Foundation for Offshore Structures
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Module 1
Lecture 12
Pile Foundation 3

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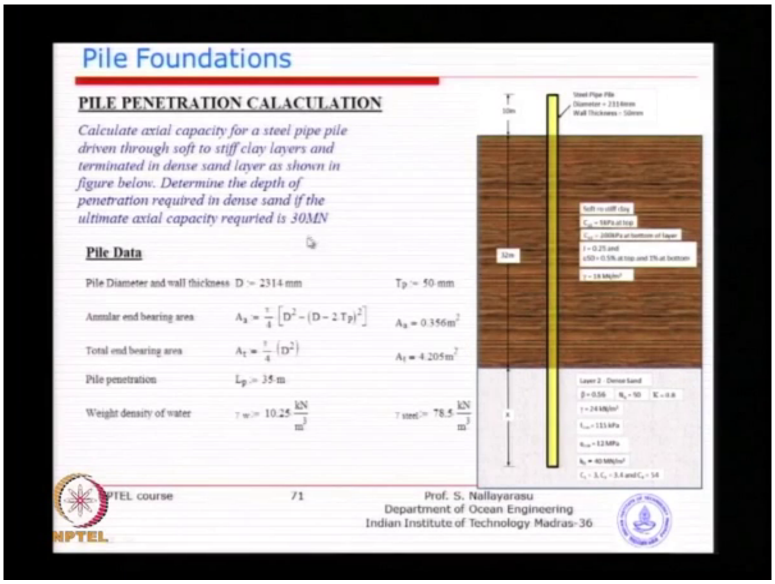

So this is the second type of problem that you can see here is to determine the penetration into the particular layer to achieve a require capacity in this case I think you can see here the required capacity is 30 mega newton you have a 32 meters of soft to stiff clay with strength varying from 5 kPa at the top to 200 kPa at the bottom of that layer. So you can see the strength is varying in this relation because of (())(0:42) deposit which we discussed earlier on you know as the deposition keeps happening the bottom of the layer that particular layer especially the clay type of material gets consolidated and gets better and better over the years.

So this layers has got a linearly varying most of the time you will see clay type of material nonlinearly varying but this particular problem for your is of solving just I have given linear. So 5 kPa at the top and 200 kPa at the bottom and below which you see a very dense sand so with looking at this particular arrangement itself you can easily see that we want to drive the pile to the better layer because provision of pile and idea of the deeper foundation you can see that if you terminate the pile at this clay layer even at this level you are not going to achieve any end bearing.

So that you must get it in your mind because we want better bearing capacity stronger layer is definitely going to help, of course you need to see where you can just penetrate the minimum required you know depth I think which we discussed about the various cases 3 cases we saw. So in this case whether we want to go for 3 diameter just to achieve end bearing or you want to go further down to take into account some more skin friction all depends on what is the strength available from this layer.

So this is a very interesting problem which you will face in real life. So the idea is you see here the second layer is a sandy layer now if you remember recollect the data sandy layer means the skin friction as well as the end bearing depends on overburden pressure, overburden pressure depends on the depth to the location so unless you assume certain depth and then iterate you are going to actually get the answer anyway, the answer is not straight forward.

So you may have to actually guess probably a first value quickly do it and then see whether it satisfy otherwise you have to go back because every time you do not have a x value means you cannot find out what is the overburden pressure if you do not have overburden pressure you cannot go and find out the beta times P not which is the skin friction as well nq times P not is your the end bearing.

So that is there the difficulty when you are trying to find out what type of penetration. In many cases you will find the methodology of generating pile capacity curve which I described the other day you divide the layers into several sub layers find out the capacity make a relationship between the capacity versus depth once you have that then you can straight away.

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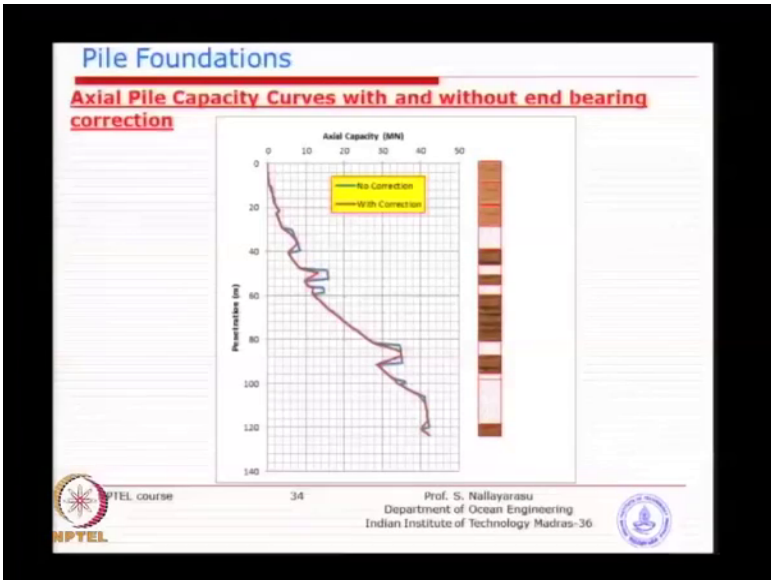

For example if you go back to that picture once you have established such pictures something like this once you have established this this does not depend on the penetration this is basically for a given penetration you can go on find out what is a capacity or for given capacity required by the loading you can find out what is the capacity and the penetration. So this you can develop without the help of what you need to know is the penetration, what you need is a diameter definitely you need a diameter. So every penetration you assume and you calculate and then relate that. So this graph is very useful and most of the time this will be available from the geotechnical report where somebody has come up with bore whole information.

So they will give only problem is only particular diameter may be there because they will not know what diameter you will come up so that is the time you may have to generate more diameters. So this to generate will take more time in the classroom exercise, for example in examination time do that is why we will not go into here because to generate this it may require a half an hour one hour or even more so the best method is to adapt what we were discussing here, that problem is in a wrong place.

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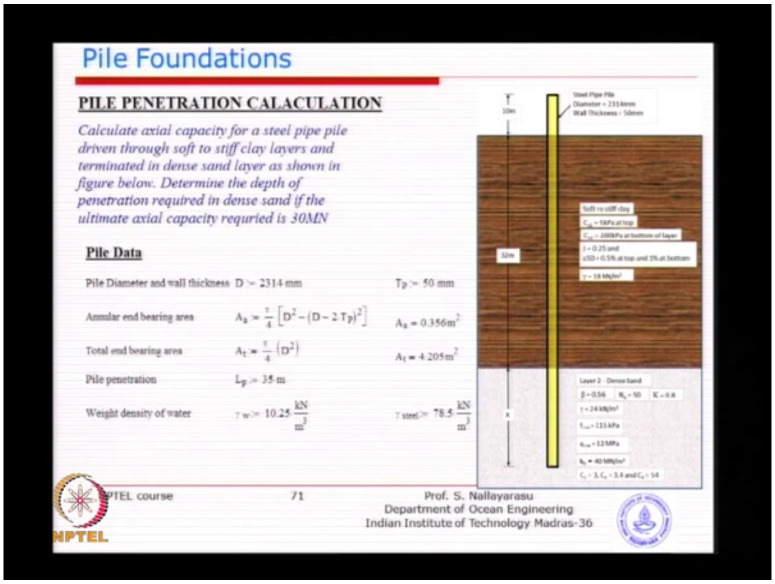

So what we want to find out what is a capacity available we know very well that once you know the capacity of this pile within the 32 meter the quantity is known then the remainder quantity is supposed to be taken from layer 2, so that is the idea you can find out.

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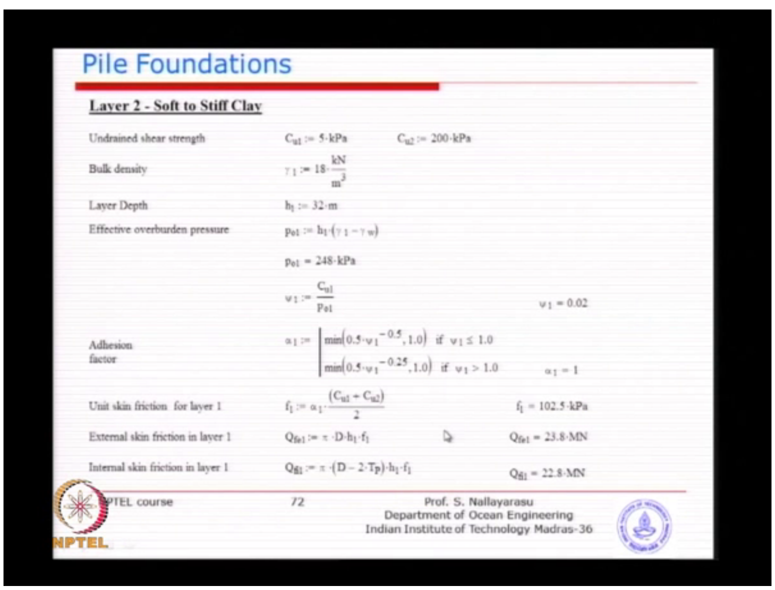

So finding out the capacity of the first layer is very easy because this alpha method is going to be used I think I do not have to describe again and again only difference here is the strength value is varying from 5 kPa at the top and 200 kPa at the bottom and you may have a several methods to do it you can actually do what is alpha value at the start, what is alpha value at the bottom and just use the average value because only c is varying, c varying means xi value will vary because you have xi is the ratio of cu by P not, P not is also varying.

So the best way is to you divide into sub layers but for examination point I think if you do a at least 3 points or even 2 points which is okay you can actually verify when you get time you divide into several sub layers you find the answer slightly different but not excessively different. So layer 2 you can see here the capacity arising from external skin friction and the internal skin friction is around 23 to 24 mega newton, what we require is 30 mega newton. So you are very clear that you are not able to satisfy layer 2 itself not giving you the required capacity.

So this is layer 1, layer 2 is a dense sand so what we need to do is now we assume x value and start going by few iterations you know first you assume you know very well 22 mega newton versus 32 is about 10 mega newton is required if you have the values of limiting parameters like say beta as well as the limiting skin friction and also limiting end bearing is given to in that table will be given the API table will be given you can do quick check how much depth is required in order for us to get the remaining 10 mega newton.

Then you can assume a closer value instead of assuming 2 meter, 3 meter, 4 meter so the best guess will be very useful because you can reduce the time required to find the final answer. So that is how you solve this type of problem and I think after that it is a similar capacity evaluation whether it is a plugged case or unplugged case and then you can finally conclude most of the pile will be plugged.

So we will go back to our original sequence of going through the next stage, so far what we have learned its summary is trying to find out the skin friction capacity and end bearing capacity of piles the principle behind is very similar like our shallow footing only difference is your steam is having frictional capacity whereas in terms of shallow footing you only have a bearing pressure at the bottom.

So we have a combined advantage of end bearing as well as skin friction internal external because you have a tubular pile. Now all this procedure is well established and there are several alternative methods just now what we have learned is only simple methods prescribed by the course, if you go into literature there are other empirical methods or even various into the methods you will find but just we need to satisfy the cores and specifications we need to follow the methods prescribed by the course.

Otherwise if you actually somebody recommended these methods are suitable for the location that you are dealing with several times that happens you know locality the cores disclaimer will read it will very clearly say that this is only a generic method in case if you find deviations or require from the course you may have to adapt depending on the situation the experts have to decide.

In a similar case what will happen when you do a design using API, for example even in any known locations and you actually do a pile testing and you find that the capacity is different from what you have actually arrived based on the cores. So the decision is not correct adapting a 100 percent core methods, so what we will do is we will apply correction factors to either the strength value or to the method itself several cases specialist to engineers we have recommended that we need to modify.

So you know site specific modifications maybe required which all depends on the engineer involved. So far these methods give you the capacity versus depth for the pile foundation especially for tubular open ended piles. Now what we want to find out is the deflection related characteristics we have decided to give a factor safety of 2 I think all of you will remember 2 factor safety for normalized basically operational roads or 1.5 for extreme storm conditions. Now how do we limit ourselves that these factor safeties are going to provide us the required the operational condition.

For example I do not want the deflection vertical deflection to exceed say 20 mm that is our original operational requirement for the platform to survive without any excessive deformations. Now you have no relationship right now to the bearing capacity and the factor safety and the deflection, so that is what we are going to derive basic idea is how do we relate this lot of testing has been done over the several decades of you know pile installation time as well pilot testing is done in fact before you go for a construction of actual structure you do the testing first that means you will construct exactly the same pile as the pile that is the part of the permanent structure which we call it you know ultimate load test or spare test you know you are not going to use that pile you will just do the construction exactly similar do the testing that means you will fill the pile you will actually go to the ultimate fail stage and then you will find out whether the characteristics of that load deflection is similar to what you have actually arrived.

So based on that lot have corrections have been done over the years. Now what we will see is again what is given in the course especially for axial deformation curves. So let us see what the cores are saying how the relationship is as you know very well if you look at the steel, steel relationship between stress and strain are lower end displacement to certain extent is linear after that it becomes if you actually look at tensile test results from your laboratory you will see very straight forward understanding of linear relationship to certain extent and then it becomes elastoplastic and then naking and failure.

So exactly similar people have established only difference here is tensile testing cannot be done because soil particles are individual so you can only do a compression testing which I think we have described in.

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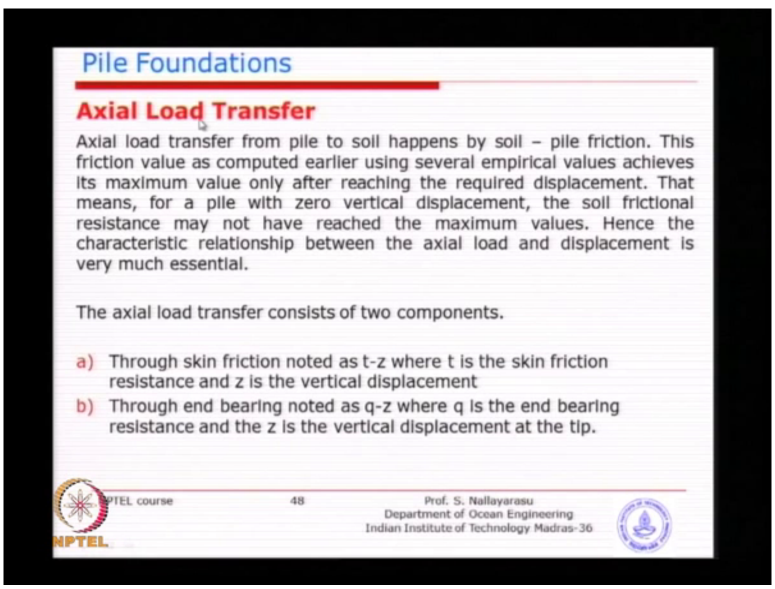

Based on that results you can find out whether what type of deformation it goes through and can come up with relationship historically they notation to understand that axial deformation characteristics is t-z, z is the vertical displacement, t is the skin friction which we have used notation called f no.

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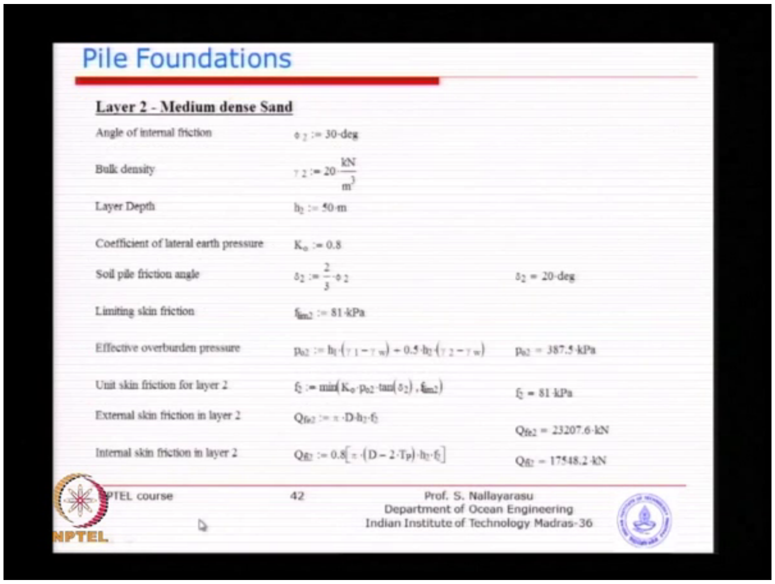

So for if you look at the notation for I think f f limits something like this. So when you achieve the maximum value then it is denoted as t or t max sometime we leave it as t. So when you have friction value is between 0 to t max if the friction value is in between pile is not going to dislocated because the soil is keeping the pile in the same condition, once it exceeds the maximum friction value which is ultimate once the soil particles get displaced with respect to the pile surface at a particular location then the pile will start going down.

So you can see the demarcation it will be having 0 to certain value the pile will have a minimum displacement but after once dislocated or the f max is reached you will see a plastic deformation. So specifically you can call it elastic perfectly plastic after that it just goes through a indefinite deformation.

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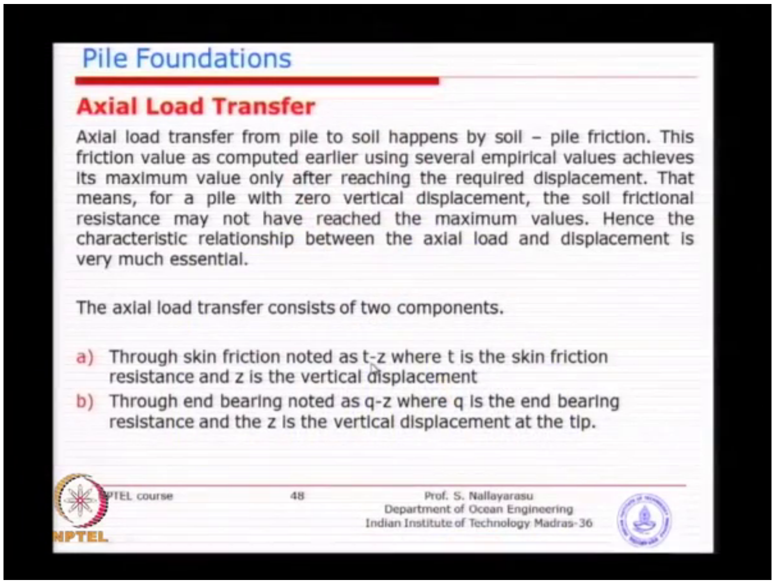

So this t-z curve where do we find and how do we relate between the 0 to t max whether it is straight forward one line or is a curved line like if it is like steel you will expect a straight line but you may not get because of heavy risk definitely nonlinear.

And that is where we find the problem of interaction between structure and the soil slightly complex compared to other analysis so you need to do a nonlinear response analysis that means if you have displacement of 1 mm for 1 kilo newton it is not that 10 mm for 10 kilo newton it is going to be nonlinear it is not a linear proposition, so that is where we are trying to establish. So there are sets of curves, one is for both are vertical one is the skin friction which is the side frictional resistance versus displacement, the other one is end bearing versus the same vertical displacement but at different locations.

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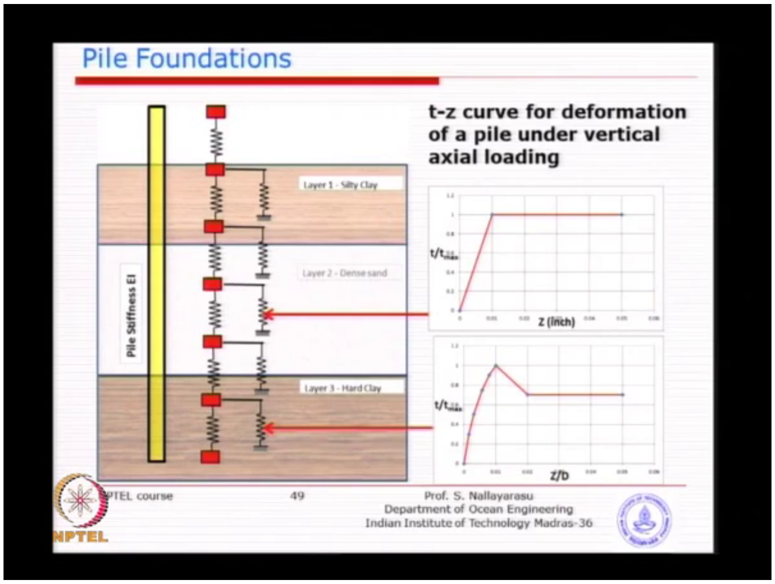

So how do we look at, how do we synthesize a pile is you can see here you can divide the pile into several sub statements of unit length 1 meter, 2 meter, 5 meter depending on the accuracy required and each of this pile is denoted by a red color box having a certain stiffness value, modulus and then moment of inertia, sectional area and these parameters represent both axial stiffness as well as bending stiffness. So what you are looking at each of this pile segment is connected by soil spring on the sides of course this spring is representing the pile itself is for axial you can find ea, t modulus times your axial area. So the sides springs are attached to rigid datum on little bit far away ground imagine if the pile is trying to move the soil in vicinity is also trying to get dislocated but when you go away from the pile say 2 diameters, 3 diameters the disturbance of the soil due to the pile load is going to be minimum, I think that is what we saw in our the first you know analogy of bearing process.

You know the further you go away the bearing process from the foundation load is going to be minimum, further you go down below the pile tip also going to be smaller because of the dispersion that is happening. So you can see here at a slight distance away little bit distance away 10 percent of the diameter 20 percent of the diameter the mobilization of the friction or the strength value from the pile to soil is going to be minimum so you can consider that soil as going to be rigid datum.

So the in between soil is trying to behave (())(16:26) failure so you see you can understand. So this spring value so called the frictional spring which is what we want to find out if it is a linear spring like what you see on the first picture, for example see here it is a very good linear spring goes to the maximum value and then it becomes plastic deformation. Whereas if you see the second spring here is starting itself is nonlinear means the relationship is not proportional is going to be non-proportional to the strength versus displacement and then has a behavior which is getting degraded and then plastic deformation.

So you can see there are two different ideas proposed and has been tested and then validated. So you can see here in the sandy layer is linear and then perfectly plastic, in the clay layer is nonlinear and then at a certain deformation it becomes lower strength then the strength that you will achieve at a lower displacement and then becomes plastic. So this is the two shapes which we need is we need a coordinate points or we need a equation, you know if you are able to describe this by an equation then it is good or if you are able to find out the various points and then you can use them in your calculations.

So ultimately why do we need this when you are doing a system analysis, for example you want to study the jacket overall behavior of load displacement you need to describe soil as a spring and transfer these springs into a analysis because after all every structural element is a spring element it could be axial spring or it could be a bending spring or it could be (())(18:13) spring. So similar idea you translate the soil material as a elastic or inelastic material with a spring value whether it is linear or nonlinear.

Once you do that once you do a characterization like this, this becomes part of a structural analysis so you do not need to worry about you know the soil as a separate material you need to divide and then analyze. So that is how most of the offshore structures are characterized you have a structure you have a soil, soil as a engineering martial you transfer the strength properties in terms of spring and then you analyze. So this becomes part of the structural system you divide the structural into say various sub components each component is attached to the next one for example this element is attached to the previous and the next and also attached to the side soil value with a certain spring once you establish this then you can carry out the analysis most of our structural analysis we go within the linear so called elastic analysis.

So if you are able to get a spring and if you are the deformations are within this limit, then this also become part of it as simple static analysis will be able to solve the problem but once you have this type of nonlinear every time you need to find what is a structural displacement, for example in this case if you go to this what is the displacement the pile goes through go back to the soil and correspondingly what is a strength available and you take it whether that strength is sufficient enough to transfer the load from the pile if not enough then you go for higher deformation and find out what is the strength available and then go back to.

So you do an iterative analysis so that is why the pile soil interaction is always is going to be iterative because you are trying to find out what is the strength required in the soil to transfer the load of the pile or the super structure into the ground with the expected displacement is lesser than or equal to your value. So that is the so iterative solution it takes considerable amount of time that is why many times if you are able to get a linearized thing then you do not need to worry about it because it becomes simplified because you will be using only the once single spring value.

Whereas here you got multiple of values because every time we can a tangent you will get a slope you will take another tangent you will get another slope. So every time your spring value changes depending on what is your displacement, for example if initially if we take a initial modulus or initial value of the tangent relationship between the load and displacement you will get one value that is how you get your e value I think if you are remembering stress strain characteristics the initial modulus is same as the modulus at yield.

Whereas here if you look at this every time you change your tangent value at this point you will get a reduced value and that is the thing that you are going to do iterations. So the purpose for which we are trying to establish the t-z relationship is to incorporate this into a load transfer relationship with structure.

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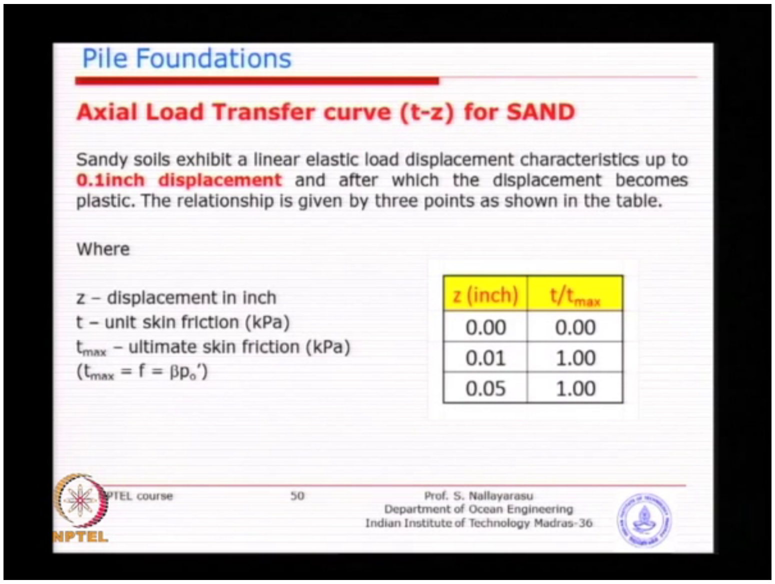

So just quickly look at how the sand material and what was given by the API, so you can see here 0 of course no strength is available and at maximum of 0.05 inch, so you can see here this is typically a unit is given many times it is given in a normalized equation in this particular case old (())(21:41) of API is giving you this but of course in the new versions they are trying to normalize this and maximum value of t max is achieved.

That means you calculate your frictional resistance of the soil using P times P not times beta which is the maximum value which is called ultimate skin friction which we have already learned to calculate for a given layer you can calculate that will be the maximum value you can achieve after displacement of 0.05 inch which is quite a small value you can easily understand why these grand sized particles so called cores material even if you just displace by a little bit they lose the transfer of forces by contact because frictional resistance is purely by the contact surfaces the particle one over the other, once you displace a little bit they go disconnected and may not be able to transfer any force.

So that is why for sandy material you do not have too much of displacement to achieve maximum resistance after that it becomes plastic deformation once they get dislocated there is no more load transfer can happen and that means deformation is very large.

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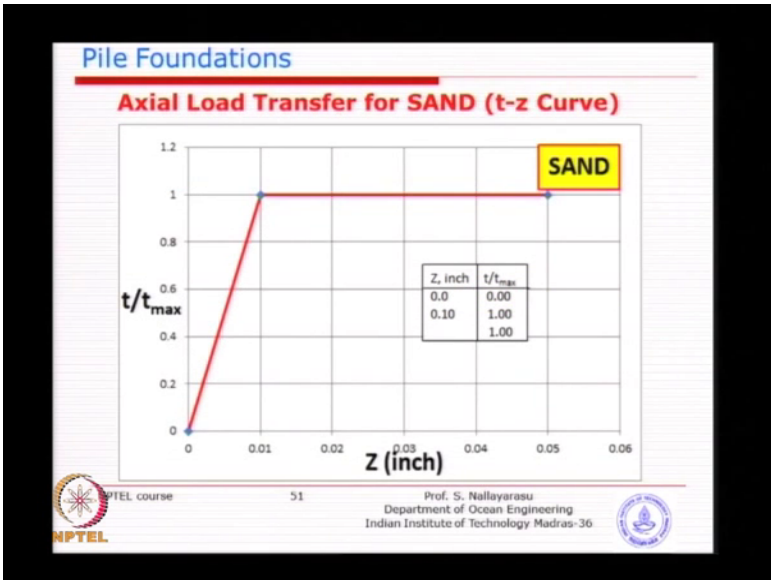

So that is why you see the graph something like this 0 to 0 and then maximum value at 0.01 inch in fact 01 inch and then it becomes. So basically that is the maximum value and then after that it becomes almost constant, so that is the type of relationship initially prescribed but now there is there are some changes to this which I will share with you tomorrow because the code is still not in force they have revised but yet to announce for implementation which we will it will take some time because the just now the code is in review time every company has been given opportunity to give comments.

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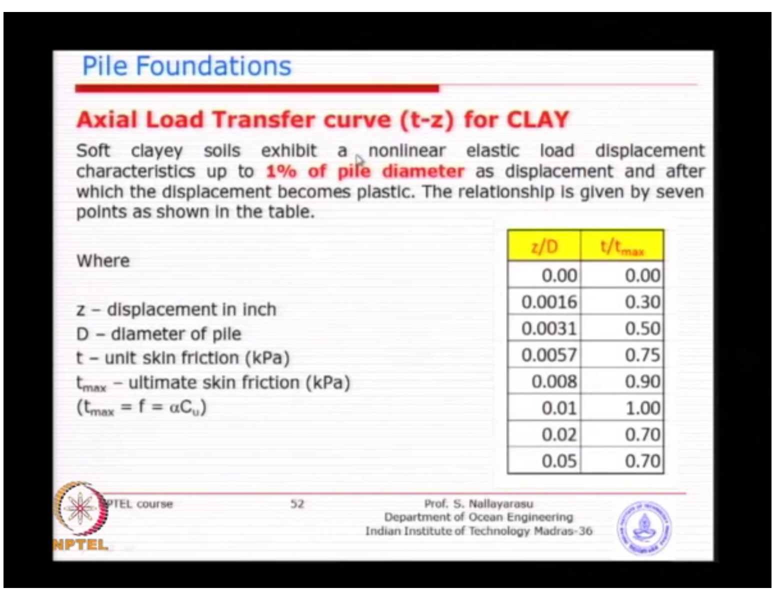

And for clay type of material you can see here the f value is alpha times Cu which I think you all know very well alpha is related to C and P not you can calculate that for a given location and this f is ultimate because that is the maximum value after which it is going to fail terribly. So this is assigned as a t max so you see here is a normalized coordinate system with respect to diameter. So you can see here z is the displacement D is the diameter as the z by D is increasing it achieves the maximum value at 0.01 you know.

So that is 1 percent of diameter, is it? Whereas the other one was actually in terms of inch so that is the difference that we need to remember. In the new code they have actually normalized to this type of number which you see a slightly different idea.

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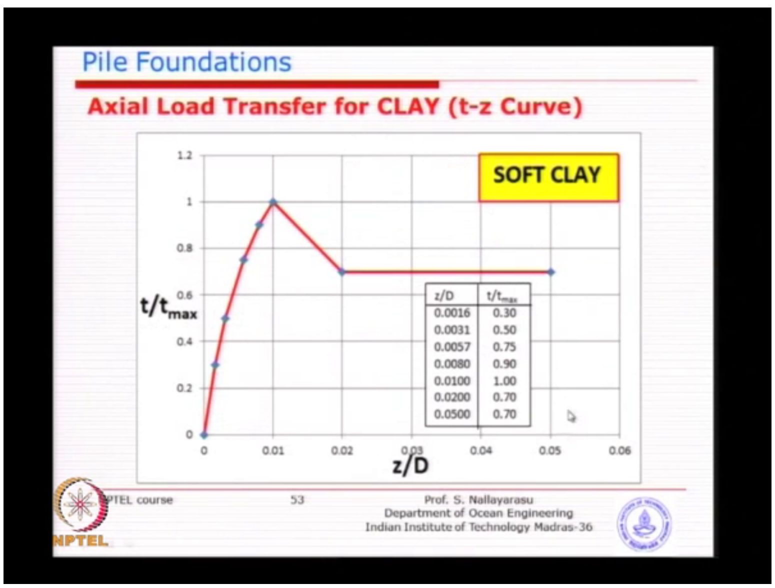

So in between in order that if you connect this point and this point you will get a linear so in order to make sure that the nonlinear relationship is established or you are able to generate if you look at the first paper done by Meyer Huff in fact it was described by equation the same profile was described by equations of slightly complex nature which you will find very difficult to remember.

So API has discretized it given four points, so you can just use these four points described in between you will use the linear that means from here to here you will straight straight line which is reasonably acceptable we are not going to get something big and then come down so that is why the linear between the points is okay. So if you are able to find out what is the value maximum available for that particular clay then you come down what is the value of displacement to diameter ratio will happen and based on that you can use your displacement.

This is for soft clay you must remember which we need to introduce what is soft clay I think we discussed this one few classed back that difference between soft clay and the hard clay if you cut vertical cut for example soft clay will try to fall down and come stick with the structure or foundation. Whereas this hard clay what will happen when you cut it will stay as it is, so the demobilization of the strength after disturbance is very minimum. For example you take a pile you start driving if it is a soft clay after disturbance after several weeks the soil will come and (())(26:28) to the pile system.

Whereas the hard clay it may actually stay where it is because of its own characteristics because is unable to crumble down and then come back that is one of the bad characteristics of stiff clay even though we call it stiff clay is better for foundation but for pile foundation is not very good because you will not be able get the skin friction back and that is one of the issue determined by several researchers by doing field testing and they demarcated that we have to differentiate between the good advantage of soft clay versus the disadvantage of the hard clay or stiff clay we call it.

Soft clay the demarcation is 96 kilo Pascal so if any undrained shear strength is less than 96 kilo Pascal then it is called soft clay and beyond which we so approximately you remember 100 kPa.

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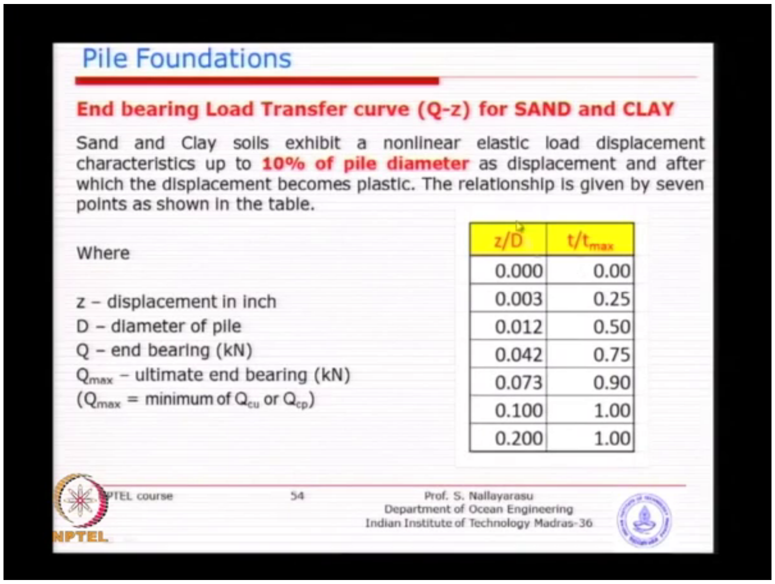

Now if you see here the end bearing so this whatever we saw just now was for skin friction at the sites of the pile, so let us move onto the end bearing which is basically at the tip of the pile both sand and clay were given only single relationship so you can see here z by D is a normalized relationship between displacement and diameter up to 20 percent of course 10 percent diameter it achieves the maximum capacity.

That means you could see one important thing we discussed in earlier sessions there is always going to be a problem when you try to share skin friction and end bearing, there is a contradicting statements just now you can see you drive a pile in order to achieve a maximum end bearing capacity the piles should have achieved 10 percent of its diameter as a vertical displacement you can easily understand the more vertical displacement you go through the soil beneath any lose material is getting compressed the pile is trying to transfer the load by end bearing.

But what will happen when you try to achieve 10 percent displacement of the pile all the skin friction is already broken because you see here if you look at just for clay and for sand even worst 1 percent of maximum displacement the ultimate strength is reached and after that it becomes plastic deformation which is not atoll good. So this is exactly the problem where when you try to achieve the maximum capacity by end bearing you will lose all the skin friction or if you try to achieve full skin friction using only limiting the displacement to 1 percent of the diameter you will never ever achieve the end bearing because end bearing capacity depends on larger pile tip displacement the more that you compress especially for concrete type of piles.

For example when you are boring bored pile mostly common in onshore structures you do a boring and remove the soil I think I have explained you the methodology of installation remember we are poring bentonite slurry inside to stabilize a soil and then you replace the bentonite slurry by pumping in concrete. Now you see here this process or the tip of the pile will form a very soft layer of concrete because there will always be debri you may not have removed it 100 percent.

So when you completely erect the enforcement cage the bottom of the pile will have a soft characteristic. So as you apply the load the pile will crumble you know basically at the tip it will try to break imagine if you take one hard wood and try to poke on to a strong ground what will happen the tip will crumble, exactly that is what will happen to the bored pile the tip of the pile will start crumbling making a larger displacement.

What happens is once you have a larger displacement the skin friction is broken that means you cannot take any more skin friction because the bound between the soil and the concrete is broken and this exactly the problem even in the in terms of steel pile, once you have a larger pile displacement at the tip the whole pile is going to go down skin friction is gone a lots and lots of debate as well as literature you can find in the articles in several journals how much you should be taking as end bearing when you take how much percentage of skin friction lot of publish in the literatures.

The problem is more for concrete piles and steel piles API does not actually give you any recommendation that you should limit this much or you should limit the skin friction but what is says when we do the calculations for end bearing for sand because we know very well that end bearing in clay is not very good very small that is why they are limiting the end bearing to certain value which we saw some limiting end bearing values. So as long as you follow the rules given by API this may not be a major problem that is why we have to strictly follow the limiting values.

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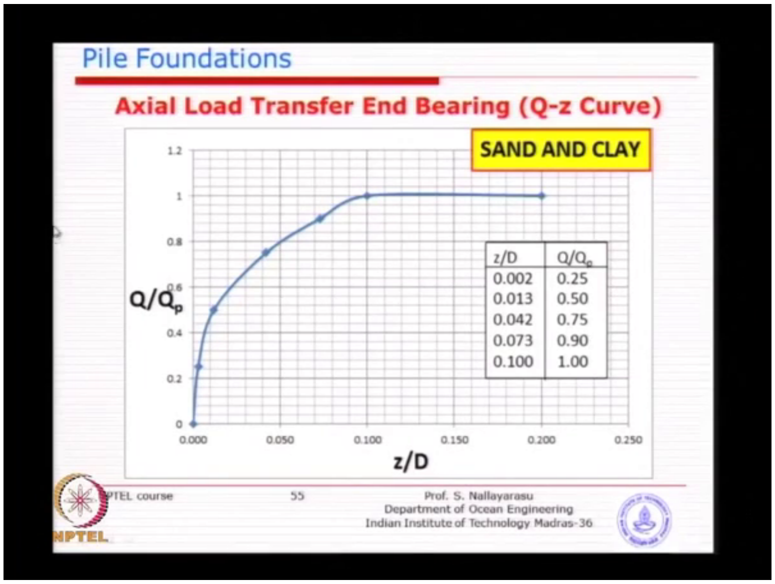

So the end bearing if you look at the graph is highly nonlinear starting to from the starting point itself you can see here every time it changes. So this actually was also proposed by not Meyer Huff other researcher a continuous equation so almost like a parabolic curve which API has just digitized and given in terms of discrete points which we will be able to use it for our programming purposes when you are actually transferring this data to any computer based analysis so you will require to specify this points.

So what we requires is to calculate the t value the t value for in between is skin friction and when it becomes maximum will be your ultimate strength. The relationship looks something like this so it achieves the maximum strength at 10 percent of the diameter after which it becomes plastic deformation.

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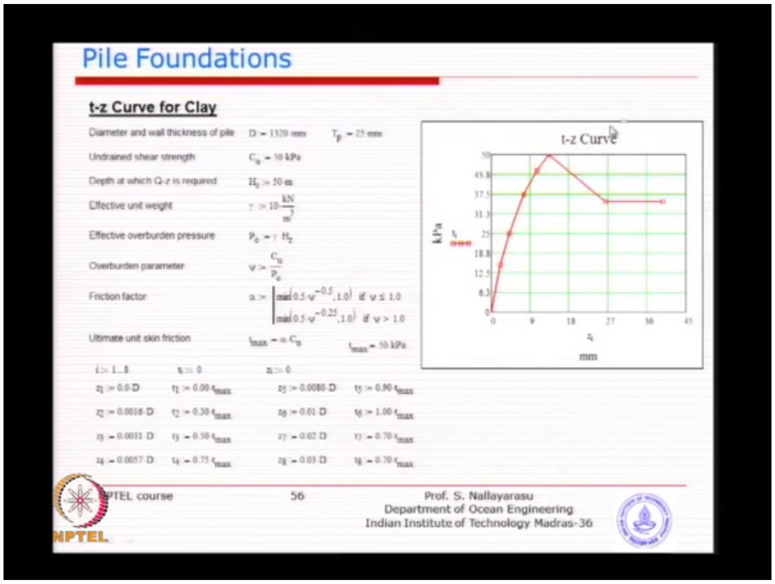

Just look at one of the example just to understand this is for I think is a clay type of material undrained shear strength is given as 50 kPa which is a medium clay not very soft not very stiff, diameter is given depth at which this relationship is required is given you know 15 meter below seabed.

And then you have density of soil is 10 kPa 10 kilo newton per cubic meter and you can calculate the P not value which is your overburden pressure 5 times your density and since it is a single layer is very easy. Imagine if it is several layers are above before the 50 meter then what you need to do is you need to calculate the effective overburden pressure of those layers plus the layers (())(33:42) to the point of consideration.

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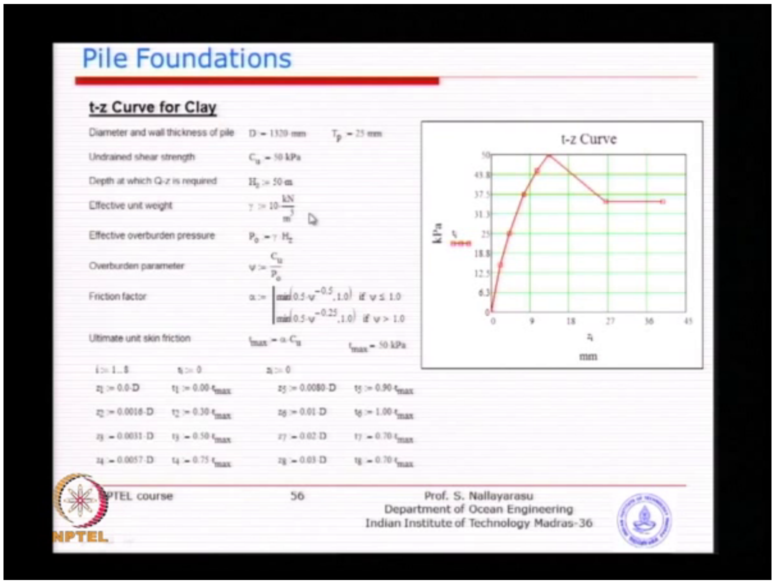

So you have to be little bit careful if you are given a multiple layer question in your analysis and then you find out the xi value and then alpha value and then finally find out the f which is assigned as t max because that is the ultimate value after which it becomes failure. So you need to understand the notation the difference between t max f t max is the maximum value of f which is going to be achieved or mobilized. Now you know the relationship between you know the z and the t max is given in the API graph or the table.

So you can see here the first point is 0 times t by t max was 0 so you just go back here t by in this relationship this is 0 so the second point is 0.016 and 0.3 so that is what I wanted to show you. So you can see here z by D was 0.016 so I want to find out what is the value of z, so z multiplied by diameter, diameter is given here and then t max was already calculated so I can find out 0.3 times t max will be the t value at that deformation.

So the deformation is 0.0016 times diameter it could be few millimeters so it could be somewhere around 3 millimeter I can say. For 3 millimeter deformation 30 percent of the maximum shear strength or not shear strength the frictional strength is achievable. Like this you can develop for all the 8 points or more points if you have the graph and then put up a relationships. So you can see here instead of ratio now z in terms of deflection and basically the skin friction in terms of actual kPa value I can find out the relationship and this is what we need to establish.

So the next time if you are given the required skin friction what will be the corresponding displacement or limiting deflection if you are given that is the maximum value you can use not the maximum value that you derive from alpha times cu depending on what is a deflection. So this is a typical t-z curve for clay type of material which I am sure you should be able to derive without any question the only thing we should remember and note down is multiple layer soils calculation of alpha depends on the previous layers the density and the depth and the thickness so you should be able to that without any problem.

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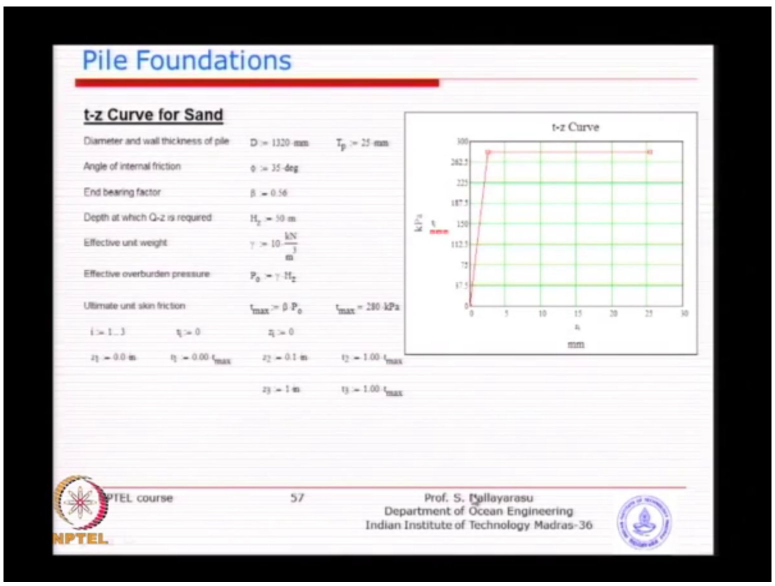

t-z percent is a similar only thing is little bit easier because it is only a single linear point and the sand is given overburden pressure is given and this assigned overburden pressure to the maximum value and corresponding z you can fix up is 0.1 inch and you can see here is 2 and a half millimeter you get the maximum skin friction.

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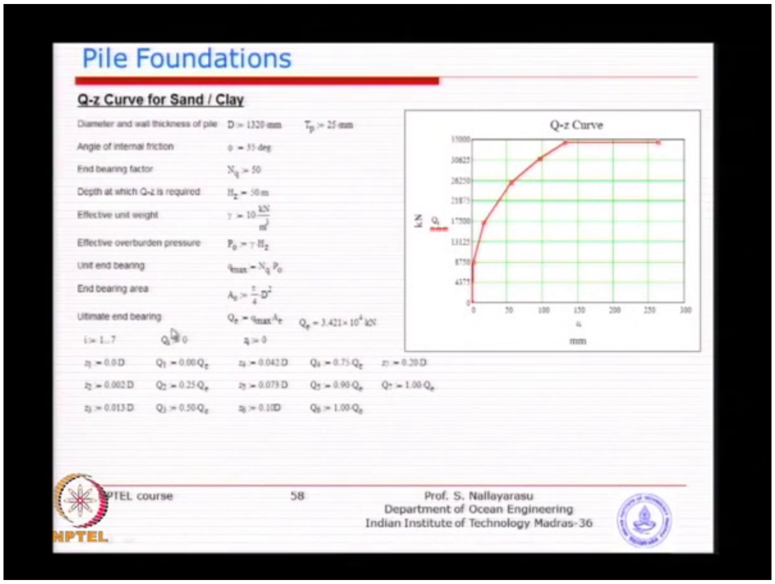

So that I think gives you an idea if you go to qz curve similar only its difference is we are going to find out what is the value of end bearing coefficient from the table because you will be given angle of internal friction and based on which you can go to the API table and find out what could be the value of limiting end bearing value what could be the value of the nq the end bearing factor which is in this case is 50 and subsequently we can find out the unit end bearing which is nq times P not and you find out what is the limiting end bearing value limit to that value and then correspondingly.

In this particular case we try to multiply by end bearing area so that you can actually plot the displacement versus the end bearing itself full end bearing whether it is plugged or unplugged and then the corresponding points are given here it was z by D versus q by q max, q is the actual value, q max is the maximum value you will achieve when the displacement is at the 10 percent level so. So imagine if I decide to do a linear relationship for example from here I want to just go up to this point just I do not want to do a nonlinear whether it is conservative or non-conservative we can decide, for example if you do that for a given value of 50 millimeter of displacement if it is a linear relationship you will get a lower capacity.

Whereas nonlinear you are going to get slightly higher capacity. So does not worry us as long as your assumptions are conservative to the design side this is because of the convex type of curvature that you are seeing, but what if the nonlinear relationship is concave type of relationship it is like this then your linear relationship is not very good. So you have to see the situation you have to see the difference for example in this particular case let us spend 1 minute for a 50 millimeter if I have taken a linear somewhere here I think it will reach I will get a capacity of 13125 kilo newton, is it?

Now if I go to a nonlinear graph I will get somewhere around 25,000 now between 13,000 and 25,000 is almost double the capacity, so should be do a linear or should be do a nonlinear the answer lies in the margin that you want to leave it, you know basically 50 percent do you want to leave it maybe too much. So that is why you need not conclude under basis of simplicity you should see what is the strength you are losing many cases you know it may not be like this only foundation where you are looking at like the linear to nonlinear is that so much extra capacity.

In other engineering martials you may not get you go to nonlinear you get only 5 percent. So 5 percent you may think why do we need to go to nonlinear why not we do a linear relationship simply for the design process. Whereas here we will not be able to do is because the losing capacity is almost another 100 percent which is not going to be very good. So that is why historically we use nonlinear pile soil interaction analysis because already soil strength is very rare to come by good soil so that is why we have to follow this principle.