Foundation for Offshore Structure
Professor S. Nallayarasu
Department of Ocean Engineering
Indian Institute of Technology Madras
Module 1
Lecture No 32
Pile Group Effects

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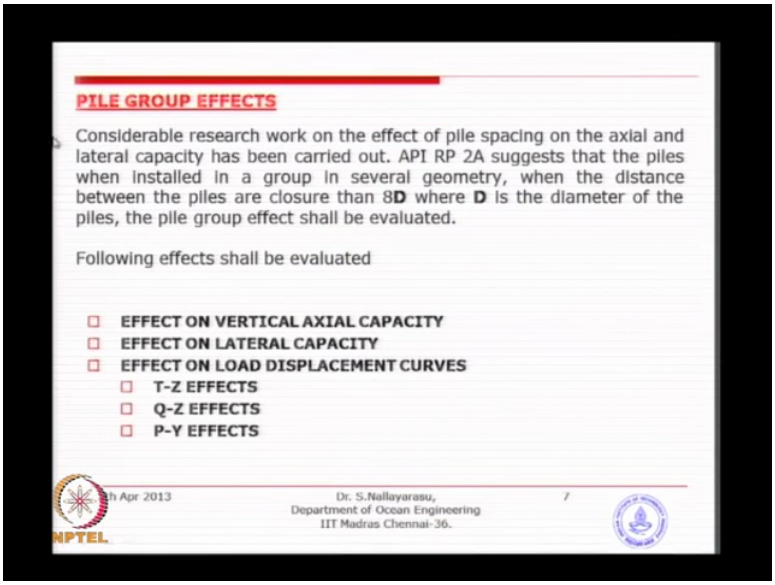

So we will continue with the effect of pile spacing on the capacity, so various thing needs to be investigated. Actually quite a bit of research has been done only the limitation is not much experimental, mostly on numerical modelling, empirical and to some extend several assumptions has been made like multi-layered soil has been taken, a single layer soil, average properties, so lot of simplification has been done but though will say limited experimental work API recommends certain aspects in terms of simplification for design purpose, so if you are able to maintain the spacing of piles beyond 8 diameter, if the diameter is 2 metres make it 16 metres probably the effect of interdependency on the response due to load on the other pile is very minimal you can say we can ignore and is not that it is going to be 100 percent not affected but to maintain 8 diameter is going to be a big problem.

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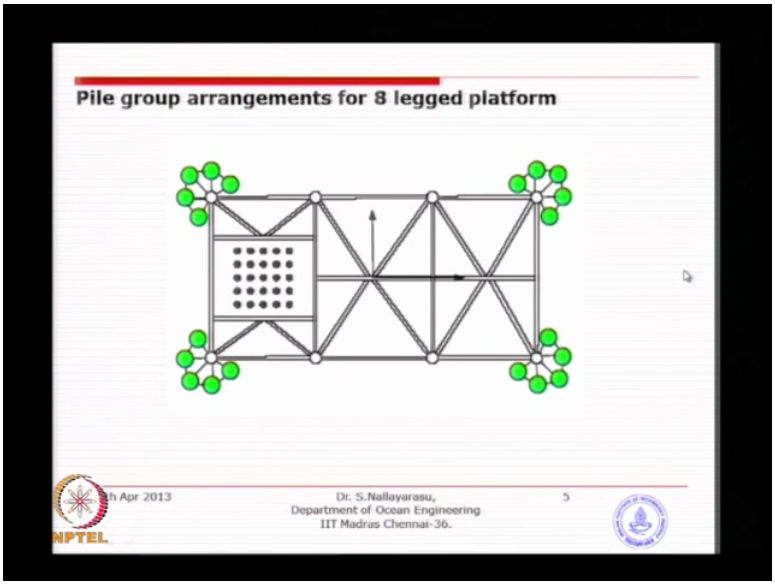

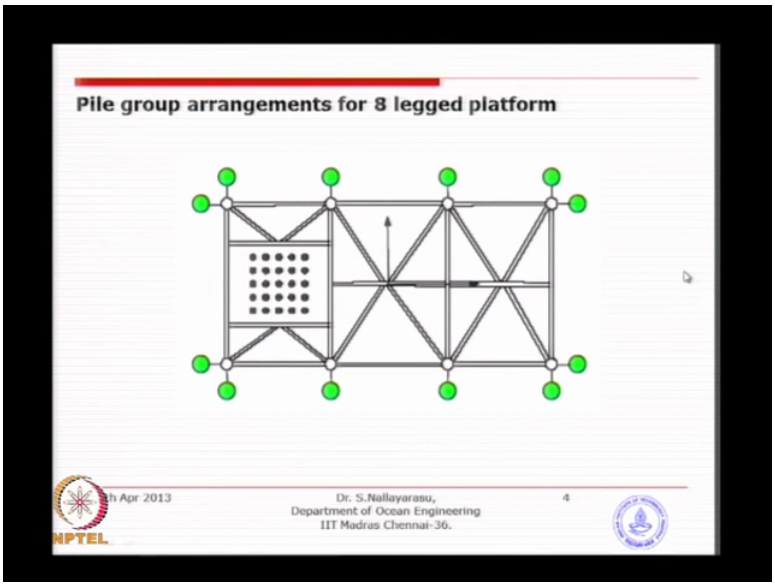

So if you just go back to this picture for may be the simplest picture like this, if I have to maintain 8 diameter distance between this and this having a pile diameter of say 1 and half to 2 metres the distance become considerably large, so what will happen is you may not be able to actually have 2 piles on the corner, you actually will have to have a single pile because if you look at the distance between this pile or this leg to this leg could be around 10 metres, 15 metres 16 metres, so were actually indirectly telling is you cannot have a group of pile, you can only have single pile at each leg.

If you want to have 16 metres, what will happen is this this pile will go this way in this pile will go this way or you can just have it any direction to make a distance which is practically impossible, so that is what the conclusion we are trying to make, so we are not actually going

to come to the conclusion that we will work out what is the effect of group and then fix the spacing, we actually fix the spacing and then look at the group because we are forced to do it where as in in case of onshore for example if you go to this type of pile configuration if you feel that having a group effect is too much then you have little bit of flexibility, you can make it may be 3 diameter, 4 diameter, 5 diameter maybe you can manipulate whereas in terms of off storage structures manipulation is limited there is what you need to get in your mind that we are not going to work out piles spacing and then come back with design capacity, so that is something is very much specific to jacket type of structures.

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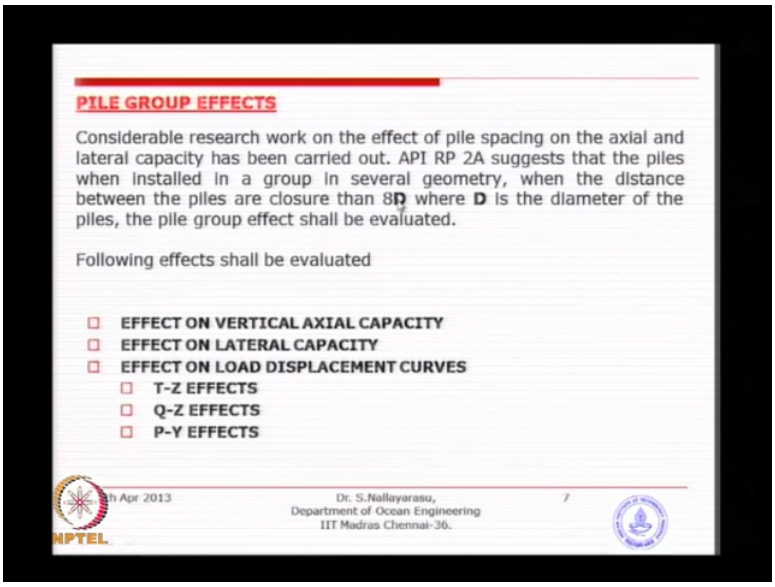

So 8 diameter suggestion means if you are able to maintain spacing like that maybe we can ignore but otherwise if you have less than that then you look at each one of the aspect and look for reduction in the capacity, so far we have already worked out axial capacity means of skin friction, means of end bearing and also lateral capacity 3 things we have already worked out. 3 displacement relationships also we have worked out basically TZ, QZ and then PY.

Now these also will get degraded because what happens is the soil in the vicinity is actually overloaded because the load from another pile is coming and because of that that means the pile will deflect more than what you supposed to get, if you actually do a calculation based on single pile analysis, so that means the load deflection characteristics so going to change that means it is going to degrade for example if you have a 10 mm displacement and 100 kilo Newton is your capacity because of interference from another pile what will happen?

Either the capacity will reduce for the 10 mm or for 100 kilo Newton the displacement will be larger, is not it? Because the contribution from another one is coming and disturbing it, so we need to (())(4:04) the graph by either multiplying capacity by reduction factor or multiplying the displacement by a multiple factor will always be greater than 1, so we call it t multiplier or the load multiplier, so either way one will be value greater than 1, the other one will be value less than 1, so that is what our interest is to find out what reduction effect that we are trying to achieve when you make the pile spacing less than 8 diameter.

So that is called the group effects in total you know basically you have axial, and bearing and then (())(4:42), so in here we are just going to look at what methodology available today of course you could best possibly do experimental study which will be difficult to do because a lot of work involved, time involved you can do Numerical analysis using finite element technique or other or you can use simply what is been suggested by various literature based on empirical or…so mostly we have going to use in the industry we are just trying to use what is available but in some cases specific to each project you may actually do a study of your own including either FE analysis or something similar to arrive at your comfortable level of what has been suggested in the literature? What is specifically for…because the (()) (5:32) projection has been given for industry use though lot of research is there when directly trying to use it in the design work is very limited, so that is where you will find some difficulty.

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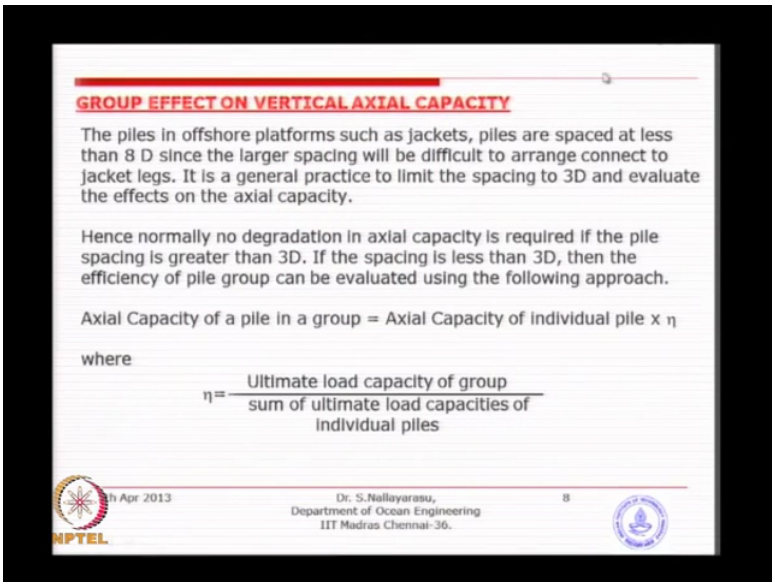

So let just quickly start with what is the axial capacity effect? So normally if you look at say 2 piles, the pile is circular section and installed at a specific spacing say 2 diameter, 3

diameter and when you apply a combined loading on this…normally when you look at onshore structures normally you have a pile cap, a combined concrete cap and you apply the load to the cap and the pile is (())(6:15) equally, if the pile stiffness is same both of them and the stiffness of the pile cap is almost symmetric then you will get 50 percent load on one pile, 50 percent load on another pile.

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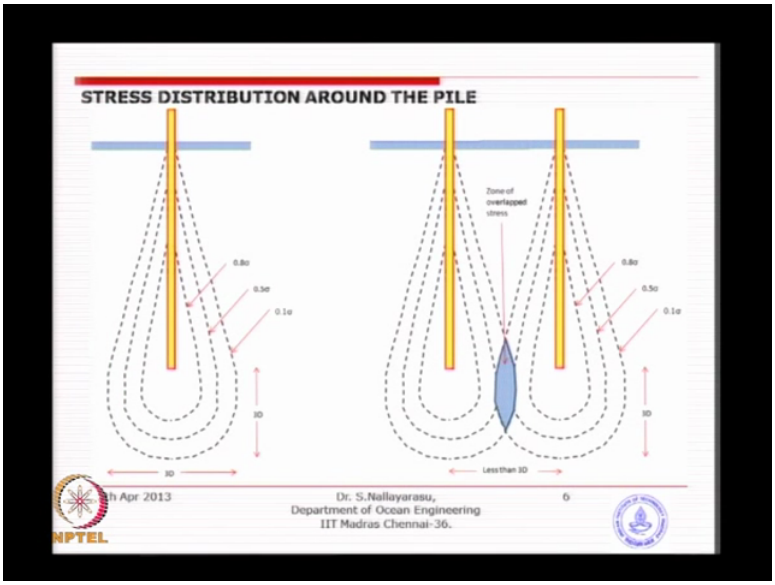

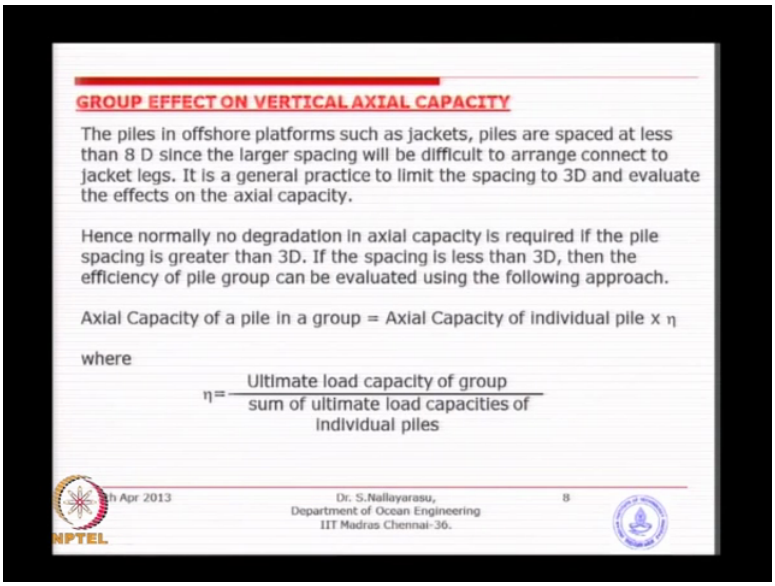

Now in this load goes down the soil and then the soil is loaded and as shown in earlier sketch, some part of this below the ground is going to be loaded twice, so basically that and when you try to fill this soil, some failure pattern will come for each file and it is going to fail together. If you keep this pile very close, what happens is classification of the soil in this zone between the 2 pile is going to be very fast compared to this soil outside, so what happens is

we need to find out what is the failure load or ultimate load of this and ultimate load of the combined system and that ratio is called the group efficiency.

So ultimate load of pile group capacity, group capacity how do we evaluate is something that we need to just devise a method whereas the sum of ultimate capacity, so each pile or if it is same pile, pile capacity multiplied by number of piles, you can do this whereas if you have different pile for example in a group we have one metre diameter, 2 meter diameter or different types different shapes then you just cumulatively add all the pile capacities and this gives you an idea that the group efficiency or the efficiency factor will be greater than 1 you know if you have this pile group is higher but many a times you will find pile group capacity may be smaller this is what we are looking for because…

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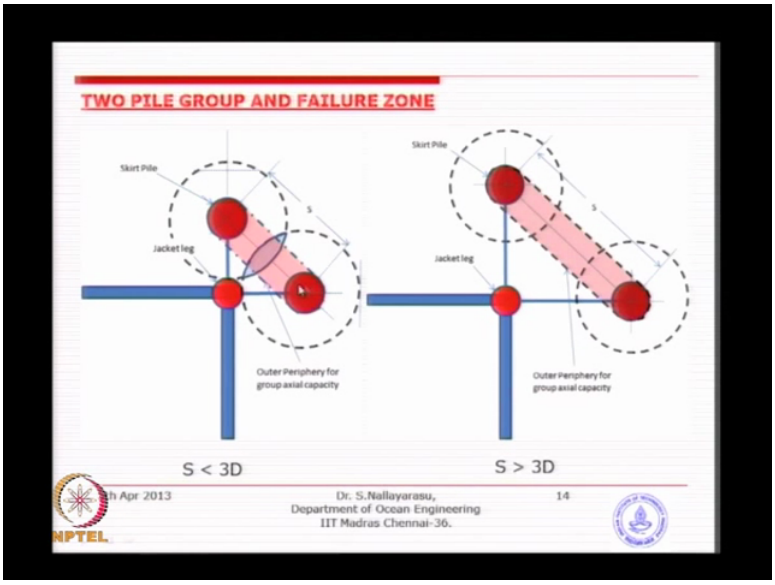

So basically if you look at some of the pictures, I will the show you before we go further, you look at this particular picture you see here one corner I have enlarged for you to understand, so you have the 2 numbers of piles this is one pile and this is another pile, is not it? Now when you actually try to make of failure of a single pile applying axial load the failure surfaces is on the surface of the pile itself, is not it? Because the skin friction between the soil and the pile is trying to shear off, now if the pile is so close almost getting together when the spacing is so small, the failure may also occur along the periphery of the drawn circle here, so basically semicircle and then a line joining this pile and this pile, so they are going to go together if you have a rigid pile cap on top the load is just shared equally, so making sure that the soil becomes part of the pile because it is too close it is just compressed.

So what happens is the capacity of the group can be calculated, the skin friction between the soil and the pile times the surface area is not anymore a 2 circles times the length, it is just going to be a the surface that I have drawn here as dotted line connecting the pile to this pile and you can see here this (())(9:20) will be taken, so when capacity will be smaller, the group capacity will be smaller as long as you keep this…the distance between this point to this point is less than the half you know the surface area of the pile itself, because when it becomes too small then the capacity of the group will be smaller but as long as you go larger the group capacity is going to be definitely larger because the distance becomes.

So you can see the dependency of the spacing (())(9:49) as long as you just keep away indirectly instead of going into your analogy of load transfer from one pile to the other pile overloading, as long as you can keep it away a larger the distance the failure surface is going to be bigger and then you are getting capacity bigger, so in terms of single pile capacity what you normally do this skin friction multiplied by pi D times L, is not it? That is what we normally do for a single layer soil, for a group what you are going to do is, you are going to calculate the surface area of this because that is the interface.

The only difference is the skin friction between soil and pile is here whereas in this particular place there is no pile but it is our soil to soil failure because the soil between the pile is getting almost similar to the soil, so maybe slightly less skin friction value may also have to be used because here is a pile to soil, here soil to soil, so that is basically the idea. The block capacity is calculated as the block surface area multiplied by the length multiplied by…if you have a multiple soil instead of single layer soil, you just simply calculate the same methodology what you are using calculate the skin friction in each layer and cumulatively add the capacities and so on.

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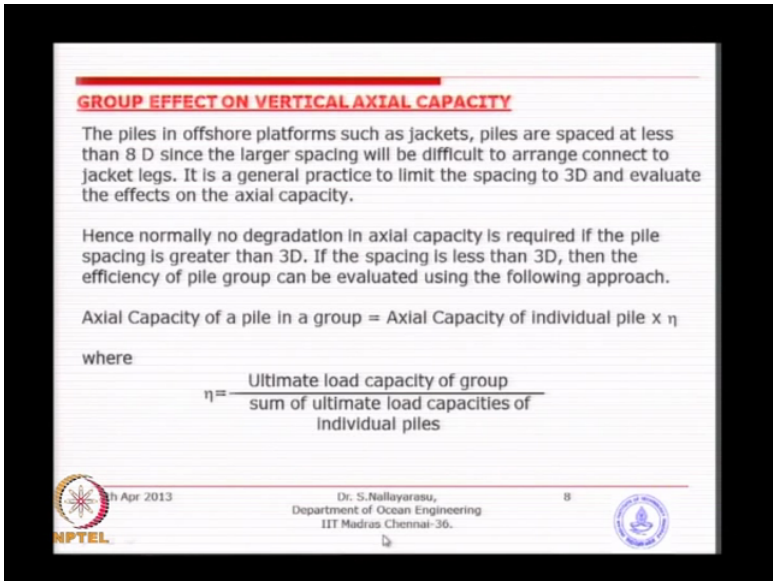

So basically that is the idea behind the ultimate group capacity has to be established by somehow, either the way that I have explained or you do an experiment or you do other means of evaluation and basically the individual capacity also easily can calculated by soil engineering friends or by other means.

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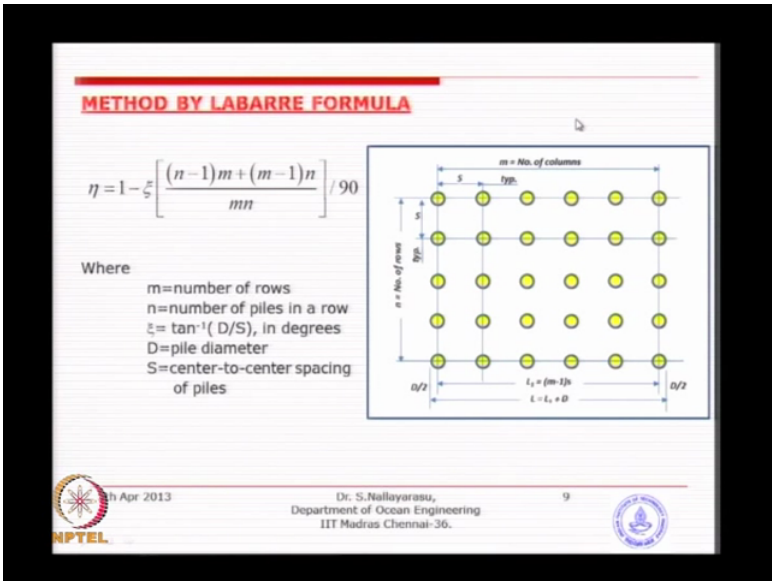

There were several research work done by quite a number of people, basically several empirical formulas do exist but not specifically for our type of work you know basically for onshore structures, so you see here Labarre formula using the spacing between the big group of piles just for onshore industrial type of structure wherein use small diameter pile normally we do not use for beyond building structures.

Now I think 20 years of 30 years back the large diameter piles were very rare because installation methodology was not that much possible because a hammer was not available, making such type of file also very difficult, those days they use to use 200 mm square concrete piles, 300 mm square concrete piles precast piles but now nobody goes for such type of thing unless very limited equipment availability, so you can see here several number of piles gather with a big raft which you will have the structure completely, so instead of going deeper instead of going bigger diameter, smaller diameter smaller size not necessary that they will be circular, they can be square or rectangular piles, concrete, steel, timber sometimes people have used timber piles.

So many of them the idea is spread the load go to a better stratum, so basically that is the kind of idea, so when they were looking at the failure surface will be somewhere around here you know basically you take the peripheral rectangular surface joining all the pile surfaces so you will see that that is a failure surface or calculating the capacity of the group itself, so the formula proposed by Labarre is just little complicated, number of rows, number of piles in another perpendicular direction and zeta is the angle, D is the diameter of the pile and S is centre to centre spacing between 2 of the piles, so basically using this formula the efficiency of the group can be calculated by using this simple rectangular system, so number of column and rows is basically the arraignment of piles. This was used several years back, nowadays even onshore projects we are not using it because almost every particular specific area require different type of configuration, this is only possible for such nice rectangular RA of piles.

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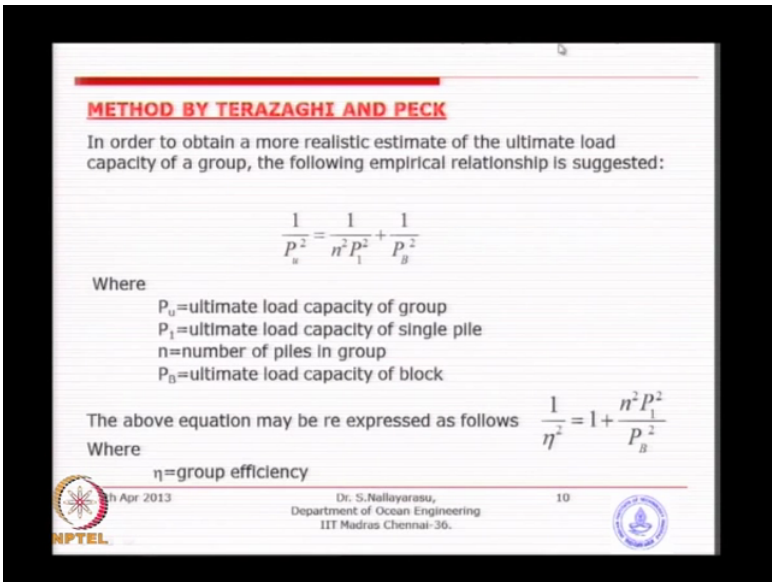

The other one proposed by Terazaghi and Peck as early as 1960s you can see here as a reversed capacity formula, the ultimate capacity of the group is equivalent to 1 by n square P 1 square, P 1 is nothing but your capacity of individual pile and P B is the capacity of the block or the group, so basically you can calculate using the method I was explaining, you just find out the peripheral area of the pile group multiplied by the soil pile interface friction and times the length will give you the block capacity and P 1 is the conventional axial capacity you calculate by means of you know skin friction times the length times the surface area and you resolve this formula to get the ultimate capacity of group which was proposed by this, so you can rewrite this equation in terms of 1 plus n P 1 by P B square is 1 by eta square so you can just reverse it and you can get the efficiency of the group.

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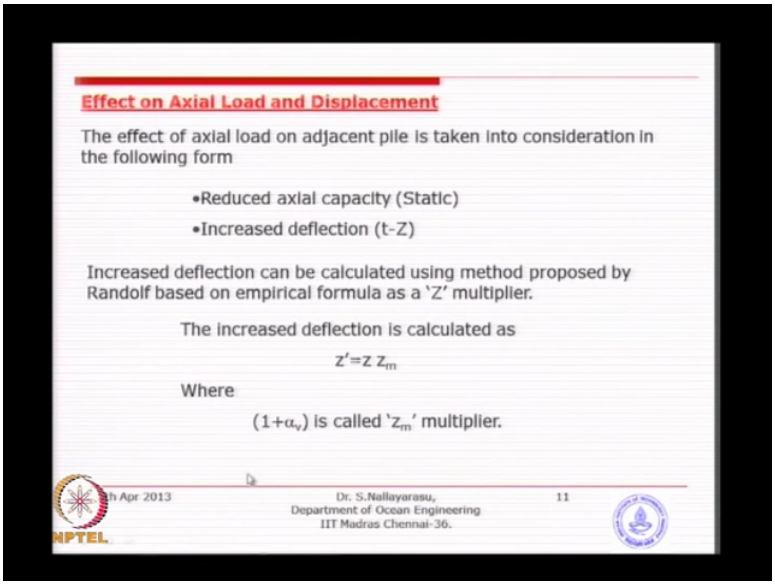

So in terms of offshore Systems what we will how do we calculate the effect of at least 2 piles bust then it can go to 3 and 4 because most of the projects if you look at the pile configuration they will have 2 or 3 maximum very rarely you will have number of piles more than 3 and 4 it will be very remote situation, so this looked at 2 piles and the contribution of the 2nd pile to the 1st pile on load capacity reduction or increased in deflection will be looked at, so the increase in deflection of the of the pile in consideration basically the original deflection calculated by the single pile load deflection graph multiplied by multiplication factor is basically Z M or whatever terminology you can give is nothing but 1 plus alpha v, so this one if alpha v there is no group effect alpha will become 0, so alpha v is always going to be somewhere higher, so basically you can add and multiply. So you have 2 things to look at

one is the capacity reduction the other one is displacement increase in terms of either TZ or QZ.

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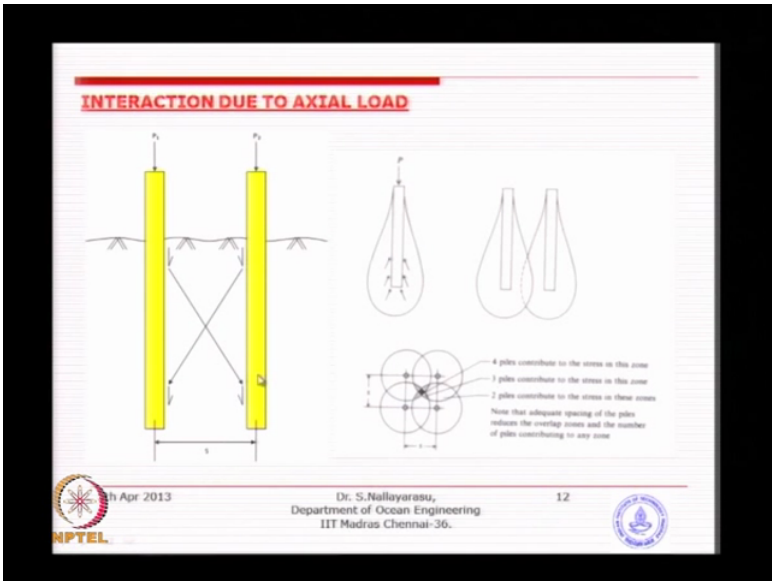

So typically if you look at loading on each pile if they are equal then it is easy to compute otherwise you have a load of P1 on the 1st pile and P2 on the 2nd pile and the contribution of P2 towards or particular location, we do not know where it is depending on the spacing the location will be different, so it is going to contribute a vertical displacement increases because there will be vertical displacement of the pile due to P1 you already have your P T Z established for each layer and for because of P2 because it is too close there will be a deflection increase on the pile 1 because of P2, so this is this cross correlation. Suppose if we have 4 number of piles you see here like the one that we were looking at you will see a certain portion of the pile, soil interaction basically the soil is subjected to 4 times the loading, so you will see that that is the concern that we have which is going to be the evaluation technique.

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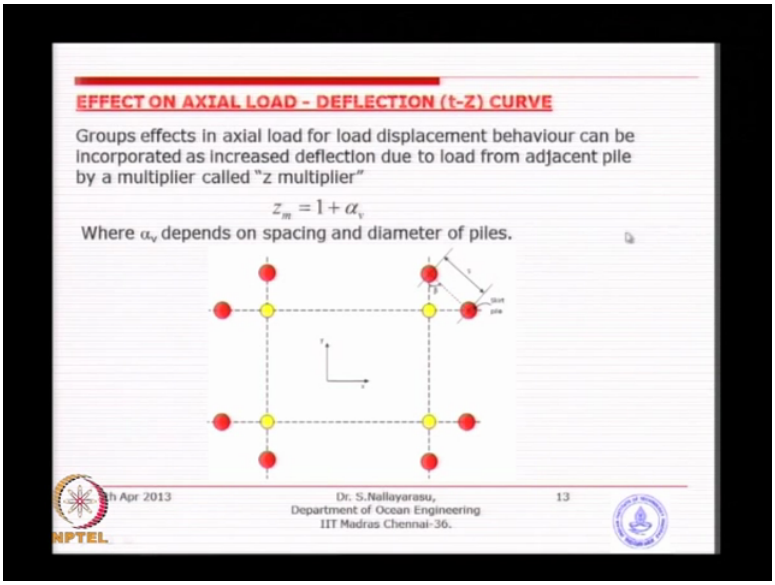

So basically the pile configuration which we have seen earlier, one of the important thing is loading which is also going to contribute for example if the loading is going to be exactly along the line of the pile centre line for example this is pile 1, this is pile 2 if the loading is along this, so the 2nd pile is in the actually the shadow area of the pile 1 which is going to be full effect but if the loading is on the y-axis, so then what happens is part of the loading is going to be just getting some influence whereas it is not going to be full effect if the load is along the y-axis there will be one loading here another loading here.

So basically the orientation of the pile with respect to loading is another parameter which will actually influence but then in offshore structures especially horizontal load, what we are talking about is horizontal load, vertical load of course you will have so the load orientation the orientation of the piles with respect to the parent support structure is also going to be important parameter in terms of evaluation which we need to take into account but for the vertical loading I do not think you need to have much problem, so in here Z M is nothing but 1 plus alpha v.

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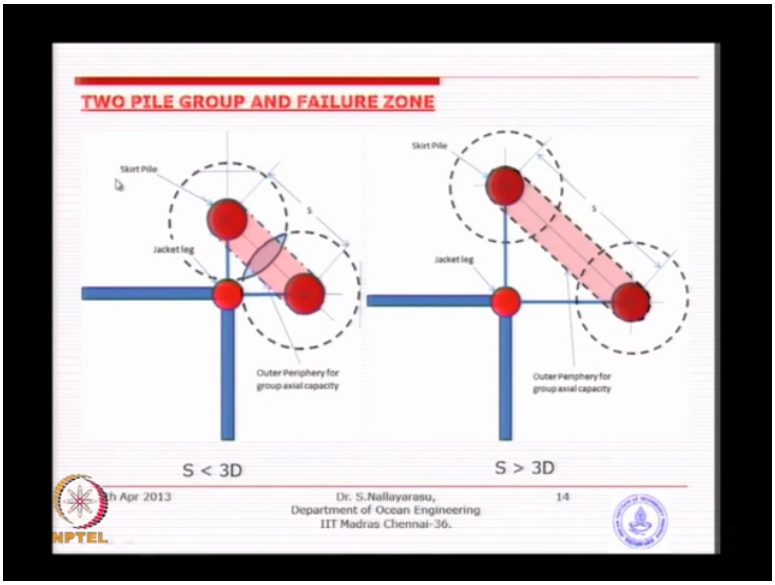

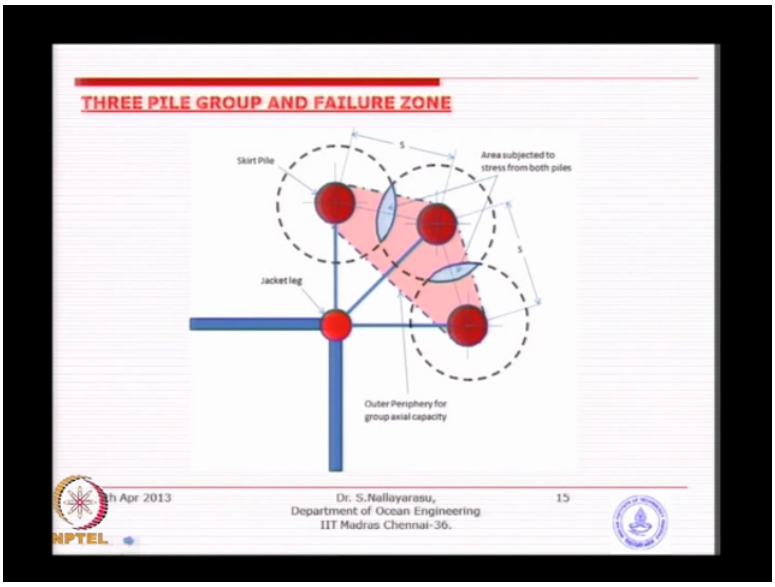

This is the one we were talking about earlier on you know too close spacing this is what will happen, if the spacing is kept larger than 3 diameter, so you can see there but this bulb is keep on increasing if you go back to the 1st picture which I was showing as you go down the bulb size is increasing, so the deeper you go you will see that the overlap will be slightly more, so for 3 pile system if you look at it you will see that there is interface overlap between these 2 piles as well as the other 2 piles whereas these 2 piles there is not much because it is already very far so but if you look at the failure surface as a group you can see here this is bound by the outer surface this basically joining the outer 2 piles and this inner pile.

So for a 3 pile group system if you try to bring this one in here what will happen? If you keep that in the line you may not actually get the spacing requirement even if you want to

maintain, so that is why you have to just go out, you keep make sure that this (())(19:24) is maintained whatever spacing required or if you want to keep like that even if you keep the pile here then this pile have to go this way and this pile have to go downwards.

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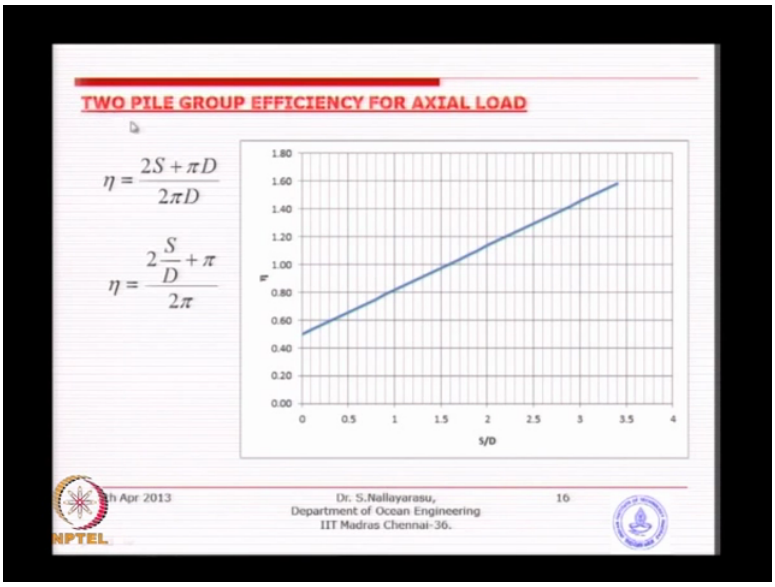

So if you just draw just for the 2 pile group efficiency, you can see here the efficiency…the spacing ratio is spacing divided by the diameter and efficiency, basically if you look at 3 diameter or in fact you can go back to the efficiency of one if you just keep it at one point about 1.6 diameter for actual capacity, so you are going to get almost not much effect but if you come less than that then there will be reductions for example if you keep one diameter spacing you will have almost 20 percent is gone, so that is the indication that you should look for but normally most of the codes suggest that you keep the diameter space, diameter the spacing ratio as around 3 not only respect to axial capacity but also lateral capacity because lateral capacity what has been suggested is 8 diameters as overall spacing, so if you keep it a 3-D you may actually not get any axial reduction but you make it large reduction in lateral capacity that is what the idea. So this basically how it is calculated?

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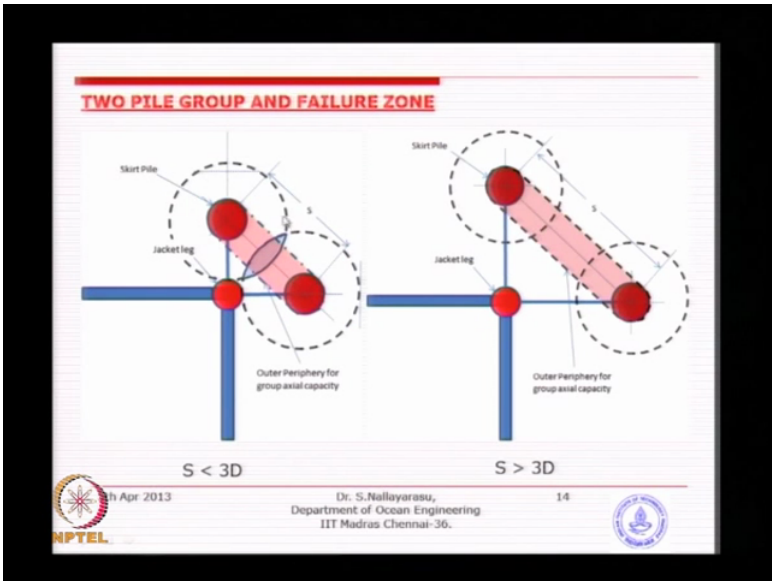

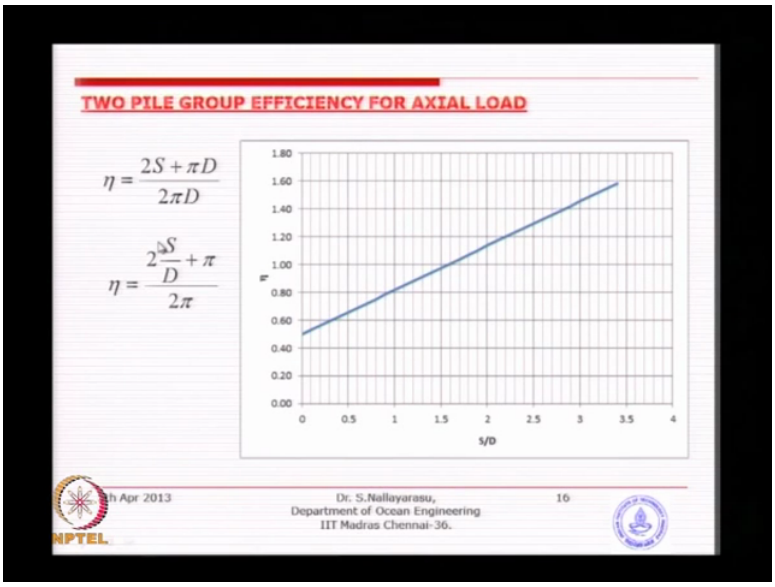

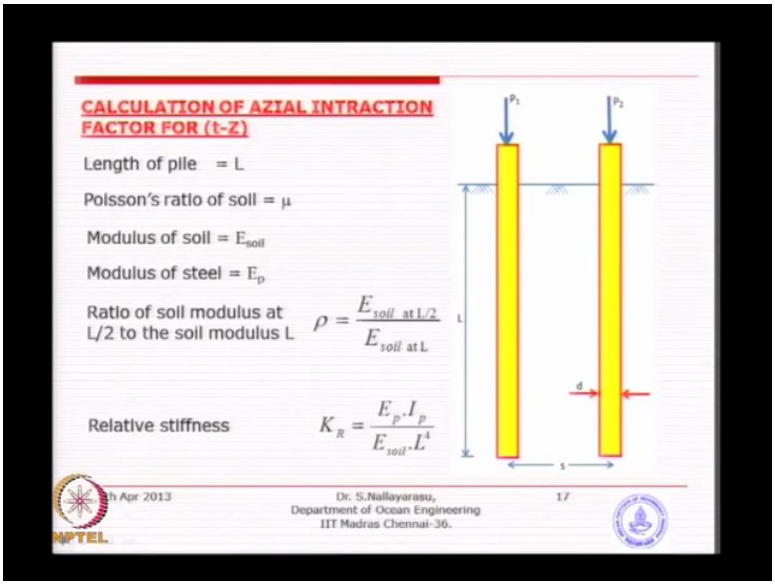

If you go back to this picture you can calculate this is basically pi D by 2 and there is some other pi D by 2 and plus 2 s because s is the spacing of piles, so simply multiplied by skin friction and multiplied by the length, so you get a group capacity. Individual capacity is 2 times pi D times L, is not it? So that is the formula that has been used here so that you can just find out where we are and this is basically based on simple assumption of same soil and just uniformed calculation but if you have multiple layers soil and different…so you make it slightly different indication is axial capacity is not as vulnerable as what we were thinking you know you do need to go to 8 diameters you may actually keep it somewhere around 2 or 3 diameter which is good.

Theoretically speaking your block capacity is going to be okay as long as you keep it beyond 1.6 diameters, so that is the idea that we need to… If you keep it at one diameter that means it is a touching pile you know basically half diameter here half diameter here the piles are constructed just one next to other, I think most of the time they do it in retaining structures sometimes you might have seen piles are constructed one after the other without any gap for retaining structures, so basically that is the idea.