**Soil Structure Interaction**
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**Lecture - 9**
**Soil – Structure Interaction for Shallow Foundation:**
**Concept of Subgrade Modulus**

So in the last class, I have discussed to design raft foundation or how to design a raft foundation on clay and then I have discussed in previous classes that different bearing capacity expression and then how to determine the safe bearing capacity for isolated footing resting on sand. Now, today I will start the main soil structure interaction part and then first part I will discuss about the soil structure interaction for shallow foundation and then I will introduce the concept of sub-grade modulus or reaction of sub-grade modulus and then I will discuss about various models, soil structure interaction models in next classes.

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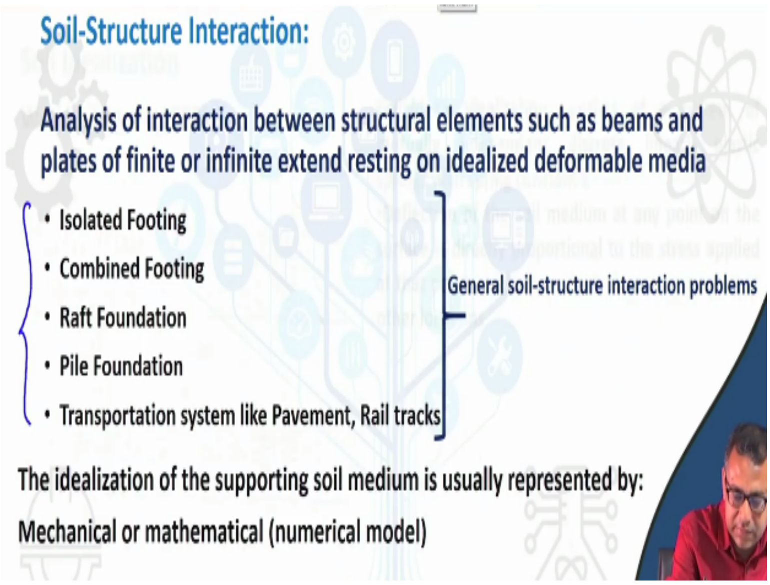


So, first what are the things that I will discuss in the soil structure interaction part that basically the definition or the things that I will cover in this course is the analysis of interaction between structural elements such as beams and plates on finite or infinite extend resting on idealised deformable media. That means, in this course, I will concentrate only the interaction between structural elements such as beam and plates, which is resting on deformable medium or soil medium, and then these beam or plates can be finite or infinite also.

Then for every cases, I will also give you the application areas where I can apply the these models basically for different soil condition and different loading condition, and then in one lecture particularly, I will discuss the real application of these models to determine the properties or the settlement, bending moment or shear force of different foundations. Now, in the previous lectures, I have discussed the conceptual or conventional foundation design for shallow foundation design on sand or clay, but here if you have noticed that we are using the loading intensity resting on the soil.

That means we are not considering any structural element, we are only considering the intensity of load that is acting on the soil and then based on that, we apply two basic criteria, one is settlement criteria and the bearing capacity criteria and then we will design the foundation okay. That means we apply the load and we check whether the soil is capable to take that load or not and for that soil what would be the maximum settlement and that settlement under that load is within permissible limit or not.

So, these two criteria is we basically check during our previous problems and to check those criteria, we have to use some theories for bearing capacity as well as the settlement. Now, when you are designing a foundation, then not only the settlement is the one basic criteria because for conventional design, we use settlement and the bearing capacity are the two major criteria, but in addition to that, we need to know that what is the bending moment or the shear force coming to that foundation?

Because that part we do not consider in our conventional foundation design, because when you design it for the structural part, we determine the bending moment to provide the reinforcement that is separate, but for considering soil and the structural interaction, what would be the bending moment and the shear force or the intensity of the loading or the reaction? Those things we do not consider during our conventional design of foundation, but here in this lecture, in this course, I will consider those interactions.

Considering those interaction, I will determine what would be the settlement, what would be the bending moment or the shear force or the slope on a beam, on a structure, or a foundation and to determine those things, we have to idealise those foundations either as a beam or as a plate. Now, those beans or plates can be finite or infinite depending upon where we are using those elements. Now, as I mentioned in my previous classes also that for shallow foundation, it can be isolated footing, combined footing, raft foundation, and then we will apply these models for the pile foundation and some transportation system like pavement and rail tracks.

So, these idealisation or these models in this course, I will apply on these areas okay. These are our general soil structure interaction problems that one I will apply its isolated or combined footing, I will apply these concepts in raft foundation, then pile foundation design, and transportation system like plates or pavements and I will give that which type of model I will use where, those examples I will show.

That means in addition to that, the soil structure interaction problem can be used for any underground structures like ship pile also and retaining wall also, but those things I will not discuss in this course. I will discuss in this course in the following areas only, isolated footing or combined footing, the raft or the shallow foundation, pile foundation, and transportation system like rail tracks and pavement design okay.

Then what are the models, types of models, these models can be mechanical or mathematical types or it has sometimes the closed form solution or sometimes we use the numerical tool to solve these model to determine our required properties.

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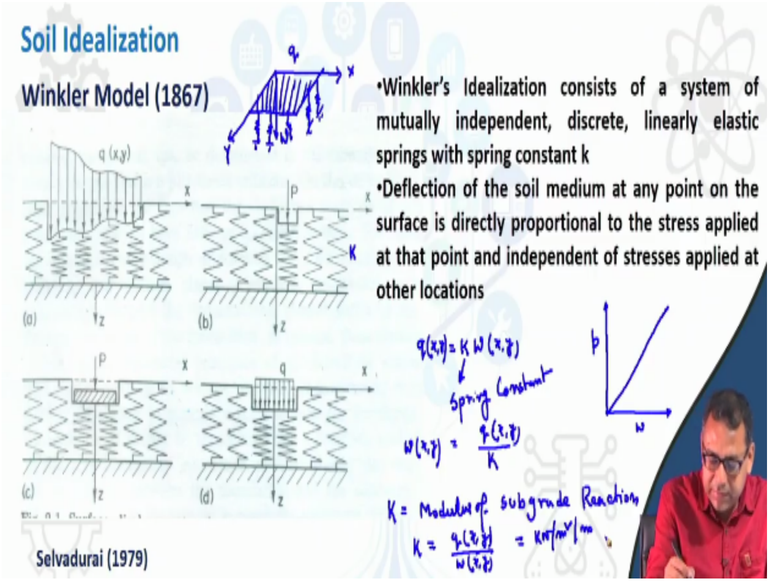


So, before I start that part that first let talking about the idealisation of the soil medium or any medium. So soil medium idealisation, first the model or the idealisation is proposed by Winkler okay, that is in 1867. What was the idealisation? The idealisation is that we replace the soil by springs. So, these are the springs that we use as per the Winkler model. So, these are the idealisation. So, Winkler idealisation consists of a system of mutually independent, discrete, linearly elastic springs with spring constant k.

So, that means we have a spring, so these springs are independent, that means these springs are not connected to each other, these springs are linearly elastic. That means if I draw the settlement and stress diagram for the spring, that means these are linearly elastic okay. So it is linearly this stress versus settlement or stress versus strength deformation pattern is linearly and this spring constant is k, so that means, we have idealised the soil. So, that is why you can see in this figure a where UDL is applied on the spring.

Depending upon the intensity of the loading, this spring will deform and here a concentrated load is applied on a spring, so it will deform and here these footing is applied on a spring **so** and that is the concentrated load, it will deform, here also UDL with uniform intensity. As the intensity of the loading is not uniform, so, it is nonuniform, and that is why the deformation is also nonuniform. Here it is uniform, so, that is why deformation of the spring is also uniform. So, that means, these are the four cases where we idealise the soil with the spring.

Now, then it is mentioned the deflection of soil medium at any point on the surface is directly proportional to the stress applied at that point and independent of stress applied at other location. So, that means one particular point, the deformation, if that deformation w, if I take it is x,y, x,y means if I consider it is x direction, it is y direction, and this is the w direction deformation. So, that means, this deformation if I apply the loaded region is this one and below that there is a spring okay and then this q is the loading intensity.

Then, the stress applied at any point is proportional to the deformation of all, the deformation of any point is proportional to the stress applied on that particular point and it is independent to the stresses applied to other points because there is no interaction between these spring. So, that is why this is as the q is proportional to w, that means, there is a proportionality constant k is used. This k is nothing but the spring constant okay. So, that means q applied stress at any point is equal to k into deflection of that part.

So, that means if I know the spring constant, if I know the q, then we can determine the deformation. So, that means, the deformation of a point will be equal to q x,y divided by k. So, if I know the spring constant, if I know the intensity applied on a particular point, then we can determine what would be the deformation of that point. Now, this k is called the spring constant as we have replaced the soil by spring, but in terms of our soil mechanics or foundation bearing, this k is called as modulus of sub-grade reaction okay.

So this k is called the modulus of sub-grade reaction and as the k is equal to the q, that means stress at any point and then the deformation of that point, so the unit of k is kilo newton per meter square per meter okay. Sometimes it is written as kilo newton per meter cube also, but I would recommend you to write kilo newton per meter square per meter because in foundation bearing, the kilo newton per meter cube is generally the unit of unit weight. So, that is why we can write the k unit is kilo newton per meter square per meter. So, this is called the modulus of sub-grade reaction.

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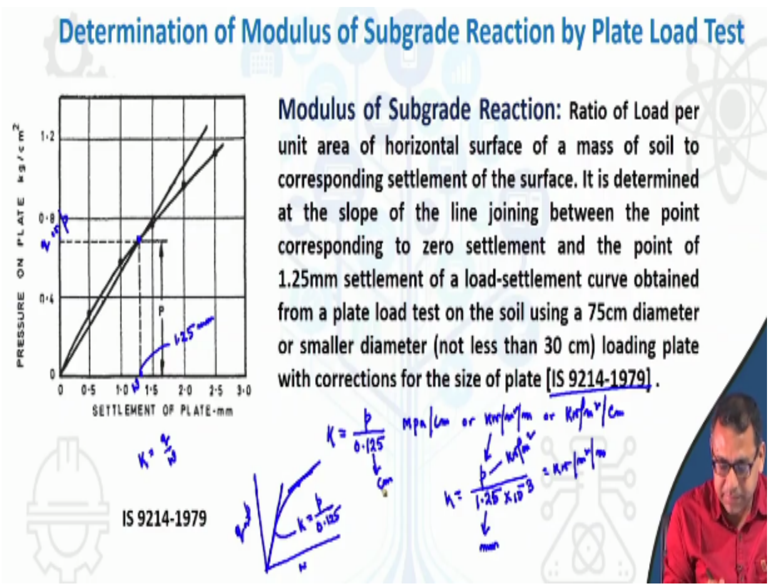


So, next we will discuss that how we can determine this modulus of sub-grade reaction. So, first that means, the soil is idealised with the spring. The spring constant is termed as the modulus of sub-grade reaction. Next, we should know that property because here ultimately in this model, our aim is to determine the deflection under a known intensity of loading. So, to determine the deflection, we should know what is the parameter k value. So, here only one parameter is involved.

So it is generally known as the one parameter model because the only one parameter is k, that is modulus of sub-grade reaction. So now, we should know this parameter, then only we can determine the deflection under a known stress. So, how will determine this modulus of sub-grade reaction? The modulus of sub-grade reaction can be determined with the plate load test okay. In lecture 5, I have already discussed what is plate load test. So, by using that plate load test, we can determine the modulus of the sub-grade reaction.

So, what is here written, the ratio of a load per unit area of horizontal surface of a mass of soil to corresponding to settlement of that surface. So that means that if we have a load, this is the stress or load versus settlement plot, then modulus of reaction, we can determine that stress of a point and corresponding deformation of that point. That means if this is the stress of a point q of a point and w is the deformation, then the modulus of sub-grade reaction will be q by W. So, as I mentioned in plate load test, we will get a load versus deformation or load versus settlement plot.

Suppose, this is the load versus settlement plot, so modulus of sub-grade reaction we will get the stress of a particular point. Suppose this on the curve, the stress of a particular point divided by the corresponding deformation. So, that will give us the modulus of sub-grade reaction. That means, here it is determined at the slope at line joining between the point corresponding to 0 settlement and the point of 1.25 millimetre settlement of a load deflection curve obtained from plate load test using a diameter of plate 75 centimetres or smaller diameter, but not less than 30 centimetres.

Because that means, you conduct a plate load test with a plate dimension of 75 centimetres or less, but not less than 30 centimetres, then you will get a load versus settlement plot. Now the k value is equal to the stress corresponding to 1.25 millimetres settlement. So, suppose here this is your stress versus settlement plot, so this is in terms of millimetre, so this point is 1.25 millimetre okay. So, corresponding stress q or p you determine, so k will be p by 1.25 here.

So, unit will be either if p is MPa, then MPa plus centimetre or it will be kPa $kN/m^2$ okay, here it will be centimetres, so it will be your $k_i$ in $kN/m^2/cm$, so depending upon which unit you are using. Here if this is per centimetre, if the p value is MPa, then this will be MPa per centimetre. If p value is kPa, then this will be kilo newton per meter square or kPa per centimetre or if it is kilo newton per meter square, then it will be p divided by 1.25, then you have to convert it for the meter also.

It is in millimetre, so it will be $10^{-3}$ okay. Then in this case, this deformation is in millimetre and this is in kilo newton per meter square, then you can convert it into minus 3, then this unit will be kilo newton per meter square per meter okay and 1.25 is millimetre okay, remember that. So, this way that means, stress corresponding to one 1.25 millimetre or 0.125 centimetre okay. So, this is one definition and this is as per IS 9214-1979 it is given. Alternatively also, IS score recommended some other way to determine the k value that I will discuss later on.

So, that means we will get the k value and one thing I want to mention that suppose this k value initial portion should be straight line, linear, because if you look at your load versus settlement plot, suppose this is your stress q or p and this is your deformation, then this settlement plot maybe something here. So, you can determine the k value at any point okay. That means at any point to consider, then you take that stress and corresponding settlement, so you will get the k value, but this k value we should consider the initial portion okay.

So, that means, initial portion should be straight line, that mean that is the straight portion we are talking about. This is the k that we are talking about, p 0.125 okay. So, now, if initial portion is not straight, then what we have to do? We have to take this point which is corresponding to the 1.25 settlement, the you join this zero point, then this will be a straight line, then slope of this line will give you the k value, which is the same as k corresponding to p divided by 1.25 okay.

So, that means the slope of this line also you can take as a k value, then that will be also giving the same value that you are considering that is the p divided by 0.125, but 0.125 in centimetre and one 1.25 in millimetre, but if you see this curve that as I mentioned, we can determine k value at any point over this curve okay, but the initial point, then you can take the k value in here also, here also you take a k value, you can take the slope on this point, then also you can draw a tangent on this point, then slope will give you one k value okay.

So in this way, your k value will also change over the load settlement time, but that the initial one is called the initial k value. So, but in the initial problem we are talking about, these springs are linear, so that is why we will concentrate only the elastic zone, later on when I will discuss the nonlinearity of the model, that means when you introduce nonlinear springs, here as per Winkler idealisation that your springs are linear, so that is why we will discuss only the linear part.

So, that is why we will consider the straight portion, that means initial linear portion and then we consider this k value, but later on, when we discuss the nonlinear spring, then how to change this k value over the load versus settlement plot that also I will discuss, in that case your k value will not be constant, it will change over the settlement. So, that means if you change the settlement, then your k value will also change, but for this linear model, your k value is constant over the linear portion.

We will consider only that linear portion because we consider that our model is linear. So, that is why it is clear that how we will determine our k value from a load versus settlement plot okay.

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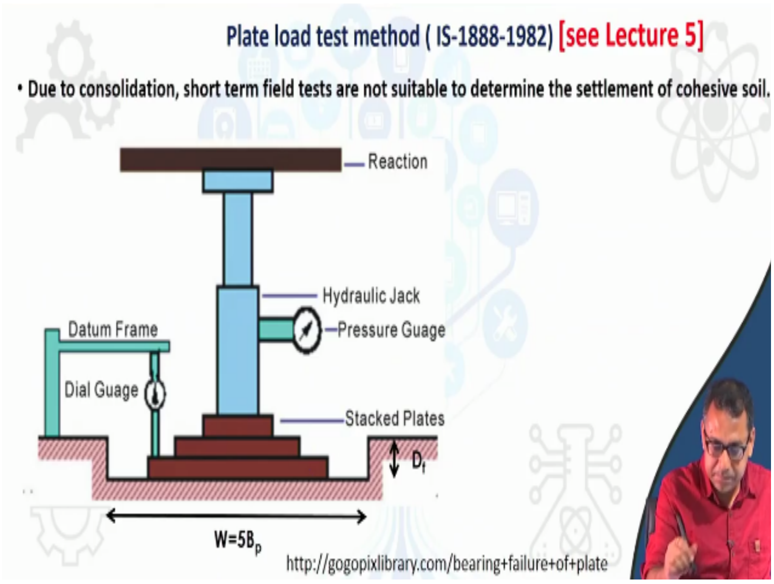


So next one that quickly I will just go through this the plate load test method that I have discussed already in the lecture 5, you just go through the lecture 5 and you will find that it has been already discussed. So, as I mentioned that for any type of field test, the plate load test is also not recommended for the cohesive soil because of its long term behaviour. So, this is the arrangement. So, these are the plate whose diameter 30 centimetres to 75 centimetres diameter range.

These are the stacked plate and we have to apply the load by the reaction and then that load we measure by probing ring or nowadays we can use the load cell or the settlement will be determined by the dial gauges or by the LVDT. Now, ultimately we will get the load versus settlement okay.

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Then these are the setup, this is the setup I have shown.

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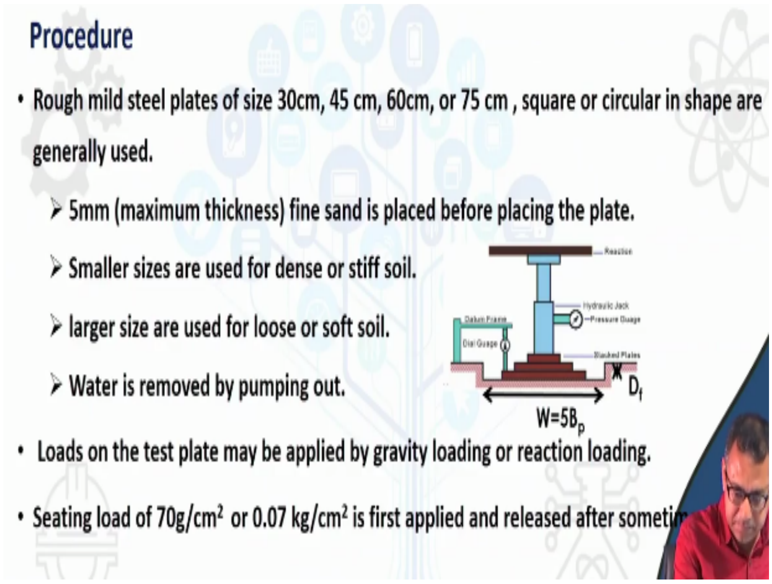


These are the description that you have to provide a 5 millimetre fine sand is placed before plate is placing and generally size of plates is 30 centimetres, 45 centimetres, 60 centimetres, and 75 centimetres. It can be circular or square. And generally for the dense or stiff soil, smaller size plates are used and the larger size plates are used for loose and soft soil. Then loading are applied vertical by reaction and before we start the actual loading, a seating load of 70 gm/cm$^2$ or 0.07 kg/cm$^2$ is first applied.

Just correct it, in the lecture 5 it is mentioned 70 kg/cm$^2$, actually it is 70 gm/cm$^2$ or 0.07 kg/cm$^2$. So seating load is 0.07 kg/cm$^2$ is applied and then it is released, then the actual load is applied, sometimes you release and actual load is applied.

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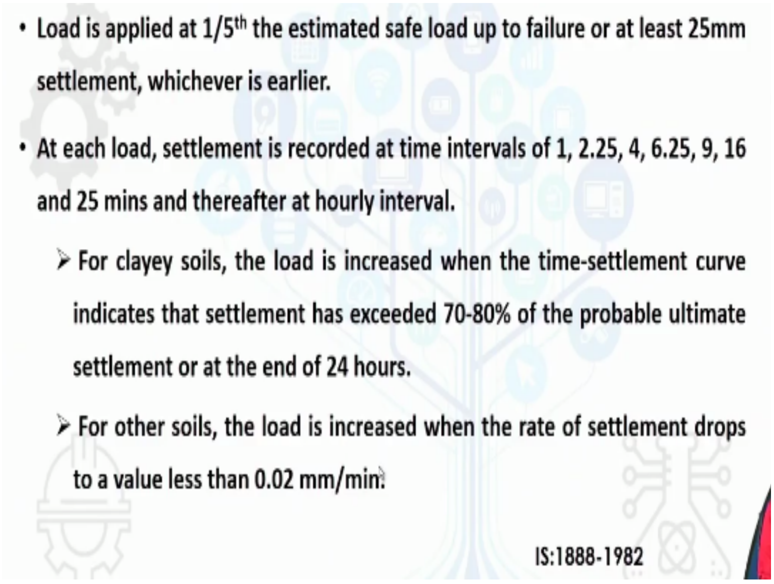


So, next is that loading is applied one-fifth of the estimated safe load and it can go up to the failure or at least 25 millimetre settlement, whichever is earlier. Then at each load, settlement is recorded for certain interval and these are the times and it is then taken after one hour interval. For the clay soil if the 70% to 80% settlement is already occurred, then you can stop or you can apply the next increment of load or after 24 hours we apply the next increment of load. So, increment of load is decided by one-fifth of the estimated safe load.

Then for other soil if the rate of settlement is 0.02 mm/min, then we apply the next increment of load. So, we have to apply the load, then we have to give the time to settle. So, that means when it is under stable condition, so that mean this is the condition that 0.02 mm/min if the rate of settlement is there, they we will take the reading and we will apply the next increment.

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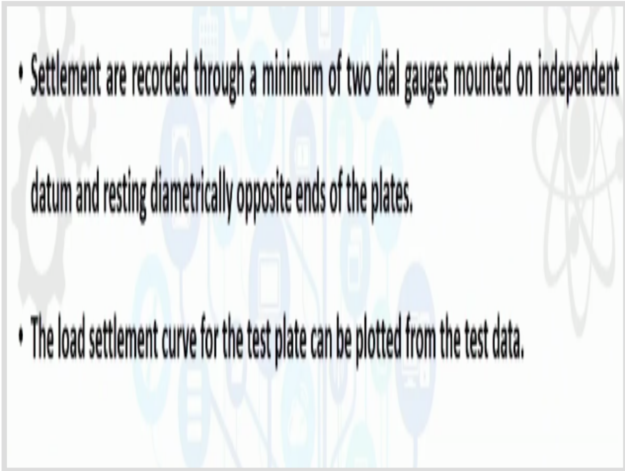


Then we apply either two or three dial gauges. If it is 3, then 120 degree difference, and if it is 2, then two opposite diagonal of the plate okay. So, then ultimately, we will get the load versus settlement plot of this curve.

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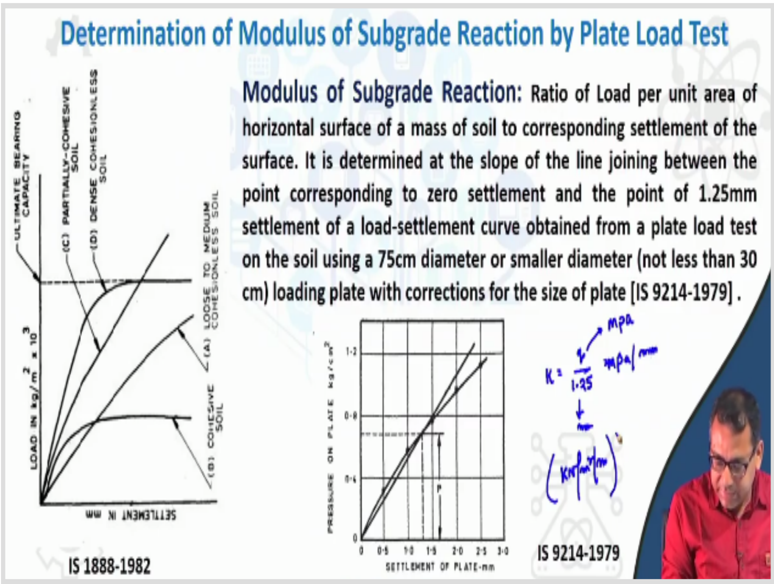


So, that is the curve and this I have already explained. So, this is the curve load versus settlement for different types of soil. So, this is the particular curve. So, initial portion that means the stress corresponding to 1.25 millimetre settlement, that means k is equal to stress q or p 1.25 millimetre. So, this is millimetre, so unit maybe it is MPa /cm or this will be as it is given in millimetre, so you can go it is MPa / mm or depending upon finally we can go it for kilo newton per meter square per meter, but this is if q value is in MPa.

So, if your q or p value is in mPa and it is one 1.25, so this will be MPa /mm okay or finally generally we can produce it at $kN/m^2/m$. This will be the initial linear portion only. So, in the next class, I will discuss that what are the factors affecting this k value, because as it is mentioned that if we are applying on the surface of the loading, but in actual case if we apply the foundation in certain depth, then you have to apply some correction.

So, if we apply different sizes of plate and then how to use the real foundation k value, then we have to apply some correlation. So, those correlations I will discuss in the next class. Thank you.