Geotechnical Engineering II / Foundation Engineering
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Lecture - 17
Settlement of Foundation

Good morning, let me introduce a new topic after bearing capacity this is a new topic the Settlement of Foundation and you know that when a footing is let me go to the next slide and then I will show you.

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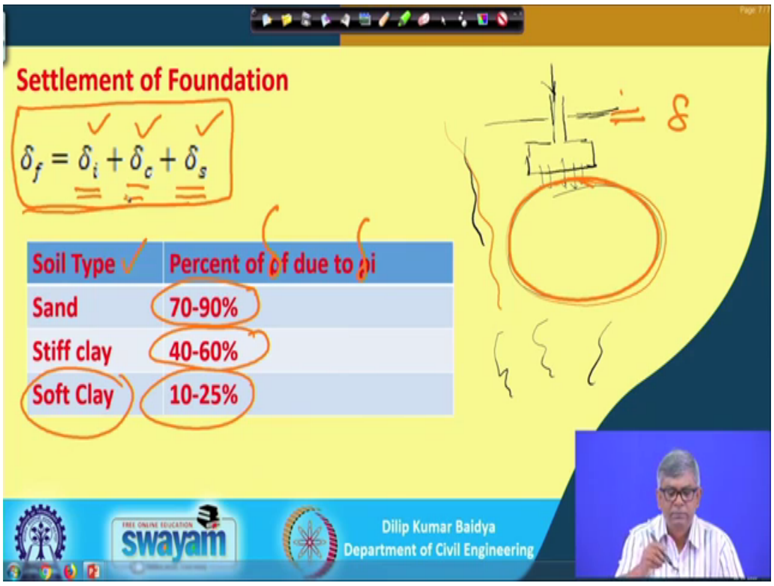

Suppose there is a footing suppose like this and it is loaded and then you will have because of this loading that bearing capacity failure is a one possibility if the load is excessive and another possibility is that because of this loading the foundation will go move downward and because of the compression of the soil in this zone. And this compression because of many reason some of the things I have discussed in the soil mechanics also and you might have read some in the previous courses.

And that this compression of the total compression what we will see at the surface will be consisting of three components. And they are actually so, so, this is the one; that means, it will be consisting of three component as I have already mentioned. And suppose if there is a surface movement because of this foundation that movement is total suppose delta and since I have mentioned that delta will be consisting of three parts and they are actually this is one part this is one another part and this is the another part.

So, delta f; that means, delta footing or delta final also sometimes say the final settlement will be delta i plus delta c plus delta s. Delta i means it is a immediate settlement; immediate settlement will happen will happen because of the elastic property of the soil like a member if I pull if there is a circular member like this. If you pull or push then because of this either tensile or compressive load either it will be elongate or it will compress similar to that when the load is applied to this soil it will be under subjected to compressive load and under that compressive load and because of the elastic property of the soil there will be some compression and that is called immediate settlement.

And then another thing is if the soil is fine grain and saturated and when you apply load then I have discussed in the beginning also in the review of soil mechanics that there will be a consolidation mechanism will appear and that consolidation mechanism is what actually because of this loading that your poor pressure within the soil will be developed. And then with time that poor pressure will be dissipated and then that extra load will be transferred to the soil grain when the load transferred to the soil grain.

Then the soil grain will be push towards each other and then and that result in actually compression and that reduction in void ratio that delta c in the consolidation settlement that happens because of the reduction in void ratio of the soil mass.

And that is the property that mechanism will be there for saturated fine grained soil. And another is delta s that is after completion of the consolidation settlement still after a long time also there may be some amount of a settlement and that is called say secondary settlement and that happens because of many reason a creep and other effect. So, these three parts actually will be the total settlement of the foundation. If the soil is only on sand then we may not see the consolidation and if it is on the only clay and then in the clay soil then elastic also will be there it will be small but, consolidation will be major and this also may be there.

So, like that depending upon your soil type different parts will have different magnitude. So, if I summarize that then you can see here that it is given soil type and it is sand stiff clay and soft clay and percent of rho f the rho it is not rho since I have used delta. So, this is delta percent of delta f due to delta i so; that means, delta i means immediate settlement. So, when it is sand the total settlement will be consisting of 70 to 80 percent because of the elastic settlement when it is a stiff clay it is 50 percent elastic settlement 50 percent maybe around consolidation settlement and if it is a soft clay then it is 10 to 25 percent, it is elastic settlement and majority will be consolidation settlement.

So; that means, now the foundation can be resting on a different type of soil at different groundwater condition and because of that if I apply the load then you have a settlement and that settlement can be of combination of delta i delta c and delta s. So; that means, you have to learn to find out how to find out delta i how to find out delta c and how to find out delta s? And let me show you the next slide.

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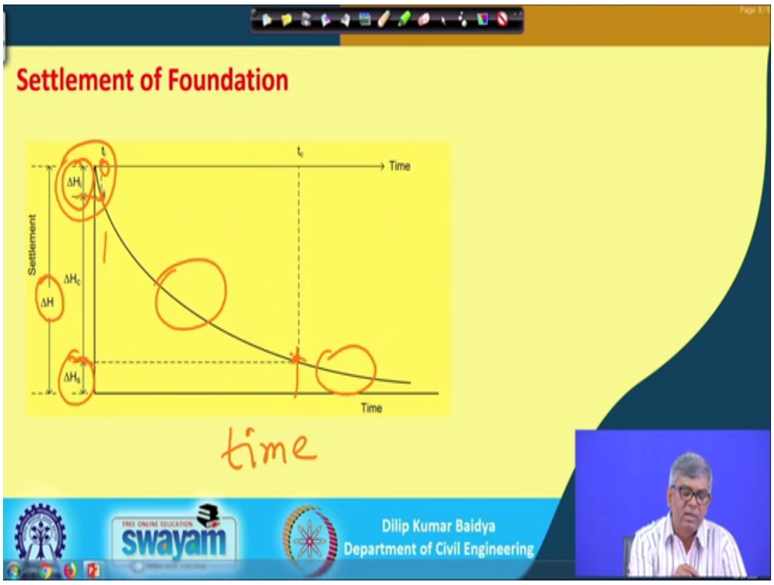

And you can see here that that is another point I want to highlight here that as I have told that there are three components; delta i delta c and delta s and if i plot this total consolidation total settlement over time settlement over time then you get a plot like this is time axis this is time.

And you can see this,this is total settlement of suppose foundation delta H and then you can delta H and this is actually delta i this small portion is because of the it can be more also with some soil, but suppose it is a c phi soil then your delta Hi is this much and time is this much. That means, immediate settlement will happen actually immediately very little time. Whereas, consolidation settlement starts from here and may be end up consolidation may be here and that means, from here to here is the consolidation settlement that amount is generally large and fine grained soil. And you can see to complete the consolidation it starts from here and end here; that means, this is a long time the consolidation settlement is a time dependent that is generally several years it may take some time.

And you can see the beyond this end of consolidation the foundation may further undergo some amount of compression and you can see very mild slope which is going downwards and ah; that means, with time there may be some amount of settlement that is because of creep and arrangement of particles etcetera. And that actually you can see delta s that amount is quite small again and time actually cannot predict actually we can estimate at maybe 10 year or 20 years then accordingly you can estimate how much it will be. So, it is supposed to be continued for or long so; that means, from this figure I wanted to highlight that the foundation settlement will be consisting of three parts; one is immediate settlement, consolidation settlement and secondary compression.

And this immediate settlement will be immediate the by the name itself or it is called elastic settlement and consolidation settlement is a time dependent it amounts sometimes it will large for some soil and it will be for a long over a long time it will be happen. And secondary compression also after end of consolidation till maybe further compression and that with time how much. So, that can be estimated there are some methods. So, we will discuss that.

But here I wanted to point out that this consolidation settlement is a time dependent and immediate settlement is the quick means, immediately after loading and secondary compression sometime is not that important most of the time we do not compute we do these two. So, we will try to learn these two aspect elaborately.

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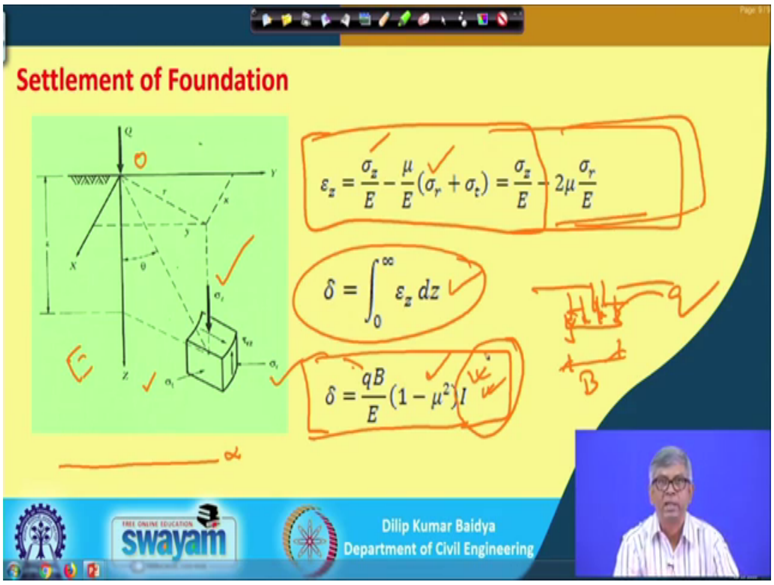

And you can see now which I have discussed also in the soil mechanics and also you might have learned from some other books and other that when that is a load applied on the surface. And if I consider a axis symmetrical case and then there will be component of forces that will be vertical pole or vertical stress there will be sigma t, sigma r, then tau and all those things will be there.

And if I consider one element so, somewhere here and that strain on that element will be can be written in this by this equation. And sigma z is the vertical stress component, sigma r is the radial component and t is the tangential component. So, this three component and for axisymmetric case sigma r and sigma t is equal then you can further modify this into this form or this form.

And now this epsilon at a particular point and if I integrate that epsilon that strain over the depth of the soil then I can I can get the total settlement this is for elastic. I am considering now elastic only assume the soil is elastic homogeneous subspace and there is a load applied on the surface and because of that loading are at a particular point I am trying to find out the strain and then I am trying to find out the settlement by integrating over the depth. Suppose the soil is extended up to this then I will be integrating from 0 to suppose this is suppose theoretically infinity. So, that actually I can integrate.

And this is a detailed mathematical um procedure and it is a theory of elasticity can be book can be made for details, but finally, if you do if sigma r sigma z whatever given by the bossiness if I substitute here and integrate by this way then finally, you get and the a settlement expression similar to this.

So, we can see here the q is the, if there is a footing here then that q is actually a pressure applied on the soil through the footing. So, this is q and B is the width of the footing and E is the Young's modulus of the soil E and mu is the Poisson's ratio and I is a in is an influence factor. And this influence factor actually to incorporate that the footing shape may be circular strip rectangular or any other shape and also similarly footing can be of a flexible type or rigid type.

So, to consider those effect consider all those things this I can be brought here one factor. So, qB by E 1 these are the things are known and this is the thing to be calculated. In fact, if we integrate this for different soil foundations saved with different pressure distribution we can get different expression, but those expression finally, expressed in a generalized form keeping this only one unknown is kept and that unknown actually for different soil or different sorry different footing size at different pressure type this will vary.

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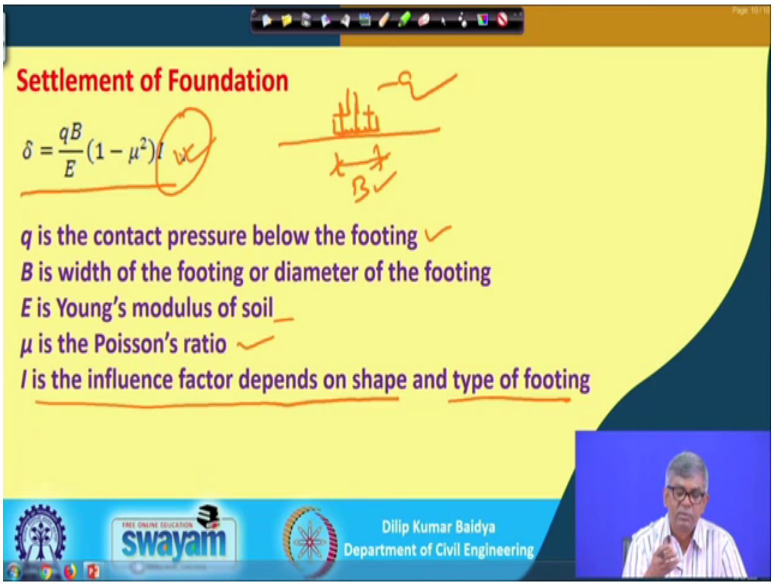

So, I will go to the next slide and. So, that you can see here that expression delta equal to qB E by 1 minus mu square I and q is the contact pressure below the footing; that means, if the footing is here. So, so through this footing what is the pressure? That is q and B is the width of the footing. If it is a rectangular then it is a smaller dimension if they strip the width of the footing it is square in the width of the footing and if it is a circular it is diameter of the footing. And E is the Young's modulus and mu is the Poisson's ratio and I is a influence factor depends on shape and type of footing; type of footing means whether it is rigid or flexible or some other in between.

So, this is the expression we can use for finding out settlement. So, that mean I need actually if I want to estimate for a particular footing for which loading is known Young's modular soil is known Poisson ratio is known I need actually I.

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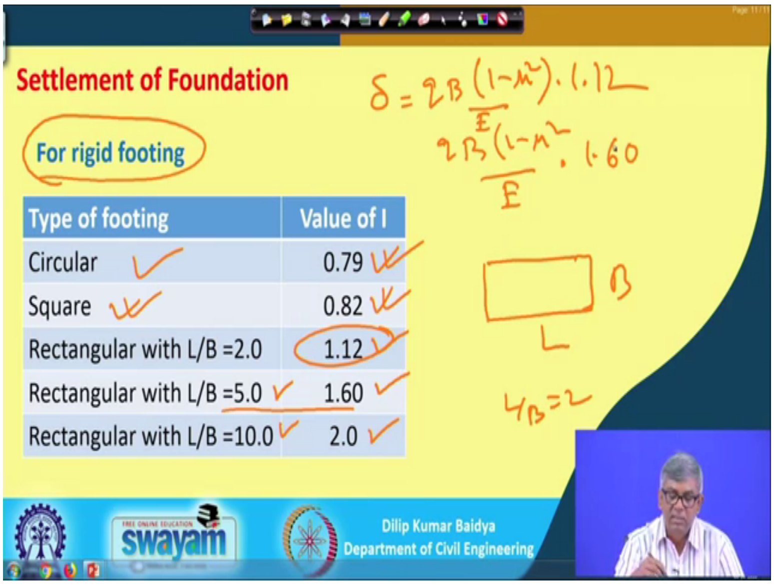

For that actually there is a different people actually over the time calculated those integrated and finally, given the value. And you can see if the type of footing then if the if the rigid footing if the footing is rigid if the footing is rigid and then again type of as I have told you that I is function of footing type and shape.

So, again now circular shape it is a rigid footing of circular shape then I will be 0.79 if the rigid footing of square shape then I will be pointed to rectangular footing with L by B is 2 L by B is 2 means, this is like this if this is L and this is B. So, L by B actually 2 then this I is 1.10 and rectangular footing again with L by B equal to 5 1.6 and L by B actually 10 then it is 2 and in fact, if the L by B become more than 10 better to assume by the strip.

So, up to that actually I have given the value so; that means, if I want to find out a footing of rectangular footing of L by B equal to 2 L by B equal to 2 then I will be getting the delta will be equal to q B qB 1 minus mu square multiplied by I will be directly I will take 1.12. Similarly, if I want to find out L by B equal to 5 then it will be same q B 1 minus or qB by E actually qB 1 minus mu square by E multiplied by 1.6. So, like that I can easily find out using these values.

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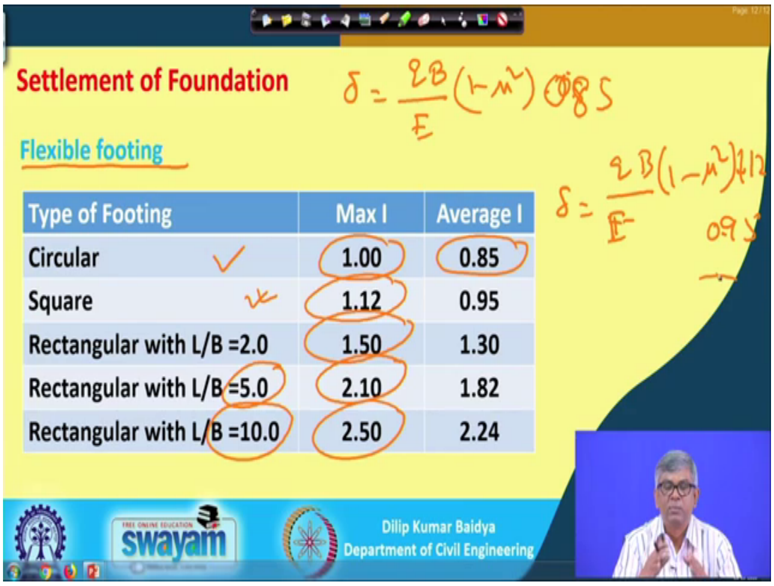

Similarly, if the footing is flexible if the sorry if the flexible footing if the flexible footing and again different shape will be a circular then when the footing is flexible actually settlement will not be same everywhere. When a rigid footing their settlement is same everywhere and when the flexible footing settlement with different places will be different and you can see your the expression we have got.

According to that expression I actually for circular footing is maximum I is 1 for square footing maximum I is 1.12, for rectangular footing with ratio 12, maximum I is 1.5, rectangular footing with L by B equal to 5, the maximum value of I is 2.10 rectangular footing with L by B equal to 10 they are actually maximum value of this actually 2.5.

So, sometime since a different point actually a different settlement so, because of that instead of using that maximum value sometime we may take average value which will give you better design. So, sometime that there is a some people actually given this average value also average I for circular footing is 0.85; that means, for a flexible footing if I want to find out circular flexible footing of diameter B then I will get delta will be equal to q B divided by E multiplied by 1 minus mu square multiplied by 0.85 sorry 0.85.

So, instead of I can I could have taken, I can work also based on maximum value then I will use 1, but if I would not be use average value then I will use 0.85. So, this is the way one can find out. Similarly, if they want to use I want to estimate settlement immediate settlement or elastic settlement for square footing of width B. Then I can find out delta will be equal to qB by 1 qB by E 1 minus mu square multiplied by a maximum it will be 1.5 sorry square it is that 1.12 and if I want to use average value then I will use 0.95.

So, like that by this equation and combination of this equation and this table one can find out the elastic settlement of the footing if you know the width of the footing and elastic modulus and Poisson ratio of the soil is known.

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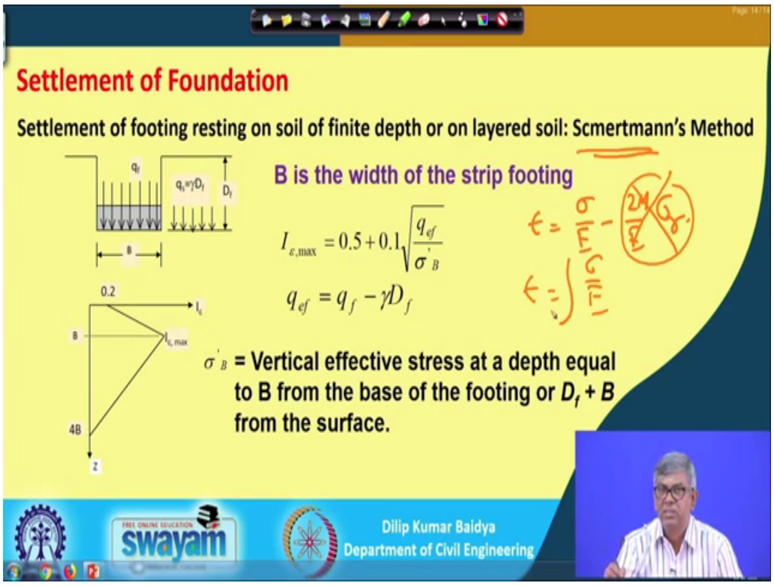

So, this is actually your plane actually the footing is resting on homogeneous elastic half space what is the meaning of it? That means, your footing is here and suppose and this one up to a great depth the homogeneous same soil is there and in that case that; that means, we have integrated 0 to infinity.

So, the theoretically we assume that a soil is same up to the quite large depth. But sometime in actual and the field condition there may be multiple layers below the footing and also it may be um up to some depth the soil and then there maybe rock that means, there is a soil there is a fine it. In that case we will not be able to use that equation because the I is obtained based on the integration from 0 to infinity whereas, from some depth to infinity that some depth that is actually soil is not compression which is a rock incompressible if I consider in that case that will not be applicable.

So, for that actually to find out the settlement resting of footing resting on a finite layer of soil or one resting on a multiple layer of soil then we have to use some other method some other technique and that technique is suggested by a Scmertmann that is actually this is the name of the person Scmertmann he has suggested this method. And I have shown that your epsilon equation equal to sigma by E minus 2 mu by E into sigma r and then what is this below the footing just close to just close to the foundation and below at sigma r has some value significant value.

But, if you go little deeper like 0.5 B your B beyond then this sigma r value is very very small ok. So, because of that in the contribution of strain effect of this may not be that significant and can be ignored. So, simply I can do epsilon equal to sigma by E. If I know the vertical says and divided by E if I do then I can get the strain and again if I integrate this strain then I will get the compression they are I have just ignoring some portion and which will be actually favorable.

So, because of that considering this concept, the Scmertmann are these observation, Scmertmann suggested this method. Again for developing this method what the he has observed that he has tried to see the vertical stress distribution when will be load apply the load on the surface when you apply load on the surface through footing how pressure distribution will be there below the footing. So, that he has tried to observe and he has seen the pressure distribution or something like this it is a curve at some depth it become maximum and close to a surface some finite value and at some depth it will become 0.

So, based on this observation for different size of footing he has suggested to model; one model for strip footing you can see for strip footing this is the model and in this actually what he has given?

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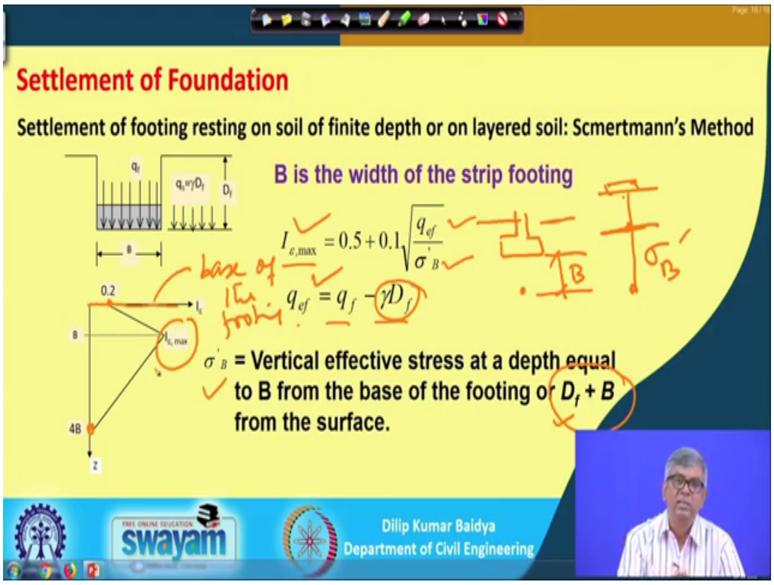

That this is actually this line actually it is just base of the footing base of the footing from here he has given a diagram the at the base of the footing value is 0.2 and at a depth of B that is instrument factor that is the Ie max I epsilon max and at 4 B depth that the epsilon that strain because of the load at this load applied at this surface at 4 B depth suppose strain is 0.

So, that is the concept he has used that surface with this 0.2 at B depth that is I epsilon max and at 4 B depth it is 0. And he has given the value of I epsilon max in terms of 0.5 plus 0.1 under root q effective by sigma B dash and q effective is are effective equal to qf minus gamma D f. Qf actually if it is a truth of footing if you applied pressure is q here and since footing is placed at a depth D so, gamma times Df can be subtracted to find out q effective.

So, if you know the q effective and then sigma B dash sigma, B dash is what? At B depth from the footing base what is the effective stress that to be obtained. So, if the footing is here and if the footing is here below from the below the footing at a B depth at B depth what is the sigma B dash effective stress. So, that to be calculated and q effective to be calculated and then using this equation one can find out I epsilon max and then I will get this dark diagram ok. So, I will get the 0.2 here at B depth is this much value and at 4 B depth is 0. So, then I will get this diagram once I will get this diagram so, everything is clear that written here.

Sigma B dash is vertical effective stress at a depth equal to B from the base of the footing or Df plus B from the surface; that means, if the footing is somewhere here suppose footing is here then I am taking the I max will happen at this depth this depth actually B. So, B from the base of the footing or Df plus B from the surface of the footing. If the footing is on the surface then it will be simply B and if it is B is at a footing is at a depth D then that is Df plus B from the surface.

But, if I consider from the base of the footing it is b. So, that sigma B to be calculated q effective to be calculated Ie at max to be calculated then complete this diagram. Once this diagram is completed then using this diagram how to find out the settlement, I will come later on and this is model is applicable for only strip footing.

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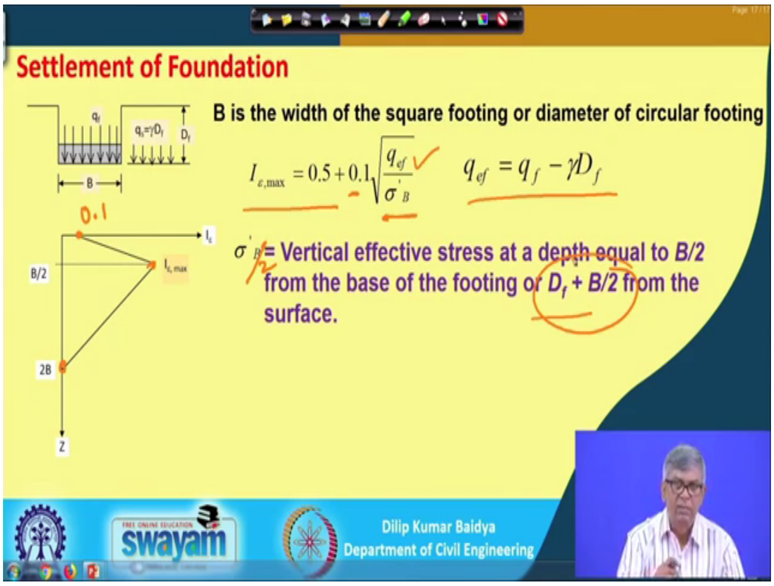

Similarly, he has given for a another type of footing that is which is applicable for square and circular square or circular footing and this is the diagram. You can see here this value is missing this will be 0.1 and you can see the diagram is almost similar only the value is changing you can see there actually at B depth from the base it was becoming Ie max.

Whereas, here in the circular and square footing it is becoming maximum at B by 2 depth that is only one difference they are actually value as surface value as 0.2 here surface value is 0.1 that is second difference. And there actually is final strength becoming 0 at B depth and here actually 4 B depth and it is actually here at 2 B depth there it was 4 B depth here it is at 2 B depth.

So, three differences one is this value at the surface Ie max at a B by 2 depth instead of B depth and I strain 0 at 4 2 B depth instead of 4 B depth. So, these are the three changes near addition to that Ie max equation also my minor difference it is 0.5 plus it was 0.2 times this, but it is 0.1 times. Now, since the value is 0.1 and q effective is same q f minus gamma df and this sigma B dash is also same at a sigma B dash is here also different because, sigma B dash instead of sigma B dash I can write sigma B dash a sigma dash B by 2 because, it is from the B by 2 from the base because I am trying to find out maximum from B by 2 from the base of the footing.

So, these are the things. So, if a B if the base of the footing is a B by 2, but if I want to find out from the surface of the footing then Df plus B by 2 this has to be remembered very carefully so, that we once you know this two model. Using this two model one can find out the settlement using this equation.

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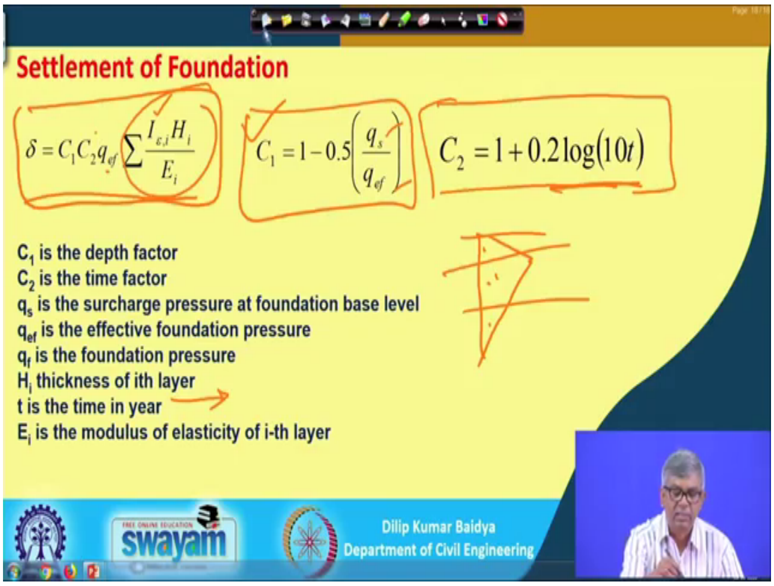

This is actually final expression of settlement equal to delta equal to C 1 into C 2 into multiplied by q effective sigma I Ei Hi divided by Ei and what is IEi?

So, diagram was like this your diagram was something like this, but in this different layers maybe there. So, different layer what is the value of I i so; that means, IEi multiplied by thickness divided by E. So, that way we will get the settlement of particular layer similarly if I go to a second layer. So, I E 2 a multiplied by H 2 divided by E and then we will get second layer.

So, like that all if n number of layers are there so, n number of component will be there. So, that to be some and that multiplied by q effective multiplied by 1 multiplied by C 2 will be the total settlement. The C 1 expression is given like this C 1 is equal to 1 minus 0.5 qs by q effective, qs is the pressure through the footing is applied and q effective already I have mentioned.

And C 2 is 1 plus 0.2 log 10 t and t is the time; that means, this is a because of to introduce the secondary are a long term settlement that long term settlement can be estimated by using this expression or factor called long term settlement. And 10 t is given t is time in year actually if it is said that what is the settlement after 6 months then it has t to be taken as 0.5 if it is mentioned that after 10 years, then t will be taken as 10. So, by using this equation I can find out C 2 by using this one I can find out C 1 and from the using the previous diagram I can find out this component and then this will become the total settlement of the footing elastic settlement. So, with this I will stop here.

Thank you.