Geotechnical Engineering II / Foundation Engineering
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Lecture - 19
Settlement of Foundation (Contd.)

Good morning, welcome you all to this lecture on Foundation Engineering and we were discussing on Settlement of Foundation in the previous lecture and same will be continued for few more classes. And I will today introduce, actually I have mention before that total settlement will be consist of three components, one is immediate or elastic settlement then consolidation settlement and secondary settlement or secondary compression.

And initially I took the elastic settlement or immediate settlement and I have also shown the application with the help of a problem. And now I will entered to consolidation settlement and this is actually you might have learn through your soil mechanics.

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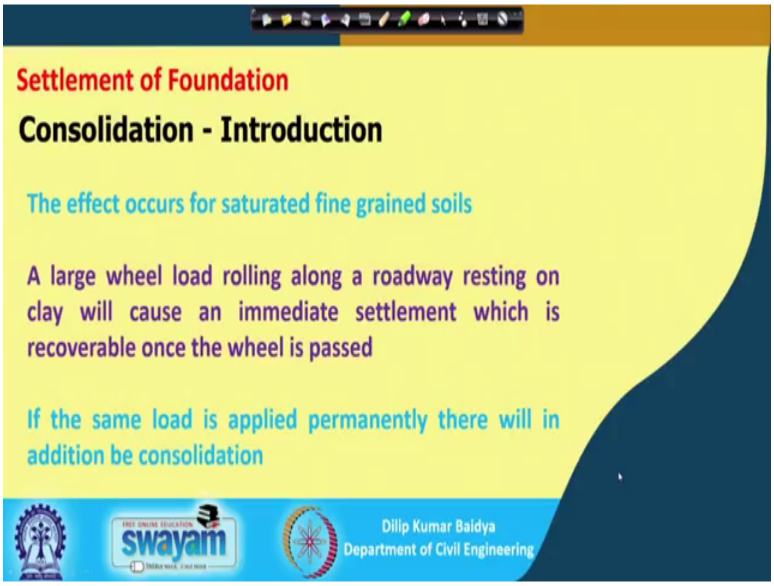

And this is the what is actually this is the effect happened to saturated fine grained soils and for example, elastic settlement and consolidation settlement if there is a large wheel load rolling along a roadway. And then we will see that the soil will immediately, the wheel will depress because of elastic settlement and when the wheel moves away from that point and then it will be mounts by the recover it actually the no permanent settlement.

But if that wheel load it permanently kept for sometime, in addition to that whatever elastic settlement we have seen there will be some amount of permanent or consolidation settlement because of these consolidation phenomena. And what is this consolidation phenomena actually, this is actually basically as I have mention that it is a it happens on saturated fine grained soil and when the saturated soil loaded and then both soil particles initially and since the water is incompressible. And, then when the additional load is applied until unless the water comes out from the wide spaces then actually there is no chance of change of void ratio. Consolidation again is nothing, but change of void ratio.

So, all wide space is initially occupied by water, until unless some amount of water coming out then your volume change or decrease in void ratio is not possible. But when you apply load immediately after loading that, if the because of the fine grained that the path for coming out the water is very narrow and because of that initially that external load will be reacted in the form of excess pore water pressure. That means, if there is a, if there are number of soil grains like this soil grains are like this.

So, inside this grains are in contact suppose and then inside this there will be pore pressure and because of that pore pressure actually what will then that when the water is pressurized. Then it will have a tendency to release the pressure, then what will happen through these narrow openings between in between the particles water slowly you will slip out and that will help to reduce the pressure. And when the pore pressure is reduce then what will be the extra pressure where it will go then that pressure will come to the soil and when the soil particles will be pressurize get extra pressure then there will forced to come to closer. So, and that way actually this void spaces finally, will be reduced and that is the way actually consolidation take place.

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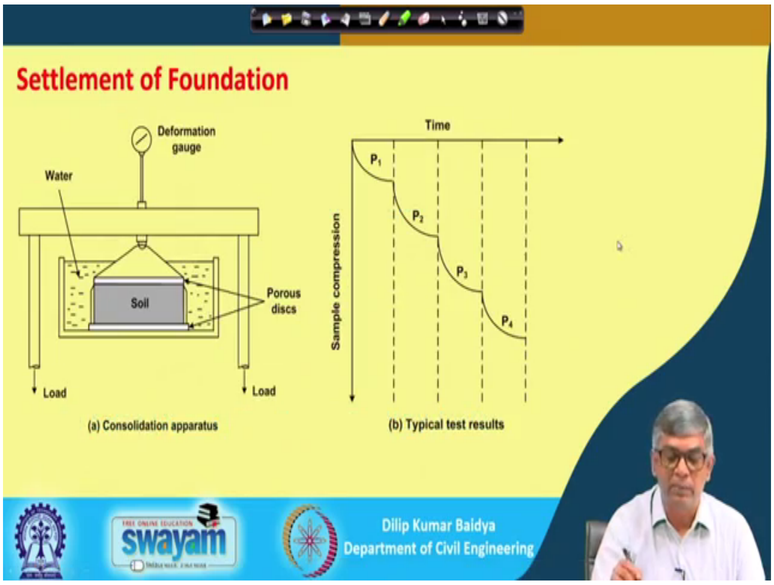

So, this is the then another aspect if you test in the laboratory on a soil sample and if you apply load P and then we will see over a time the soil will sample will compress. And at some time you will not see any change; that means, under that loading the consolidation is complete and then another thing is that if you subsequently apply further another load then again we will see that there is a compression starts and at the end of sometime compression stops. That means, the consolidation also depends on magnitude of force or load or pressure.

So, initially so if the smaller pressure then some amount of corresponding to that pressure consolidation will be there and if you again apply load again there will be consolidation like that. So, but when we are going towards end; that means, after several cycles of consolidation like that towards end if you to consolidate you need more pressure actually that is the thing.

So; that means, what I want to mention here that the consolidation suppose this is a layer suppose and this layer and suppose this is a footing this is a suppose footing. And then load is applied through this, if you apply load P 1 you will have some delta consolidation. And again if you apply some load P 2 which is greater than P 1 then again there will be in addition to this there will be at the end of consolidation under P 1, again consolidation will be start and again there will be another delta c 1 that was suppose then delta c 2. So, under load P 2 also there will be another consolidation that P 1 plus P 2 delta 1 plus delta 2 will be the total consolidation like. That means, when load with the change of loading the consolidation also will be changing, the amount of consolidate depends on largely depends on amount of loading. And then next thing is the number of ways actually consolidation settlement can be obtain.

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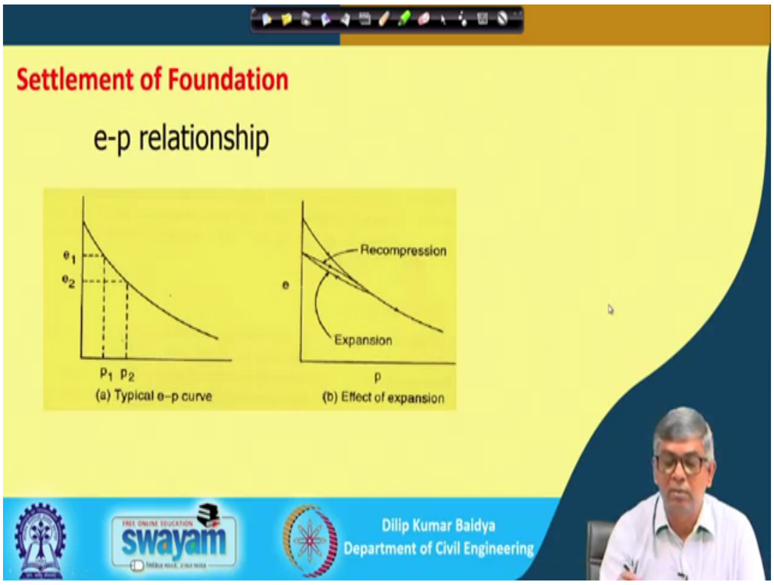

So, we will discuss one or two methods and you can see that as I have mention that consolidation is nothing, but change of void ratio ok. So, if we increase the pressure we can see in this excess along this we have increase the pressure and pressure was less here. So, void ratio was large, when increase the pressure void ratio is decreasing. So, e p curve you should look then you will be a curve you will get e versus p plot will be like this there will be a curve line.

And you can see that always that higher and lesser pressure void ratio will be more and higher pressure void ratio will less and if you go do actually if you this is suppose consolidated. And then if you if you unload then recompression will be somewhere here it will not reach to these only, it will be slightly less than that. And if you again further loading then it will come in this path and it will after reaching to this unloading point again they will continue to the same part.

So, this is the another thing compression recompression if you see the you will see this is the way consolidation e versus p curve varies this is some observation, but using this actually. So, change of void ratio with respect to pressure change of pressure you know that is the 1, by observing this how to find out the total consolidation suppose the layer is several meter of several meter thickness. Suppose this is 3 meter thick and footing is applied, footing is put here and then because of these what will be the total settlement here that to be obtain?

So, we know that if I apply P 1 some void ratio if I apply P 2 some void ratio if I know P 3. So, that behavior if I get, from that behavior I can estimate what will be the total settlement. So, that is the one I will try to see subsequently.

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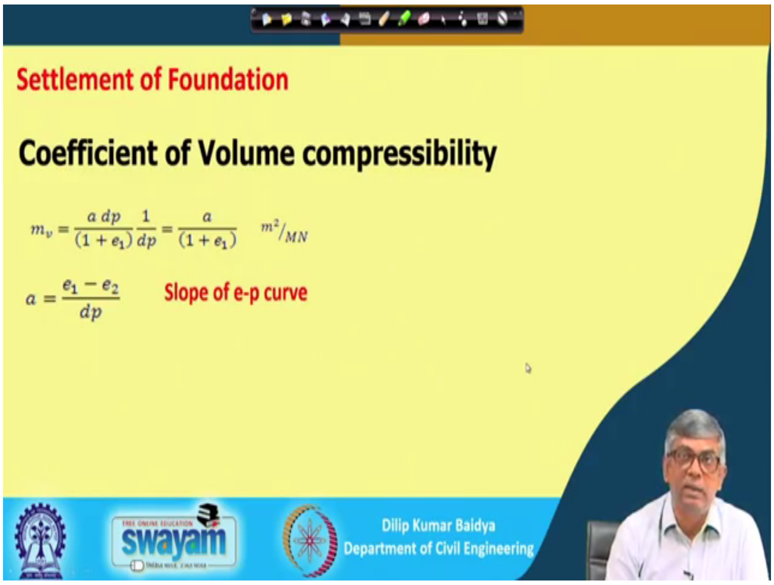

We can see here that in soil mechanics you might have learn this that there is a term m v m v is the coefficient of volume compressibility and this volume compressibility expressed a dp 1 plus e 1 by 1 by dp and then this get cancelled. So, it ultimately it become a by 1 plus e 1 and you need to use meter square per mega Newton or meter square per kilo Newton or mega meter square per Newton and this is the 1.

So, the e 1 is the initial void ratio and a is the slope of ep curve, suppose there is a e versus p curve, e versus p curve something like this and then if I at any point at any point if I take very small distance two points and then you can find out change of void ratio or change of pressure and that ratio if you find out then you will get the a value. Or the slope at any point that will give you the a and that is actually it is a e 1 minus e 2 by dp or nothing, but de by dp.

So, we can find out that m v volume compressibility if I can if I plot e versus p and from there what about the pressure range if I want to find out the within that pressure range what is the value of e a a I can find out and from that a I can find out m v once I get the m v from definition actually.

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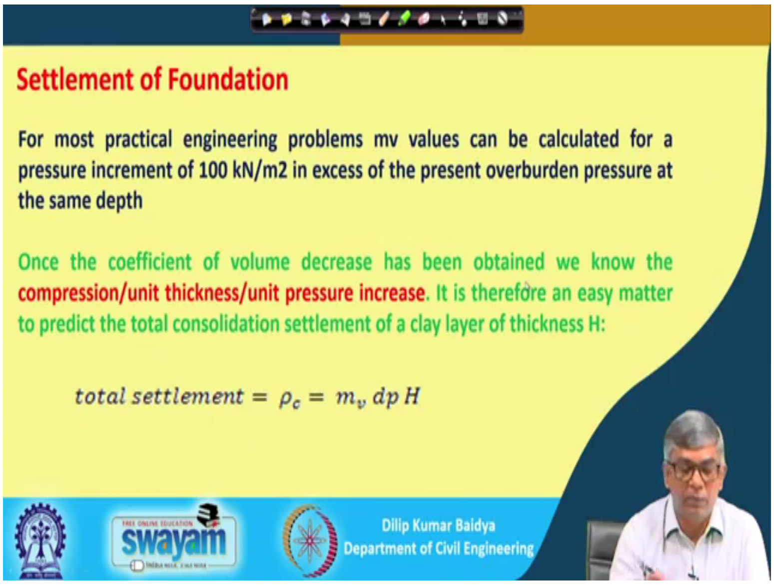

You can see that for, I will just say for most practical engineering problem m v values can be calculated for a pressure increment of 100 kilo Newton meters square in excess of the pressure over. Suppose if there is a footing suppose here and this is a consolidating layer. So, I can find out what is the present effective overburden pressure and m v value how we will calculate? I will just take a sample and I will plot e versus p and what range I will do 100 kilo Newton per meter square in excess; that means, if it is 100 now then I will do a two to hundred kilo Newton per meter square.

So, based on that I will plot and from there actually I will find out the e e versus p curve from there I will find out e a and from there I will get m v. And from definition on m v actually is the compression per unit thickness per unit pressure increase; that means, total settlements if there is a at any point actually if any point if any point this mv is known that m v if I multiplied by the thickness of the layer and then multiplied by the pressure increase then ultimately it become unit of meter.

So, compression per unit thickness per unit pressure so, that if I do that then I will; that means, if I multiplied by the thickness and then multiplied by the pressure increase then untimely we will get the m v. So, it was by these this so if I want to find out the settlement then I have to multiply this. So, if I know the m v value of a soil then multiply by the thickness of the layer and then the pressure increase, this two things if you multiply then I will I will get. So, this is consistently we are using consolidation as a delta. So, let it be delta consolidation delta c. So, total settlement will become your m v multiplied by dp multiplied by H. So, dp is what actually suppose we calculate the m v for the effective overburden pressure.

That means, because of the we will ignore this foundation because of the soil weight above this layer what is the overburden pressure, that is existing overburden pressure and now m dp means what? When we apply the when you construct the footing because of this footing actually at this layer there will be some extra pressure will come. And that pressure has to be calculated there are some method I will discuss later on so how to find out the dp because of the foundation load at the middle of the clay layer so that has to be obtain so, that is dp and m v is calculated from dp curve and h is a thickness of the layer.

So, that will give you the total consolidation, this is one way of calculating consolidation settlement and. In fact, m v is not constant as I have mention over the depth with the go deeper and deeper then it will change. So, generally if there is a layer thickness is very layer is very thick then it is preferable to divide into number of parts the then it will give you and if I suppose this is the thickness of layer I can divided into two parts. So, I can apply equation here, apply equation here that way it will give you little better result.

And also if I want to find out by this method it is preferable to find out m v a different depths if it is a suppose 10 meter thick layer. So, I should find out at 2.5 meter, 5 meter, 7.5 meter, 10 meter and then we can apply each layer separately then that will also give you better results. Or if you apply for a single value; obviously, you will get a approximate value not never be very accurate results.

Otherwise if the layer thickness is known and sample is collected and it is consolidation test is conducted and then void ratio change with the pressure change that plot if I do from that plot I can find out m v. Once you know the m v then you multiplied by thickness and then multiplied by the pressure increase because of the foundation load on the layer.

So, that is the thing if you do then you will get the consolidation settlement though m v is not constant, but if it is no option is there not many samples are tested then based on that we can take some value, same value and get the approximate value of settlement.

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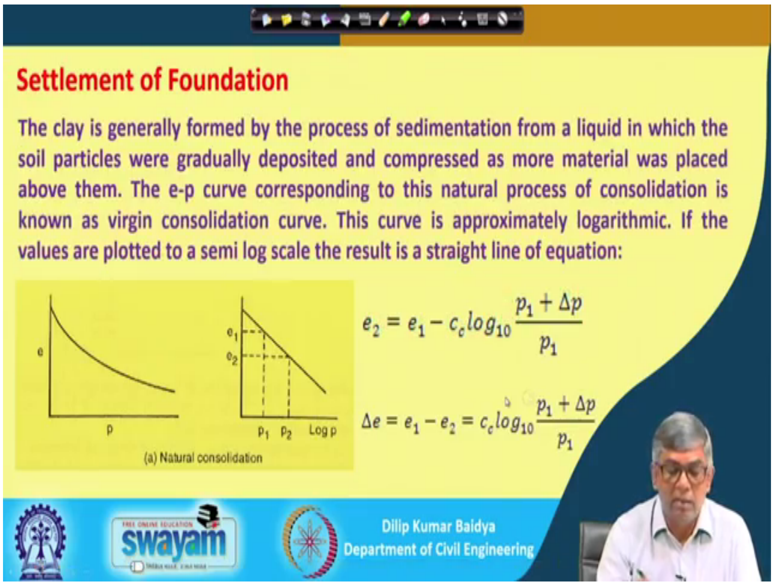

Now, there is a another method of calculation. That is actually the clay is generally formed by the process of sedimentation; that means, the that soil formation I have discussed or you might have started in soil mechanics that it will be initially fine particles will be with water and when the velocity will be reduced the fine particle will deposited. And that deposition initially will be thin then what that subsequently layer will be deposited and when and then upper layer because of the weight of the upper layer lower layer will be compressed, settled, deformation will take place that is nothing, but natural consolidation.

And that natural correspond consolidation for that if you got the if you plot the e p generally you will get like this e versus p will get as I have mention. And if you plot them in a semi log plot same thing e versus pressure, if you put in a semi log 1, then we will get a straight line. And that is actually this curve is approximately logarithmic and the values are plotted to a semi log scale the result is straight line of equation and this is actually generally that is called virgin consolidation also.

And so; that means, whatever load is applied the before that there is no other heavier than present load is not applied to the soil layer. So, that is also called with this consolidation process is called virgin compression. And for this type of compression when happen and if you test the soil sample and then e versus p if you plot it will come like this and same thing if you plot in a semi log; that means, e versus log p then you can you will get a straight line.

And if you get this straight line the from that what we can do we can see pressure p 1 e 1 and pressure p 2 and e 2. That means, the slope of this line will be actually delta e delta e by the slope of this line will be delta e by log 10 base p 2 by p 1. This will be actually and that slope we call that actually compression index. c c this is this slope of this line is called c c compression index that is delta e; that means, e 1 minus e 2 divided by actually log p 2 minus log p 1 supposed to be. And log p 2 minus p 1 means actually log p 2 by p 1 that is what it is done.

So, this is actually slope of this line and if this is the slope of the line then I can find out if I apply pressure p initially and then if I apply pressure p 2 suppose cc is known then e 2 can be obtain e 1 minus slope multiplied by this. When p 1 2 in addition to the p if there is delta p is applied, this is delta p suppose. So, p 2 become p 2 equal to p 1 plus delta p if it is applied then actually what is the e 2 value, e 2 will be smaller than e 1. So, e 1 minus slope multiplied by log p 2 by p 1 that is what it is done.

So, ultimately you can see delta e equal to e 1 minus e 2 equal to c c into log or cc equal to del e by log 10 p 2 by p 1. So, this is the one thing from this curve you can find out the compression index and using this also you can find out the consolidation settlement and that is called compression, that is cc method. So, we will see that next one.

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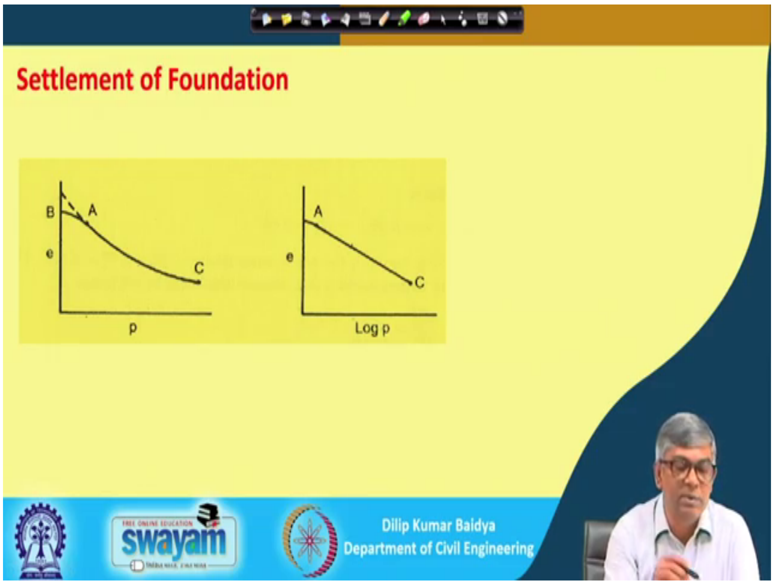

You can see many a times when you collect a sample and if you load it and then corresponding pressure versus void ratio plot then we get a curve like this. Initially it will not start from the higher value and decreasing constantly. It will be a low value and their curvature will be reverse and like that and then it will be a smooth curve down word curve like this. What is this actually suppose a point is what corresponding to what actually, when you sample when you collect the sample from a ground that is some there that time that the soil particles are will have a soil must will have a will be subjected to a particular pressure.

And when you sample it and take it out the pressure will be released pressure will be reduced. So, because of that you will be that that is why it is if this zone is a recompression zone. So, once this so when you reach to point A; that means, the pressure corresponding the field pressure then it will start from here face new curve, this portion is a virgin curve and this portion is B to A is the recompression curve.

So, because of that so if I put e log p, e versus p the same curve actually from A to C will be straight and A to B this portion will be little curve. So, we can ignore that part. So, between the portion which is straight I can consider that only because the beyond A that is because of this releasing of pressure there is a curvature, there is a defined curvature we have obtain, but actual nature you would have not collected the sample and same under same pressure we would have tested then you could have got from here actually.

So, because of that we need to, when you plot e versus p though initial there is a curve we know that virgin consolidation curve when you plotted in the semi log plot it will be a straight line. But normally the soil collected and tested, if I test and then based on the test results if you plot in a semi log paper then we will see initially there will be little curve and then from there it will be straight line. Why this curve portion?

Because of this is a recompression zone, this is not actual consolidation this is recompression because of pressure release its volume change is took place and then when we apply pressure the again compression will take place. It will go up to this one phenomena and beyond that there will be normal that is when we are increasing further from the field pressure. So, we generally consider this portion only, the straight portion and ignore this portion.

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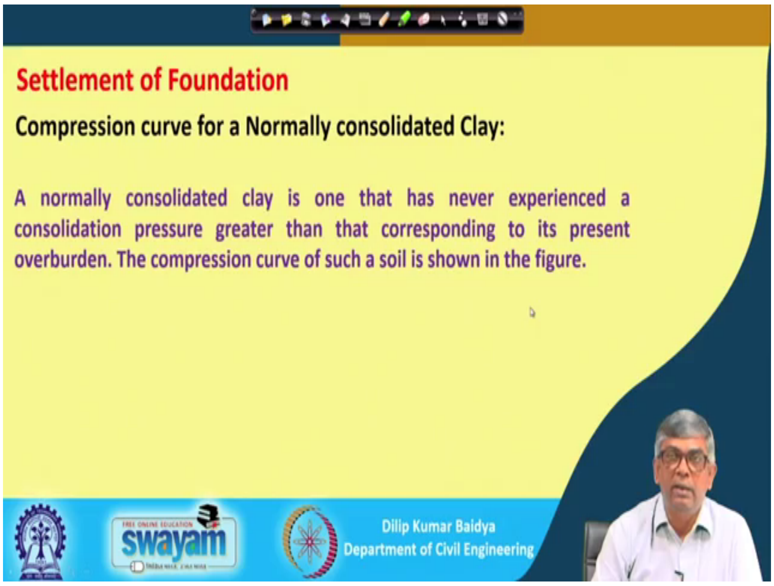

And then a normally consolidated clay is one that there is a in the there are in the field when you calculate consolidation there are two type of consolidation is there. One is normally consolidated, another is over consolidated; normally consolidated soil means what? The soil which has not been subjected to a higher pressure then the present overburden pressure.

So; that means, if there is a if the if you see the history than if I collect a sample from here whatever pressure we will get and it might have not got greater pressure than that. So, that is called normally consolidated soil.

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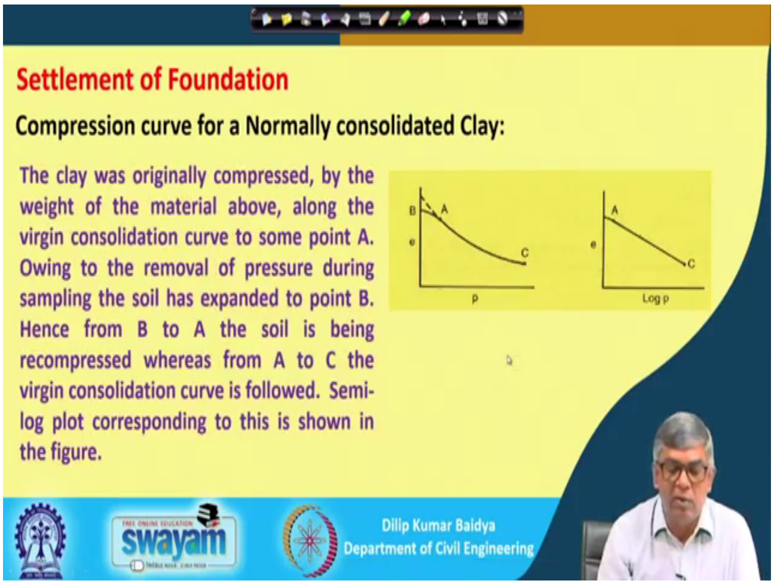

And when the soil is normally consolidated then plot is like this that I have already explained and then.

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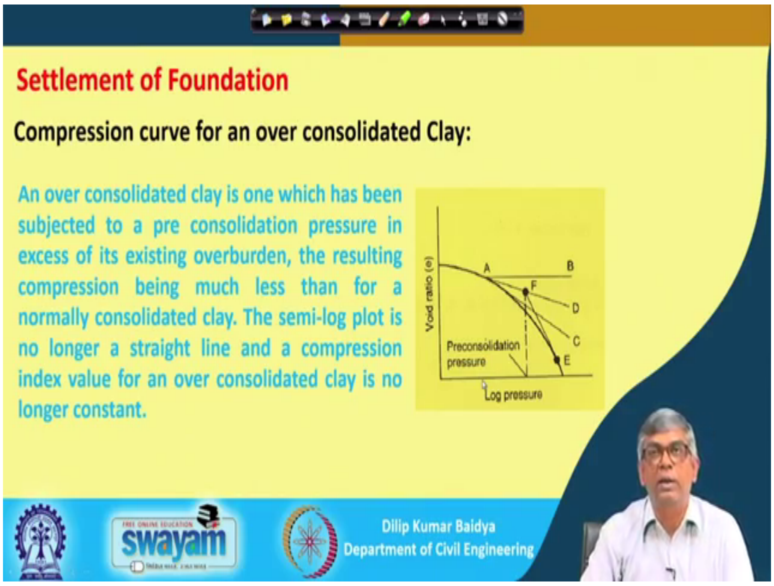

And if the soil is nor not normally consolidated; that means, the thus that is; that means, another one is the over consolidated; that means, if there is a deposit of clay layer suppose. If deposited clay layer something like this and then if I collect sample and find out what is the present overburden pressure and you may find that if you know the details of this the soil layer. You may find that this soil layer has been subjected by subject to a higher pressure then the present overburden pressure that means; it was already consolidated and because of some reason may be pressure is released. So, this type of soil this is called over consolidated there may be present overburden pressure whatever present overburden pressure it has been subjected to a higher pressure then the present one.

So, if the soil is over consolidated then we have to find out that over consolidation pressure and there is a method called suggested by Casagrande. That is how to find out over consolidation pressure and to find out this over consolidation pressure there is a sorry, one more thing I missed actually the normally consolidated soil as I have mention that if I plot normally consolidated soil we typically get a curve something like this. That means, initially there is a little curve and then straight line.

Whereas if I plot over consolidated soil if I plot over consolidated soil we will never get a, never get a straight line will be continuously curved one parabolic, a parabolic curve. Even though you plot this is log, this is log p and this is e and this is e versus log p and this is actually normally consolidated normally consolidated and it is over consolidated. If it is over consolidated this is this is never be a straight line, if it is not straight line then how to then automatically what it will be the conclusion this soil must be a over consolidated soil.

So, if it is a soil is over consolidated soil then the normal the normal consolidation theory whatever I have shown before; that means, the slope of the line is cc equal to delta e divided by log 10 base p 2 over p 1 this way we calculate and then there is a some formula find out consolidation settlement discuss. So, this is actually not there, that particular slope is different points slope are different.

So, to calculate the consolidation settlement for over consolidated soil generally we need to find out what was the over consolidation pressure, first we have to determine. And to determine this over consolidation settlement there is a procedure suggested by Casagrande and by according to this method actually what you have to do? You have to find out the point on this curve by I estimation, you have to find out the point of greatest curvature suppose this point is A.

So, you have to first locate the point of greatest curvature once you get the point of greatest curvature from there you have to draw an horizontal this is the one suppose A B it is the horizontal. And again from that point A you have to draw another line actually that is tangent, tangent to A. So, suppose this is A C, A C be the tangent to this point.

And then next part will be if this angle we have got A B line and A C line. So, it has got an angle between ab to ac there is an angle. Then what you have to do? You have to divide this angle is equally and that may and draw another line, suppose dividing this angle suppose CAB, angle CAB is there you can divide equally divide equally by line A D, you can draw the line A D.

So; that means, what is the procedure first find out the point of greatest curvature from their draw a horizontal and then again from that point draw a tangent and then that between the tangent and horizontal there will be angle and that angle you can divide equally by a line drawn A D. So, that so that we have got a A D line.

Next part is when this see the e log p curve and then you will see the it is continuously curve, but towards end maybe little tendency or becoming set and that portion actually you have to tangent, draw a tangent and produce backward suppose this is the one; this is the one. This towards end of the curve you draw tangent and produce backward to intersect line A D and when this line intersect with A D this line, that suppose this intersecting part is F suppose, intersecting point suppose F. And this F actually finally, you can the value F you can produced here on this the when you produce on the x axis read the x axis and that value of pressure will give you that is nothing, but reconsolidation pressure.

So; that means, what you have to do normally if the soil is normally consolidated then if you plot e versus p it will be curve, but when you plot in the semi log 1. That means, one side linear one side log then you will get a straight line. Whereas if the soil is over consolidated and if you collect the sample and test it and if the test results you plot in a e p curve that is curve and also if you plot in a semi log also it will also give a curve. Then in; that means, when you get a e log p curve curved 1 then that is actually the over consolidated soil if the soil is over consolidated then you need to determine the value of pre-consolidation or over consolidation pressure.

What is the procedure procedure as suggested by Casagrande the look at the curve find out the point at a greatest curvature suppose shown in the in this curve as A. And from a draw a horizontal and also from a it draw an tangent and then between this horizontal and tangent there will be angle made by this divide equally by another line suppose A D suppose this one and then from the main curve of the e log p curve. from the end you draw a tangent produce backward to intersect the divide dividing line that is ad and that intersecting point become the point and from that point you produced vertically on x axis and then read the x axis that gives you the preconsolidation pressure ok.

So, this is the so, that mean normally consolidated means the soil which has been which is present overburden pressure is the maximum overburden pressure or the soil layer has not been subjected to a higher pressure than the present overburden pressure what is the over consolidation pressure that the soil layer which has been subjected to a higher pressure than the present overburden pressure and in that case your e log p curves will not be straight line. And if it is not so if it is so, then you need to find out pre-consolidation pressure, what is the method that is method is pre Casagrande method and Casagrade method how to find out I have just explain I will not repeat again.

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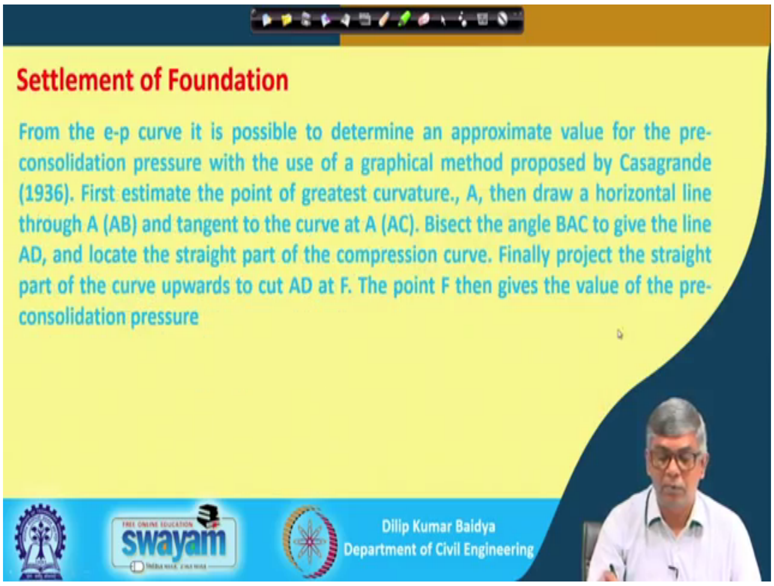

So, this is the procedure also written what I have mention, all are written here you have to draw a line on a from horizontal line from the point of maximum curvature then draw tangent. Then divide the angle then tangent from the state portion of the curve produced backward to intersect A D and find out locate the intersecting point F, from F you actually produce downward on the x axis and then read the x axis.

The x axis valued pressure the pressure value with the x axis is nothing, but the pre-consolidation pressure of the of the soil ok. So, this is the way you one has to find out the pre-consolidation, once you know the pre-consolidation pressure then we following next step we can find out the consolidation total settlement that I will come I will discuss a later on; thank you.

Thank you.