Foundation of Offshore Structures
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Module 1
Lecture 9
Bearing Capacity of Foundations 2

So today we will today just see the few equations to calculate the elastic settlement of you know shallow footings or spread foundations followed by file foundation will start up the actual course you know we have seen few equations earlier on in the last class regarding numerical formula for inter-relating the bearing capacity and settlement which is basically an numerical relationship you got to use carefully.

But this one just now what we are going to see is the reason why we need to know the settlement as I mentioned in the first few classes basically the reason for foundation is well known you know the load transfer to substratum without effecting the super structure behavior and the acceptability criteria that means the response of the structure is to be within the limits. One of the response for most of the structures is the vertical displacement which is substantially important because it will hinder the operational requirements of the whether it's a building, bridge or optional platform. So basically that is the idea.

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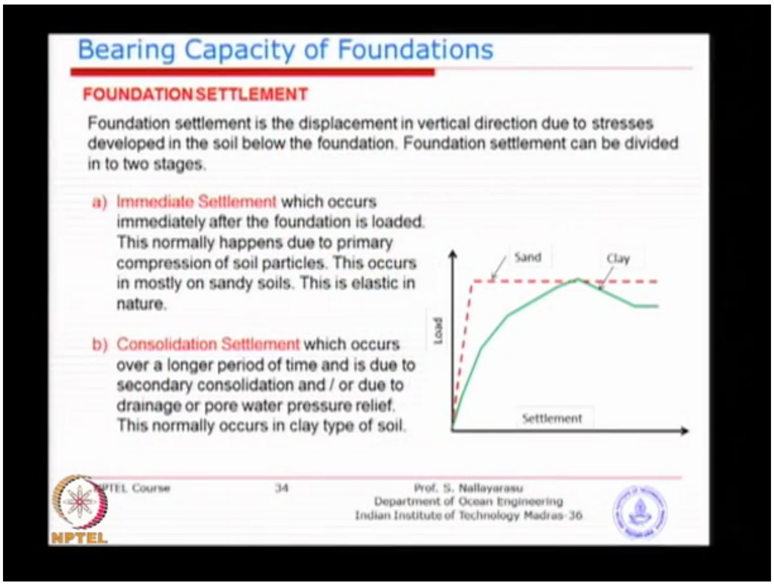

So the bearing capacity equation as derived by Terzaghi as well as modified by others that is not really have any relationship with respect to the settlement criteria or the relationship between the capacity and displacement. Now we could possibly relate by doing some relationship with respect to the displacement and the capacity by doing a load test for example when you actually want to establish that such relationship you can go to the field you carry out load test by means of applying external load and then record the displacements and then derive it , relationship it could be linear it could be nonlinear depending upon the type of material. For example steel, when you do such things in a tensile test you actually get a stress versus strain load versus displacement.

So in the steel material for substantial portion of the strength you have a relationship which is very straight forward linear, then after that it become elastoplastic, whereas for soil you could see from this picture just now we have two different class of materials course grind versus fine grind, course grind you have coefficient less soil basically grind size material like sand or clay which is fine powder plus mixtures.

So you could see distinctively a behaviour difference between sand and clay sand behaves almost like stimular to perfect elastic elastoplastic you can see just straight line and then just straight away go into hundred percent plastic. That means as long as the particle get displaced or dislocated due to loading they simply fail and you can’t repair them.

It won’t be able to come back so a permanent deformation. Similarly clay instead of going linear relationship because of the type of behaviour you have a compressibility and you see a almost nonlinear. So this is the thing that we want to relate and find out how they behave in case of a multi-layered soil you are not going to have complete sand or complete clay for throughout the depth of the bearing stratum . So may have various layers of different materials or even within one layer you may have a mixture of materials like sand and clay.

So we need to just assess. So what we really need is one important property which I have given you a big table few classes back relationship between SPT value and modulus of elasticity which is very-very important because that is what is required to establish the stress strain characteristic or load displacement characteristics. So immediate concern for us is basically the immediate settlement for any type of foundation as soon as you complete the construction due to its own self weight or the loading just occupied by the structures in immediately after the construction completion or the consolidation settlement basically after a longer period of time due to consolidation of clay type of material where you will see that substantial portion of the settlement is taking place.

So we need to just see which one is going to affect for off shore structures we are not really too much worried about the consolidation settlement because we have different type of foundation which is very much essential for onshore type of structures where you have a shallow footings or small different foundations. But the immediate settlement is very much important for us, as we place the jacket on top of the seabed with low pile foundation because we have just spread footing or matt foundation I would say.

When you place the jacket on seabed the immediate settlement immediately after the placement is very much important because after few hours we are going to do piling. Once the piling is done the jacket is secured well with not much going to happen afterwards because the pile is very deep foundation taken to barring stratum. So the, the temporary stage where the jacket is placed on seabed and basically we don't want this jacket to settle too much so that you water level you know the relationship with the jacket top in not changed.

Ok, few hundred millimetre is acceptable but few meters is not definitely going to be a acceptable criteria. So how much is acceptable is supposed to be decided by the engineer because you can always adjust if you know pre-hand that you have calculated deflection is 500mm you can actually design the jacket 500mm higher so you know very well that at this particular sight the jacket is going to settle by 500 so elevate your super structure interface by that much.

So that's the idea of this why we need to know the settlement for us especially for offshore structures is to establish the bench mark levels for the interface between jacket and the, the substructure. So we will only look at quickly how do we estimate a immediate settlement on two classes of soils.

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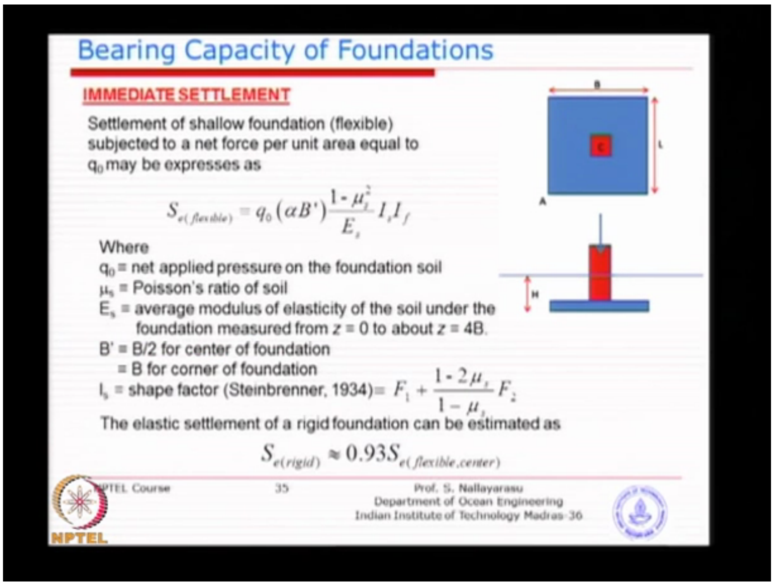

The first one is the you know the general elastic formula you could easily see this is very similar to derivable from basics of stress strain criteria.

So this Q knot is nothing is but the applied pressure due to the structure placed on the top of the soil and Mu and ES is the elastic properties Poisson's ratio and you know the elastic modulus. The whole thing depends on this particular value the larger it the smaller the displacement. So basically that is where the whole matter realise on. So when you are doing a soil test in the field you get the SPT value relate to ES or if you take a soil sample to the laboratory you do a actual test you could possibly get the ES values from there.

So basic idea is deriving this two properties is very important remaining is only based on geometry and the type of loading and the the influence coefficient just as matter of location and basically the shape of the foundation. So these two coefficients can either be calculated by equations given here

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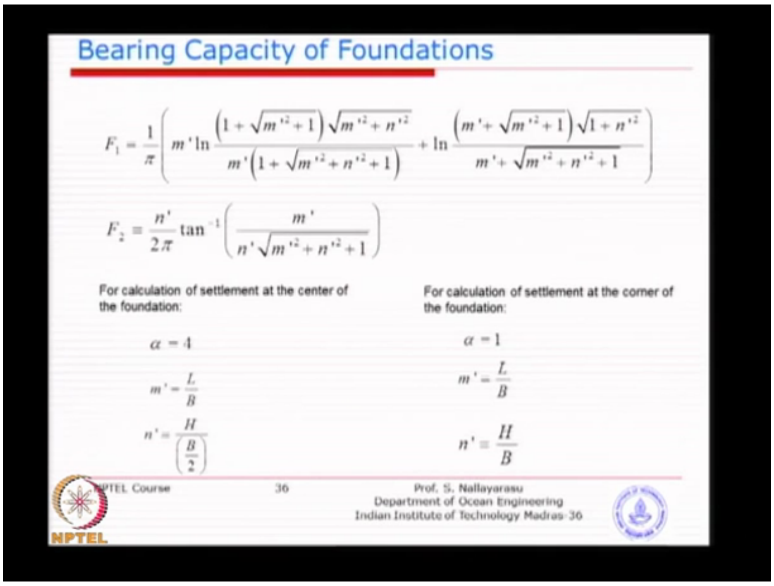

little bit complex is actually derived from(())(07:26) equations for stress below the up load applied on foundation is a simplified form.

In fact if you look at (())(07:34)equations you will have several cases whereas I have only taken case for displacement at the corner of the foundation or displacement at the centre of the foundation.

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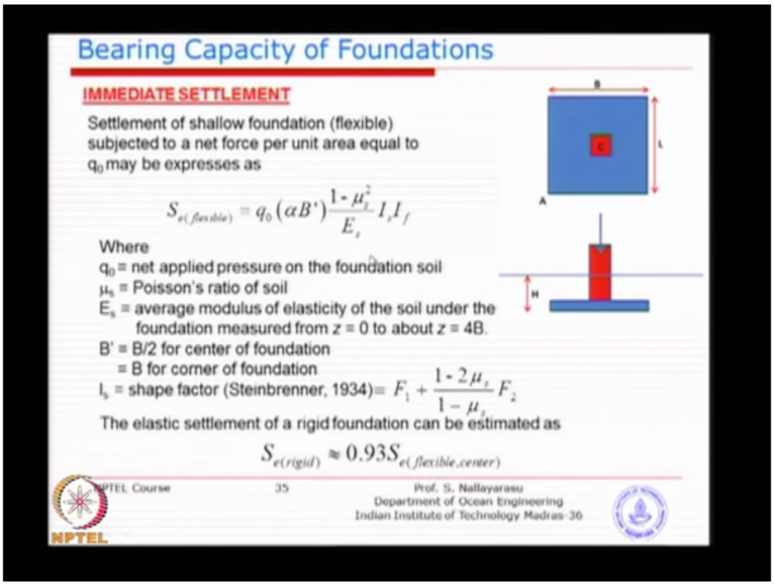

So basically two points and this particular equation is just basically derived for flexible type of foundation means it will have elastic deformation or you can also find out just taking a slightly reduced by rigid foundation.

So you could do that, but ultimately what we h will require is the applied pressure one minus Mu square divided by ES which is very similar to a the stress strain equation for steel except that you are going to multiply by the influenced coefficients and the shear factor. The shear factor can be calculated as proposed as by (())(08.22) runner using these equations F1 and F2 can be found from this two equations for a different locations this is what was proposed.

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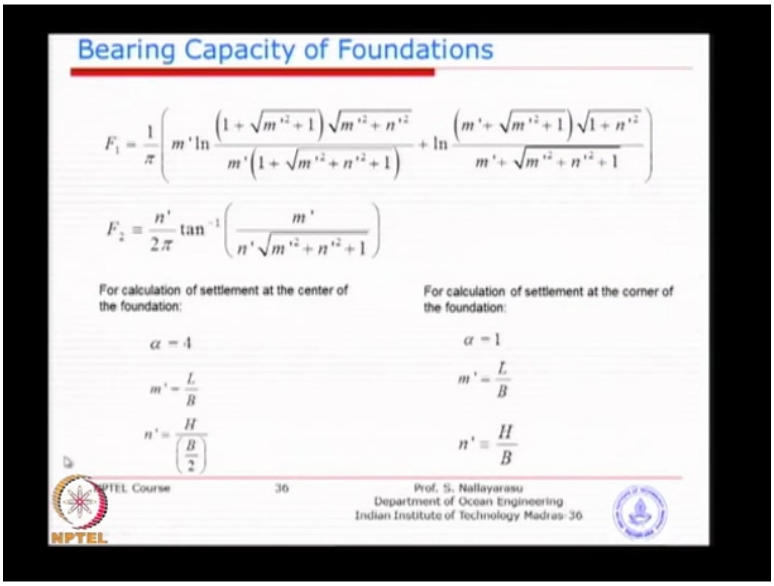

Basically the alpha is four M dash and N dash is the normalised length and width and for calculation settlement at the corner of foundation which is at one four corners anyone of them if it is a rectangular. Alpha is one and M and N is, so you have to substitute these values of M and N to calculate the F1 and F2, and F1 you once calculate you can calculate the shear factor.

So basically that is the idea very similar to we were having shear factor for barring capacity for circular, rectangular and square shape and then we need to have calculation for the influence factor.

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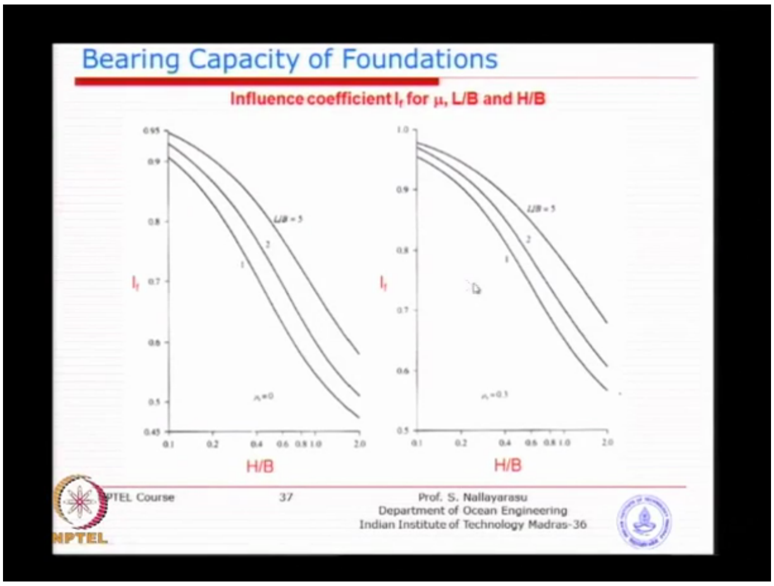

This is basically the you know as you go down along the depth from the base of the foundation you can see that the influence of the soil pressure is reducing.

I think we have seen this one the first few classes you can see that as you keep going down the soil pressure get dissipated means the spreading is more the average pressure will be less. So then you have a effect on settlement will be also reduced. So this charts I have just taken from the original paper from (())(09:44) basically plotted with respect to H is the depth L and B is the length and width of the foundation. For different values of L by B I think there are four charts basically.

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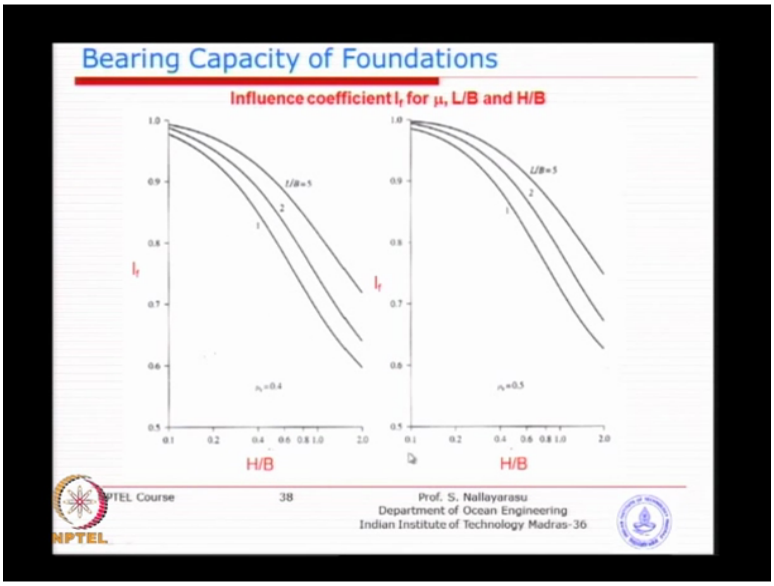

You can read basically here L by B is 5. So you can read that chart and get the IF coefficients and basic idea is the calculation of settlement can be easily found so main matter is the elastic modulus.

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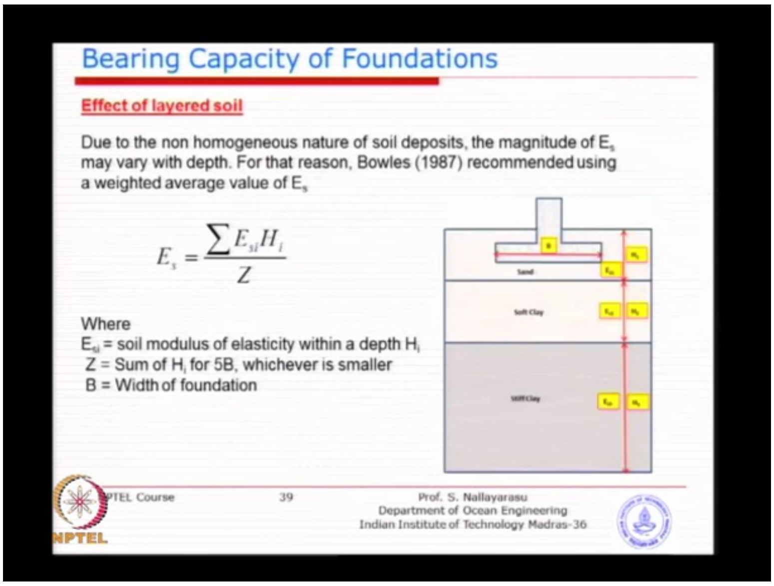

Now if you have a realistic soil normally you don't have a single layer soil in any type of bearing stratum you will have multilayer soil, so what we normally needs to do is try and find out an average like what was proposed by Bowl's as early as 1980's.

Where you can find out a weight average with layer thickness is available H1, H2, H3 and then you do the each layer modulus of elasticity and then find out the weighted average. By doing this you are taking the influence of these lower layers in the settlement of the foundation at the top layer so basically as the pressure goes down you can see that the effect of that will be taken into account by taking the average modulus.

There are several techniques available one of this is approximate method where you can do this or you can actually calculate by FE analysis by modelling the whole soil stratum which will be time consuming instead the influence can be taken care by averaging the modulus of elasticity and go back to use the same equation

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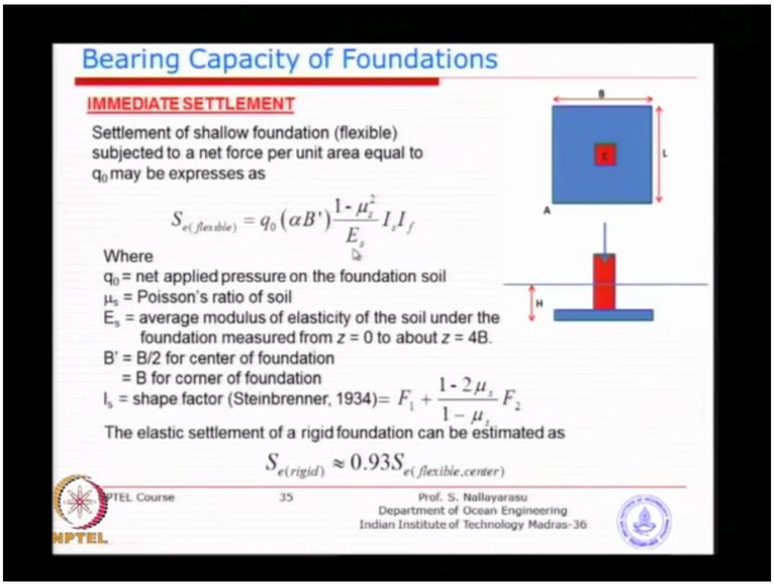

What you see here instead of ES you will be using the, it is very similar to arranging this springs in series.

You know you have a soft spring slightly better spring and so net effect of all the springs together is basically taken into account in the settlement of. The last one is very important

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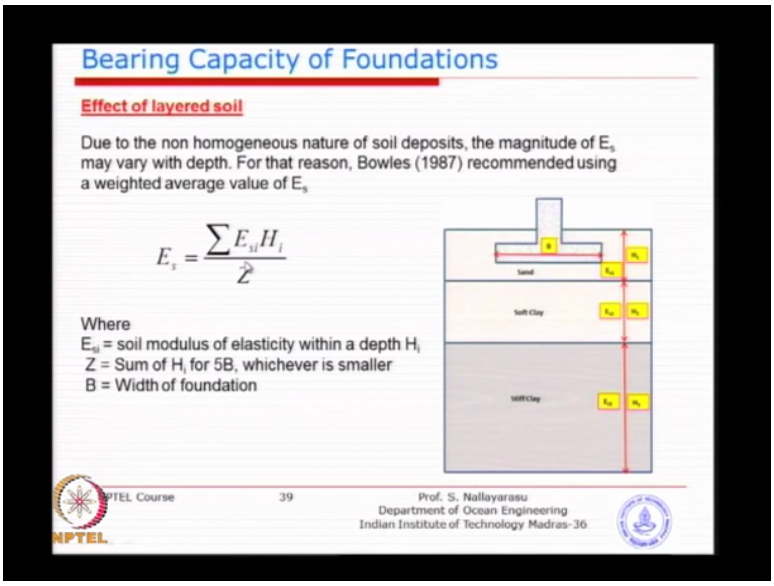

Because most of the times in mudmatt type of foundation first 2-3 meters will be soft clay after that many-many occasion you will see a sand and then you will have strong layers. So if you only take the soft clay you will see that the foundation is going to settle by substantial amount.

But off course that pressure if it is soft what happens is the soft material transmits the pressure to the next layer, the next layer starts going down. So that is basic idea is how much is that, is it same as the soft layer or slightly better off than the soft layer. So that is why we need to take this into account. So think with that we will limit we will not go into consolidation settlement we may not require for our off shore foundations and we will quickly jump on to the pile foundations which is the primarily part of your course.

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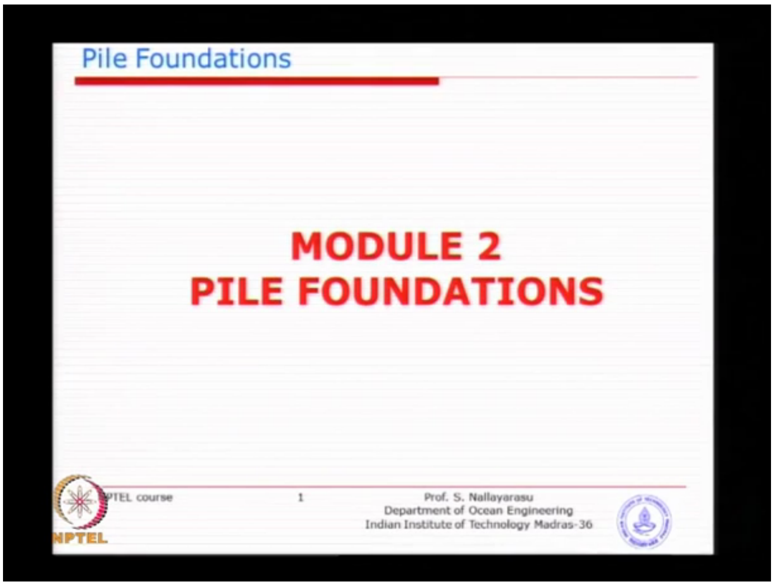

So basically we will be looking at you know substantial period of time in number of classes for understanding the pile behaviour.

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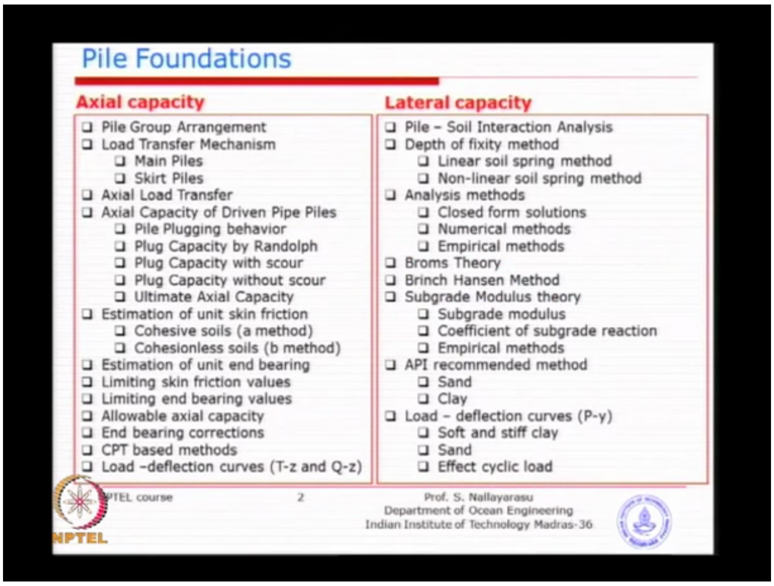

We will apply what we have learned for the last few classes on bearing capacity of shallow or spread foundations and settlement and apply that principle to deeper foundation which is basically the pile foundation and we will focus purely on driven steel pipe piles not the concrete piles.

I think we have just got introduction of concrete piles last time. But we will not focus so much as it may not be applicable to offshore structures so we will quickly look at actual capacity first for the first few classes before we go on to lateral capacity. The actual capacity consists of several things we will see one by one. As starts from pile group arrangement and then the load transfer how it happens I think we have seen that and them the actual load transfer capacity by means of assessing the soil characteristic in a layered soil and then estimation of skin friction estimation of N bearing which is very similar to what we have done just now for a shallow footing.

Shallow footing what we have is only N bearing means is a contact pressure between depth soil and the foundation. So here in pile foundation also you will have that in addition because the arrangement of the foundation is such that you may get a frictional resistance between the pile and the soil. So you got two components to estimate and then we will look at the factor of safeties as per the course and then there are corrections and then various other methods.

Finally we come down to the load displacement relationship which is very important just now we have got bearing capacity for shallow foundation we have estimated S vertical displacement by means of a simple elastic theory using modulus but we have never related them you know most of the cases it is not related. You know when you are designing a building we don’t relate them so much because we calculate the capacity we come back and establish the settlement.

If the settlement is higher we have two things to do either reduce the load or increase the foundation area that is what we iteratively we do in your design of onshore structures. Whereas in offshore structures such iteration is simplified by making a relationship between the capacity and displacement so that you can use in the starting time itself, what is the required capacity for a given settlement, so just take the graph even if it is nonlinear you can program it and that is the idea behind establishing such relationship basically called TZ is the vertical you know capacity in skin friction and displacement.

Similarly QZ is the N bearing capacity and corresponding settlement so that is the idea behind. Lateral capacity also as important as actual capacity as we discussed earlier you know the offshore structures are subjected to considerable lateral loads so what we need is need to make sure that the soil capacity is taken into account appropriately. To resists the horizontal forces to make sure that the response is calculated.

So here we have a several ideas in fact a lot of ideas I would say I have just collected reasonable information which are relevant to offshore structures and then try to go from there. In here we also establish the relationship between the lateral load and the lateral displacement of the soil material. In various types of soft clay stiff clay sand and then due to cyclic load you know as you know the wave load is going to be cyclic.

Unlike gravity loads is static so what happens to the soil? You know when you are keep on moving back and forth, the soil gets remoulded, soil gets loosen or may actually loose the strength completely and it goes progressively the top soil near the sea bed may actually get looser very fast compared to the soil below. So at it goes progressively when the soil is top layer is getting reduction in the strength, what happens to the next layer and next layer on so.

So how long it will take because the structure is going to be there for several years and you can see progressively degradation will happen we called it the soil degradation due to cyclic loading. So all those things we need to learn this are all something special for offshore structures which we normally don't look at it in onshore structures. So we will just quickly go through the vertical foundation.

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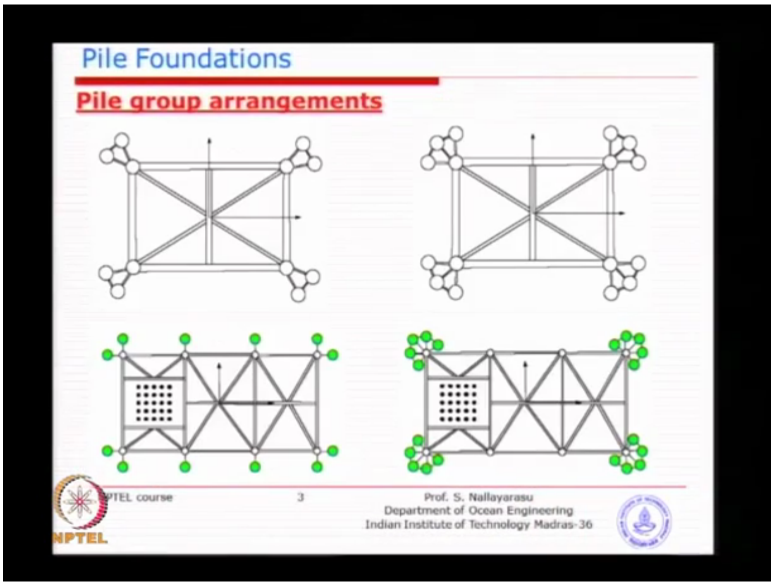

I think by this time you are familiar with the foundation types for offshore structures for sure you will not have concrete piles. You will have steel poles and that too open ended sections, that means take a hallow circular section both ends are open and start driving down into the ground. You so can see this is not a displacement pile but partly displacement.

Well as you are driving the portion of the material or the wall thickness has to be displaced but not similar to a concrete pile where if you have a full concrete pile driving into the ground the whole soil forming the cross section of the pile has to be displaced. So you will not see too much of soil displacement in this case but off course reasonable amount of compaction will happen inside the pile because the soil is squeezed in between.

So open ended steel tubular pile driven into the ground that is first case, the second case open ended steel tubular pile but not driven into the ground but bored and placed into the ground and then grouted. I think we discussed about these two cases wherever you have encounter of very hard soil unable to drive for example what you can do? You can still do this by making a drilling, place the pile and do the grouting.

So the soil to grout interface grout to pile interface whereas the actual driven pile you have a soil to pile interface only. So basically 99% of the time we have driven pipe pile directly into the ground. The drilled and grouted piles very rare because is very expensive number one and not preferred by anybody including the owners because it is quite time consuming. You know to drill hundred meters of depth you can imagine it takes an (())(19:25)amount of time and effort. So you see these pictures here I have just given you the plan view of the jacket hope you can understand.

Normally you will have four corner piles in each jacket in this particular case because of loading is substantially higher you have several choices for example you can have instead of one pile of one X diameter you can make the one pile double X diameter, isn't it? So basically you can do that means that diameter can change but how much diameter is an acceptable criteria to practical installations.

Which is something is very easy to find the equipment availability is the most important criteria. So normally the pile diameter doesn't go beyond 96 inches at least in this region we have not seen any piles having diameter more than two and a half meter. So you can imagine you don't about driving a pile of 5 meter diameter 10meter diameter so forget about such type of ideas normally about two to three meter is the type of diameters .

One and a half to two meters, two meters to two and a half that is the kind of range. So when you are designing a pile foundation average diameter or the maximum diameter you should remember two and a half meter max so when you exceed such a criteria of two and a half meter you have only one choice, you can increase the (diamet) the length of the pile which is again going to be problem because going to deeper also is going to be insulation related issues.

So that is the time you go for the third choice of increasing the number of piles around the load transfer corner. So you take this corner for example if go to this picture the loads where substantially larger in that (parti) bigger platform you put several numbers of small diameter and limited depth foundation which does exactly the same purpose and (())(21:17)has got some capacity cumulative addition of all of them we will see later whether that cumulative effect is same as the group effect which we called it group efficiency which we can discuss later on.

But the idea is splitting the loads into several sub groups like 1,2,3,4 and then each group has got individual piles forming total capacity. So that is the idea you need to keep. To do that you need to know what is a practical range of values. Diameter range 1 meter to 3 meter depth range say from 50 to 100 meters do not design a foundation with 500 meter penetration then it will be impossible to install.

So you need to always think about how it can be done, whether it can be installed or not installed that is the idea that you need to keep thinking. So that is the that is the reason why you can see that different-different configuration there is no fixed configuration to any type of jacket because the loads and the type of soil in individual location is different. So that is why you see here in this particulars the jacket size seems to be similar not very big different in fact but you can see here number of piles are more number of piles are less in each corner.

Distribution of piles to the middle also has been done so there is no fixed rule that if it is a eight leg jacket only two piles per corner or four piles per corner. All depends on the configuration of the super structure. The pile group arrangement is actually something that will be arrived by the engineer or designer depending on the situation depending on the ground conditions predominantly affected by the ground conditions.

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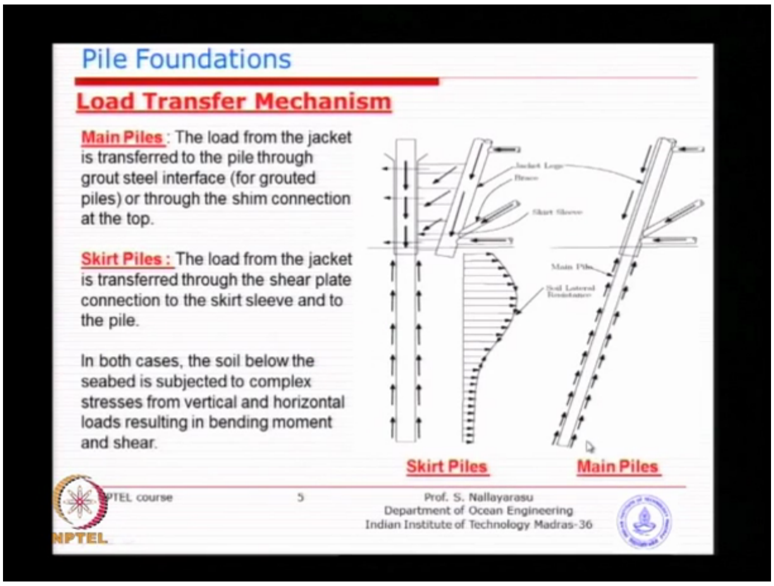

How the load transfer is predominantly happening for a offshore type of foundation I have just drawn the part of the jacket and part of your skirt pile so this is basically the jacket leg and this is a skirt pile I think most of you will remember I have shown you some pictures that the load from jacket has transfer through the platted connection through the outer shell and then to the pile and predominantly goes through friction.

Why did we choose to go for pile foundation is to transmit the loads to a , a bearing stratum which maybe far away from the seabed that is one of the reason, second you could see that when you are doing this you also get a substantial frictional resistance from the pile surface both inside as well as outside. So as you are trying to go and trying to search to bearing stratum if you never find what will happen? For example I have to look for a layer where soil is very good.

When I try to penetrate the pile down there and want to get a maximum bearing from the soil itself but if that such layer is very far 500 metres away, are we going to search in and go down to 500 metres? Not really. So what we will do is we will terminate the pile wherever and take into account the frictional resistance of pile surface and cumulative effect if it is sufficient enough to take the loads will stop the pile.

So there are two types of pile foundations one is you know the N bearing piles or the frictional pile you could go either way or you can have a combination of frictional pile plus the N bearing depending on where you terminate the, the pile itself so it doesn't mean that we will always keep in search of the layer that takes the full load very similar to the shallow foundation.

Remember when we were looking at the shallow foundation we highly rely on in fact 100percent capacity is coming from the contact pressure between the foundation and the soil. Now if you don't have enough capacity you do increase of soil foundation interface that means make the bearing area larger or you actually dig the ground go deeper and make the foundation there. That's what normally is been done but in such cases if the bearing layer is very far that foundation will not be suitable because you can't excavate 100 metres of depth and go on start making a foundation there.

So that is the time you change your idea to instead of a spread footing make a smaller foundation size and go down and try to . So the pile foundation concept is very clear we are looking for a solution where the load can be distributed to various layers as well as to a bearing layer even if it is at a slightly longer distance from the seabed.

So you can see here the arrows indicate is this friction between the material which is a steel material to the soil similarly on the inclined pile you can see here on the better pile main pile is exactly same only that the pile is not vertical you can see here is slightly inclined but what we are looking at is the frictional resistance between the pile and the soil.

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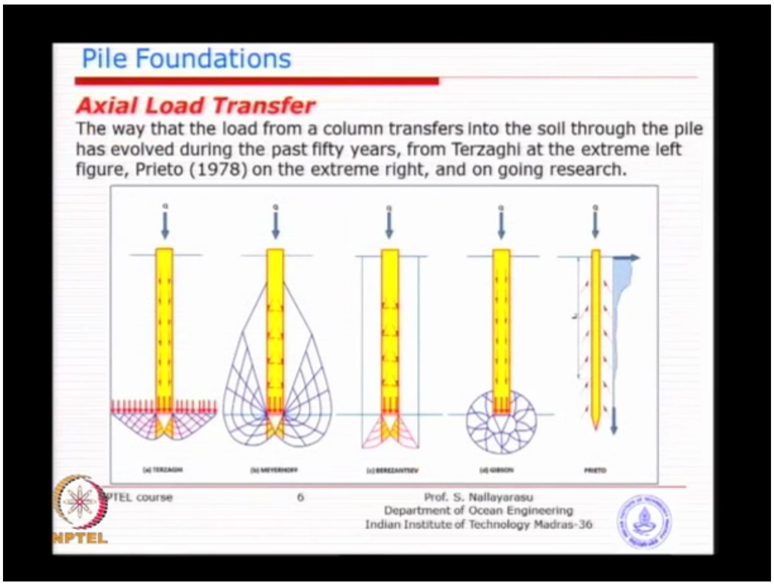

As early as Terazaghi timed to the recent times different ideas different concepts (()) (26:29)how the load transfer can happen.

You can see the first one is very similar to shallow footing you know he has come up with an idea exactly same you know the distribution of stresses beneath the pile foundation except that the load is carried by the stem and goes down to a terminating layer and you just draw your pressure diagram and try calculating your capacity in a similar way what we have derived few classes back.

Exactly the same idea and you could see here on the right hand side the overburden pressure on the sides of this pile is the very important criteria that he has considered. So the more the overburden pressure the less the chance of pile displacing the soil around and fail. So that means the deeper that we go you get a very good capacity at the end so that is basically the N bearing.

In addition you may also have the file trying to receive resistance from the side of the soil which depends on the relationship between this soil and this soil. Imagine I have a soft clay and then very good rock at 15 metres below I take the pile foundation and install when the pile reaches the 15 metres rock foundation the total load transferred to the pile will straight away go and resisted by the rock, because the rock is high stiff compared to the soft clay compared to the material or foundation material is steel.

So if you look at the relative stiffness of steel, clay and rock what will happen? Full bearing will be taken by the rock itself not by clay so in such instances skin frictions shall be ignored. Because it is not able to the soil is unable to take it because the full bearing is coming from because the rock is very wrong very-very strong. So that is why the relationship between amount of skin friction and amount of N bearing is going to be a topic where you won't find a solution in fact is iterative technique how much load is transferred or shared by the skin friction.

How much load is shared by the bearing is depending on the type of soil especially if you have the difference is very large the material N bearing material to skin friction material if the difference is too large is going to be very big issue of finding the sharing but most of the offshore foundations we have the soil we will not go for pile foundation if you find a rock very early. You know we will go for different type of foundation.

So that's why you don't find such problem. So if you go to the mayor Horf from the concept of this he has tried to distribute more you know friction cum bearing to a slightly higher part of the soil followed by other researchers you could see different ideas and different configuration. Off course we still go back to Terzaghi slightly modified because all other proposals that not so good so the first proposed by Terzaghi still used by many codes only with some modifications.

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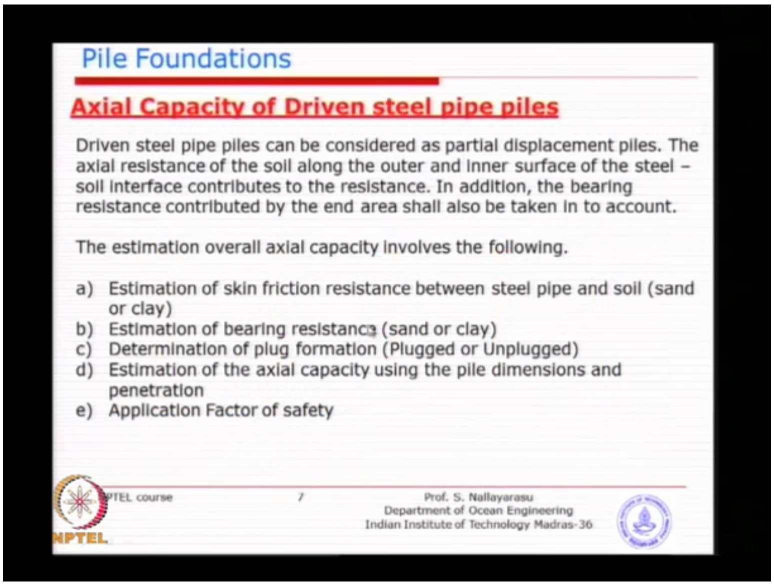

So how do we estimate the capacity of the pile in this case the capacity of pile mean does not mean that the capacity of steel material in this case when we talk about actual capacity of driven steel pipe pile means is the soil capacity not the pile capacity you understand very carefully pile capacity is different, pile capacity is the structural capacity of the section which we have learned in the structural mechanics at design course.

In here what are talking about is actual capacity means the capacity of the soil surrounded in their vicinity of pile to take the load with whatever displacement relationship we are going to calculate. So in this process what we are looking at is the skin friction between the pile surface which is a steel surface plane there is no roughness of on the surface except the actual surface structure of steel we don't go and do any roughening exercise as we think about making the friction higher means, if you have a roughened surface what will happen?

You have a better frictional but we don't do it because is also expensive. So the frictional resistance between steel pipe, plane pipe as made from the mill to the soil it can be sand or clay it can be any combination. Estimation of bearing resistance at the bottom which is basically up here at the tip how much it can rest, how much it can give you the vertical capacity in in terms of N bearing.

Very similar to shallow footing how much is the capacity at the bottom, so which is basically we called it bearing resistance or sometime we called it N bearing either way both denote the same. And then determination of plaguing or non-plaguing this is basically what is really going to happen, we need to just we will talk about this today that really happens when you take a a open ended pipe an then just drive into the ground, when you drive into the ground you have a resistance from the external surface of the pile as well the interface between the internal surface and the soil because the soil is inside.

As you drive soil also goes inside of the circular section. Now when you are keep driving you stop and then just pull the soil, what will happen? Pull the pile the pile will try to come out and you can try at easily any place even you can take a small pipe once you drive you take the pipe out if the soil falls down. You know when you when you pull out the pipe, what will happen? The soil also tries to fall down. Why?

You know if this friction between the inner surface and the soil is very high if the soil friction is very high compared to the weight of the soil itself what will happen? The soil will not fall down the soil will be there because the frictional resistance compared to the weight of the soil is larger than we actually when you pull out the pile the soil will be still inside. Which means that the frictional resistance is very large inside compared to the weight of the soil which we called it plugged pile.

The pile becomes or the soil becomes part of the pile so though you are driving a open ended pipe after reaching certain distance what happens is the soil gets plugged inside becomes part of the pile then the behaviour will be as much as driving a concrete pile with no opening that means is a solid section you drive. So can imagine when you try to drive a pile open ended section after driving certain distance what happens? The pile becomes difficult to drive because the soil inside it becomes part of the hallow section.

So we want to see where whether we are getting into the situation, if you get into the situation may be very difficult to drive so that is why we want to find out whether plugging or unplugged file we want to determine. Why we need to do this? because if you if you have a plugged pile the end is closed though you drive you driven the pile without end closed but actually achieving slightly deeper you have got a full end closed because the soil becomes part of the pile.

Now when you apply the capacity, you will apply the capacity to the full area rather than the steel area. So that is the idea behind this. So we want to find out when it will happen. The easy idea is the frictional resistance inside is greater than the weight of the soil than plugging. So you can easily find out you know what is a capacity what is the weight of the soil, weight of the soil is easy to establish because you can find out height multiplied by the density so very easy.

As long as so height times submerged density you know because all our cases or submerged cases. So basically the plugging or unplugging is nothing but soil becomes part of the pile after driving is supposed to be a criteria then estimation of actual capacity is easy because now you have external friction, internal friction and N bearing or external friction and only the N bearing. Depending on whether the pile is plugged or unplugged.

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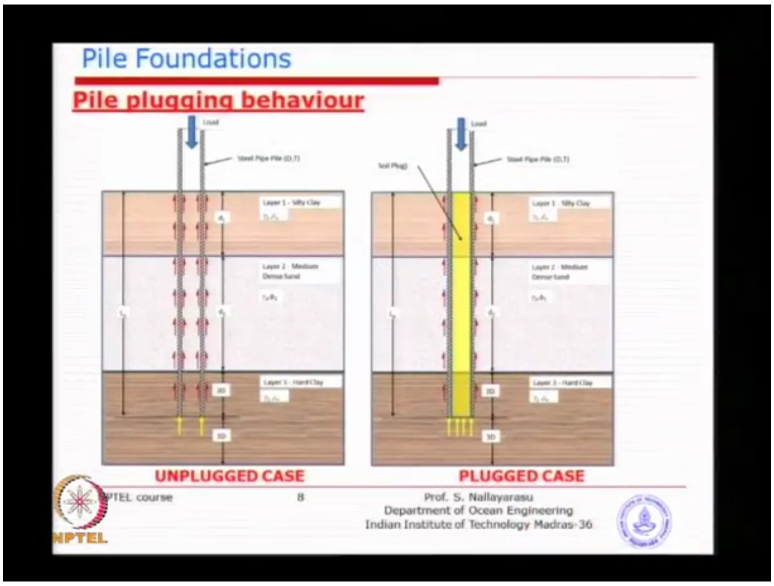

You can see from this picture that is what the idea I was trying to explain. Before you see this picture on the left side you have unplugged case I think is easy to understand no? because you got a friction outside, friction inside and a a bearing only through the annular area of the steel pipe wall which you can calculate you know easily if you that outer diameter and wall thickness you can find out what is the area.

Area times the bearing or the unit bearing very similar to the bearing capacity you calculated for the footing size except that is going to be deeper whereas when you come to the right hand side where you can see here external friction and full N bearing but the soil is part of the pile so even if you apply this pressure what should not happen? The soil plugged should not get moved away, it should have sufficient friction, you understand the idea know?

When you can is not only that the soil plugged has got sufficient weight but also should have sufficient friction for example if you want to take N bearing like this you apply the N bearing what will happen? If the internal friction is smaller the whole soil plugged will get moved away which means that you have underestimated the overestimated the bearing capacity. So that is the plugged case is nothing but soil plug forms inside suppose you want to make it artificially, how can we do this?

You want a very good bearing capacity at the end so you could also do that. You just take out the soil from inside by using several drilling techniques, after driving the pile remove the soil and just put the concrete inside. In many cases we do this. whenever you require additional capacity for repair type of work where the capacity is not sufficient you remove the soil and then pour concrete inside full.

As soon as the concrete get set together with the pile then it become actually a solid pile where full capacity from N bearing can be achieved. Some cases you know whenever we encounter such problems like capacity is not adequate then we try to do this. So formation of plug by nature is simply we can leave it or formation of plug by artificial means to establish higher N bearing capacity can also be achieved.

So pile plugging or unplugging is something that we need to understand because this is where we are going to differentiate between the capacity vertical capacity. That’s what I have just explained so far.

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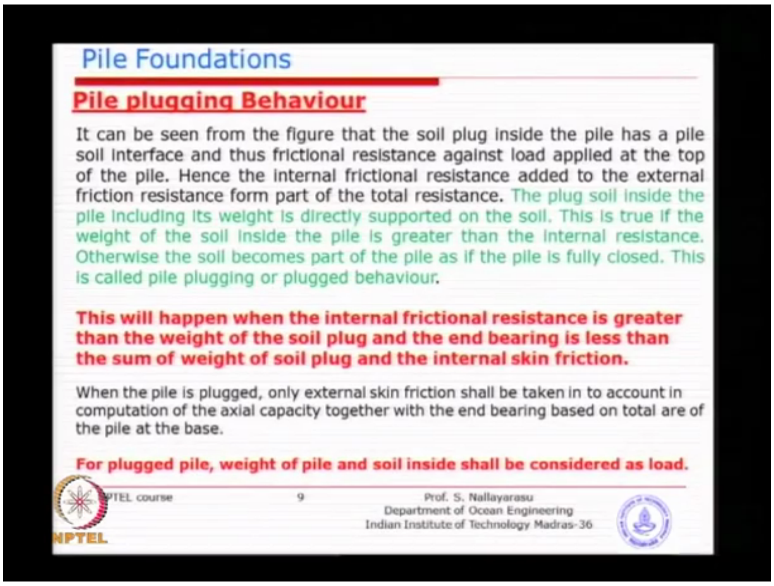

When and where it will form as long as you know the internal friction weight of the pile, weight of the soil and compare it and if the weight of the soil is higher then the friction capacity it will become unplugged.

Or the other way around friction capacity is higher and the soil weight is layer loser lower then you will have a plugged capacity. So you need to establish this first before we go into the, now there is just one difference whether we go back to this picture very nicely drawn

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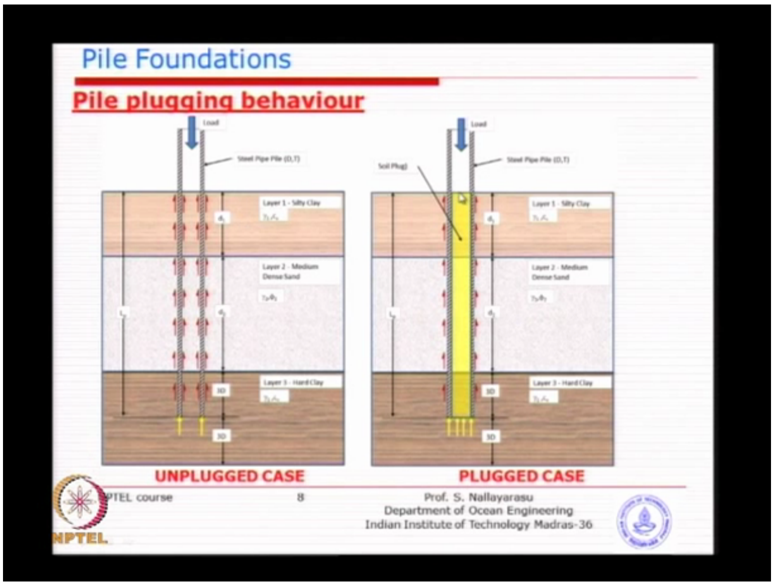

that you can see the internal soil plug is coming to the level of the external surface of the seabed.

Theoretically it should be like this you know when you just take a a thin cell you drive into the ground or drive into a material you suppose to have levels internal external same as you drive this pile by vibration there are several things to happen for example if you take a sandy material granular material you try to drive this pile into the ground what happens is the soil inside is confined cannot move anywhere but the soil on the top always going to be loose as you try to drive and vibrate the soil the soil gets densified and may reduce in height and this is what was observed by several field test.

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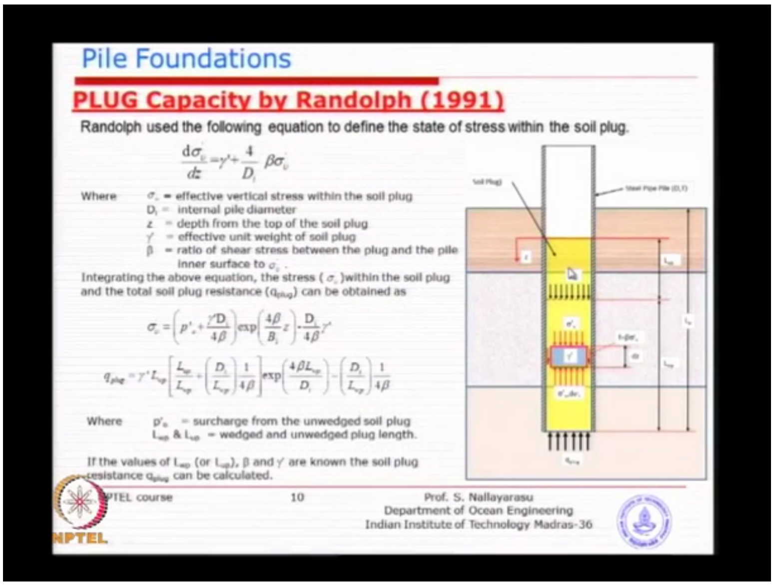

Especially when you are driving the pile in a granular material they find that the pile plug is not coming all the way to the level of the external soil surface and we called it pile plug ratio you know basically the pile plug ratio equal to one means the pile length into the soil and pile plugged length in inside the pile is same.

If the pile plug ratio is 90% 80% 40% depends on how much pile plug in that we can see here one more important thing is soil at the lower part of the pile gets densified soil at the top part of the pile may not be that much denser than compared to the, so you can see here there is a because of the disturbance that you are doing to the soil during driving.

So he has proposed a certain form of equation depending on the pressure or the vertical pressure at the soil locations he derived certain relationship which will give you the pile plug ratio so as soon as you drive the pile you measure the length of the pile soil plug inside and put it into this equations you can derive whether you will achieve full length bearing capacity or there maybe a reduction in the N bearing capacity

Because when you apply a N bearing capacity of this much if the plug is only 50percent you are not going to achieve because the length of the plug is less, the N bearing capacity is going to be, now how to de we calculate the N bearing capacity reverse for example the N bearing capacity can be calculated based on what is the type of soil below, you know if you have a rock N bearing capacity is capacity of a rock itself but also depends on the frictional resistance of the piles soil interface plus the weight of the soil.

When you add them add them together the N bearing capacity must be lower than that, if it is higher the plug will move upwards so though we have a very good material here very good bearing stratum if the pile plug soil plug inside plus the frictional capacity is not sufficient you cannot take that much bearing capacity at the bearing stratum because the plug will start moving upwards.

So that means the N bearing capacity is limited by the soil plug weight and the frictional resistance of the soil itself so that’s what he is trying to derive by the reason why he has given this exponential formation is the reduction in the frictional strength as we go down.