Geotechnical Engineering II / Foundation Engineering
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Lecture - 15
Shallow Foundation (Contd.)

Good morning. Once again, let me continue on Shallow Foundation. And almost we are done on shallow foundation; one or two aspects are left that is actually so far we have discussed a situation where at the end of a column, we generally giving you footing that is a isolated footing or below a continuous wall or some similar type of structure, we are giving you a footing. They are actually isolated or a strip footing and both are actually shallow foundation.

There are also a few more categories of shallow foundation are there and they are actually in various situation. They are essential actually, is not like that I just optional. It is actually essential some time Some time isolated footing or strip footing is not the solution not able to get the solution, then we have to go for that type of foundation and one such foundation is combined footing.

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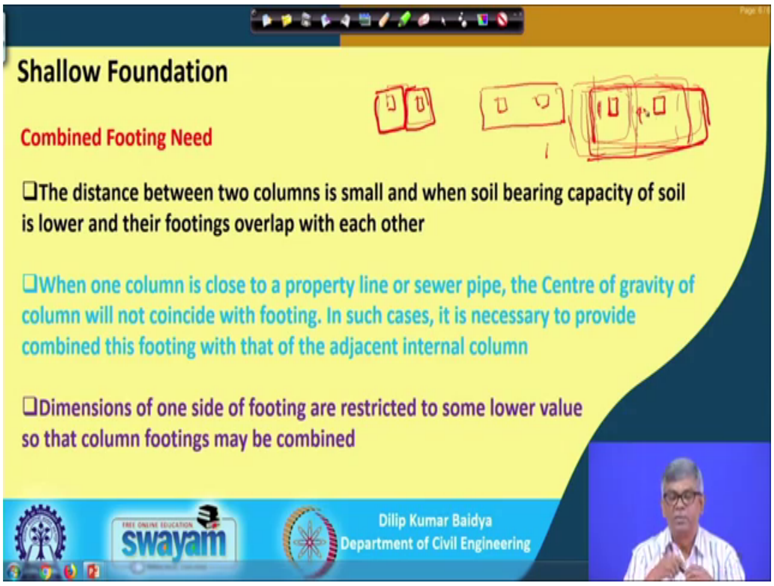

So, let me see that the combined footing. Before going to the combined footing, combined foot what is combined footing actually, when that is a one or two two or more columns are connected by a single footing, that is called actually combined footing and again combined footing can be of different types. I will only discuss simple combined footing the rectangular or trapezoidal type and when we need actually the actually, when that distance between the 2 columns are small and also the soil bearing capacity is lower and their footings. And then if you design if the soil bearing capacity less then, when you want to provide the area required and then we may find that both the columns whatever area we are providing, they may overlap like I will just show you here.

Suppose, one column is here, another column is here and we are designed a footing for this and again another footing is this. So, then if you go for a isolated footings for this two, then we are actually there is a overlap sometime or sometimes they are very close or there may be very thin may made soil is left where actually difficult to do excavation. These are the situation mainly we required to, in that situation instead of doing two separate so two columns are there and we can give a single footing and that is called combined footing.

And then and there are some this, this is another one type of column combined footing and sometimes suppose there are two footings; one is here a column, one column we suppose somewhere here and another column is somewhere here. This column suppose I will give you a isolated footing, it is all right. But this side, there may be a property line if I want to give a isolated footing here, it go beyond the property line. In that case, actually we have to restrict the foundation up to this line and how to do that, then some load can be transferred to this. So, that to do that, we can connect both of them and give a single founder single foundation. That is another requirement.

And then, dimension of one sides of footing are restricted; that means, sometime footing cannot be this side. What is the dimension are actually this side is restricted. So, this is also similar to that only that may be if there is a restriction that you cannot go as required, in that case actually our solution will be to provide a common foundation to your both. So, that how will you do that if I connect from here to here then this side, it will be little longer so that CG of this force a tool a load and CG of this area should be common so that, the footing below the footing, your pressure will be uniform.

The both center of gravity of the application of the load and center of center of the area if the same, then your a pressure below the footings supposed to be uniform and that is our requirement and we want that. And for that actually so this become, if I make a single two single footing here and here it is all right, they will be going through the center but when it is restricted, then it is this load is not going through the center.

So, to make uniform pressure and transfer some amount of load to this footing, so, we can connect both and give a common footing in such a way that the CG of the area and the point of application of the load should be should coincide. So, that is the way we do. So that means, what a what are or what are the reason actually we go for combined footing; one is the one reason is when the load is heavy, when they are closely spaced and another thing is and when this bearing capacity is less and second thing is if there is any corner footing sometime because of the restriction of the property line, you may connect we may have to connect through that they are in nearby columns. So, I will make the combined footing and with a requirement that point of application of the combined two loading should coincide with the center of the area of the footing.

So, that is the way you can do and another thing is similar to that again sometime maybe footing cannot go one side beyond this line or if the footing of this side dimension because of the line and some other line you cannot give the particular dimension of the footing in a particular direction. In that case also, we go for this type of combined footing. And when you do combined footing, how they look like?

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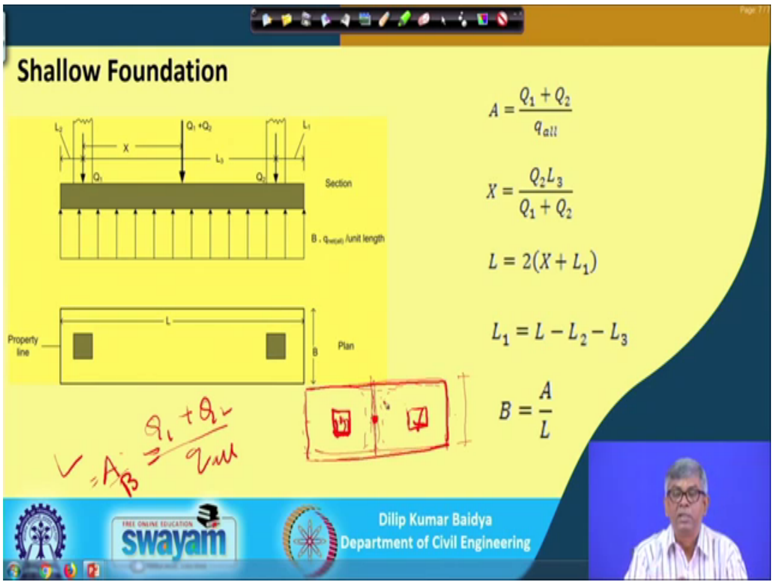

Combined footing look like this. This is actually one typical type of combined footing is given. But actually if there is a simple without any problem, suppose 2 columns are having heavy loading, but there is no restriction etcetera suppose there is a column 1 and there may be a column 2 and they are carrying heavy load identical everything they are same.

In that case, I can make a isolated footing here; I can make a isolated footing here but because of this covering the most of the area, so I can go for a combined footing in that case, what I will do? I will combined them and make a common footing and since everything identical, so, the load and everything is same, then it will be here and I can make I can find out the area requirement suppose your load Q 1, one load is Q 1, another load is Q 2 and your bearing capacity suppose Q allowable, that gives you area required, that gives you area required and then I can assume a particular width and from there, area by width actually suppose if it is B, I can get the length.

So, this length and this length; obviously, it should be from both direction since same distance it should be, it will be equal distance from here to and here to here and here to here so that this will be because of these two loading below the footing, pressure will be uniform. Now, this is a very simple type but what are the other reason why we go for combined footing you can see here. Suppose, the restricted length here is L 2 and footing dimension is given from center to edge is L 2 and loading is here, Q 1 loading is here, Q 2.

And suppose I want to make a combined footing and in that and between the column, distance is known suppose L 3. In that case, L 1 and L 2 also known suppose restricted this length or cannot be more than that in that case my total length of the footing is known ok, length is known, length is becoming how much?

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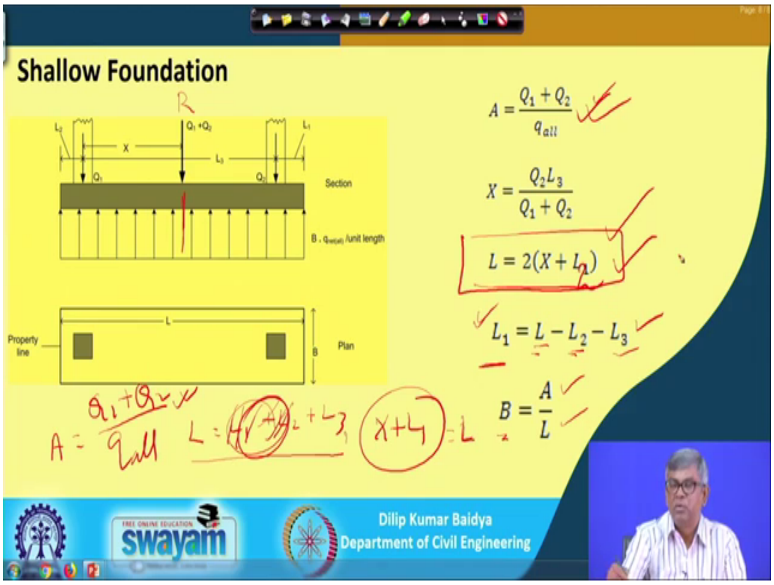

Length become L 1 plus L 2 plus L 3; length is known and area also known because if the soil bearing pressure is Q allowable. So, area equal to Q 1 plus Q 2 by Q allowable ok. So, now I have to sorry this L 1, L 2 may be may not be known. Suppose L 1, L 2 may not be known; actually we have to provide. Suppose, L 3 is known and one of them L 2 or L 3 L 1 is L l 1 or L 2 is known. So, first area is calculated from this equation and then X; that means, the point of application of this load; suppose Q 1 and Q 2 is unequal, we do not know where it will act acts.

So, in that case, I can take moment respect to with respect to this point and it is at a distance X if it is a acting, then if it is Q 1 and Q 2 suppose; that means, say R. So, R equal to Q 1 plus Q 2. So that means, X into Q 1 plus Q 2 must be equal to Q 2 multiplied by L 3 and from there, I will get the X and your L will be what is the length required? Because, I have told that point of application of this resultant force and the your CG of the area should be same.

So, to make that, actually what happened is that that X plus X plus L 1 must be the half of the footing. So, because of that, so total length must be then multiplied by 2. So, that is what L is determined like this, L equal to twice of X plus L 1. Suppose this is given an L 2 to be decided. So, in that case, I can find out this way and if it is L 1 also not then in that case L 1 to be obtained how L 1 can be obtained, L 1 can be obtained L a already provided L minus L 2 minus L 3. So, from there you can find out L 1 and B will be ultimately that the width. This is B will be A by L.

So that means what you have to do? When there is two unequal load, first of all you have to find out from the center of one of the column you have to find out where it is acting. So, that X to be determined and from the X and from the column to the restricted length one side, so either L 1 or L 2 if I know, then the X plus that L 1 suppose L 2 you suppose known X plus L 2 it should be L 2 actually. It should be L 2, X plus L 2 because X plus L 2 become half of the footing length and twice of that should be the length of the footing so that your CG will be here.

So, if this is the one twice X plus L 2 then L 1 will be L minus L 2 minus L 3 because total length is L and L 3 and L 2 if I subtract from L, then become L 1. And once you get you get L and if you get A, then you can find out B. So, this is the way one can find out the you one can design the combined footing to have uniform contact pressure below the footing. So, this is actually this length is instead of L 2 if it is something else. So, accordingly the length will be varying so, that to be considered.

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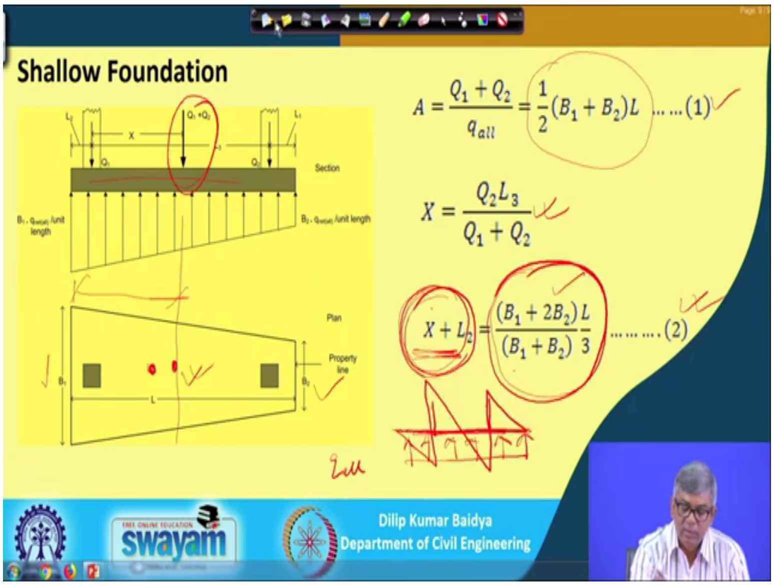

Similarly, you have a shallow foundation. There may be another type of footing that there were 2 column and having unequal load, again there maybe some restriction in one side. All those things maybe both side X restricted from this column, we cannot go beyond L 2 from this column, we cannot go beyond L 1 something like that if it is given.

Then, sometime you will you may not be able to do a rectangular footing. To make uniform pressure below the footing, you may have to go for trapezoidal footing. So, that is the thing shown here like before like before if the soil bearing capacity is q allowable, then you can find out area first Q 1 plus Q 2 by Q L allowable. This is the one and this area this is the area required and now if I assume, the width this side is B 1 and width this side is B 2 and this length is L because of all this restriction L may be known. Like for example, L 3; that means, spacing between the column is known and from the left side column what is the distance you can go, from right side column what is the distance you can go, if you know all, then L will be known.

So, if I know B 1, B 2 and L, then what you can find out the area of this area of this footing. So, that actually can be equated. So, half B 1 plus B 2, so trapezoidal area; area of the trapezoidal section is half both the width summation of the width of the both side are multiplied by length distance between the both side in parallel side. So that means, the half multiplied by summation of the parallel side multiplied by the distance between the parallel side.

So, this is the one I can find out area in terms of B 1, B 2 and L by this and I can find out from the allowable bearing capacity and load of the footing by this. So; that means, from these, I can set one equation and in this equation what are the unknowns B 1 and B 2 unknown L is actually known. So, B 1, B 2 unknown, so to solve B 1, B 2 actually to get the value of B 1 B 2; that means, I need one more equation. How to get one more equation? I can find out since two loadings are acting. I can find out from this left side, what is the distance the point of application of the resultant force, I can find out. So, that is the equation similar to the previous one.

X will be Q 2 L 3 divided by Q 1 plus Q 2. So, this is the way I can find out the X. Now, if I with the X if I add this L 2; that means, what I have to do? My requirement is the point of application of the load and CG of the area should be same. So, that means, X plus L 2 I can consider that from the left side, this is the point of application of the load from the left side this is the point of application of the load suppose this one. So, this is the point of application of this is a one from the left side, this is the distance; that means, X plus L 2 distance; that means, CG is acting. And now if I know this trapezoidal area, I can also find out the CG of this of this area in terms of B 1, B 2 and L.

So, in terms of B 1 B 2 and L, the CG of the trapezoidal area from the left side that is the expression, B 1 plus 2 B 2 divided by B 1 plus B 2 multiplied by L by 3. So, this is actually I am getting from the L L and B 1, B 2 that is theoretical CG in terms of unknown B 1, B 2 and L from the area I am getting and I am getting this area this distance also I can get from X plus L 2. So, this must be equal because the CG of the load and CG of the area should be equal to make sure the pressure below the footing is uniform.

So that means, the that means, I this is this I am getting this is known actually, X can be calculated based on this and L 2 also known this is known and here actually B 1 and B 2 is unknown L is known. So, again, I can set another equation 2 this one and a 1st equation is this, 2nd one equation is this. So, I have got now two equation, I have now two unknowns B 1 and B 2; that means, I can solve for this and get the value of B 1 and B 2. So, that B 1, B 2 actually will be the actual which is not known actually if I find out B 1, B 2; that means, that this is the area required to support this 2 column giving uniform contact pressure below throughout the footing.

So, now actually if you want to find out that pressure here, per linear length. So, since width is more, width multiplied by Q will be the unit pressure here and width multiplied by Q will be the unit pressure here Q 2 multiplied by Q per unit length. So, this is the way actually I can along the length, I can find out the load distribution and then based on that what I can do, I can find our bending moment diagram, shear force diagram and based on that bending moment shear force diagram, I can design this footing actually how much will be the thickness and what should be that reinforcement required all those.

Similar to that in fact, I have missed that point when you do rectangular footing also, once you get the length and all and then suppose a rectangular footing we have designed and finally, length is this and one column is this, another column is this and contact pressure is here. So, like this. So, because of this loading, it is like a simply supported a beam with this type of uniform loading. So, I can easily find out the bending moment and shear force diagram and based on that, I can design this section and reinforcement required. And that is actually your purely your concrete design actually reinforced concrete design.

So, I am not going in detail. So, when it is a simple rectangular section, the pressure diagram uniform it will be like that, but when it is a trapezoidal, then your pressure distribution along the length of the footing will be like this. Because, this side is though pressure below the footing is uniform but multiplied by this width will give the pressure here and Q multiplied by this will give the pressure here. And that means, linearly varying pressure now and here actually, bending moment shear force diagram a bending moment will be linear actually. It will be something like this your shear force diagram will be something like this and bending moment diagram will be your curve parabolic.

But when there will be a linear variation of loading is there, in that case your bending moment will be your shear diagram will be parabolic and moment diagram will be cubic parabolic that of course, you might have learned in strength of materials and all. The similar way, once you get the dimension, the geotechnical engineers has the role based on bearing capacity all and all to provide the dimension of the footing required. And then, after knowing the dimension one can go for bending moment shear force diagram and then go for actual design; that means, applying the reinforced concrete theory. And you can provide what is the thickness required, you can provide what is that enforcement required and all those things. So, I am not going in details to this.

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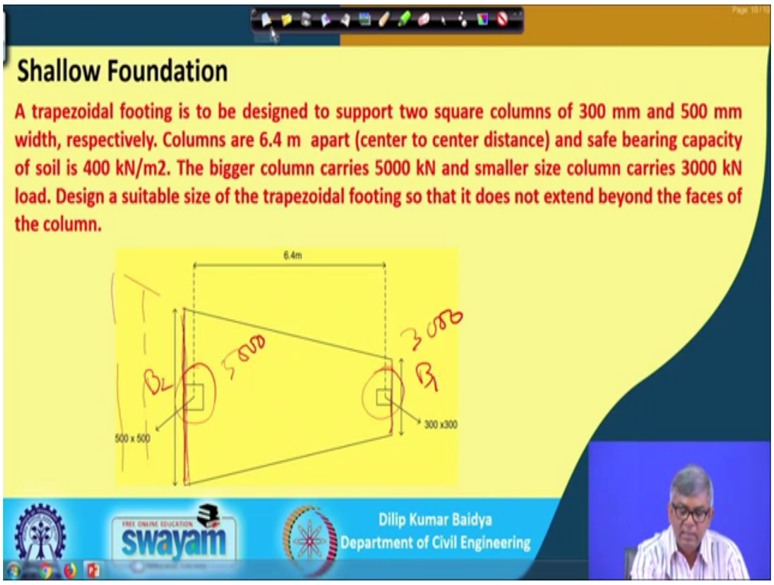

Next part, I will just take one simple example. Example is given like this you can see that a trapezoidal footing is to be designed to support two square columns of 300 millimeter and 500 millimeter; that means, two columns are there; one is 500 by 500 square footing, another 300 by 300 square footing.

And columns are 6.4 meter apart; that means, and that is apart can be face to face, but it is mentioned center to center; that means, center of this footing to center of this footing is 6.4 meter. And shape bearing capacity of soil is 400 kilo Newton meter a kilo Newton per meter square, the bigger column carries 5000 kilo Newton load and smaller size column carries 3000 kilo Newton load, that meant here actually 5000 and here it is 3000.

Design a suitable size of the trapezoidal footings so that, it does not extend beyond the face of the column; that means, you can see this. This is the column my trapezoidal footing could have gone up to these or up to this somewhere, but this is the restriction is given, the column the face of the edge of the footing should coincide with the face of the outer face of the column. So, that is this is the restriction similarly this is the restriction; that means, by this restriction, what we have done we have restricted the length of the footing. And what is a unknown, then I have unknown this width and this width B 1, B 2 and B 1 ok.

So, these two unknown there, so I can now whatever method I have described before, if I apply that I will be able to find out B 1 and B 2.

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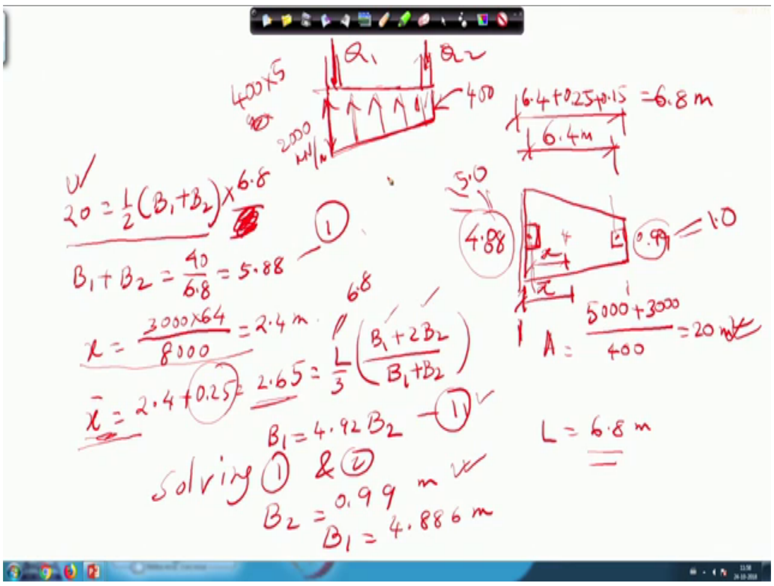

So, I will go to the next slide and show that maybe I will show that I will draw the first and your these distance is 6.4 meter and then outer is outer to outer distance will be 6.4 plus this half of this put this 500. So, this will be 0.25 plus half of this is 300; that means, 0.15, all together will be 6.4 plus fours 6.8 meter.

So, this that means, L become L becomes 6.8 meter. And area actually how much area will be known actually Q 1 plus Q 2 Q 1 is 5000 plus Q 2 is 3000 divided by Q allowable is 4, 400. So, if I do this, then you will get the idea equal to 20 meter square. So, we have got this. So, that; that means, I will get one equation, 20 meter square. 20 will be equal to half B 1 plus B 2 multiplied by, L actually 6.8 divided by 3 sorry, it is not there.

So, half B 1 plus B 2 into L, that is the area from here I will get one equation and this if I simplify, then it will be B 1 plus B 2 will be equal to 40 by 6.8. That will be equal to 5.88. And, I can find out now x bar that mean x then point of a application from this point this is x ok. So, this is this x will be this x will be equal to 3000 multiplied by 6.4 ; that means, L 3 divided by Q 1 plus Q 2; that means, a 8000. That gives you 2.4 meter.

And that means, your x bar x bar actually; that means, from the edge to the center of the footing that become x bar. So, that x bar will become your 2.4 plus half of this footing; that means, it will be 0.25; that means, 2.65 ok. And then, at this 2.65 must be equal to L by 3 B 1 plus 2 B 2 divided by B 1 plus B 2. So, this is the 2nd equation and if I simplify this equation; that means, this is L equal to actually 6.8. If I put all those thing and simplify, then I will get finally, that your B 1 equal to 4.92 B 2, I will get this.

And that means, I will get that means, I have one equation this another equation this and if I solve these two equation 1 and 2, then that will give you solving 1 and 2, we will get B 2 equal to; B 2 equal to 0.99 and B 1 equal to 4.886. This is meter, these are a meter um, these are meter square, these are meter. So, 0.99 per for; that means, I have to provide this side with 4.88 and this side width as 0.99. So, exactly we cannot provide this way.

So, we can approximately provide 1 meter and here you can approximately I provide 5 meter. So that means, this is the design of trapezoidal footing; that means, both side is restricted and columns are heavily loaded and because of that we have to find out the dimensions. And this dimension actually what I have done, I know the allowable bearing pressure, I know the load. So, I can first find out the area required. And since between the column distance is known and from the center of the column to the edge of the column is known and edge of the footing is known, that two quantity to be added and if I do that then I will get the length of the footing. And this two part, first to be obtained and then once this area is known and based on unknown B 1 and B 2, I can find out the area that is the one and that gives you 1 equation.

And, the second part is say two loading that applied in different location and of different magnitude, I can find out with respect to one column what is the point of application. And then from that center of the footing to the distance of the left side, if I add that become the CG from the of the area from the left side. So, that I have done. The x bar is become x first I have calculated and then x bar I have calculated just I have added the hub the column width. So, it become 2.65 and if there is a trapezoidal area, I know the theoretical CG in terms of length of the parallel sides and length of the actual footing a distance between the parallel side.

So, that is the thing L by 3, B 1 plus 2 B 2 by B 1 like that. But, if it is from this side, that equation will be changed. So, that has to be remembered and carefully used that whether I am doing from this side or from this side. If it is from this side, this equation will change and in fact, it will become B 2 plus 2 B 1 by B 1 plus B 2 into L by 3. Since, I am taking from this side if B 1 plus 2 B 2 by B 1 plus B 2. So, this equation, I will equate from with the x bar and then I will simplify, then I will get a relation with B 1 B 2 and these two relations if I am getting and thereby using this two equation, I will be solving that for B 1 B 2 I will get 0.99 for this smaller side and 4.88 for the longer side.

So that means, I can provide a reasonable size; that means, approximately 4.88 can be rounded to 5 meter and 0.99 can be rounded to 1 meter. So that means, this is the final size of the trapezoidal footing and after getting this trapezoidal footing, I can draw the pressure diagram actually this is the column; sorry this is the column and another column is suppose somewhere here and footing also here. So, your pressure diagram will be something like this because this will be Q multiplied by Q; that means, 400 that is 400 multiplied by width is 5. So; that means, 400, 2000 here actually, it will be 2000 kilo Newton per meter actually.

And here it will be 400 multiplied by 1 so, it will be 400. So, the one side is 2000; one side is 400 and they will be joining linearly. So, now, for this loading this sorry this diagram will be upward direction, pressure will be upward direction. So, because of this and here actually suppose this is whatever maybe this is Q 2 and this is Q 1, this can be considered.

So, this consider these two support and this is the loading and for that we can draw the shear force diagram, we can draw the bending moment diagram and based on that critical bending moment using the critical bending moment, you can design the section of the slab required So, and then also based on this critical moment, you can find out the reinforcement required and that details actually, I will not be doing here that maybe learn you can learn from reinforce concrete design for footing. With this I will stop here.

Thank you.