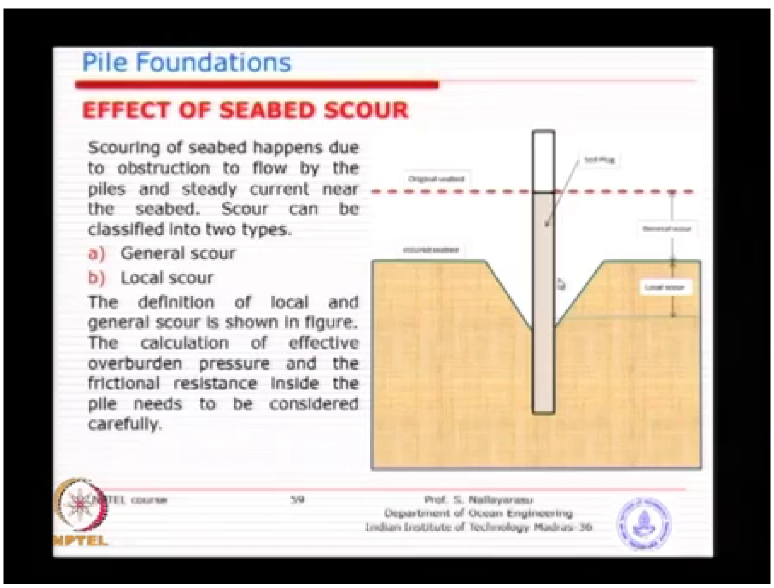
Foundation for Offshore Structures
By Professor S. Nallayarasu
Department of Ocean Engineering
Indian Institute of Technology, Madras
Module 1
Lecture 13
Pile Foundation 4

So we will continue with the pile foundation yesterday we were looking at t-z and q-z we will now look at the lateral capacity just before that we will just touch upon the effect of you know this scouring of soil around the pile I think we will be talking about this topic in detail the causes and type of its scour and the material characteristic around the pile after driving. So but in general this scour can be classified into two categories, one is the overall scour the soil gets removed you know in a larger part of the area surrounding the structure or there could be a localized scour what you see from this picture you know around the structure.

(Refer Slide Time: 0:52)



The causes and the nature of scour and the type and lot of details will be discussed later but what is the effect of this on the t-z and q-z what we have seen, t-z maybe a very little effect because sorry your q-z will be very little effect because it will be very deep at the tip of the pile whereas the t-z effect at the nearer surface will have effect because some soil is permanently removed that means the skin friction is not available at the first few meters.

Now typically the local scour and the general scour you know depending on the site, depending on the characteristic of soil, depending on the flow around the structure, for example if it is a calm water no scour can happen. So generally scour is also associated with the current in the near vicinity of the structure where you are constructing. For example if you have a river flow or a steady stream of current which you might have studied in your hydrodynamic (())(1:45) in your design course we were talking about you know the ability of the flow to carry the particles lying on the surface of seabed you know if the specific gravity or the particles are smaller it gets carried away easily if it is heavier like solid particles of sand and graval may not be able to carry forward.

And that is why when we are talking about scour means sometime we provide a scour protection in terms of bigger rocks so that they do not get carried away, but natural scour can be classified into like a general overall scour if the flow velocity is so uniform that it carries a lot of particles around and takes away. Whereas the local scour is typically is associated with the circulation and the you know the AD formation very close to the structure itself, for example if you go around stand in the beach you will realize this scouring is happening every time when you step into water I think you can easily understand the idea why it happens you know in the near vicinity of the structure the circulation happens if there is a flow around and also AD and tries to lift the particles up and the stream of current carries away as soon as the particles gets slightly lifted up from the seabed.

So that means flow velocity abstraction and the specific gravity of particles or three parameters which is associated with the scouring. Now this scouring what is does to our stress especially with respect to vertical overburden pressure it reduces because if you see here the general scour 2 meter of material is removed away that means when you are talking about overburden pressure at just any depth below this much of material is not there even though you could also conclude that the skin friction is lost in this depth but also the effect of that below down because the overburden pressure reduces.

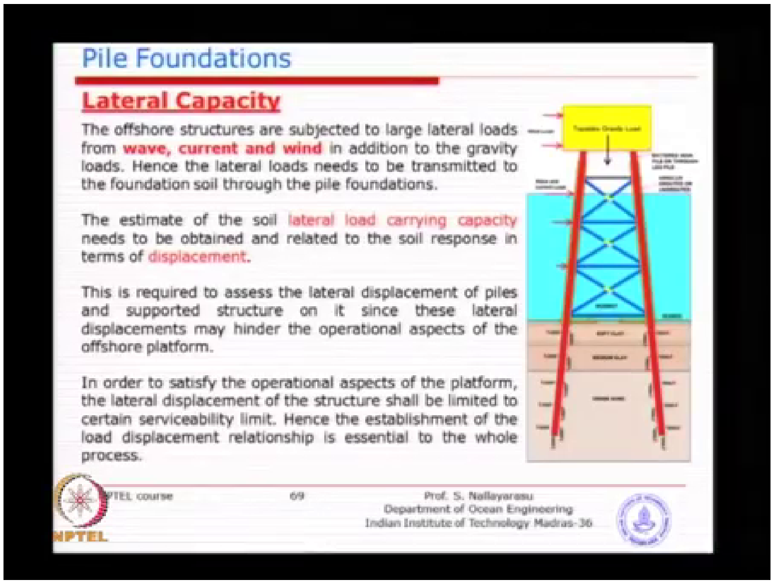
Once the overburden pressure reduces whether you are calculating alpha or beta also going to reduce so that is why you know this scouring needs to be taken into account when you are trying to do either bearing capacity calculation or t-z, q-z calculations how much of the soil is removed. Of course if you look at the general scour is very easy to understand you know basically that much of height is removed. Whereas the local scour is not exactly that you are going to remove the total depth of local scour from your overburden calculation because some amount of soil still exists you see here triangular winch so you could take advantage of that we will see the calculations little later on.

With that I think we could conclude the understanding of vertical capacity and vertical capacity related to the displacement. So we had t-z, q-z we will quickly go on to this problem we have seen already on to a lateral capacity of you know pile foundations which is very similar idea only thing is the approach will be several means I have lots of different methods we need to find out which will be suitable for what type of situation. So this lateral capacity unlike we have vertical capacity wherein assembly of skin friction and end bearing what is straight forward method.

Whereas here we got you know various methods proposed depending on relative stiffness of the pile and the soil and that is what we are going to see how the pile is going to behave if it is a clay type of soil how the pile is going to behave if it is a sandy material or rock or a mixture of you know multiple layers how the pile is going to behave and if the pile is steel pile how it is going to behave, if it is a concrete pile how the behavior will be or if the pile is very short or very long like if you talk about costal structure you have about 10 meter, 15 meter shallow depth piles how they will behave in terms of lateral bending and displacement.

If it is offshore structural systems like jackets you have 100 meters of pile going down into the ground, so when you are applying a horizontal load to the system how the bending behavior and the displacement behavior. So depending on this situation you have to select one of them and then suitably apply.

(Refer Slide Time: 5:58)



So we will just go into little bit of basics as you can see here when offshore structure is supporting you know the super structure which is predominantly gravitational loads you know you might have little bit of wind load very similar to onshore structures but then the magnitude of it is not going to be too high but the substructure is subjected to reasonable amount of wave and current loads which is what is causing you know the horizontal displacement of the structure.

Now that is the reason why we try to embed the foundation into the ground imagine if it is only a pure gravitational load and if you have sufficient bearing capacity at the surface we do not need to really worry about it you know the structure will be stable in terms of vertical equilibrium as well as horizontal equilibrium or even overturning equilibrium. Now because of the substantial amount of horizontal loads you would not be able to substantiate without embedding the foundation into the ground, that is why the more the horizontal load you will see that starting from 1 meter below ground normally if you look at the residential building they do not dig too much depth for foundation maybe 5 feet, 10 feet you know shallow foundation with spread footy but as you go even in onshore structures high rise buildings 10 storeys, 15 storeys you will start going for reasonable depth of embedment of foundations system so that the horizontal stability as well as the overturning stability is achieved without much problem.

So basically you see here in a typical offshore structure you know the thumb rule is if you have a 100 meter water depth very easily your pile foundation is another 100 meters you can see the order of magnitude is almost but does not mean that you know 20 meter water depth you have only 20 meter pile there also you will have at least 50 to 60 meter pile foundation depending on the situation of the soil layers but typically most of the shallow water structures raising from 50 to 100 meters the pile foundation is almost more than the depth of water or the jacket depth itself.

So that is the kind of foundation system we are looking if you have that is why I have just drawn the sketch also in the order of magnitude you can see double the height of the jacket as the pile foundation length. You see at the bottom we have already characterized the vertical springs or so called the frictional resistance between the pile and a soil as a linear or nonlinear spring which describe the characteristics as soon as you apply the load the load is getting transferred from the jacket and to the pile and to the soil spring as a soil springs take the load the jacket and the whole system is trying to settle down.

Similarly if you look at horizontal loads rising from wave, current and wind are trying to displace the structure since the piles are driven through the structure itself so it is going to bend the piles and transmit the loads at the seabed level to the pile itself because beyond which is only pile is there, there is no structure. Now this pile will definitely transfer or transmit the horizontal loads to the neighboring soil around creating forward pressure depending on whether the load is in the forward direction or in the negative direction.

So if there is a load in this direction the soil beneath in this area is going to get compressed depending on the characteristics imagine if it is only a 1 type of soil just uniform characteristics from top to bottom then you will see a specific load or the pressure versus displacement and that is what we are looking at how much is getting compressed depending on if it is a very dense material like dense sand is not going to be getting compressed that much because the particles are fully filled the whites ratio is less but imagine if you have a very soft clay is going to get compressed and is going to move a lot.

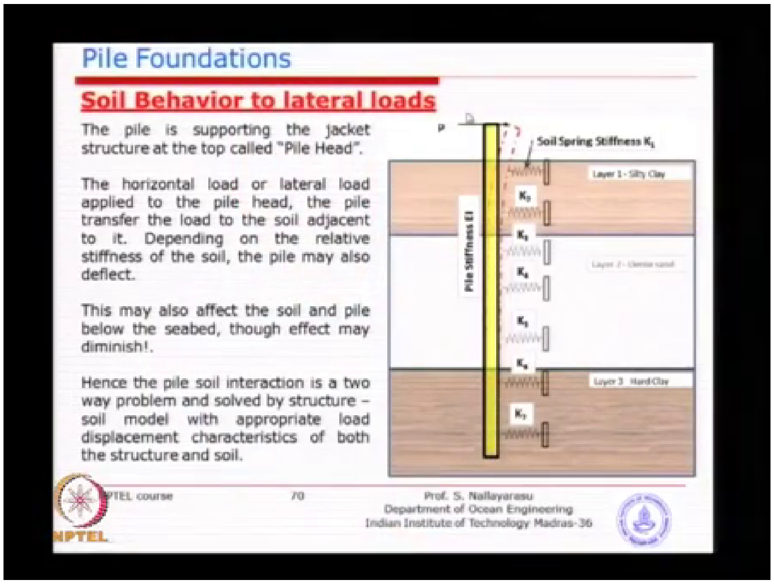
So that is why we need to find out this characteristics which after all the displacement at the top of the structure is very important because is operational related if it is moving too much back and forth you may not be able to do the you know the drilling and production that efficiently as you will consider in the onshore oil fills. So that is why the horizontal displacement though it may not be very critical unlike residential building or other buildings on land where you know the large moments can cause other functional failures it could be cracks, it could be you know damaged to your architectural finishes unable to utilize.

So functional requirements can be violated fortunately in offshores structures this is not the real case you know most of the structures are built using ductile material like steel you may not be really worried about a small displacement like we call it small even it is meters. Whereas in onshore structures if you have meter means it is disaster, is it? So that is why because we build using ductile material the displacement is not a real cost for concern unless it goes to a level where it actually prevents us from doing the function such as drilling and production where they are not limited by 10 millimeter, 15 millimeter, 20 millimeter it could be several centimeters of displacement.

So but though we have a luxury of larger allowable displacement we should still evaluate what is the type of behavior in the soil because the larger the displacement is not only the displacement is not only the displacement we are worried the stresses in the pile itself is going to increase because larger the displacement more the bending moment, more the bending moment is going to cause additional stresses so that is where we have to see whether it is a small displacement problem or a large displacement problem.

And that is why we need to evaluate this each type of characteristics of soil how it is going to behave.

(Refer Slide Time: 12:09)

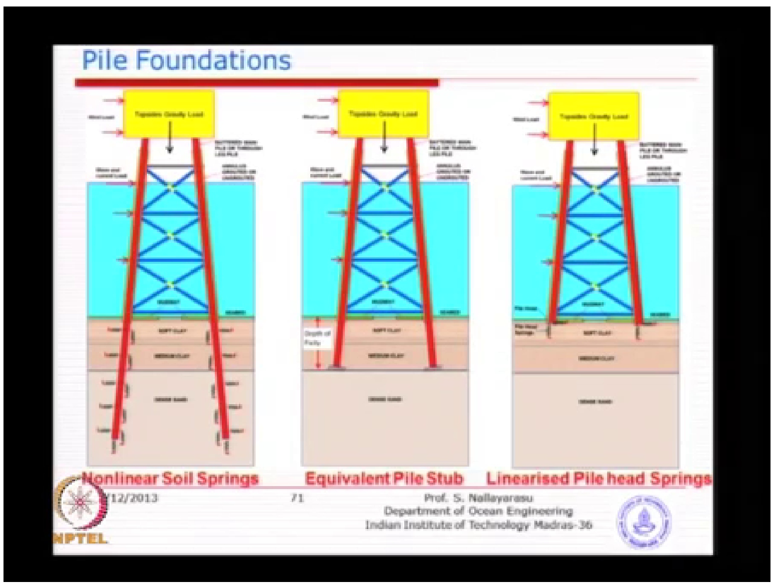


And as we discussed yesterday regarding the vertical spring we can also characterize the soil as a horizontal spring as you can see from the sketch with a relative stiffness of the pile and the soil. Imagine if you have a very rigid pile very large EI value is not atoll going to bend and the pressure that is going to be put on the soil is going to be very minimum because the hard work is done by the pile or the other way around if the pile is to flexible is unable to take any load is just going to bend as much you apply the load straight away put the pressure on the soil.

Now you can see the relationship between the pile and the soil is going to be very important to find out what will be the net displacement if the pile is too rigid you will get a slightly different behavior, if the soil is very bad and still you will get a different. So the relationship between we call it the pile soil stiffness ratio is relative stiffness we call it is very very important and that is going to characterize how the behavior is going to be that is why the EI value plays a major role and if you turn this problem into upside down basically make it horizontal is nothing but the beam on elastic foundation you might have studied in your applied mechanics course in the B tech time you just make this whole thing horizontal you know the beam is resting on a stiffness which is in this case is soil.

And if you have a uniform stiffness is going to just bounce back like this if it is a non-uniform stiffness like what we have here because the soil at the top is going to be very lose and soft and as you go around it is going to be. So you will have a non-uniform response behavior and that is what we are going to study in this particular topic and several methods we will just go through one by one and the terminology called a pile head is nothing but the connection between the super structure or so called sub structure to the soil pile interface and most of the time pile head is taken as the mud line unless you have a larger seabed scouring then the pile head will move down to wherever the scoured surface of the seabed just now we were seeing local scour versus general scour is the transition between the structure to soil is called pile head and that is the place where we normally derive the forces from the you know the (())(14:25) plus the environmental conditions.

(Refer Slide Time: 14:35)



Now if you look at this picture we could actually idealize our self into analysis of the system in several means and in fact we do this many times some cases for example we want to limit ourselves to a linear analysis in a early stage of the project where we do not want to spend too much of time we could easily find out spring at the tip of the structure where it could represent the whole of pile soil below the seabed.

So if you are able to find out an equivalent spring which could be linear and can be supported there instead of a rigid support what we are trying to place here is a spring support. So once you do that then the structure analysis and design becomes quite simple many many times you try to do this because it is quite simple it linearizes the foundation into a from nonlinear to linear and the calculation for the substructure and superstructure becomes very straight forward or even we can go into a an approximation where you can assume after certain depth the pile behaves no displacement that means is almost fixed at that particular depth.

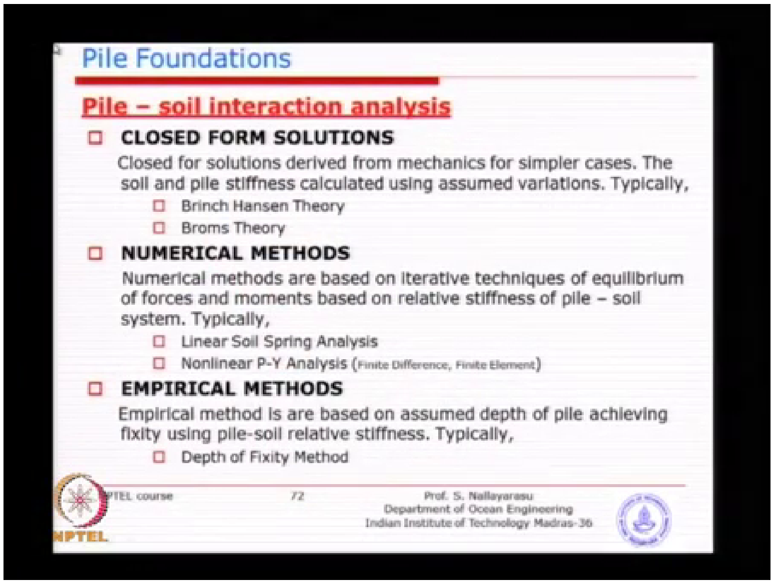
That means when you apply a horizontal load the pile does not get influenced below this depth and that point of fixity where we can arrive by thumb rule several thumb rules are available. Of course this also can be calculated in a semi empirical manner using the relationship between the pile rigidity and the soil flexibility which is also sometimes if you look at some of the Indian course they do recommend this type of semi empirical methods which are very useful in a way because is very quick you get the idea of the behavior of the structure in few minutes so that you can solve the problem.

The last one or the most commonly used for offshore structures is basically complete set of springs normally nonlinear we do not linearize it because of the nature of the soils that we have and you apply you divide the pile into several sub segments like what we saw in a picture in this picture the other day we were seeing something similar like this you divide the pile into various sub segments each segment is attached with a horizontal spring and you solve using several techniques historically you know finite difference I think you might heard of this word called finite difference scheme is a forward marching iterative scheme is has been used for several decades to solve a problem where you do not have a close form solution not only structures it could be fluid mechanics or other problems in science and engineering.

And that is the method which is very very easy to write a simple you can even write yourself which has been in use for several decades but in recent times this has been replaced by finite element techniques I think some of you might be going through the final (())(17:38) course slightly better than the finite difference the approximation is very close and the iterative scheme will be faster compared to the finite difference.

So that is why we will find in the recent programs or softwares most of the time the use of finite element methodology. Whereas earlier you know maybe 10 years back still people where using finite difference scheme. Why we need and all that we will just go in detail little later, so these are the three commonly adapted solution techniques to solve a structure foundation problem.

(Refer Slide Time: 18:18)



So the first one is basically the close form solutions as you can see if you look at little closer with mathematics background you could actually derive some solutions to the interface between the structure part pile and the soil but unfortunately it could be solved for single pile situation.

For example, only one pile is driven into a ground and then you have soil of a particular nature single layer Brinch Hansen and Broms' both of them have done excellent work over the last 25 years and have presented several research papers some of them are you know like first class work basically the basic work which are useful in fact even today we do use such type of solutions for simplified structures but we could not apply that to the jacket type of structures because we have multiple piles and the behavior with multiple layered soil is not going to be very easy to apply this principles.

So we normally go into a numerical solutions which is what we were talking about either a linear spring or a nonlinear spring both of them you could solve using finite difference and finite element, of course linear spring we do not even need to go to finite difference because once you have a linear spring any simple matrix methods can solve straight away the solutions to the displacement.

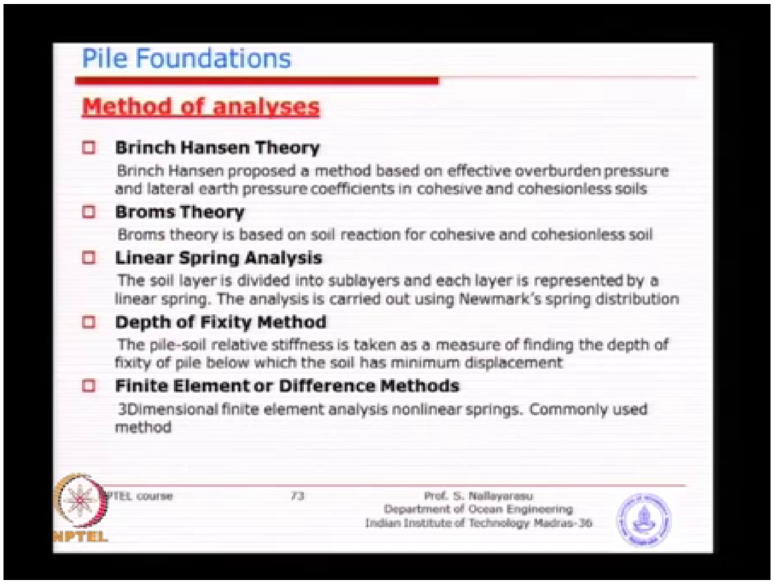
The last one I think very commonly used for the onshore structures bridges you know depth of fixity is very easy to obtain as long as you are able to represent the soil by means of a particular characteristics which is basically the lateral compression characteristics we call it subgrade reaction, subgrade pressure and if you are able to get the characteristics then you relate that with the relative stiffness of the pile and find out how much it could actually bend where could be the bending moment maximum.

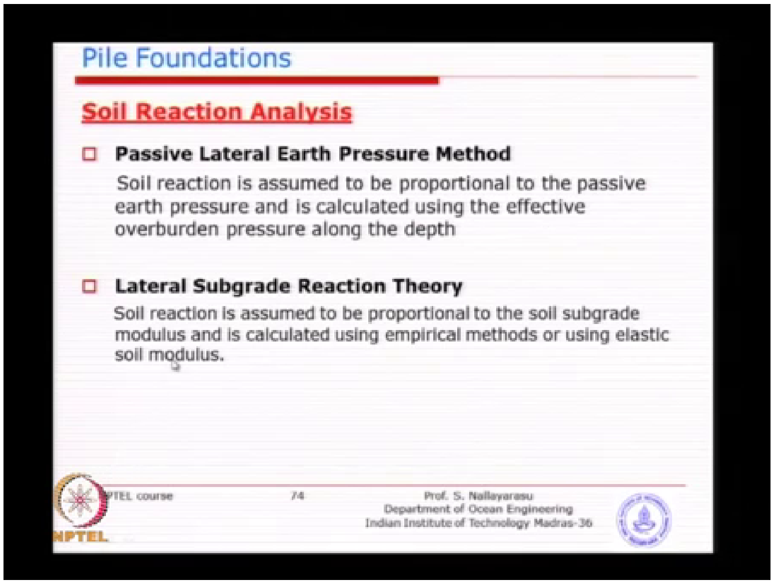
As you can see is just like a cantilever if you go back to this picture you know the whole jacket is going to behave like a cantilever as soon as you have sufficient fixity into the ground somewhere below the ground the pile is going to get almost fixed means the rotation will be 0. So basically that is the point we are looking at where the rotation is going to be 0 and that point is called depth of fixity.

So this method in fact if you are able to predict the depth of fixity very correctly to an accuracy of plus minus 10 percent I think that is the best method because you do not need to really struggle for nonlinear and linear springs because still you are predicated displacement using this method is going to be 100 percent correct as long as the fixity depth is evaluated correctly then you just solve as a.

The great advantage of this method is ones you get this depth of fixity the problem becomes a structural problem rather than soil structure interaction problem because after that you do not need to worry about soil once the pile is fixed then you can forget about the soil surrounding the point about the point of fixity. Whereas numerical method you have to do a lot of work basically you need to find out that p-y relationship from the soil characteristics that means you need to have to stress strain characteristics of soil so that means you have to go for a back to (())(21:31) test where your normal loading versus your displacement or stress has to be measured and take that and then put it into developing such relationship is going to be substantially hard work and sometime many times you find that data is not available no body have done any laboratory testing. So how do we assume so that is going to be a big challenge even today because not always you know every layer of the soil are sample that you bring to the laboratory you are going to get tested and then you have the strain and stress relationship.

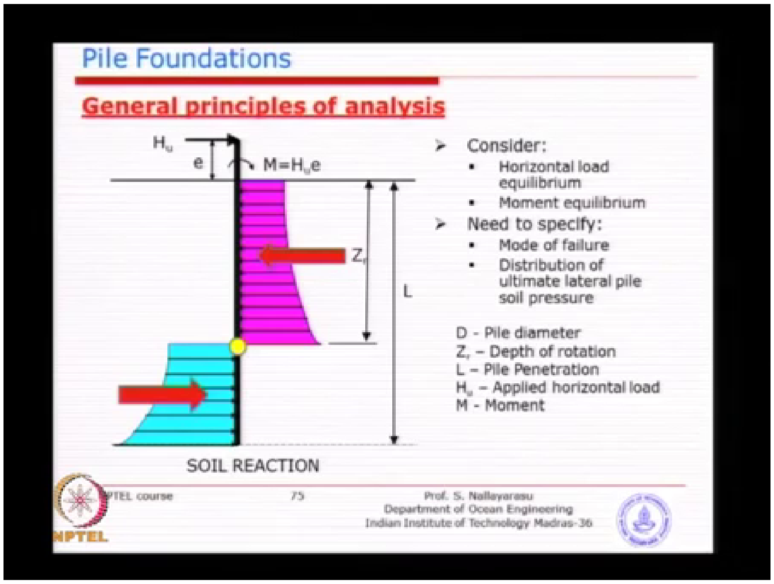
(Refer Slide Time: 22:10)





I think I have already described most of them we will go in some detail each one of the method we will see the passive lateral earth (())(22:26) reaction theory little later stage so I will not explain just now.

(Refer Slide Time: 22:29)



So the general idea of pile subjected to horizontal load so you can see here in this cartoon picture when you apply a load to the pile tip at the top of course it need not be something like this it can be even higher you know if you look at a coastal structure this depth of pile from the seabed to the top could be substantially larger like 10 meter, 15 meter or 20 meter that is why this e value generates additional moment at the pile head near the seabed.

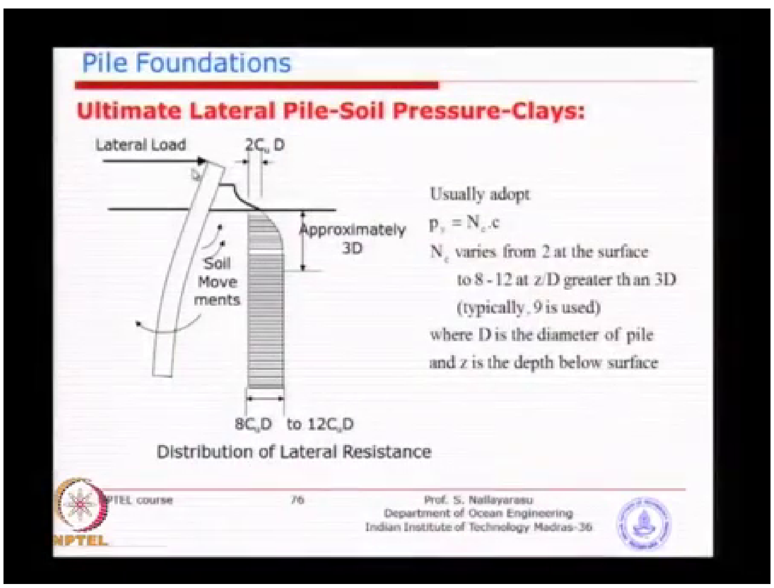
So when you apply a horizontal load something like this so what happens is the soil is getting squeezed near the surface of the seabed and that is going to provide you with a passive air pressure from the reverse direction and as the pile is trying to bend towards this direction you can see here depending on the ei or the rigidity of the pile the pile is either trying to bend or trying to rotate or the pile may actually try to move horizontally, for example if you take a very shallow depth say 2 meters and just embed into the seabed soft maybe and just try to apply a horizontal load the whole pile can actually move horizontally depending on if the pile is very large maybe rigid and very shallow.

So that is exactly the three behavior it can move horizontally or it can bend or it can rotate about a point which the pile itself will find an equilibrium because the applied load is here the resistive in the backward direction and as the pile try to rotate you could see here there is a active reaction coming here so that is basically the one method proposed by Brinch Hansen as early as 1970's and very commonly used even today for you know concrete piles in near shore or coastal applications because most of the behavior will be something like this.

So we need to find out about which depth we call it the depth of rotation we need to find out by iteration you can easily find this by means of a simple equilibrium of moment if we take moment about the point of obligation of load you could find out at what depth this whole system will be in equilibrium because if the applied moment is more you know basically the pile will topel so that is where minimum depth of (())(25:00) needs to be found, for example if you have a very shallow depth of pile apply to much of horizontal load what will happen, the pile will just come out and that is where z-r will not be able to find out.

So we need to find what is the minimum depth of embedment in order that the pile will behave in this kind of notation. So the his work initial work was so useful at that time even the large depth pile foundation where just started to be used in both in onshore and offshore construction. So he published several good papers in fact he has got designed charts even now I think many people are referring you know we can take his design charts and apply later we will see the charts itself.

(Refer Slide Time: 26:07)



The other methodology if the pile is very much longer and slightly ductile material like steel pipe piles and driven into the ground for a very large depth and when you try to apply a load this is what will happen basically the beyond certain depth the pile itself is not influenced by the application of load because by the time it is already distributed to the soil.

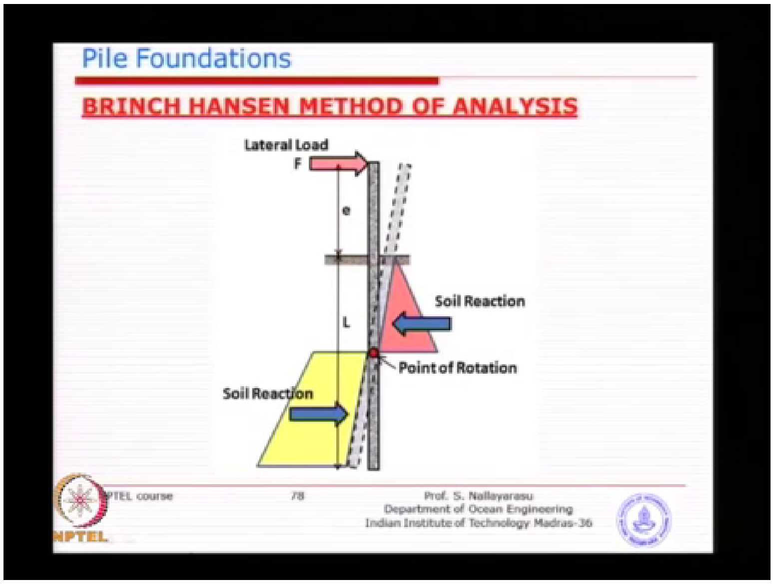
So that means is almost going to behave like the depth of fixity below which the pile is having no influence. So in this case what really happens you can see here as the pile is getting displaced from one direction to other the soil near the seabed is trying to come out hive up because is getting squeezed into it and the soil will just hive up to some extent and the top layer of the soil is going to get more squeezed away that means you are going to get loosening of the material although already you have a less denser material number 1 or maybe a soft clay and the strength is at comparing the deeper layers is going to be lesser.

So the idea behind the proportional from Brinch Hansen for deeper piles is something like the top soil is lesser reactive against the horizontal load compare to the soils below. So he assumed for typical numbers an empirical number like 8 to 12 times Cu and D is the projected width of the pile you know basically to get the resistance coming from the pile itself. So 8 times Cu so 8 or 12 is the number that we typically take it last time for vertical bearing capacity called Nc you know so similar here is a lateral bearing capacity factor which is 8 to 12.

And as you come down to near the seabed as the soil is squeezing up and you know not providing larger resistance he assumed a smaller. So he assumed the a simple profile of a parabolic curve up to a depth of 3 diameter below which you will see a uniform resistance. Based on this work basically API has modified this slightly and has adapted at 20, 30 years later, so this is what we will see later in the API code that the work done by Brinch Hansen.

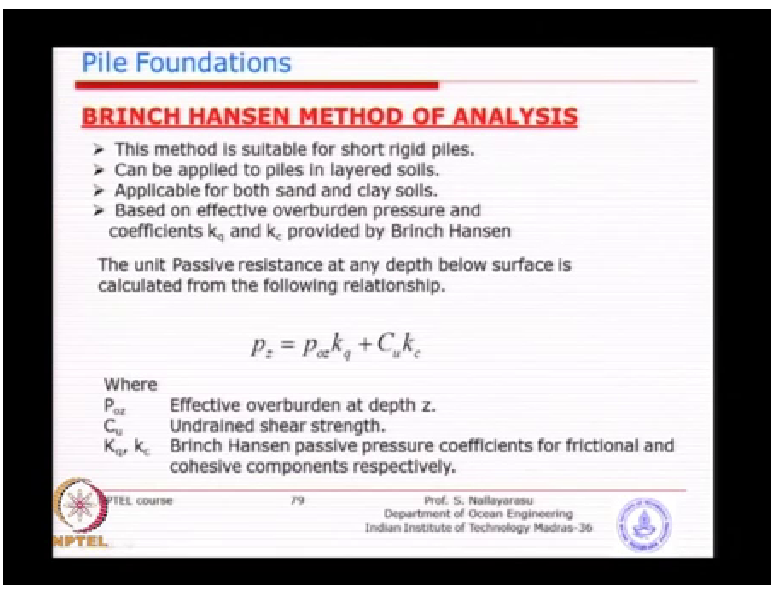
And basically you can see here this is the number adapted by API after lot of review and experimental studies they come up with the number instead of 8 to 12 we will be using 9 for the application to offshore structures.

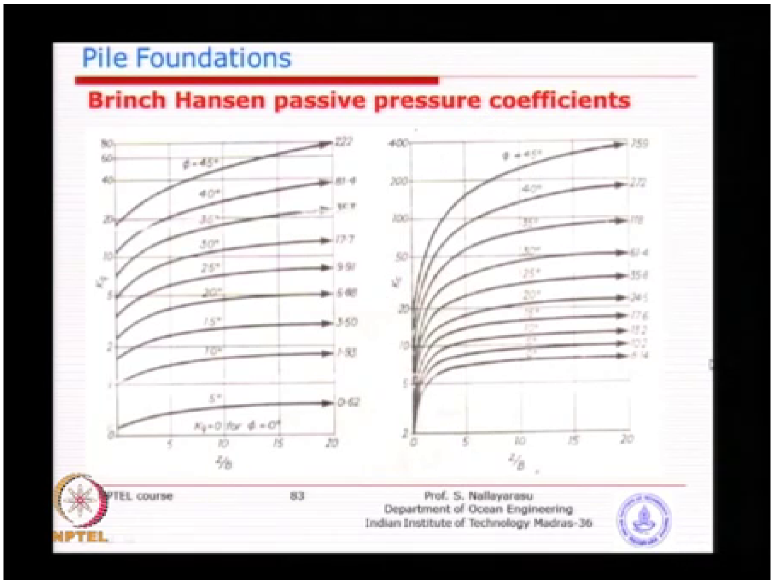
(Refer Slide Time: 28:35)

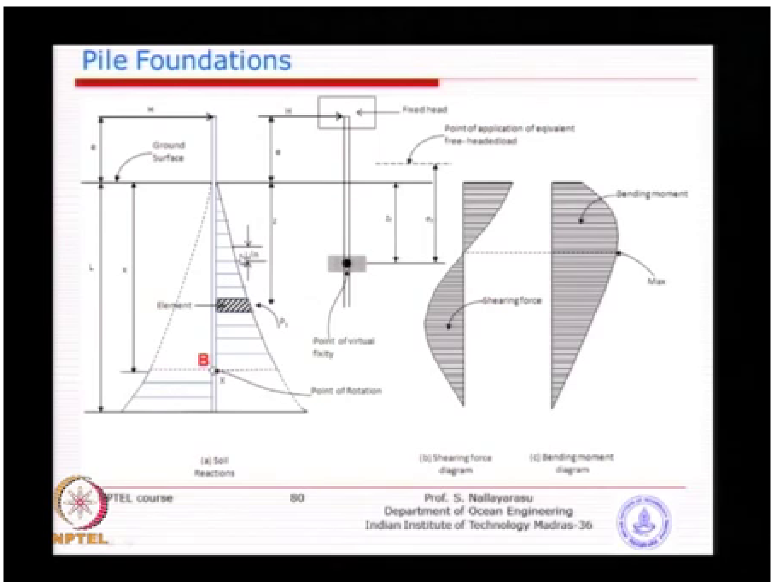


So how do we find out the point of rotation as I explained earlier is a simple equilibrium check and there soil reaction on either side is to be balancing the applied moment.

(Refer Slide Time: 28:50)







In order to find out you know the basic rotation point we need to find out what is the reactions coming from the soil for us to do that Brinch Hansen provided coefficients he call it passive pressure coefficients which is very similar to what we have seen some charts of Nc, Nq and N gamma for vertical bearing capacity and he produced such graphs for a typically sandy type of material Kq and Kc of course you will have a cohesive component because is a C 5 soil and for various angles of internal friction with depth versus diameter B is in this case is diameter and Kq and Kc are the empirical coefficients which you need to read from this graph before you can use this method of assessment basically you see here the passive resistance from the soil is calculated as a summation of the overburden pressure which is basically at any depth you can calculate the soil weight above multiplied by Kq plus if you have in that soil you know undrained shear strength if it is a C 5 soil or a C soil then you can multiply by the Kc value from this chart.

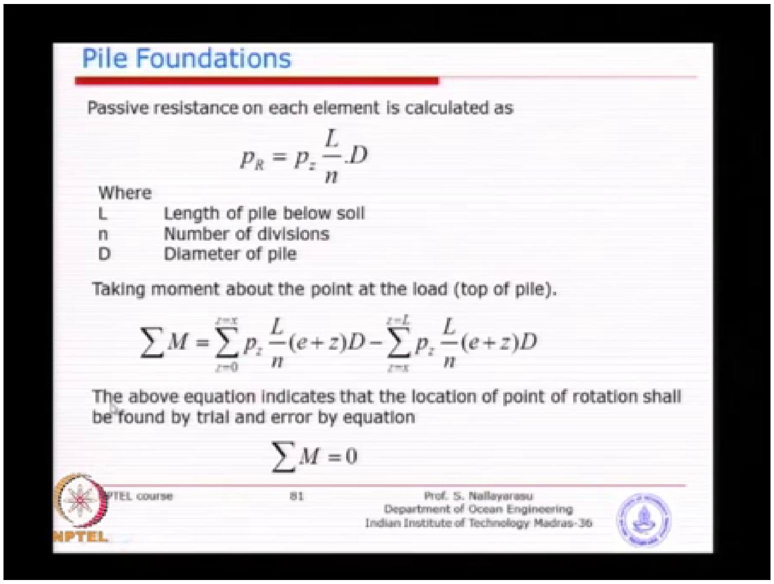
So once you arrive at the resistances offered by the soil against the pile load or the pile pressure is put on to the soil then we can go back to this solution to the equation but before that this is suitable for rigid piles so now we have to define what is rigid piles how we actually classify whether it is a pile is a rigid or slender. Then can we apply to piles in layered soil one great advantage because before this period before Brinch Hansen brought this method many times we simplify the we want to solve the problem in a single layer manner.

Though you have different properties we try to get a generalized soil property so that we can solve the problem easily but once he introduced this method it was quite useful. Applicable to both sand and clays this is also another great advantage based on effective overburden pressure and coefficients where produced or provided by him based on his test results and once you find out this p-z you just go back to this picture you try to draw the passive resistance from the soil in terms of you know the pressure along the depth.

Now what we do not know is the point where it is going to change direction. So in order to get slightly accurate result we divide the layer into several if it is a single soil type of layer you divide them into maybe less number of subdivisions or if it is changing characteristics at several locations you can still further find unit and divide into several sub layers each sub layer you could find out the overburden pressure multiplied by corresponding the coefficients or the passive resistance coefficients obtained from the chart and you can find out the pressure resistance from the soil itself.

So every layer you can find out then take moment about this point and iterate until equilibrium because basically for the system to be in equilibrium the moment at the point of load application is 0 so you can do that.

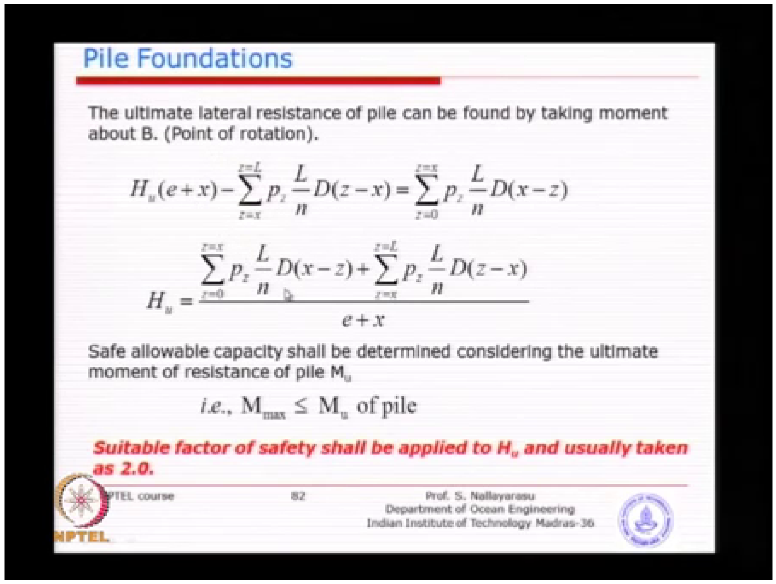
(Refer Slide Time: 32:36)



That is what I have written here each layer the corresponding resistance multiplied by diameter because diameter is projected width now so that much of resistance will come and multiplied by the thickness of the layer which is nothing but the total depth divided by number of divisions which just on algebraic idea.

And take moment and equate to 0 find out iteratively to which rotation point about which the depth is x you keep adjusting the edge x value until you get moment is equal to 0 you can assume an arbitrary value you will find an net moment some amount if it is positive you move down, if it is negative move up so just you have to just write a simple computer code or excel spreadsheet. In terms of examination point of view I think maybe we try to give you 2 iterations or maybe 3 iterations and 2 layers so you should still practice this so that you will be able to solve such a problem.

(Refer Slide Time: 33:42)

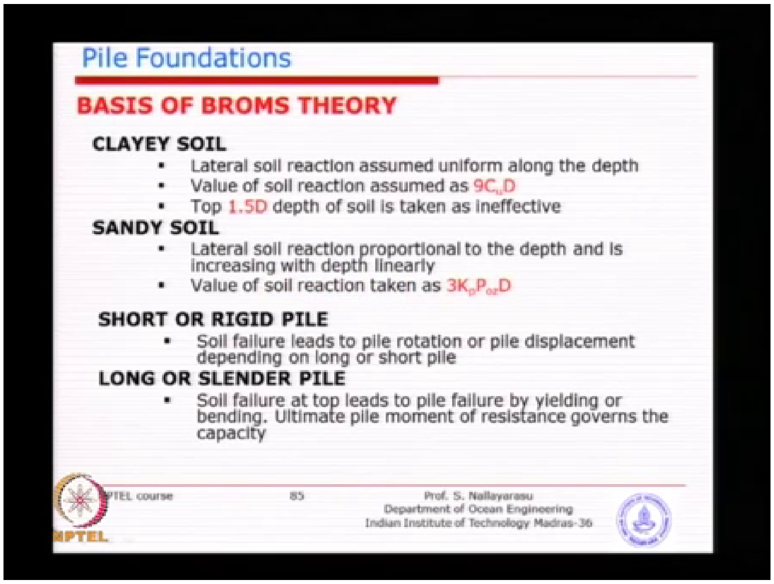


So basic idea is trying to figure out where the point of rotation once you know the point of rotation then we can actually find out what will be the capacity because once that is known then you can take moment about the point of rotation itself and find out what will be the maximum load value that you can apply for a given factor safety and you know basically very similar to the factor safety we had for vertical load minimum of 2 for operational condition and then 1.5 for storm condition but one important thing we need to realize here is not only the soil going to govern the maximum capacity that can be applied the pile also is going to govern.

So whatever the maximum load that you are finding from the soil you need to also limit that to the maximum bending moment capacity of the pile itself, for example if it is a concrete pile you can find out the moment of resistance in bending as usual bending moment calculation for the RC structure and find out whether the bending moment produced by the applied load of Hu is going to be less than that or not because otherwise instead of soil governing the design the structure part of the pile governs the design. So you have to limit that and basically that is very important check otherwise you may be thinking soil can take so much load but the pile beforehand fails.

So this method is quite useful the idea is you divide into several sub layers find out the rotation point after the rotation point then you find out take moment because rotation point moment also will be 0 and find out what load you will be able to consider at what height the height is the is more then you will have a moment is going to be more. So this Brinch Hansen method we will try to solve one problem probably in the tutorial.

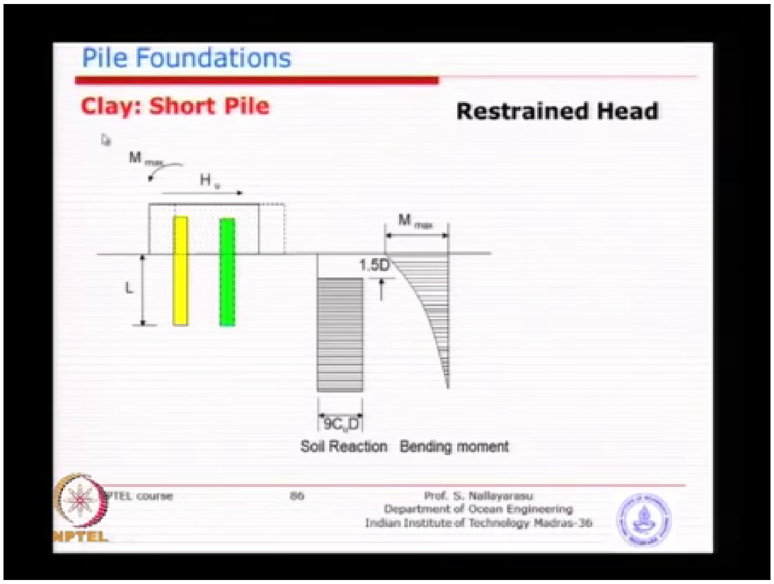
(Refer Slide Time: 35:40)



The next one is the Broms' theory which is slightly away from the methodology proposed by Brinch Hansen he has assumed very similar to the assumptions made by Brinch Hansen for clay type of soil you know some kind of pressure distribution below and try to solve both types of piles rigid and then slender. So clay and sand as well as rigid and short or long and slender both only he has taken the later part of Brinch Hansen proposal with 9 times Cu and 1 and a half times depth instead of 3 diameter variation he assumed first 1 to 1 and a half diameter there is no strength of the soil that can be taken something like this basically the first few meters of the soil has no strength as you can see mostly soil will be very much lose number 1 and when the pile is trying to put pressure on the soil, soil will actually squeeze away.

So that is his idea of assumptions and mostly very common is going to happen like this, for sandy type of material he has assumed a linear distribution of passive resistance rather than uniform or curvilinear so you can see here it is proportional to the overburden pressure not like constant value of 9 times Cu which is going to be below the 3 diameter. And in this case he has provided some information to find out how do we relate the pile stiffness with the soil stiffness and come up with so called for pile soil rigidity parameter or pile soil flexibility parameter and he has given some recommendations and what is the number that you can decide whether it is a rigid pile or a slender pile.

(Refer Slide Time: 37:50)

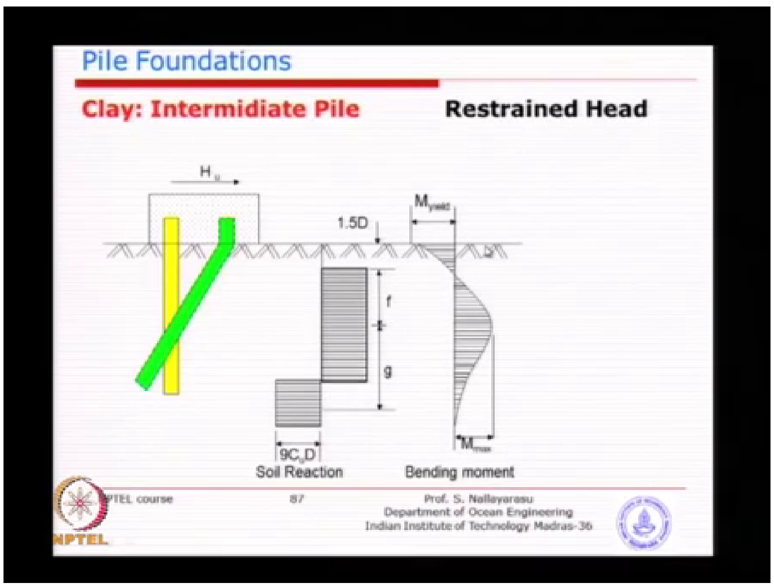


Let us look at some of the cases he studied and published in one of the geotechnical journal with close form solutions, of course very simplified he got about 9 or 10 cases I have just provided few of them so he just look at clay soil short pile top head restrain very similar to a situation in onshore structures most of the industrial structures on land you will have a group of piles few of them together with a pile head on the top I think if you go around you will see they will not go very deep they will be very small diameter piles instead of 1 pile bigger one they will have many and cast with the big concrete head you know something like this on top of which you will have the structure going up you know.

So something like this the behavior is almost like a sliding you know simply when you apply a horizontal load. So the resistance that is going to come is something very similar to what you see as a rectangular diameter clay type of soil and the pile is reasonably rigid all the piles are interconnected you may have 4 piles, 8 piles, 10 piles and then you have a very massive pile head we call it pile cap and because of that is not allowing the pile to bend because is very short and is trying to move and provide a passive resistance so called soil reaction is just proportional to the diameter of the pile or size of the pile in this case many times they use concrete piles of square in nature you know if you go around many industrial developments they will use a square sections in earlier days they use timber piles you know good (())(39:18) timber.

And the top soil about 1 to 1 and a half diameter are the soil effect is removed so you could see the maximum bending moment is a reverse cantilever pile head is fixed and soil is trying to provide reaction so you can see the bending moment is going to happen almost at the vicinity of the pile pile head interface and that is the idea very similar to most of the classical near shore coastal structures where you build industrial structures and even (())(39:50) this very similar structure we do it in the dolphins you know you have a massive pile head but the pile is embedded into the seabed with and without some amount of water depth.

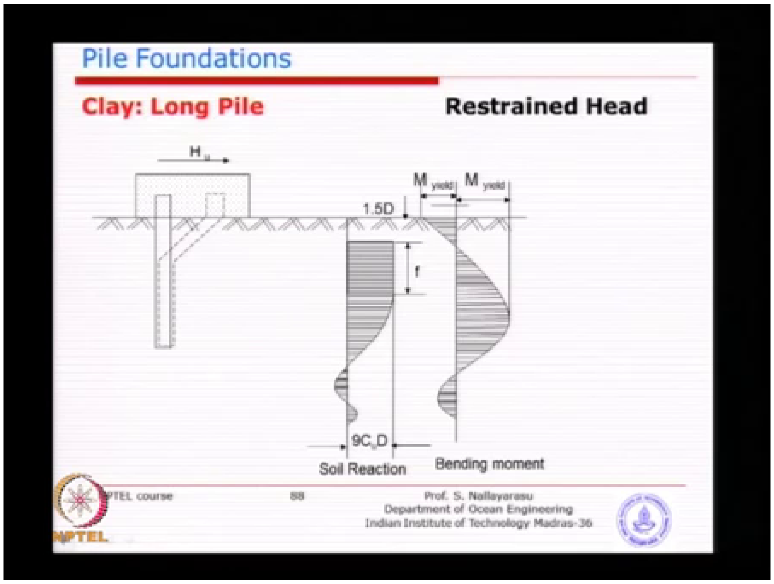
(Refer Slide Time: 40:08)



So this is the first one you could see the second one clay slightly longer pile not as what we were talking about earlier on steel restrain at the top but the pile itself is slightly slender maybe deeper depth or smaller diameter and you could see here is trying to behave similar to the rotational characteristics but also with respect to the bending at the top of the pile head and the assumptions is still same first 1 and a half diameter is no strength to be taken and then after which you can have where the change of reaction from positive to negative this just need to be moved up.

So basically this is a point which needs to be found by iterative means to get an equilibrium of forces either moment or the horizontal shear.

(Refer Slide Time: 41:02)



The next one is very similar to the Brinch Hansen proposal where the pile is very long and going to get a maximum bending at some depth which is called the point of fixity only thing is it can also have the maximum amount depending on whether it is at the this point or the point where is slightly below. So this is all this cases he has provided equations which I think at the end I have summary of those equations which is hard to memorize some of them will be very long which I have not typed I have the paper.

In the first three cases we saw the pile is connected to the pile with a rigid pile cap and the next three cases you see here short pile and unrestrained head long pile and unrestrained head. So the only difference is the pile head is not connected to the rigid pile cap which is making slight difference in behavior so it could actually rotate in this (())(42:09) something like this or it could make a bending and governed by the overall displacement or by the bending of the pile itself so that is the only difference when you are trying to come up with and without pile head.