lines, that means, this line, which is making a 30 degree angle and passing through the lower edge of the foundation and the slope line - these two surfaces should not intersect. So, if these surfaces intersect, then we cannot provide foundation in such a condition. So, we have to locate foundation somewhere else, so that this can satisfy this recommendation. So, we have to satisfy this recommendation for soil and as well as for the rock.

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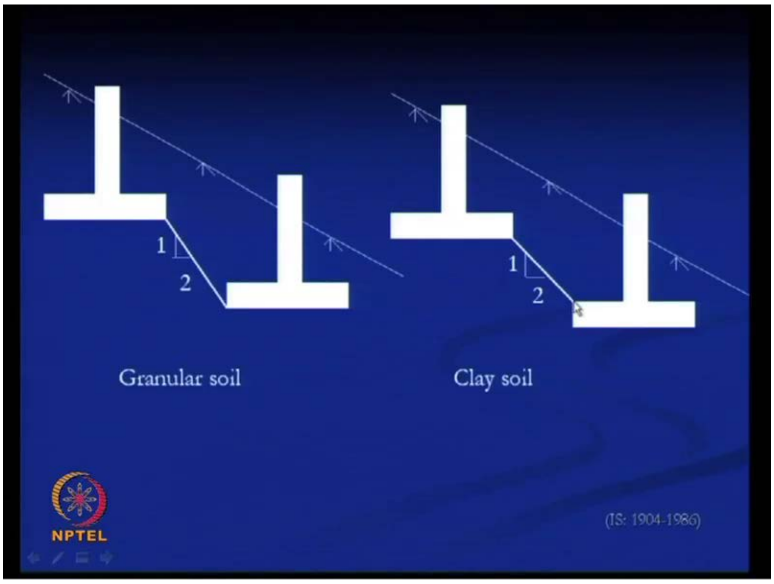

Now, the next one is that if this is the sloppy ground and foundation is at different level. These are the two types of soil and two types of recommendation. This is the upper foundation; this is the lower foundation. And for the granular soil, if we join one line; suppose this is the position of the upper and the lower foundation and if we join the line which is connecting the lower edge of the upper foundation to the lower edge of the lower foundation; that means this line should not be steeper than 1 is to 2; that means this line should not be steeper than one vertical to two horizontal (( )). So, this is the condition for the granular soil.

Similarly, for the clay soil, if I join a line, which is (Refer Slide Time: 38:08) from the lower edge of the upper foundation to the upper edge of the lower foundation, and then, this lines for the clay soil - if I join, this lines should not be steeper than one vertical to two horizontal. So, for the granular soil, the lower edge of the upper foundation to the lower edge of the lower foundation; and, for the clay soil, lower edge of the upper foundation to the upper edge of the lower foundation. So, both the cases, these two lines should not be steeper than one vertical to two horizontal. So, we have to place foundation such that it will follow this condition.

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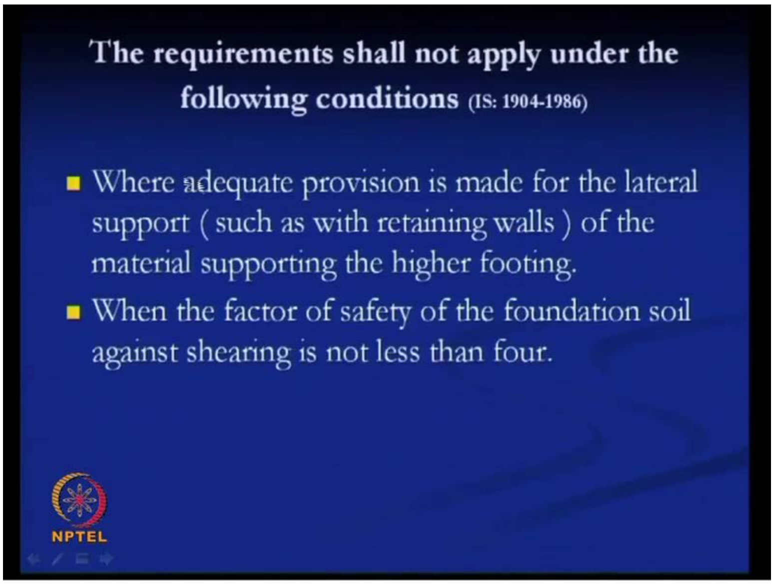

This (Refer Slide Time: 39:02) above condition - when foundation at different level; that cannot be applied when… Above requirement shall not be applied under the following condition. It is now required to apply the above conditions - these two conditions (Refer Slide Time: 39:22) for two different types of soil and this condition, where the adequate provision is made for the lateral support such as with retaining walls of the material supporting the higher footing. For the lateral support, if we provide in case of higher footing such as retaining wall, then this is not required to satisfy the above mentioned condition. Another condition is when factor of safety of the foundation soil against shearing is not less than 4. If the factor of safety that we are taking for such condition is greater than 4, then this not also required to satisfy the above requirements. So, these are the two conditions.

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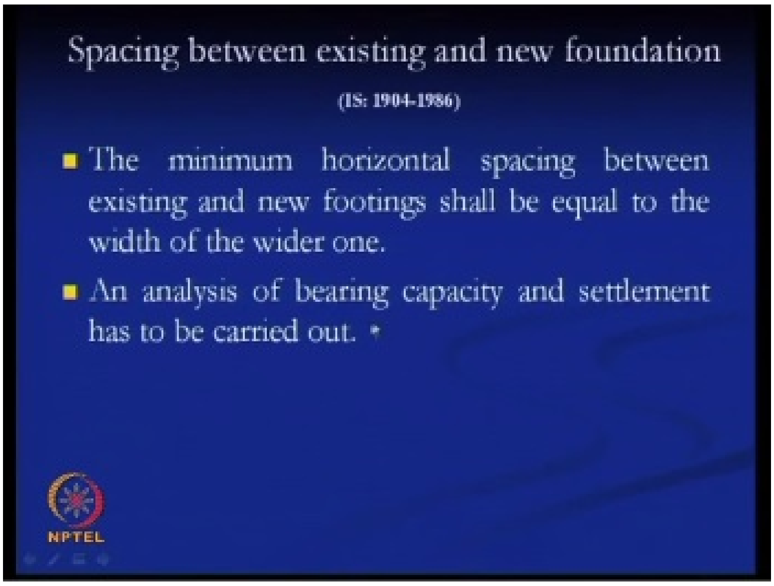

Next, this is the recommendation for the location and the depth of the IS recommendation for the footing. Then this is the spacing between the existing and the new foundation. So, IS code recommends that the minimum horizontal spacing between the existing and the new footing shall be equal to the width of the wider one. Suppose there is one footing that is existing condition and another new footing will be constructed. That is the minimum horizontal spacing or required spacing will be the width of the wider one. Suppose if B 1 is the width of the existing footing and B 2 is the width of the new footing. Then, if B 1 is greater than B 2, then the minimum horizontal spacing between these two footings: existing and the new footing will be B 1. If B 2 is greater than B 1, then this minimum horizontal spacing will be B 2.

Now, again analysis for the bearing capacity and settlement (Refer Slide Time: 41:13) has to be also carried out to consider the effect of this existing footing on this new footing. So, that analysis also has to be considered to include the effect of this existing footing. So, these are the recommendations for this spacing for existing and new foundation.

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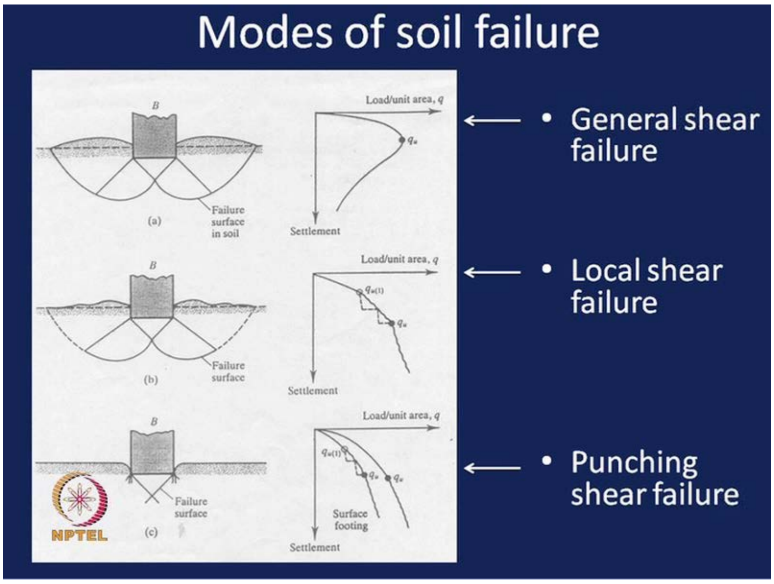

Now, next one that will go for this different types of failure mechanism. Now, we know where we have to place the foundation. Now, where… If there is a sloppy ground, then we have to satisfy the different condition. Now, if there is a level difference between the two foundation, then also we have to satisfy different condition. Now, based on that, we will locate the position, where we can place the foundation. And, if the existing footing is there, if we are constructing a new footing foundation, then what will be the minimum spacing between these two foundations - this we can know by this IS recommendation.

Now, when we apply the load… Suppose we are constructing one foundation and then we are applying the load. Ultimately, as we increase the load, that means, the soil will go undergo a settlement. And then, after a certain (Refer Slide Time: 42:44) point, this soil will fail. So, this soil failure is because due to the shear failure. So, because of the shear, if the soil strain that develops shear stress is greater than the shear strength of the soil, then this soil will fail. So, for this failure, different three modes are there depending upon the different types of soil. These three modes are general shear failure; this is the local shear failure; and, punching shear failure. So, these are the three different types of failure. So, we will explain one by one. So, this is the first type of failure, that is, the general shear failure. Second type of failure is local shear failure. And third - this type of failure is punching shear failure.

First, we will go for the general shear failure. Now, from this (Refer Slide Time: 43:53) general shear failure, we can say this is the typical load versus settlement plot for general shear failure. Here we can see that as load increases, the settlement will also increase. And then, after certain point as this settlement increases, but this load decrease; that means this is basically the peak and from here after that soil has been failed. So, here for the general shear failure, we can identify the failure point. So, this peak, this corresponding load divided by unit area - this q u, is the ultimate load carrying capacity of the soil for general shear type of failure. So, here we will get a particular peak.

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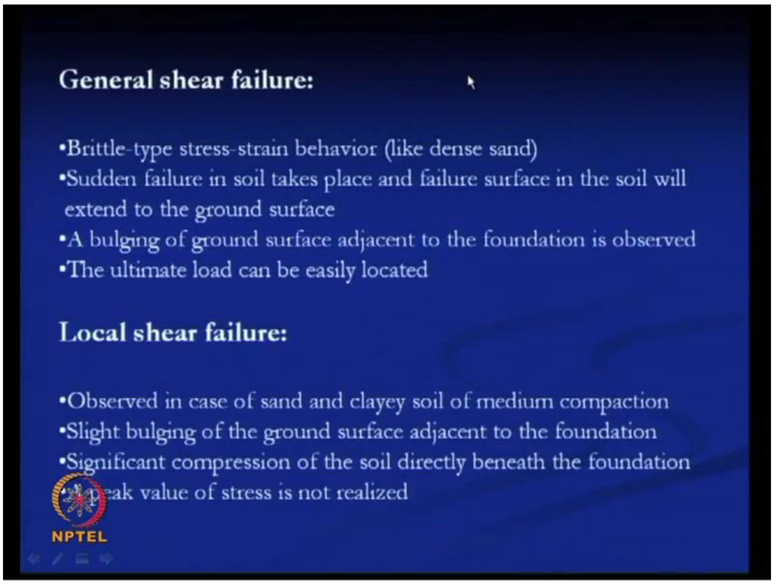

If we go for these characteristics of this general shear failure, this is basically observed - a soil like dense soil; if the soil is very dense or very stiff, then this type of failure is observed. So, for the dense sand, this is brittle type of stress strain behavior, where we will get a distinct peak. So, from here (Refer Slide Time: 45:08) we can easily determine what is the load from this type of failure. Here (Refer Slide Time: 45:19) the brittle type of behavior - a sudden failure in soil takes place and failure surface in the soil will extend to the ground surface. Here form this graph, we can see (Refer Slide Time: 45:30) there is a sudden failure is occurred. And, this is the failure surface. So, we can see, there the prominent failure surface can be observed up to the ground surface. So, failure surface is extended up to the ground surface in case of general shear failure; and, the bulging of ground surface adjacent to the foundation is observed. So, we can see this is the bulging of the ground surface adjacent to the foundation both side, is observed. Another one -

there is the ultimate load, can be easily located. Here (Refer Slide Time: 46:08) from this curve, this q u - ultimate load that can easily be located from the peak of the graph.

The next one is the (Refer Slide Time: 46:19) local shear failure. In the local shear failure - the characteristics of this (Refer Slide Time: 46:25) local shear failure - this type of failure is observed for the sand and clayey soil with medium compaction; that means sands in medium dense or in the soft soil. It is moderate type of clay, where this type of failure is observed. Now, here we can see the slide bulging of the ground surface adjacent to the foundation. Here (Refer Slide Time: 46:48) the bulging is more in case of general shear failure. But in the local shear failure, the slight bulging has been observed adjacent to the foundation both the side. Another the significant compression of the soil directly beneath the foundation is observed. So, there is a significant amount of the settlement or compression has been observed beneath the foundation.

A peak value of stress is not realized or located. From this graph (Refer Slide Time: 47:23) like the general shear failure, here we are getting a particular peak value. So, it is observed in this general shear failure. But in the local shear failure, we are not getting a particular peak. So, any peak or the failure point is not recognized. But in this local shear failure, first, what will happen that, when we apply the load, the settlement will increase. So, when this load reaches this q u 1 or this point, there is a sudden jerk has been observed; that means at this point, there is a sudden jerk; or, when there is a movement or the sudden jerk is observed, this point is recognized or these values recognize the first failure point, where the sudden jerk in the soil movement is observed. So, if the sudden jerk in the soil movement is observed, this corresponding load is recognized at first failure load. So, after that, here we can see if that the failure surface is moving towards the outer ward to the foundation. And, to reach this failure surface to the ground, there the sufficient movement in the soil is required. So, you can see these dotted lines.

As mentioned that, there is (Refer Slide Time: 49:04) a significant compression of sufficient deformation or compression is observed directly beneath the foundation. So, to reach this failure surface (Refer Slide Time: 49:13) to this ground surface, there is a sufficient amount of movement in the soil is required. At that particular point, where this condition is achieved, corresponding load divided by unit area is called the ultimate load or the failure load. Here there is basically two points: one is q u 1, that is, the first failure load; and then, the second point q u is the second or the ultimate failure load. So, this is local shear failure.

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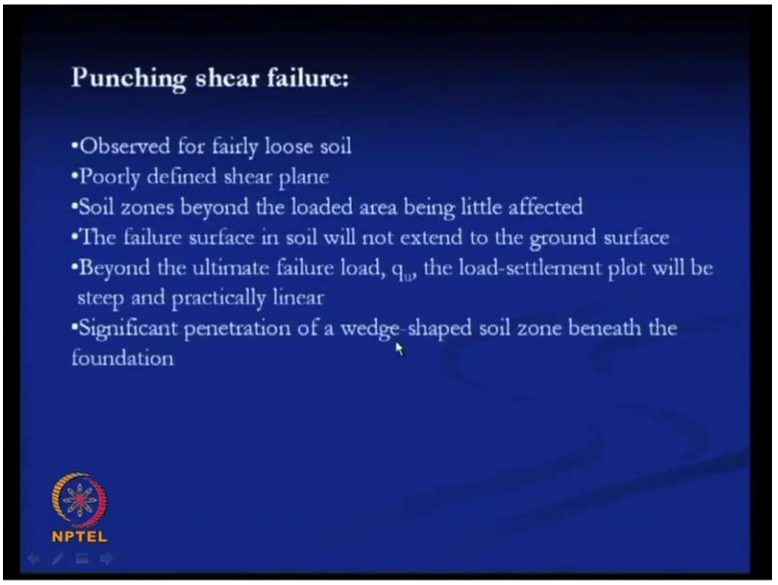

Next one is the third one, is the punching shear failure. Now, this is observed for fairly very loose soil or very soft clay. So, this is loose sand or soft clay; then, poorly defined shear plane. Here from these (Refer Slide Time: 50:09) two surfaces, we can say this is the failure surface or shear plane is observed or is being occurred. Here this is the poorly defined failure surface. There is no such that, surface is observed or identified. Now, this is shear plane. Then soil zones beyond the loaded area being little affected. Here the soil zone beyond this foundation area or loaded area is little affected. Now, the failure surface in soil will not extend in the ground surface. Here in these cases, general shear failure, the failure surface is extended up to the ground surface. But here failure surface is not extended up to the ground surface.

Now, beyond the ultimate failure load, q u, the load settlement plot will be steep and particularly linear. We can see (Refer Slide Time: 51:15) that beyond this failure surface, here also that this is say suppose the failure surface q u. This point is the ultimate failure load q. After that, this line is basically linear and this line is very steep. So, point after which the line is linear and very steep, corresponding this point and the load is called the ultimate failure load in case of this punching shear failure, because here (Refer Slide Time: 51:51) also, significant penetration of wedge shaped soil zone beneath the foundation. So, here also (Refer Slide Time: 51:57) significant settlement is observed. And will not get any peak like the general shear failure here also. So, here after this point, where this load settlement curve is very steep and linear, then this point is corresponding load, is called the ultimate failure load. So, these are the three different types of failure: general shear, local shear and the punching shear.

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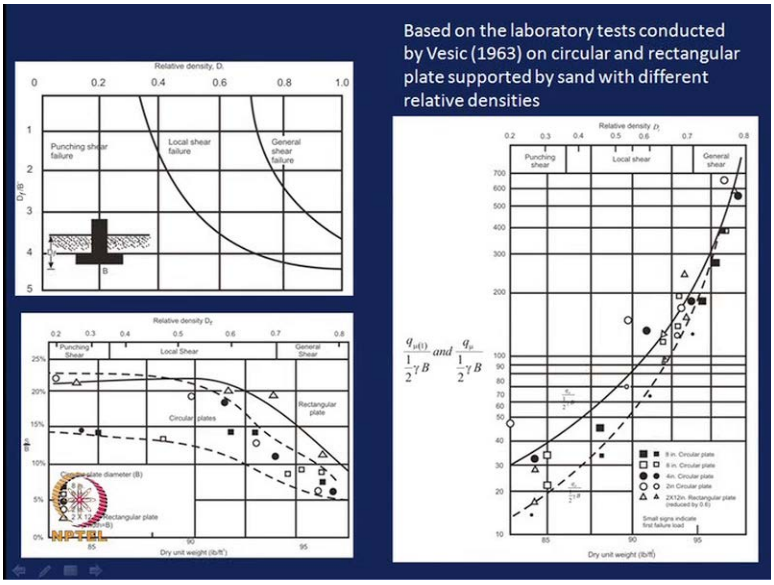

Based on the laboratory test conducted by Vesic, 1963 on circular and rectangular plate supported by sand with different relative densities; Vesic conducted laboratory test on circular and rectangular plate supported by sand with various relative density. And, he proposed zone of this different shear failure. This is the load conducted. This side axis is q u by half gamma into B; where, gamma is the unit weight of the soil; B is the width of the circular plate or rectangular plate. In case of circular plate, it is diameter; and in case of rectangular plate, it is width. And then, this is q u 1 and q u. So, here we can see, this sign indicates the first failure point, which is observed in case of local shear and punching shear type of failure, which is not observed in case of general shear type of failure; and, the bigger one is the ultimate failure load.

Here we can see (Refer Slide Time: 53:44) that, if the relative density is greater than 70 percent, then the general shear failure is observed. This is conducted on particular sand. So, general shear type of this is observed. If there relative density is in between say 35 to 70 percent, then the local shear failure is observed. If it is less than 35 percent, then the punching shear failure is observed. So, this is the graph. From these tests, we can draw the… This another chart is presented. This is (Refer Slide Time: 54:19) D f. D f is the depth of the foundation. And B star; where B star is 2BL divided by B plus L; where, if it is the square footing or circular, then B will be equal to L; then B star will be equal to B. So, in that case, we can see that this is the zone of the punching shear failure; this is the local shear failure; this is the general shear failure.

Now say suppose if this (Refer Slide Time: 54:42) D by B star is say 2 and relative density is 60 percent; then that, if we place foundation depth such that this is B D f by B star is 2 and the relative density is 60 percent, then this will be the local shear failure. Now, corresponding if the relative density is 20 and D f by B star is 2, then this is the punching shear failure. Similarly, based on this result, we can draw. This one plot is presented. This is for relative density; this is (( )) unit weight; and, this is the settlement versus by B. B is the width of the foundation. And this is the settlement of the foundation at failure. So, here we can say, if it is a general shear failure, then the settlement is observed around 4 to 10 percent. If this is (( )) then the settlement is observed say in between 4 to 10 percent if it is within this zone.

For relatively small depth (Refer Slide Time: 55:47) and in case of general shear, to get the failure point, the smaller settlement is observed; that is, 4 to 10 percent of the width of the foundation. Whereas, in case of local shear and punching shear failure, this settlement is 15 to 25 percent of the width of the foundation. So, we can conclude, if the local shear or punching shear, the more settlement is occurred to reach the failure point; whereas, in general shear type of failure, less settlement is occurred to reach the failure point. So now, in this lecture we have discussed the different components of this failure and the different locations, where we will place the foundation.

In the next lecture, I will describe about the different bearing capacity expression or equation; and how to calculate load bearing capacity of the foundation; basically, in case of shallow foundation, how to calculate the load bearing capacity.

Thank you.