Soil Structure Interaction

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Lecture - 1
Introduction

Hello everyone today is the first class of this course, soil structure interaction. So before I start the different parts of this course, let me introduce the content of this course.

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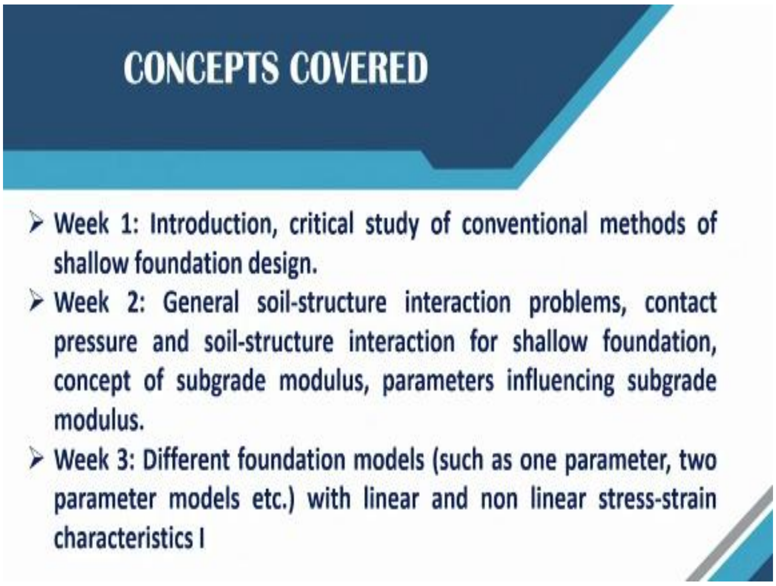

In the week 1, I will explain the traditional or the conventional methods of shallow foundation design. In week 2, I will discuss about general soil-structure interaction problems, then the concept of subgrade modulus and then the parameters influencing subgrade modulus. In week 3, I will discuss about different foundation models such as: one parameter model, two parameter model, and then with linear and nonlinear stress-strain characteristics.

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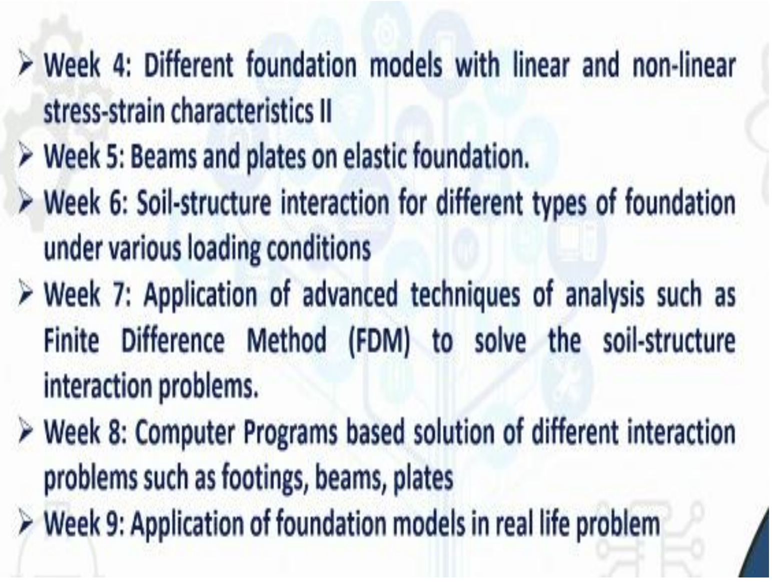

In week 4, I will continue the modeling part with linear and nonlinear stress-strain characteristics. In week 5, I will discuss about the beams and plates on elastic foundation. In week 6, I will discuss soil structure interaction for different types of foundation under various loading conditions, and week 7, I will discuss the application of advanced numerical techniques to analyze or solve different soil-structure interaction problems. Over here, I will discuss the Finite Difference technique to solve these types of problems.

In week 8, I will discuss about the computer program based solution of different interaction problems such as beams and plates. Basically, I will discuss about a part of week 7 in week 2 also. In week 9, I will discuss about different real life problems where we can use the soil structure interaction models to solve or analyze those problems. I will try to explain at least three problems where we can use these models that we will discuss in this course.

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Then, we will go to pile foundation part. So up to week 9, it will be shallow foundation part, then week 10, we will start the pile foundation part. So, basically in week 10, I will again discuss about the conventional pile foundation, load carrying capacity, determination techniques, negative skin friction, group action, and then week 11, I will discuss the interaction among different piles in a group as well as the lateral loaded piles where we can use our soil structure interaction concept to determine the deflection of laterally loaded pile under different loading conditions.

Then in week 12, we will discuss about the uplift capacity of piles and anchors. So, these are the tentative schedules that I am presenting here, but remember that I may continue, say previous weeks' topics in next week also or sometimes I can start one week topic in previous weeks also. For example, I may continue with 10^{th} week topic in week 11 also, and if required, I may start week 11's problems or topic in week 10. I will cover these topics in the next 12 weeks and we will cover all this in a total of 60 classes.

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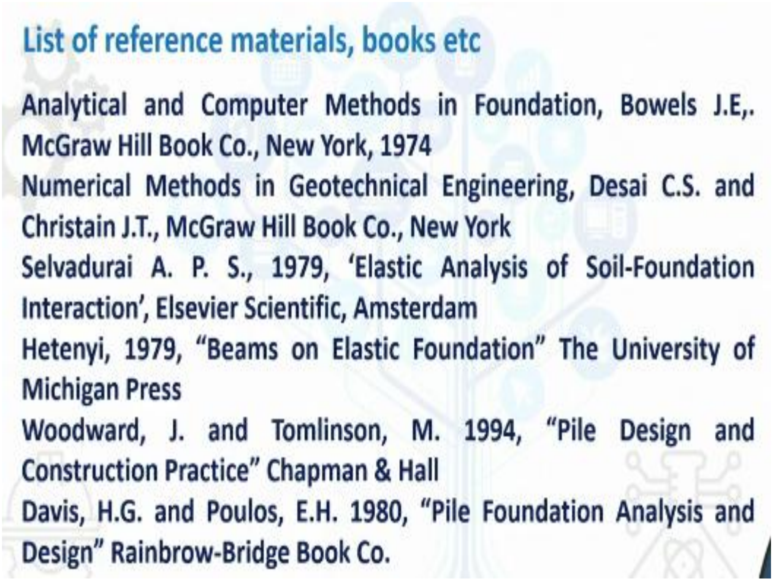

Now, regarding the books- basically I will take the help of these books: Analytical and Computer Methods in Foundation by Bowels, Numerical Methods in Geotechnical Engineering by Desai and Christain, Elastic Analysis of Soil-Foundation Interaction by Selvadurai, Beams on Elastic Foundation by Hetenyi, Pile Design and Construction Practice by Woodward and Tomlinson and Pile Foundation Analysis and Design by Davis and Poulos. I will give a number of references or I will use number of references during my classes. I will give all those references at the end of this course, i.e., in the last class.

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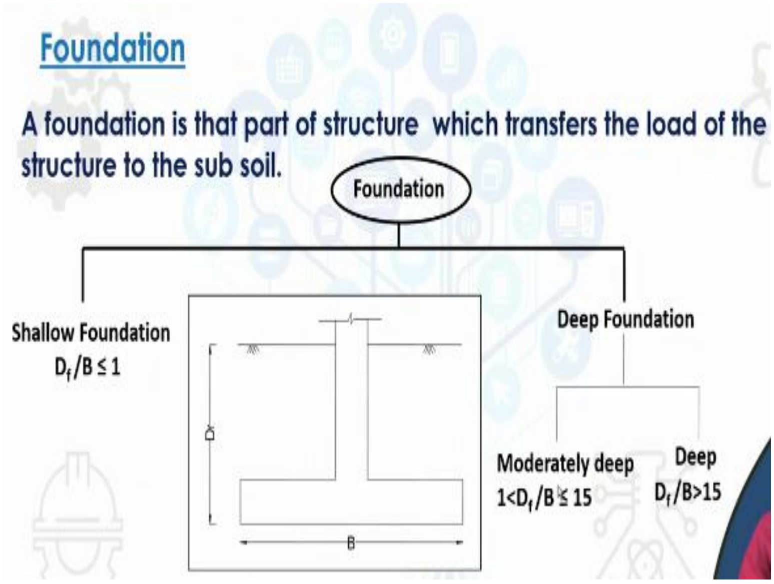

Now, let us discuss about the different types of foundation. Foundation is that part of a structure which transfers the load from superstructure to the soil or sub soil. These foundations are generally categorized in two groups: Shallow foundation and Deep foundation. A Shallow foundation has its depth of foundation (D_f) less than or equal to the width of the foundation (B), i.e., $D_f \leq B$. If this condition is satisfied, it is called a shallow foundation, and if the depth of foundation is greater than width of foundation, then it is categorized as deep foundation.

Now, this deep foundation can be divided in 2 groups: deep, and moderately deep. If the depth of foundation is greater than 15 times the width of foundation, then it is called a deep foundation, and if it is equal to or less than 15, then it is called as moderately deep foundation.

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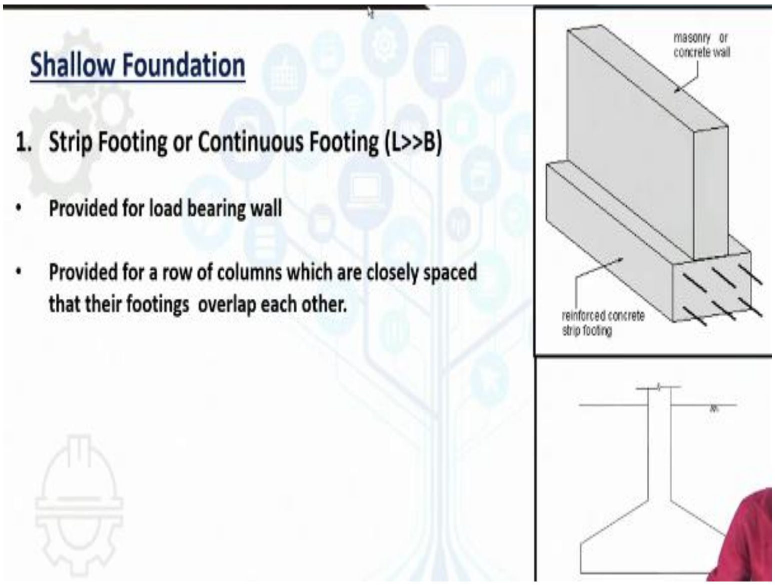

The first part I will discuss about the shallow foundation is the conventional design methodology that we use to design one and then about the soil structure interaction part. Then I will focus upon why we should use the soil structure foundation part in additional to the conventional design. In shallow foundation, according to the conventional design, we will discuss only about the dimension and how to determine it.

This includes the placement of our foundation and also the dimension of the foundation. So, to determine the dimension and the depth of foundation, we will use different methods. We will discuss about these in the first few classes.

Now, let us look into the different types of shallow foundation. A shallow foundation can be a strip footing or a continuous footing. A strip footing has its length of foundation very much larger than the width of foundation. This is generally provided below load bearing walls or retaining walls. In short, strip footings are provided for a row of columns which are closely spaced causing their footings to overlap each other. So, when the columns are so closely spaced, that the required footing dimensions may result in overlapping each other, then the footings can be combined and laid resulting in a foundation where length of the foundation is much larger than the width of the foundation.

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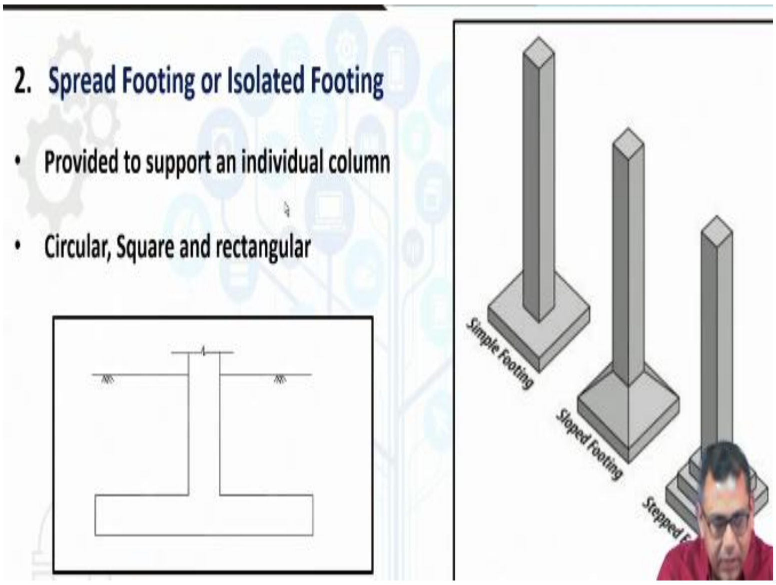

Next, we look at the spread footing or the isolated footing, which is provided to support an individual column. It can be circular, square, or rectangular. This is the footing which is used for a particular column. In the strip footing as I discussed, it can be a row of columns on a particular footing, but here, one footing is for one column. So, it can be in a simple rectangular, square or a circular shape.

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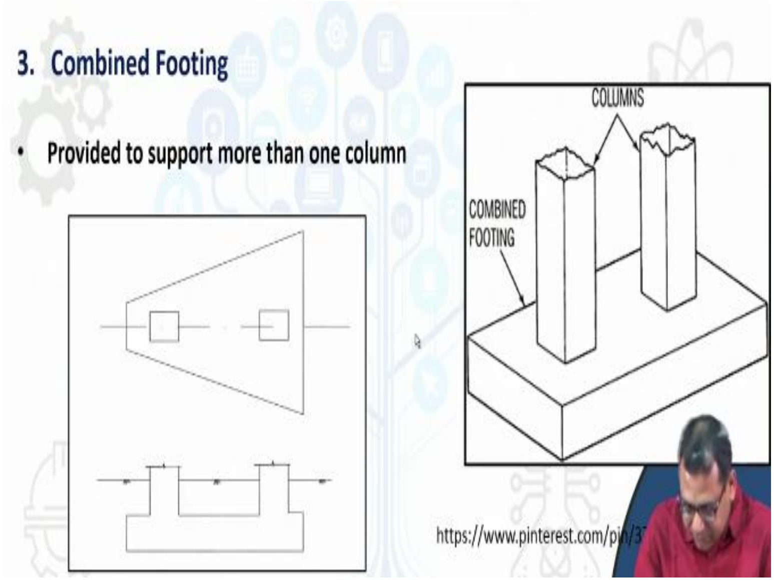

The next type of footing is the combined footing. The combined footing supports more than one column. So, we can combine two or three columns and then provide one particular footing. If there seems to be a possibility that one footing may overlap to other footing when a single footing is provided for one column, then we can go for a combined footing, but what is the difference between the combined footing and the strip footing?

The strip footing supports a row of columns and the number of columns will be more. But in a combined footing, it may not be a row of columns rather than a set of two three columns. So, when these footings overlap, we go for the combined footing or sometimes some structural restrictions may also lead to opt for the combined footings.

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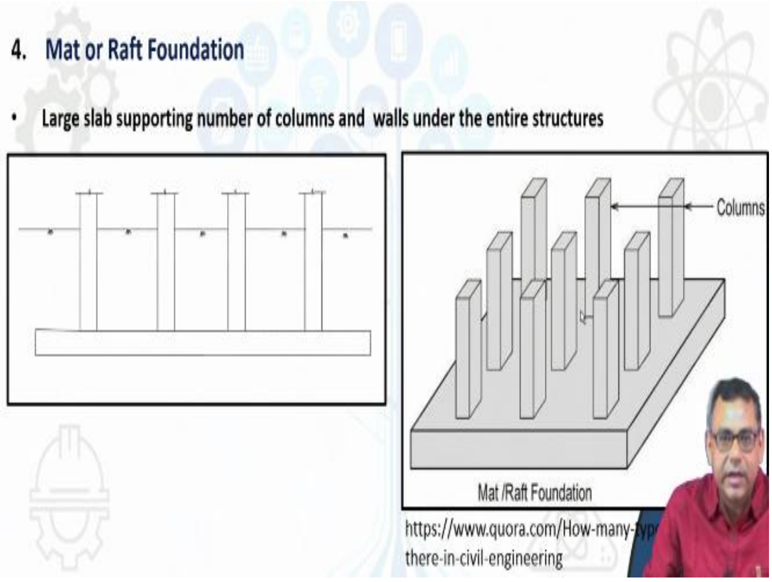

Next, we will go for the raft foundation. When we provide one particular foundation for the entire structure, supporting a number of columns (usually more than 2-3) we can call it a raft footing. In case of strip footing, it was only a row, but in a raft it is not one row, it is an entire structure, which means it can be a number of rows. That is the difference between the strip footing and the mat footing or the raft footing.

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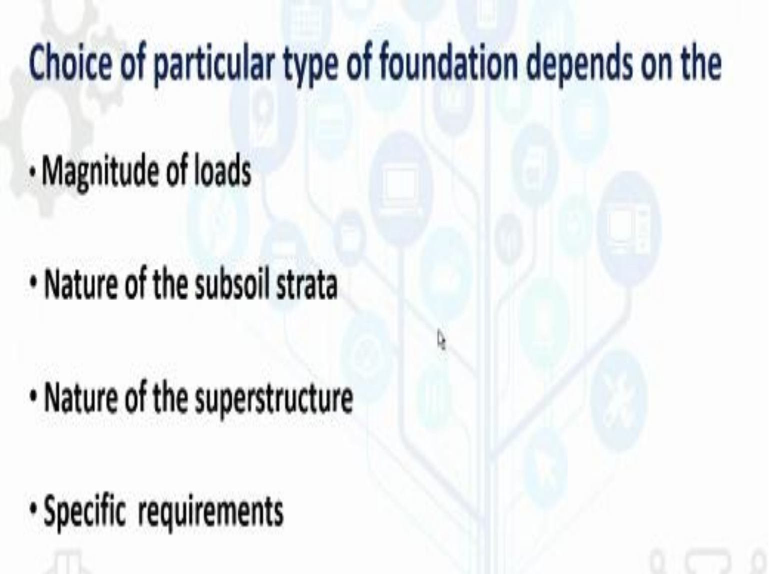

The choice of a particular type of foundation depends on the magnitude of loads, nature of soil strata, nature of the substructure and specific requirements. As I mentioned for some specific requirements also, we can go for the combined footing. Based upon all these 4 factors, the type of footing can be chosen like the strip footing or the isolated footing or combined footing or raft footing for a particular foundation.

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Design of foundation generally requires the knowledge of load that is coming onto it. So the load from the superstructure should be known well before. Then the requirement of the local building code should also be considered as the code of the particular location of designing the foundation may have some additional factors or restrictions. So, the local criteria need to be followed when designing a foundation along with the behavior of the soil or the properties of soil and then the geological condition of that soil. So, the load from the superstructure, the nature of the soil or properties of the soil and the code of the area where the foundation is being designed are the crucial aspects to be considered while designing a foundation.

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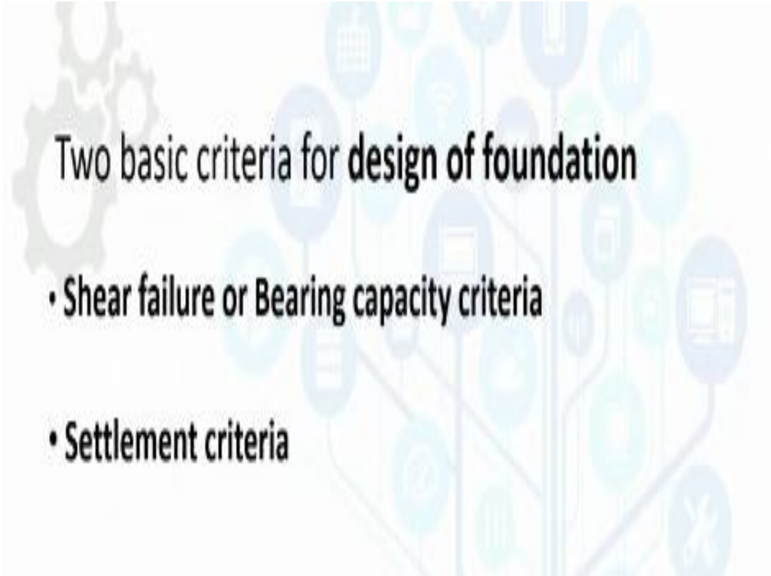

Now, when a foundation is being designed, two basic criteria of design should be satisfied: the shear failure or bearing capacity criterion and the settlement criterion. That means, the foundation should be designed such that it can carry the load coming from the superstructure or in other words, the soil will not fail under that load. The next criterion is that that there should not be excessive amount of settlement due to the load on the foundation.

So, there should not be any failure of the soil and there should not be any excessive settlement of the foundation or the soil. In this settlement criterion, the codal provision is very important. The foundation should be designed allowing only a certain amount of settlement. The amount (magnitude) of settlement which will be allowed depends on the code of that area. In essence, the code gives the instructions and this will be the permissible settlement. That means, the foundation will not settle more than that permissible value. So, this criterion should also be satisfied.

So basically, there should be no failure and no excessive settlement.

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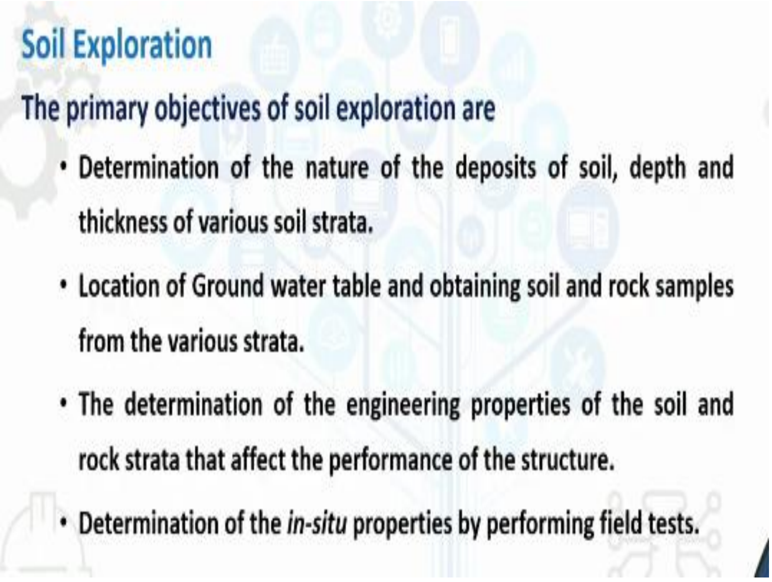

As mentioned earlier, when designing a foundation on a particular soil, the properties of that soil should be known. To be aware of the properties of the soil or different soil layers position or water table positions, is very important. So, before designing a foundation, we should have the knowledge of that soil. To get the properties of that soil, we have to go for soil exploration.

The primary objective of soil exploration is to determine the nature of the soil deposit, depth and thickness of different layers. So it's not just the thickness, but the depth, and the position where a particular layer starts or ends. Then location of the groundwater table, engineering properties of the soil or rock, location where the foundation will be laid and the in-situ properties (by performing field tests) should also be known.

There are two options: to directly determine the properties of soil by performing field tests. Another option is to collect the soil sample from the field and test it in the laboratory.

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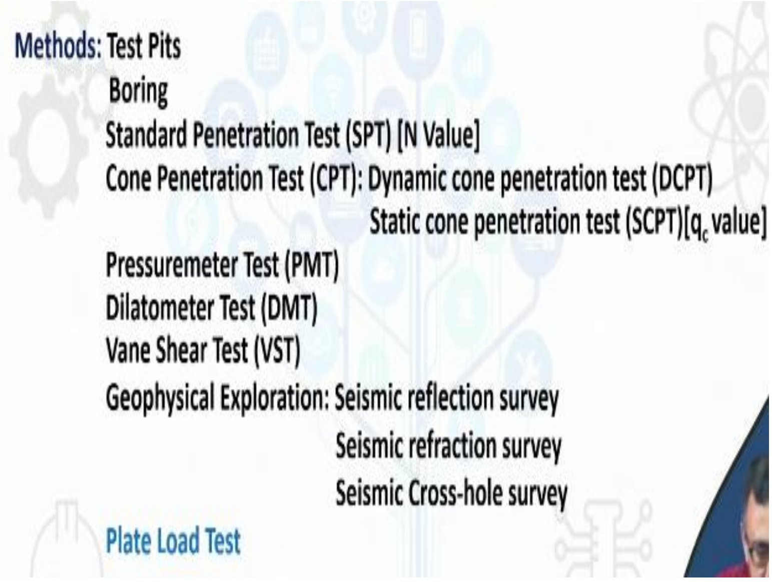

These tests have already been explained in my previous course, foundation engineering. You can go through those lectures to get a detailed idea of how these tests are done. Here is a list of tests that can be conducted to determine the field or in-situ soil properties and the type of properties that can be determined from the tests.

The soil can be tested by digging up test pits. A soil sample can be collected by digging a test pit up to the foundational level or by a boring. By boring, the soil sample can be collected, transported to the lab and tested to get the soil properties. Different types of tests can be done like, standard penetration test or SPT, which gives an N-value. The standard penetration test is called an indirect test.

So, test pit is a direct method where directly the soil sample can be collected form the foundation level and boring is a semi direct method, where the soil sample can be collected, but not reaching out to the depth of collection. But in the pit, the soil sample is collected by reaching up to the depth of collection. So, the test pit is applicable for very shallow depth and boring can be applicable for greater depth.

In both boring and test pit, the soil sample can be collected but SPT, (standard penetration test) is an indirect method. In this test, N value is obtained and based on the N value, the soil properties can be obtained by making use of the available correlations. Another advantage of SPT is that here the soil sample can also be collected in addition to getting the N value, which is in turn used for design purpose or to determine the different soil properties.

The next one is the cone penetration test, CPT which is also an indirect method. It can be dynamic cone penetration tests, DCPT or static cone penetration test, SCPT. The SCPT gives the cone resistance qc which will be used in the design purpose as well as to determine the soil properties. Other indirect tests are pressuremeter test PMT, dilatometer test DMT and Vane Shear test VST. The Vane Shear test is used in the field only where the soil is very soft.

We can also go for geophysical exploration like: seismic reflection survey, seismic refraction survey or seismic cross-hole survey. Soil properties can be obtained from geophysical exploration also. As mentioned earlier, you can go through my previous lectures of foundation engineering where you will get the detailed description of different test methods.

The last one is the plate load test which can be conducted in the field on the soil, where the foundation is to be laid or at the foundational level. From this test, the soil properties are not obtained, instead the bearing capacity and the settlement of the plate or bearing capacity and the settlement of the foundation. So, that means the plate load test directly gives the values of the bearing capacity or the settlement.

The plate load test will be explained in detail because this will be used later on to determine the subgrade modulus which is the one of the major soil properties for soil structure interaction.

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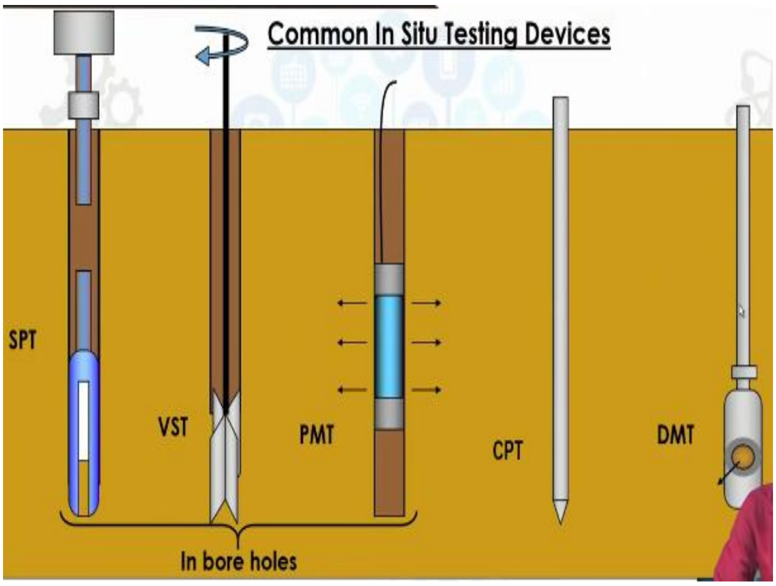

As a summary of the discussion so far, there are different tests: SPT, Vane Shear test, pressurementer test, CPT and dilatometer test. Out of these, for SPT, Vane Shear test and

PMT here, a borehole need to be excavated and for the cone penetration test and DMT, the cone would be pushed into the soil and there is no need for a bore hole.

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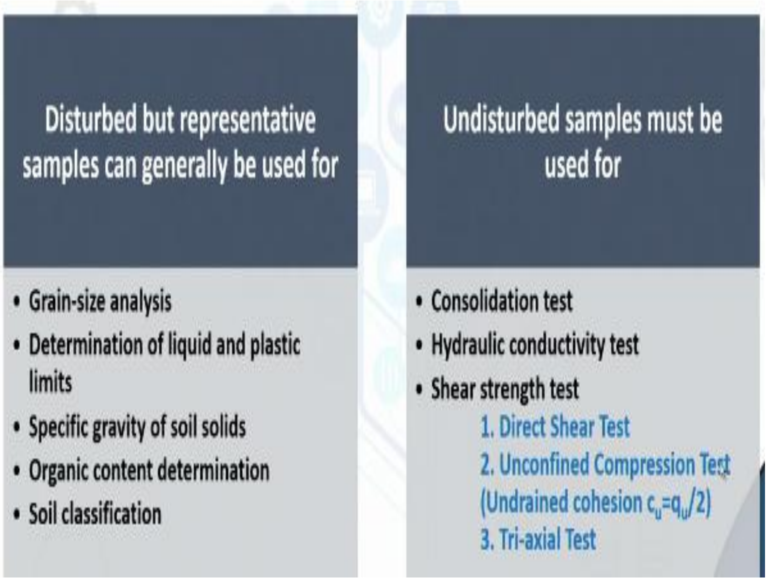

Till now we have discussed the different in-situ tests (field tests), but there are other options where the soil sample can be obtained from field and tested it to get the soil properties. The collected soil sample may be disturbed or undisturbed. Disturbed sample is that in which the soil's original structure gets disturbed during the collection of the sample and undisturbed sample is that in which the soil's original structure does not get disturbed during the collection of the sample.

That means in the undisturbed condition, both soil sample and the field's condition are same, but in a disturbed soil sample, these two conditions are different. So, the disturbed soil samples cannot be used for strength calculation, consolidation or the hydraulic conductivity or permeability test. To understand the reason behind this restriction, we have to dig back to the two basic design criteria of foundation: bearing capacity and settlement. The bearing capacity is based on the strength properties of the soil, cohesion and fiction. So to determine the cohesion or friction, undisturbed soil samples should be used. The other criterion, settlement is a function of consolidation and the consolidation is also a function of permeability. So, to calculate the settlement, the consolidation properties of the soil or the permeability of the soil need to be known. So, these tests also have to be performed on the undisturbed soil samples.

Although, disturbed soil samples can be used for some purposes like: determination of grain size of the soil, determination of liquid limit, plastic limit, specific gravity of the soil and organic content determination. These tests are done to classify the soil and disturbed soil sample can be used for these tests.

For the shear strength parameter determination test, direct shear test, unconfined compression test can be done. In the unconfined compression test, the unconfined compressive strength, qu is obtained and the undrained cohesion value, cu can be calculated by dividing q_u by 2. These properties can be determined by tri-axial test also. The unconfined compression test is generally done for cohesive soil and tri-axial test can be done for both cohesive and cohesionless soils. The tri-axial test can be done in three ways.

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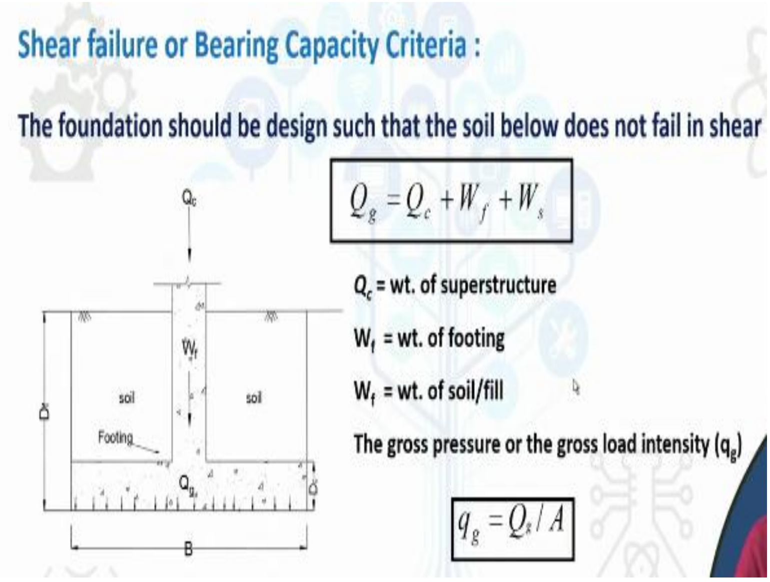

Before starting the design part, it is required to know the different bearing capacity terms or the shear failure or bearing capacity criteria. So, first we will discuss about the bearing capacity criteria. You should be aware of the terminology used in the process of bearing capacity calculation.

First of all, gross load is the sum of the weight of superstructure Q_c, weight of the foundation and weight of the soil. So, the gross pressure that acts on the base of the foundation is the gross load divided by the area of foundation.

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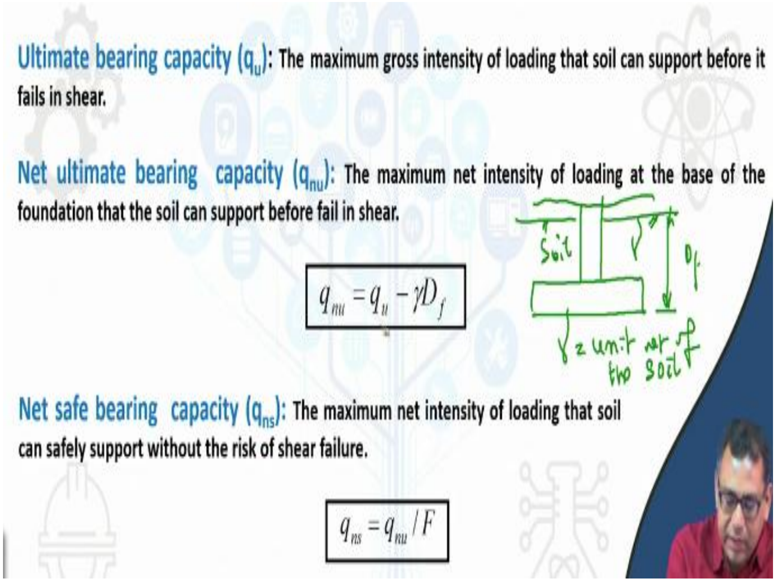

Out of the different terminology, the first one is the ultimate bearing capacity (q_u). It is the maximum intensity of gross load that a soil can support before failing. So, ultimate bearing capacity is the maximum gross load that the soil can take before failing and the gross load is, as mentioned, the load of foundation, it is the load of soil, it is the load of superstructure.

Net ultimate bearing capacity (q_{nu}) is the maximum intensity of net loading at the base of foundation that the soil can support before it fails. As the name itself indicates, net is nothing but the gross load after subtracting the soil weight from it. The foundation is the additional part along with the load from the superstructure. So, the net load will be the ultimate bearing capacity minus the pressure due to the soil. The stress coming from the soil can be determined as it would be:($\gamma \times D_f$). So, the net will be: ultimate bearing capacity minus ($\gamma \times D_f$). Then the net safe bearing capacity (q_{ns}) is the maximum net intensity of loading that the soil can safely support without the risk of failure. That means, the net safe bearing capacity is the net ultimate bearing capacity divided by factor of safety. In case of soil, a factor of safety value of 2.5 to 3 is used. $q_{ns} = q_{nu}/FS$

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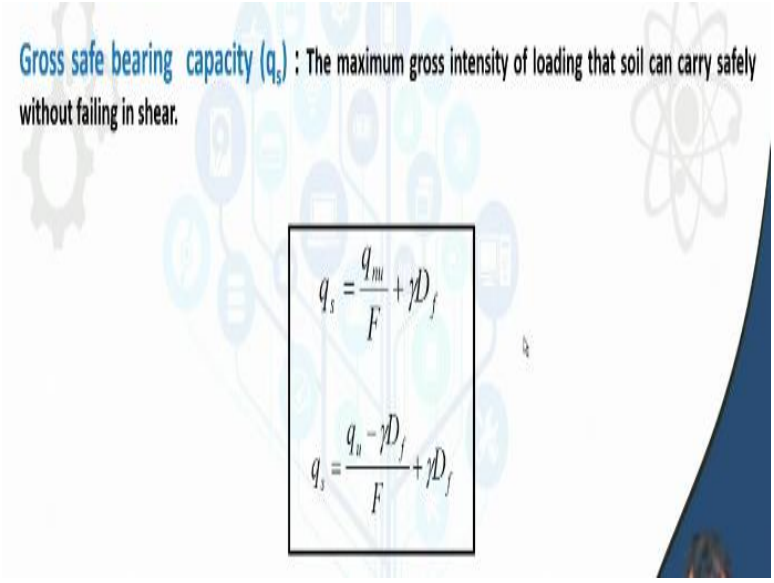

Next is the gross safe bearing capacity (q_s). It can be defined as the net ultimate bearing capacity divided by factor of safety plus gamma Df.

$$q_s = \frac{q_{nu}}{F} + \gamma D_f$$

So, ultimately it will be you qu, (ultimate bearing capacity) minus ($\gamma \times D_f$) divided by factor of safety plus ($\gamma \times D_f$).

$$q_s = \frac{q_n - \gamma D_f}{F} + \gamma D_f$$

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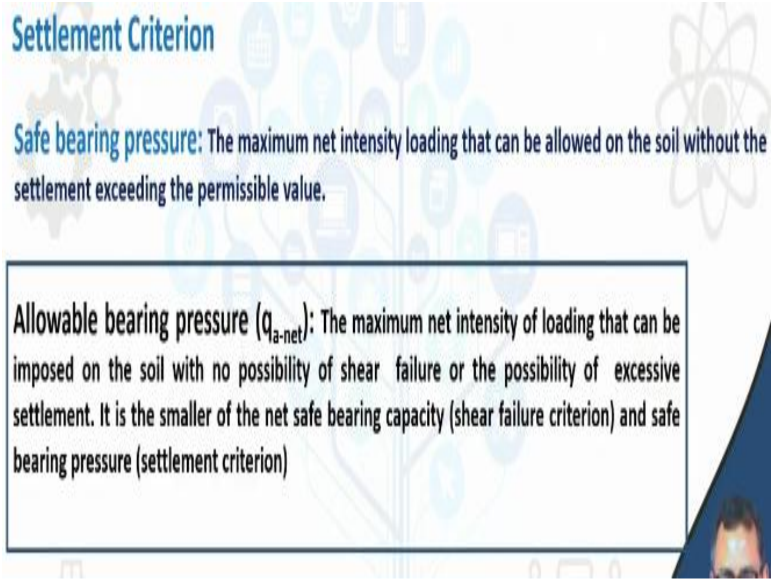

The other design criterion of foundation is settlement. The terminology discussed so far is for the bearing capacity criterion and in the settlement criterion, the safe bearing pressure will be used. What is safe bearing pressure? The maximum net intensity of loading that can be allowed on the soil without the settlement exceeding the permissible value is the safe bearing pressure. Every design code has given its permissible value of settlement and the safe bearing pressure depends on it. That means, it is the stress under which the settlement of the foundation will not exceed that permissible value.

The safe bearing pressure is in terms of the settlement criterion and there are various bearing pressure values in terms of the bearing capacity criterion. The minimum one of the two will be the allowable bearing pressure. So the allowable bearing pressure is the amount of bearing pressure that can be allowed on to the soil satisfying both the settlement and bearing capacity criteria.

To put in proper definition, it is the maximum net intensity of loading that can be imposed on soil with no possibility of shear failure, (satisfying the bearing capacity criterion) and the possibility of excessive settlement (satisfying the settlement criterion). That means, this is the stress under which the settlement will be within the permissible limit as well as the soil will not fail, or it is the smaller of net safe bearing capacity and safe bearing capacity.

These are the different aspects of the terminology that have been discussed. In the next class, I will first discuss how to calculate the bearing capacity of the soil, then in the next classes, we will discuss about the settlement criterion and then we will discuss how to design a foundation on sand as well as the clay. Thank you.