Geotechnical Engineering II / Foundation Engineering
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Lecture – 16
Shallow Foundation (Contd.)

Let me continue again once again on Shallow Foundation. And in the previous lecture I have discussed about something on combined footing and that it also one type of shallow foundation. And there are another type of combined for strap footing is there, but I am not discussing that. Let me go to another type of strap footing sorry, another type of shallow footing help shallow foundation in fact, we can say and that is actually raft or mat foundation.

And I have the way I have mentioned that most of the time one column will be connected with the footing that is called isolated footing and when isolated footing is not suitable because of some reason we are going for a combined footing. And where the different situation suitable for combined footing I have mentioned similarly, where exactly we require mat foundation? I will go fast and then different types of mat foundation I will discuss and then I will close today the bearing capacity or shallow foundation topic with this a summary.

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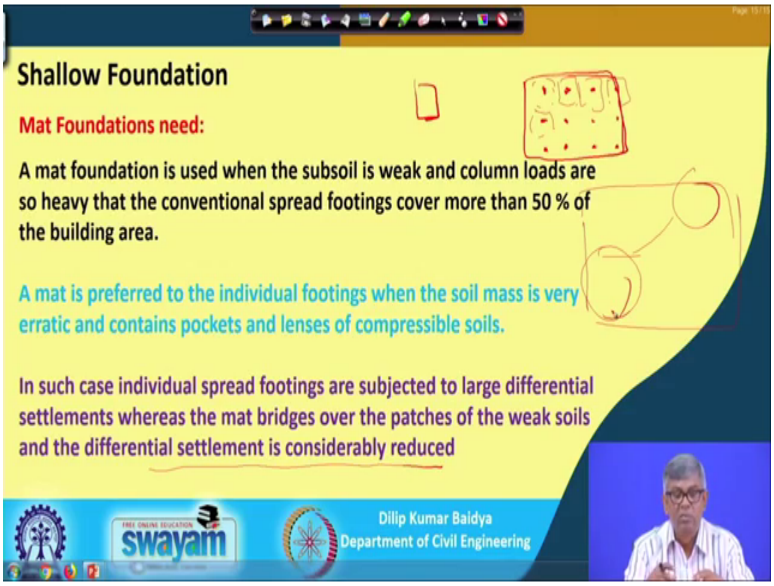

Shallow Foundation

Mat Foundations need:

A mat foundation is used when the subsoil is weak and column loads are so heavy that the conventional spread footings cover more than 50 % of the building area.

A mat is preferred to the individual footings when the soil mass is very erratic and contains pockets and lenses of compressible soils.

In such case individual spread footings are subjected to large differential settlements whereas the mat bridges over the patches of the weak soils and the differential settlement is considerably reduced

Let me see that like mat foundation need ok. Mat foundation is when the subsoil is weak and column loads are so heavy the conventional spread footing cover more than 50 percent of the building area. So, now this suppose you have a number of columns suppose like this, I will just put a dot suppose these are the location of columns, columns, column, column, column, column, column these are a these are dots are actually column. And if I designed a suppose the foundation soil condition is not good and if I try to designed isolated footing all then you will be covering almost entire area, isolated footing.

So, instead of doing so many small footing it will be easier to give a common foundation here ok. So, that is what that is the one of the areas where actually you go for mat foundation. That means, when the subsoil is weak and column loads are heavy and because of that if you designed the conventional spread footing, then it will be covering more than 50 percent or even 70, 80 percent in that situation it will be better to have a common foundation that is called mat or raft.

And a mat is prepared to the individual footing when the soil mass is very erratic and contains pockets, a loss and lenses of compressible soil. That means, a the foundation building area suppose this one and within this area there may be a large variation in soil type. So, in that case if I do isolate footing the different footing will behave differently and then that create some problem to the building and it will give distress to the building elements that may column and beam, it will be some problem will be the cracks will form.

So, that is another area when the below the cover area of the building if the soil vary too much and there are lenses of compressive of some corner suppose there is a compressible soil, some soil may be good soil. In that case if I use the isolated footing it different places within this zone, then it may have the problem to the building that is another area where actually you go for a common foundation that is called mat and raft.

And when actually because of this different condition different loading and all those thing and if we design for individual footing then what will happen different footing also will settle differently that mean differential settlement may be a problem. So, because of that that if there is different columns having different loading and too much variation is there and soil is also different, then there is a chance of having differential settlement.

Differential settlement there is a limit actually, if you go beyond that it creates problem to the building.

So, that is what that is another reason where actually if we go for this type of common foundation mat that will give a bridge, mat that mat bridges over the patches of the weak soil and the differential settlement is considerably reduced ok. So, because of this instead of two different soil, two different footing then they will settle differently, but if I give a common mat then they will try to settle together and it will minimize the differential settlement, differential settlement between the two footings. So, that is these are the different areas where we can go for mat and raft foundation.

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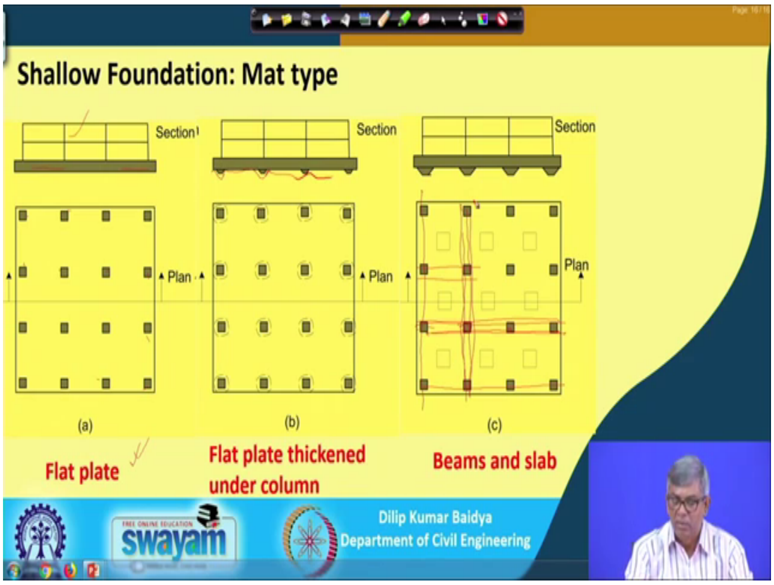

Shallow Foundation: Mat type

Flat plate

Flat plate thickened under column

Beams and slab

And then now will see the types of mat or raft in the next slide, you can see there are several types of raft and mat foundations are available. First one is here that is flat plate; that means what? You can see I have shown here both the plan, this is the plan these are the column location these are all the black spot or column location and this and this outer boundary is the boundary of the foundation. And if I take a section here then I will see this is the building part and this is the foundation part; that means, what they common plate like throughout the building just like a thick plate first constructed and through that plate the columns are erected. So, that is called flat plate type your mat foundation or raft foundation.

Similarly, almost similar, almost similar that it will be a flat plate only, but in the column location in the, these are all column location these are all different columns. In the column location wherever there is a column, below the column there may be little thickened bottom side. Initially the initially there will be some extra structural part will be there and wherever there are columns and just over that; that means, your this plate will be thickened at this column location, you can see here it is here it is here like this. And then again over that flat plates are constructed and from their actually columns are erected that is called flat plate thickened just below the column location only.

And this is actually another type, actually beams and slab; that means what? you can see these the slab will be there, but below the slab there will be beams so; that means, this columns this columns will be connected by one beam and this side also connected by beam. So, initially there will be beam like structure on the ground and then the when this two beams are meeting here from this point, the columns will be erected. From when it is meeting here columns are erected so; that means, this will be designed as a beam, this will be designed at the beam we that different loading here and here and then over that there will be a plate.

So, below the plate there will be like a beams both direction. So, this direction beam will be connected the by this beam, this direction columns will be connected by this beam that there are like a there is a net like structure will happen first, beam both direction. And on that beam will have a flat slab and then on that slab there will be from the all columns will be erected. So, this is called beams and slab type of mat.

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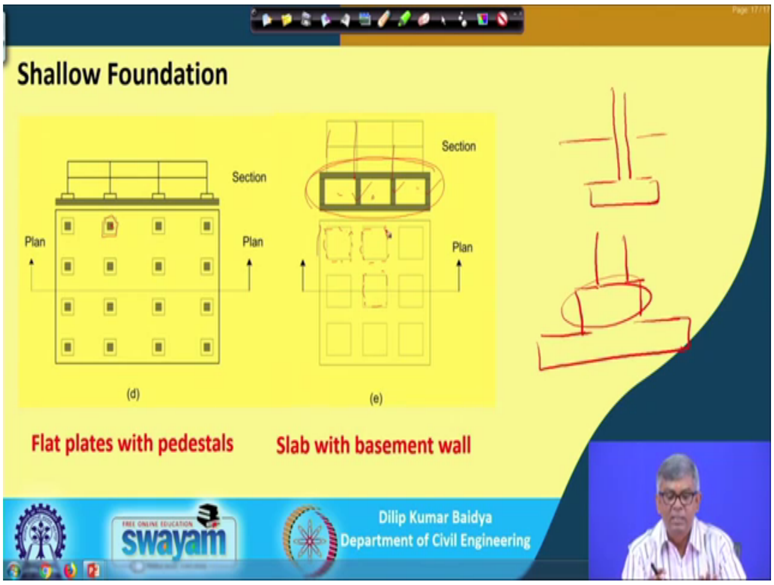
Shallow Foundation

Flat plates with pedestals

Slab with basement wall

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Next one you can see these, this is actually flat plates with pedestal you can see initially there will be flat plate like a concrete mat will be constructed and wherever there is a column. So, before starting the column there will be little wider pedestal will be made and from there it will be column will be little reduce to it and then it will be erected. So, you can see this, this is actually column the black one and because of pedestal will be this is widened and form the center of this the finally, column will be erected.

So, this is actually flat plates with pedestal that mean below the column, below the footing like pedestal footing is to be there like if I have footing can be two types. One is footing one column is like this, this is one type of footing and another type of footing is pedestal; that means, this is coming like this then pedestal will be there and then you have actual footing. This is called pedestal type of footing.

So, similar type of things will be here every column location this pedestal will be there. So, this is called flat plates with pedestals and then another type of is can slab with basement; that means, you can see these cross section you can see this cross section here. This should suppose to be dotted actually, you will not see this suppose to be dotted actually and this should be dark the outer boundary. We can see that initially there will be plate at the bottom and then there will be wall basement wall, then again there is a plate and in between there may be wall because if the building width is suppose 20 30 meter that slab cannot be so wide.

So, in between there is a need support. So, in between along the column direction you can see a column direction there will be wall intermediate wall and so that means, this is outer wall and this is intermediate wall in the similar this is actually in this direction. So, other direction also similarly will have wall. So, this is actually this part, entire box type of structure with basement wall and basement bottom floor, basement top floor this total together is as the foundation and from this basement structure that columns will be erected for the building. So, that is actually slab and basement and this basement area can be utilized, many buildings will have basement floor sometime more than one will be there. So, this is also one type of mat foundation or raft foundation.

So, these are actually just for the just to mention or to show what are the different types of foundation available for shallow foundation I am just giving this one, the design of the mat foundation actually out of this scope of this course because it is a totally concrete design actually. So, when there is a slab type so you have to design as a slab, when it is a slab connected with beams the first beam has to be connect designed, then slap has to be designed individually so there are some procedure. So, I will not go in details, only this is also one type of shallow foundation and I am just mentioning that.

So, with these actually basically your shallow foundation topic is complete. Now what I will do whatever by 10 lectures actually whatever I have given, I will try to quickly summarize so that it will be helpful to you to memorize what is, which part is important and which you have to study with a more detail. So, I will summarize very quickly.

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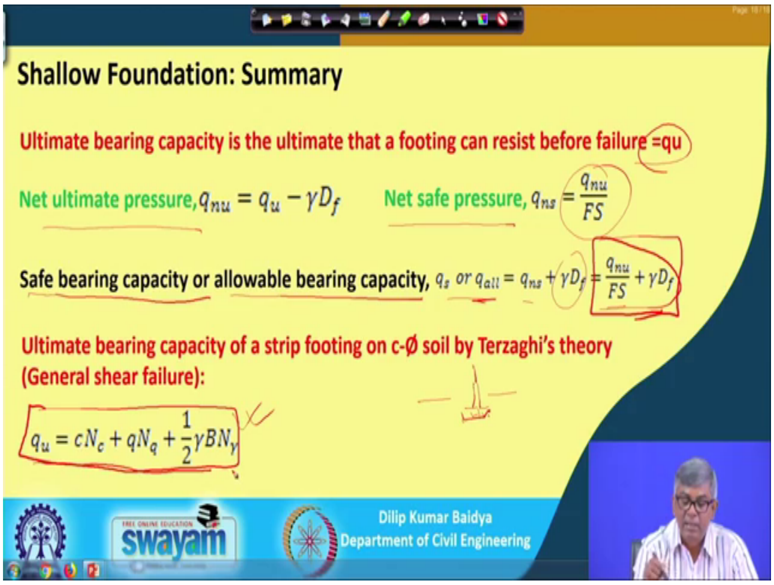

Shallow Foundation: Summary

Ultimate bearing capacity is the ultimate that a footing can resist before failure =qu

Net ultimate pressure, $q_{nu} = q_u - \gamma D_f$ Net safe pressure, $q_{ns} = \frac{q_{nu}}{FS}$

Safe bearing capacity or allowable bearing capacity, q_s or $q_{all} = q_{ns} + \gamma D_f = \boxed{\frac{q_{nu}}{FS} + \gamma D_f}$

Ultimate bearing capacity of a strip footing on c-Ø soil by Terzaghi's theory (General shear failure):

$$\boxed{q_u = cN_c + qN_q + \frac{1}{2}\gamma B N_\gamma}$$

We can see that I have defined different types of pressure that is ultimate bearing capacity in the (Refer Time: 13:07); that means, ultimate bearing capacity is what actually when there is a footing, there is a footing if you continuously you load it, then some time it will fail. So, before failure whatever pressure it is taking that pressure actually ultimate pressure and we denote by qu and net ultimate means if the footing is placed at some depth that because of this excavation work structure so that should be deducted.

So, net ultimate actually ultimate minus the structures, and net shape is what? Actually net ultimate divided by factor of safety; ultimately we use the pressure with some factor of safety. So, net safe actually what? Net ultimate divide by factor of safety, and here factor of safety generally between 2 to 3 for foundation engineering.

And finally, what will be using safe bearing capacity or allowable bearing capacity that will be equal to q ns; that means, from this equation and add gamma D f such are finally, because gamma D f itself no factor of safety is required. So, because of that I have applied factor of safety here and finally, I am adding there. So, q ns will be q ns plus gamma D f the q nu by FS plus gamma D f this become actually finally, allowable bearing capacity and that has to be used for all calculation sizing of footing etcetera.

Now, after defining this I have described Terzaghi's bearing capacity theorem, what are some assumption etcetera that also you have to go through. But I am not going to those assumption only things Terzaghi initially gave for c phi soil for a strip footing ultimate bearing capacity in general shear failure condition. And that based on general shear failure strip footing bearing capacity was given by Terzaghi in terms of three factors N c N q N gamma they are cN c plus qN q plus half gamma BN gamma and these N c N q N gamma is a function of phi it is a available in the form of chart table. And so this is the one given by initially for c phi soil by strip footing.

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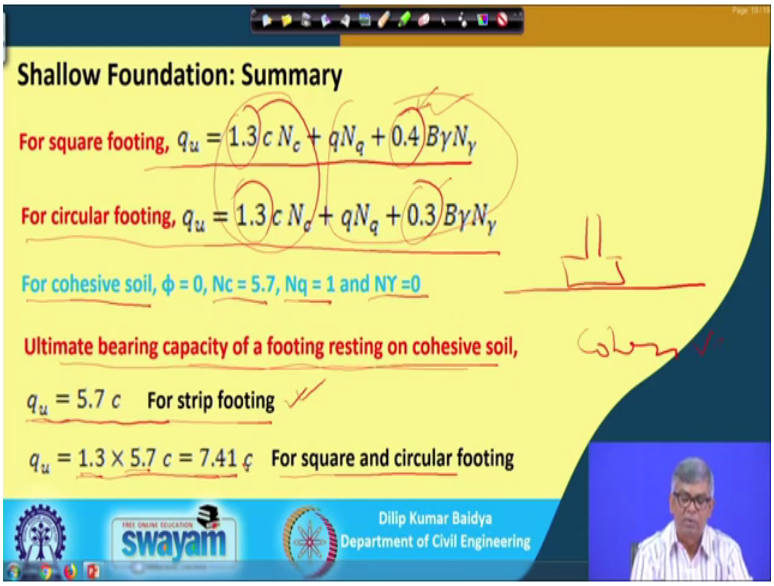

Shallow Foundation: Summary

For square footing, $q_u = 1.3\, c\, N_c + qN_q + 0.4\, B\gamma N_\gamma$

For circular footing, $q_u = 1.3\, c\, N_c + qN_q + 0.3\, B\gamma N_\gamma$

For cohesive soil, ϕ = 0, Nc = 5.7, Nq = 1 and NY =0

Ultimate bearing capacity of a footing resting on cohesive soil,

$q_u = 5.7\, c$ For strip footing

$q_u = 1.3 \times 5.7\, c = 7.41\, c$ For square and circular footing

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And if we then he has suggested also for so, ultimate bearing capacity for square footing he has given by this equation 1.3 c N c plus qN q plus 4 0.4 B gamma N gamma and similarly for circular footing he has given 1.3 cN c qN q plus 0.3 B N gamma. You can see from the strip footing, what is the difference? It is 1.3 multiplied here and for strip footing it is 0.5. When it is circular a square it is 0.4 when it is a circular it is 0.3 and B here, actually when it is strip footing it is width of the footing, when it is a square footing it is a width again and when it is a circular footing it is a diameter. So, these are the things to be remembered.

Now, if I this equation can be modified to different condition or this equation can be modified for different condition that is, what is the condition if I consider for a cohesive soil. That means, phi equal to 0 then if you go to the table we will see that Terzaghi's table N c is 5.7 Nq is 1 and N gamma is 0 and if I use 0's in the appropriate equation for cohesive soil, phi equal to 0 and then you will see that and then ultimate bearing capacity of footing resting on cohesive soil. That means, this is the footing and the soil is these and this is cohesive. In that case actually structured part also not there, since c is 0 then sorry since N q is n gamma is 0 third part also will not be there.

So, because of that q ultimate ultimate bearing capacity of footing resting on cohesive soil will be only 5.7 c for strip footing and this N c is 5.7 c is given by Terzaghi. So, 5.7 c for strip footing and when will go for square footing then it become 1.35 into 5.7 c. So, it will 7.41 c for square footing and if you go for your for it is of course, both for square and circular actually you can see if this is 0 and if this is not there. So, only this is the value so both for square and circular footing the ultimate bearing capacity of footing resting on cohesive soil will be 7.41 c. So, these are the things that mean general equation is there for a particular case I can modify the equation this form.

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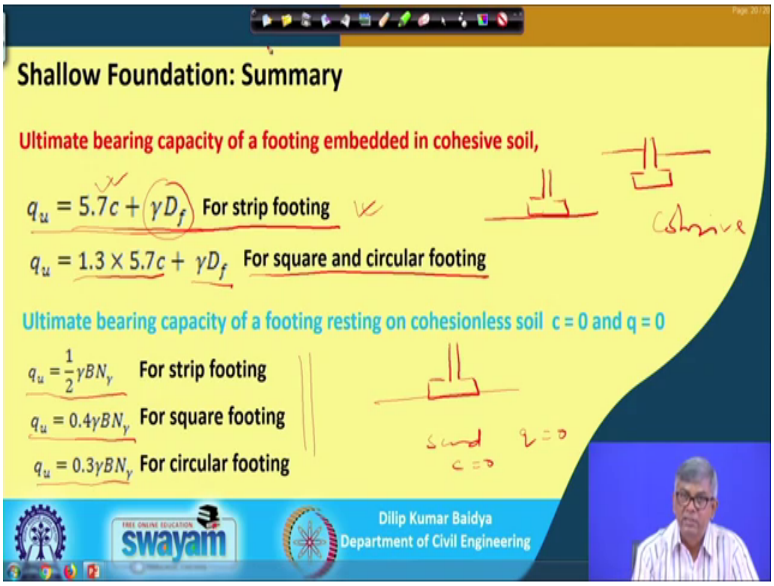

Shallow Foundation: Summary

Ultimate bearing capacity of a footing embedded in cohesive soil,

$q_u = 5.7c + \gamma D_f$ For strip footing

$q_u = 1.3 \times 5.7c + \gamma D_f$ For square and circular footing

Ultimate bearing capacity of a footing resting on cohesionless soil $c = 0$ and $q = 0$

$q_u = \frac{1}{2}\gamma B N_\gamma$ For strip footing

$q_u = 0.4\gamma B N_\gamma$ For square footing

$q_u = 0.3\gamma B N_\gamma$ For circular footing

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Next is next is actually suppose ultimate bearing capacity of footing embedded in cohesive soil. Now I have taken previous one, previous one I have taken what? I have taken footing like these this is the soil now I am considering the ultimate capacity of the footing embedded ok. So, this is cohesive soil same soil, but is embedded now.

So, for strip footing now for strip footing it will be 5 point c a 7 c it will be remain same and now second part was qN q see the Nq is 1. So, if I add Nq 1 and add q so; that means, 5.7 c gamma D f or this will be the ultimate bearing capacity of a footing embedded in a cohesive soil is this.

Similarly, if I go for square or circular footing then what will happen? Gamma part still is missing. So, it will be q u will be 1.3 into 5.7 c plus gamma D f both for square and circular footing it will be same, until unless gamma part is there is no difference between strip and sorry the square and circular footing. So, this is actually when it is embedded, when the footing is embedded and when it is footing is surface that I have shown 3 equations 2 equation when it is embedded this 2 equations are applicable.

Now, I will see that ultimate bearing capacity of footing resting on cohesionless soil; that means, c is 0 and q is 0 because if the footing. Now what is the, what is what footing I am considering? I am considering a footing resting on sand, sand means c equal to 0 resting on ground means q also equal to 0. That means, first two part will be absent. So, if you take the first equation or Terzaghi's equation for strip then your q ultimate become half gamma BN gamma and if you go to the circular square footing then we will see 0.4gamma BN gamma. And if you go for circular footing they recovers from Terzaghis equation you will see that it is 0.3 gamma BN gamma when it is on the surface. So, footing on the surface of a cohesionless soil so that is these are the equation.

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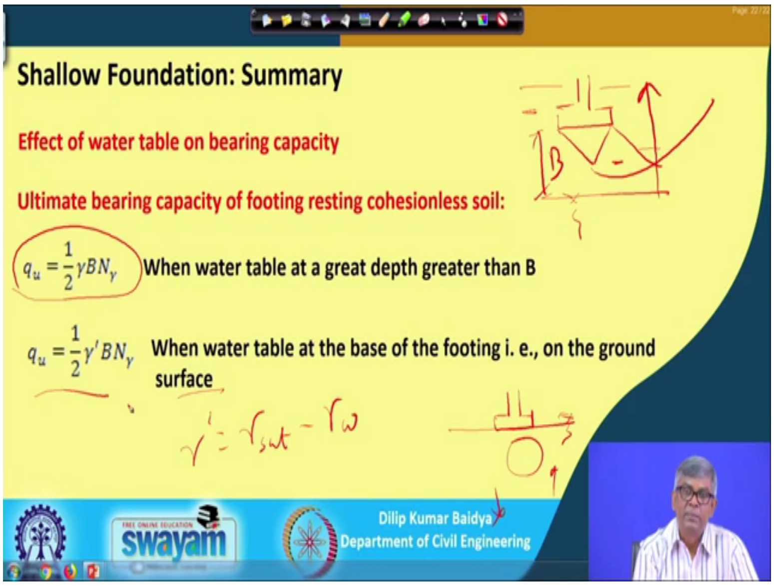

Shallow Foundation: Summary

Effect of water table on bearing capacity

Ultimate bearing capacity of footing resting cohesionless soil:

$q_u = \frac{1}{2}\gamma B N_\gamma$ When water table at a great depth greater than B

$q_u = \frac{1}{2}\gamma' B N_\gamma$ When water table at the base of the footing i. e., on the ground surface

$\gamma' = \gamma_{sat} - \gamma_w$

Next is effect of water table, see these are the Terzaghi bearing capacity we have shown and Terzaghis bearing capacity while developing what was the assumption? If the footing is here and this is the footing it has a typical failure zone and so this is the failure zone. So, water table will be much below that zone and that depth actually generally required depth is B, if the water table beyond the B depth from the base of the footing then whatever formula I have mentioned those are applicable, without effect of water table.

Now, if the water tables varying from here from here to it goes up then water table will that is actually bearing capacity will change and that application of that also I have shown in detail. But only for a particular case I have given example where suppose ultimate bearing capacity of footing resting on cohesionless soil, suppose cohesionless soil and it is resting on cohesionless soil and water table is at great depth.

Then this will be the equation half gamma B N gamma, but now water table suppose goes up and finally, came to the base of the footing. In that case what will happen? That gamma will be replaced by gamma submerge, you can see here that when water table at the base of the footing; that means, on the ground surface then your ultimate bearing capacity will be half gamma submerge B N gamma or gamma submerge will be equal to gamma saturated minus gamma w. So, this is the effect of water table.

Similarly, if the water table is changing from in between then you have to take effective, if the water table is here then the sub charge also you have to take submerge unit weight all those things I have these shown. So, these are one example the showing the effect of water table. So, that has to be also carefully you have to study.

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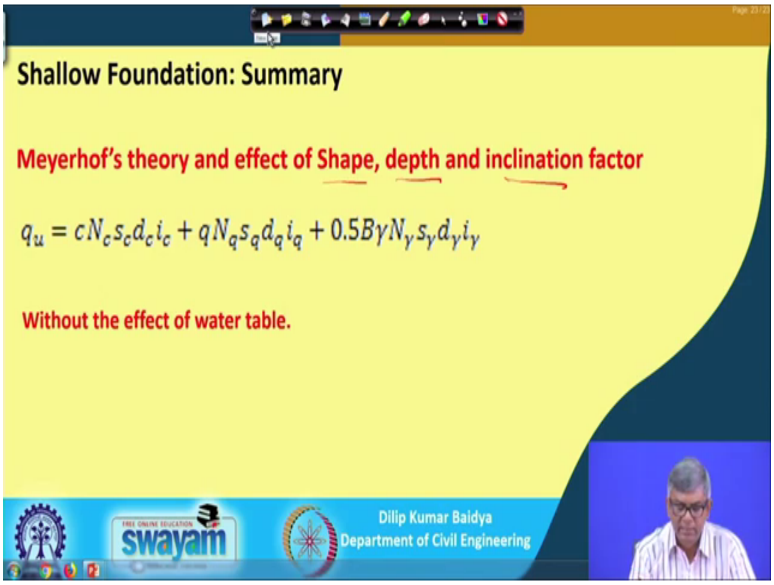

Shallow Foundation: Summary

Meyerhof's theory and effect of Shape, depth and inclination factor

$$q_u = cN_c s_c d_c i_c + qN_q s_q d_q i_q + 0.5B\gamma N_\gamma s_\gamma d_\gamma i_\gamma$$

Without the effect of water table.

Next part is Meyerhof theory, then after Terzaghi's theory I have discuss also Meyerhof theories. While discussing Meyerhof theories what I have discuss, I have introduce 3 more factors, what are those? One is actually shape factor depth factor and inclination factor shape factor for all 3. Suppose s c s q s gamma and depth factor d c d q d gamma and inclination factor i c i q i gamma.

So, all those things also I have given, but this is a generalized equation, if there is a no inclination then I become 1 if there is a depth is not if the footing is at the surface then depth factor also become 1 so it will be modified. Again if there is a cohesionless soil c part will be 0, if it is a cohesive soil then this part will be 0. So, this equation also similarly can be modified for the situation where it is.

And in addition to that because of the shape depth and inclination we can introduce different parameters and those things I have given and the way we have applied the effect of water table in Terzaghi's bearing capacity theory all the effect similarly can be applied here, wherever applicable. So, that I am not going in details it will be similar I hope that will be for you I will not repeat that part.

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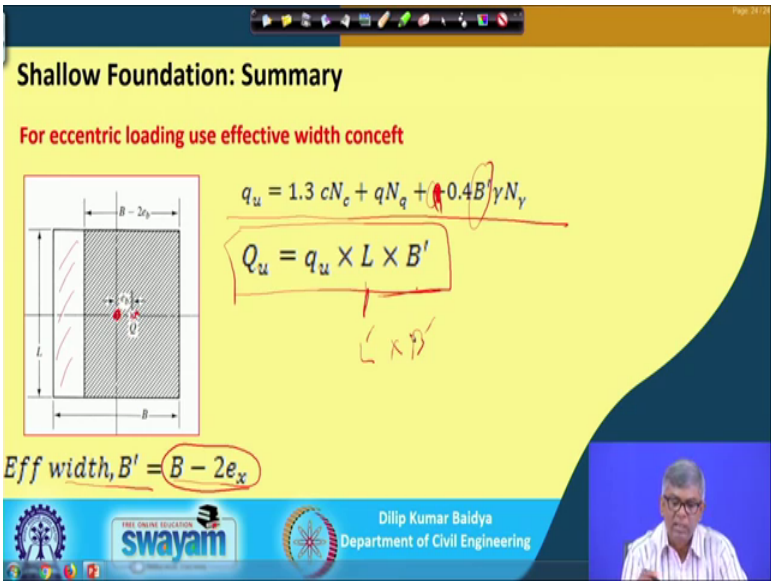

Shallow Foundation: Summary

For eccentric loading use effective width conceft

$$q_u = 1.3\,cN_c + qN_q + 0.4B'\gamma N_\gamma$$

$$\boxed{Q_u = q_u \times L \times B'}$$

$L \times B'$

$$Eff\ width, B' = B - 2e_x$$

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Next is sorry next is actually eccentric loading, when the load footing is loaded eccentrically then the effect use of effective width concept can be use. Suppose if the footing is here this is the footing area is if the load is applied here it is concentric and then it you will have uniform pressure, but if it is a load is applied somewhere here, then it is eccentric. To make the uniform pressure then what you have to do you have to make these as a center of the footing and if you want to make these as a center of footing then this some portion of the footing become ineffective.

So, to you have to finally, find out the effective width of the footing, how to find out? That B dash will be B minus two times eccentricity, once you get this B dash then same bearing capacity equation can be applied 1.3 c c suppose it is square footing 1.3 cN c plus qN q this is this part is not the 0.4 this is not there 0.4 b dash gamma B N N gamma.

So, why B dash? B dash this modified width has to be used, that is the only difference you can do and finally, to find out the ultimate load in the footing what you have to do? Q multiplied by small q multiplied by the area of the footing is the ultimate load, here actually area of the footing become L and effective width ok. And if it is a two way eccentricities, then I could have then l effective multiplied by b effective. So, that is one way of taking care of eccentricity in footing while finding out the bearing capacity of the footing. So, this is also I have shown with an example.

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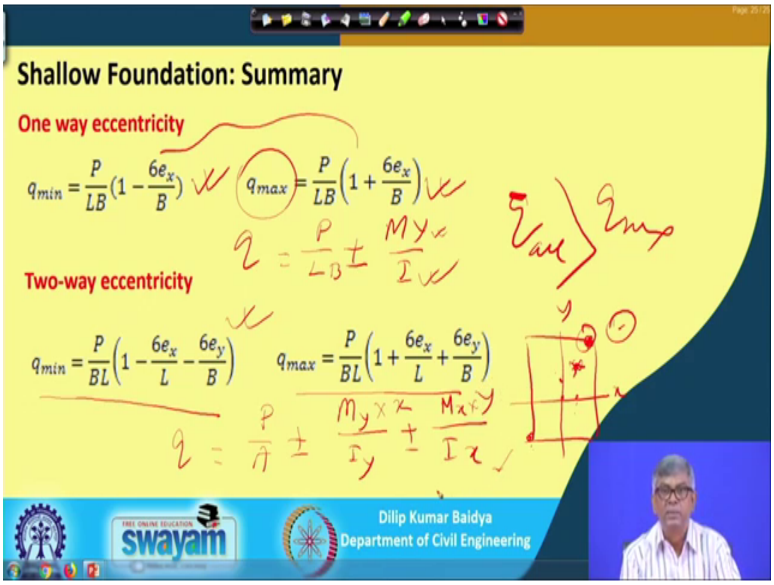

Shallow Foundation: Summary

One way eccentricity

$$q_{min} = \frac{P}{LB}\left(1 - \frac{6e_x}{B}\right) \qquad q_{max} = \frac{P}{LB}\left(1 + \frac{6e_x}{B}\right)$$

$$q = \frac{P}{LB} \pm \frac{My}{I}$$

$$q_{all} > q_{max}$$

Two-way eccentricity

$$q_{min} = \frac{P}{BL}\left(1 - \frac{6e_x}{L} - \frac{6e_y}{B}\right) \qquad q_{max} = \frac{P}{BL}\left(1 + \frac{6e_x}{L} + \frac{6e_y}{B}\right)$$

$$q = \frac{P}{A} \pm \frac{M_y x}{I_y} \pm \frac{M_x y}{I_x}$$

Next part is another way actually I have mention that when the footing is eccentrically loaded then because of this moment or if the footing carry is both moment and compressive load then pressure will not be uniform throughout the area of the footing. And somewhere it will me more somewhere it will be less, somewhere there may be chance of doing negative pressure also.

So, there are so because of that if the pressure become more sometime. So, what you have to do finally? There is a q allowable for any soil q q allowable and if there is a q max if we find out. So, your q max q max should be less than q allowable. So, that has to be make sure. So, because of that sometime you have to find out what is the q maximum.

When one way eccentricity is there then actually your q minimum this is the equation and q maximum this is the equation, generalized the equation actually q will be equal to P over P over LB plus minus M y by I actually. And if I put that value of I and eccentricity in the moment and I all if I put then it will modified to this two equation q minimum and q maximum in terms of length and width of the footing.

So, you can calculate this q maximum and you have to make sure that q maximum should not be more than the q allowable of the soil. Similarly if there is a footing, if there is a footing and eccentrically two way eccentricity and this is x and this is y and then there actually some of the load is acting here then I can imagine load is acting here because of this loading there will be a compressive. There will be compressive because of the P and because of the moment, because of this force, because of moment with respect to this side here it will be compressive, here it will be negative.

Similarly, because of the loading here because of the moment with respect to this axis moment with respect to positive here and negative here; so, that means this point actually because of the load there will compressive, because of the moment with respect to this axis positive because of the moment with respect to this axis positive. So, that mean all three will become positive it become heavily pressure pressurized, this point pressure will be maximum.

And whereas, here because of compressive positive and because of these moment with respect to these axis negative, moment with respect to these axis negative that may it become very less. So, what is the minimum and what is the maximum of here that also can be obtained and this is the equation given, q minimum is this and q maximum is this. Generalized equation actually q will be equal to P over area plus minus suppose M y, suppose this is moment with respect to M y multiplied by x divided by I y plus minus M x with respect to this moment M x multiplied by y divided by y I x. This is the generalized equation and if I put the ix iy and y value and moment in terms of p and e then that equation will be modified to this and this for maximum and minimum.

And finally, after finding out the maximum value and minimum value you have to compare with the allowable value and you have to make sure that this maximum value is not greater than the q allowable. So, that is the checked has to be done when the same thing around. So, these are the things I have covered and at towards end also I have covered other type of combined footing etcetera which I have just done. So, because of that I am not summarize this one, otherwise with this the shallow foundation bearing capacity and some sort of designed aspect is complete and I will stop here. The bearing capacity I will go for a next topic in the subsequent week.

Thank you.