Foundation of Offshore Structures
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Module 1
Lecture 21
Pile Driveability Analysis 4

The previous class we were looking at the SRD calculation basically in terms of long term capacity how much higher or lower we should consider for the soil resistance during driving. So it all depends on the type of soil as I mentioned you can see for sandy material or clayey soil you can degrade or increase in comparison to the static capacity and also it depends on the time of driving whether you have a continuous driving or interminantly you are having stoppage due to various reasons.

For example if it is a skirt pile you may not even stop you take one single piece skirt pile you start driving you may not need to stop intentionally because there is no necessity of adding segments or changing hammer things like that. But if it is a main pile you may actually have a problem of welding say segments, segment 1, 2, 3 and during that each of the time that you change hammer to remove hammer and placed additional segments you may have a delay.

So this is basically we called it restart driving that means interminantly you have a stoppage. So for several reasons you will have to find out whether anyone of this case or some of the case maybe applicable to the particular time of driving

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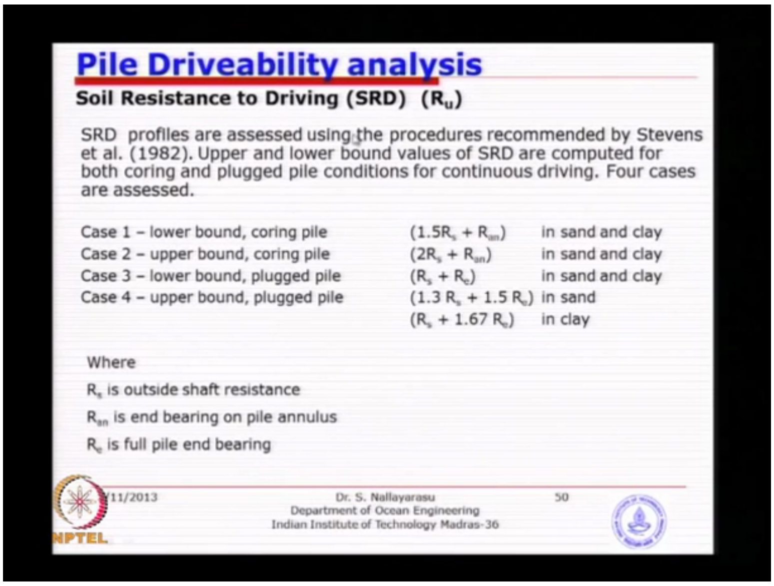

So not necessary that every one of them is applicable to every time so have to be little bit cautious on it when you have a continuously driving and 100 % clay type of soil you may not actually exceed the static capacity as the resistance against driving.

Whereas if you have a interminant stoppage you may actually come closer to pile you know the long term capacity or may be exceed in some cases. So what proposed by Stevens by his prototype studies as well as measured values at sight. He has indicated that middle east areas where the calcareous sand is predominant he found that the resistance is substantially larger values compared to long term capacity and that is what he proposed in one of his paper published as early as 1982 in off shore technology conference.

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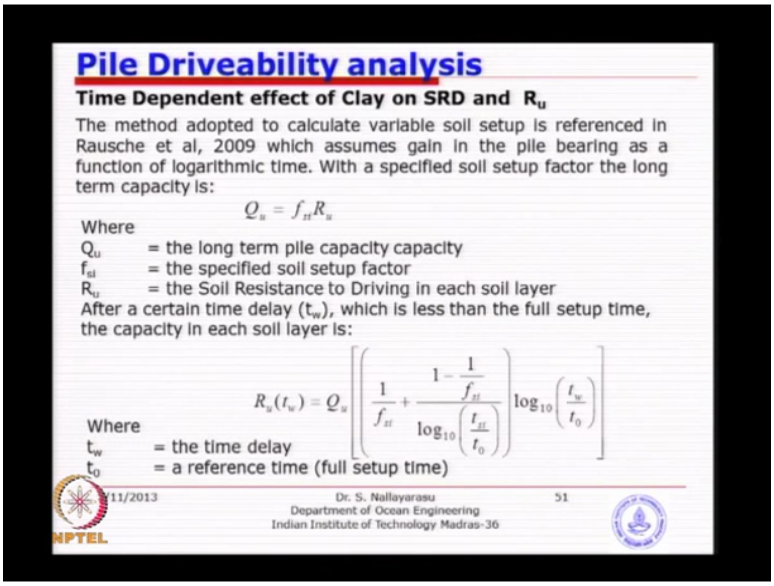

The other thing that you know always we find it difficult is the time bound capacity. You know for example you have a long term capacity of driving the pile say several months later you're capacity is constant not going to change at all. So that we called that is why we called it long term capacity means is the value doesn't change with respect to time that means soil has attended full capacity that means the (())(2:59)between the file and the soil is not going to change.

But when you come backwards from driving time to the time of achieving full capacity what is the basically the proposition whether it is linearly varying with time or some kind of relations can be developed. Unfortunately not much research is available in that particular area especially clay type of soil offcourse if it is a sandy material you don't see much of change in fact it will remain almost constant.

So what you see here this particular research paper published very recently 2009 by one of the founder of this driveability program so of the name is Rausche I feel that is how you get this GRL, each one stands for one person name they have done some work field work plus some laboratory testing of predominantly cohesive type of soils where in you disturb it during driving and then leave it after few hours few days and try to restrike see what is the resistance offered by the soil and they have come with this particular type of relationship log linear relationship.

So you can see here if you just look at this formula the QU is the long term capacity and RU is the soil resistance during driving. So you can either have the values higher or lower then Fs depending on the type of soil so this FSI is the setup factor that longer you live it, the factor will be larger suppose to be larger and then you will get the resistance to driving achieving its full capacity. That means we don't expect by default you don't expect the resistance will be higher than you know the long term capacity.

Predominantly we are looking at clay type of soil. It can only go maximum to a full adhesion or it can be downwards lower than its capacity itself. So you will write it in terms of reverse or Ru can be written in terms of Qu with one by FSI with which is what is proposed by this Rausche and his research group looking at you know time bound calculation for you know the basically the resistance offered by the soil during driving.

The T knot is a reference time and then Tw is the time delay like you start driving you disturb it and just give a 6 hours delay, what will be the capacity later on? So it was very useful tool but again it is only tested in a specific clay with consolidation ratio of point four so there could be a different equation that could arise. So that is why it is not generally used but it could be used as a guidance this particular equation can be used as a guidance just estimate see how much increase in resistance.

For example during driving you have a hammer breakdown you take two days to bring the hammer of you take few days to bring the hammer, new hammer from onshore and then transport it. So do we expect to change the hammer or we use the same hammer that we have been driving. For example you use a 600 type hammer during driving before you stoppage and then later, three days later I want to restrike should I use the(())(6:14) hammer or should I use the bigger hammer.

Just to establish whether the hammer selection is correct because you go and put a smaller hammer if it doesn't go through again you have to waste another half a day to remove the hammer and put the hammer. So that is the type of assessment you can use just to make sure that so this particular equation in the recent times we have been using in few of the projects where to estimate the time delay and the related increase in resistance against driving.

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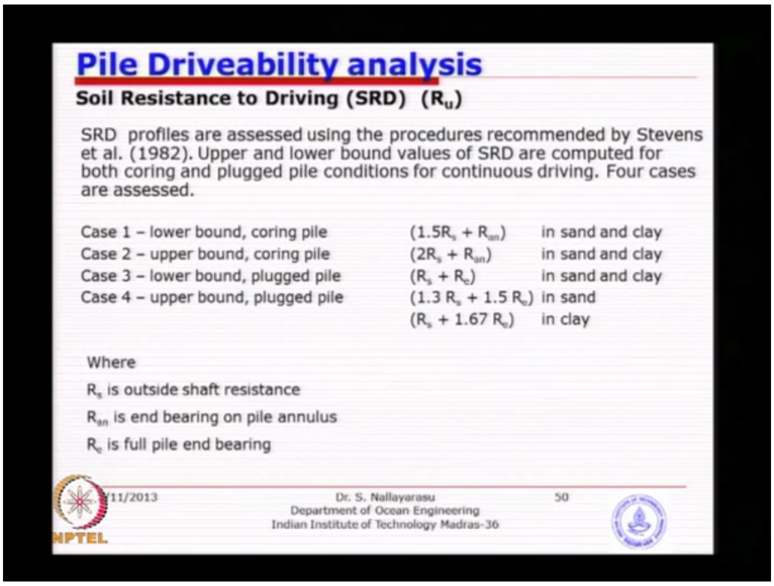

So I hope with these two slides you should be able to understand what is the long term capacity which is basically calculation to a get the pile soil interface shear failure which what we called it actual capacity ultimate capacity and then from there we have come down to the resistance offered by the soil pile interface during driving several methods. One of the method is by Stevens where he is completely relating to a static capacity with a multiplication factors 1.5, 2.0, 1.3, and so on.

But the best thing that we can get is without going into too much details, you can easily understand that the driving resistance will atleast be equal to the long term capacity or lower for mostly on clayey type of soil. For sandy type of soil mostly you will get higher but how much higher is a big question because of a densification of soil during driving because of the vibration. So these two things you need to keep in your mind that the driving resistance will definitely be smaller for clay type of soil higher for sandy type of soil depending on the situation.

Now just go to what we practice as a setup factor you know basically in the past infact it is exactly the same equation only writing in terms of over consolidation ratio.

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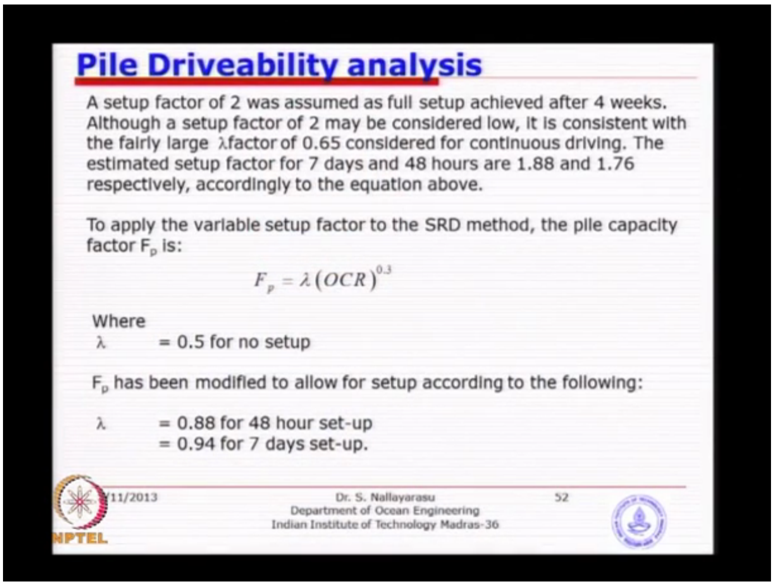

I think when we were looking at the basic soil mechanics we already discussed about this term called over consolidation ratio, the past pressure to the present situation. The more that you have a past pressure the soil already have consolidated over consolidated.

So you don't expect anymore consolidation to happen due to the new pressure that you are going to build up due to your, so that gives an idea of the history of the type of clay that you are looking at. If it is a very young clay you may actually go through a large consolidation over a next several years if it is a very old clay with past history of overloading then you may not actually expect.

So depending on this OCR the basically the contact between the pile soil interface can change infact several times if you look at the recent research papers actual capacity itself is been calculated taking into account OCR as one of the parameter offcourse API doesn't recognize those methods yet because it is not generalized but in some of the research papers people still use this as one of the parameter.

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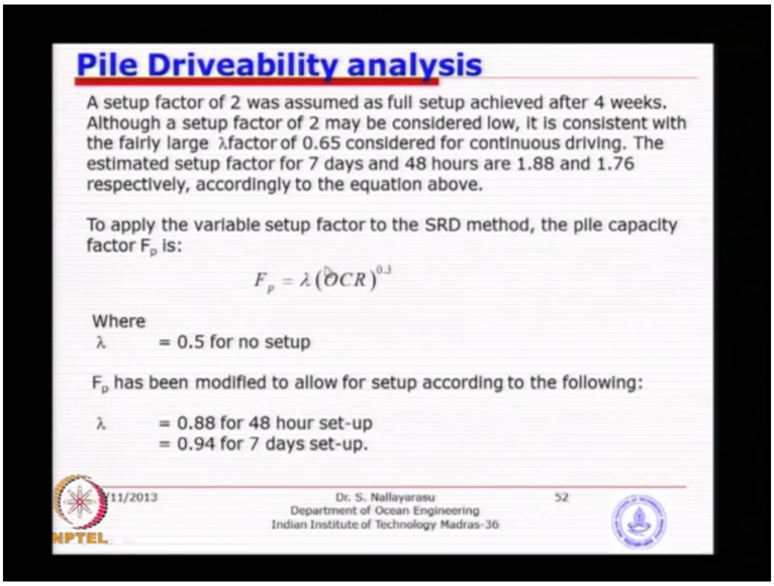

So you can see here in this particular research paper done by Raushche he actually come with a pile set of factor as a function of over consolidation ratio multiplied by as a factor which is 0.5 which is nothing but 2 one by 0.5 and for different numbers of hours or days he has proposed this type of numbers for his research work which is what he is going to use backwards in this calculation for the resistance against driving.

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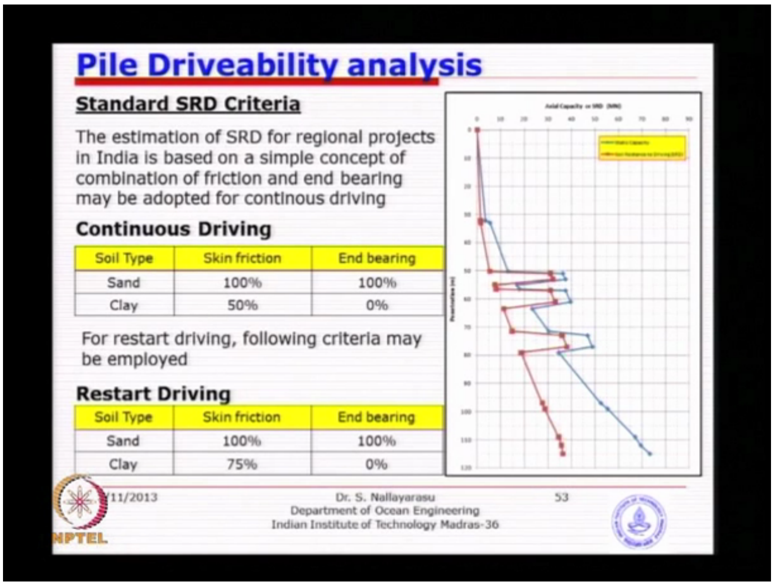

The next thing what I just wanted to show you was what is the general practice in the industry is so you have seen research by Stevens and then by this group as we can see here the continuous driving term means you don’t have any stoppage no intermediant change of hammer or change of pile segments adding of pile segments. Continuous driving is expected even for main pile because for example you take one main segment and then you start welding after use restrike that means that just first few blows the soil gets disturbed.

Then after that it becomes actually driving is continuous until you (())(10:28)come to the next time you stop. So the in between time you have a continuous driving but of the biggest problem is starting to overcome the initial increased resistance whenever you are restarting that is basically this this case where you are going to have first few blows or first few hundred blows depending on you may expect a larger resistance.

Once the soil gets disturbed and then start to move downwards then you come into a continuous driving so you can see here in the in general practice for sand we use 100 % of the static resistance which is either alpha method or beta method you are using for clay or sand you take the 100 % skin friction and 100 % N bearing whereas if you look backwards to methods by Stevens he is using 150 %.

So that is where the difference you know many of the situation we is, would like to limit to 100 % unless the data proven in the vicinity or in the particular area that it shows increased resistance mostly we restrict ourselves to 100% and for N bearing again 100 % but again depends on the type of soil. If it is a loose soil densification maybe further possible. But as you go down you can cannot expect so much of densification because the soil already dense.

Because you know the overburden pressure for several years so that is why many of the cases we use 100 % unless you have a local area data showing that higher than 100 % is required and for clay skin friction is taken as 50 % but then the N bearing is completely disturbed as the pile goes through you can see that the soil is disturbed, remolded 100 %.

So you can say zero percent offered by the N bearing from the clay. So this is the general practice for a continuous driving. Restart driving you have increased 25 % but again this depends on the time duration I think you can go back and calculate if a set of factor comes to be higher you can even reach 100 % sometimes if you give for two weeks a break because of some several problems so you come back you may actually go for longer.

Because this one, once the clay is disturbed it just keeps shearing off and that is why 50 % is used. So most of the practice you can see here on the right hand side you have a chart drawn very similar to what you were trying to do in your practice of preparing a pile capacity chart with respect to depth of driving or depth of penetration in this case so you can see the redline and the blue line.

The redline is the static capacity blue line is the static capacity, and the redline is the reduced capacity or reduced capacity in terms of you know you can call it the resistance to driving because we have downgraded the parameters of skin friction and N bearing depending on whatever whether it is a continuous driving. So I think it is given here is if I think is a continuous driving so you can see suddenly so much difference.

So what you can see here there are three clay three sand layers one two three you see a large resistance those layers predominantly coming because the N bearing is there, you know so that is the this as the areas that you will see that the hard driving maybe expected because the resistance is so much. Once you break down you can see here driving at 50 meter you have a resistance of something like 32 mega newton.

But driving at 90 meter you have only 22 mega newton. So you can see here you initially have a larger resistance once you punched through that layer then after going down becomes easier so this is where you are you are driveability or so called whatever we are learning about driving schemes to establish what hammer is required is just to overcome this particular layer where the soil has got higher resistance.

So at that time if you have a bigger hammer you are able to punch through. Otherwise what will happen you will be keep hammering there pile may actually get over stressed but then you are not able to penetrate through because your hammer inertia what you have is not sufficient to punch through. The idea whole idea is to find out what hammer is required in order to do this penetration because you have suddenly increased resistance because of such type of soil at that level.

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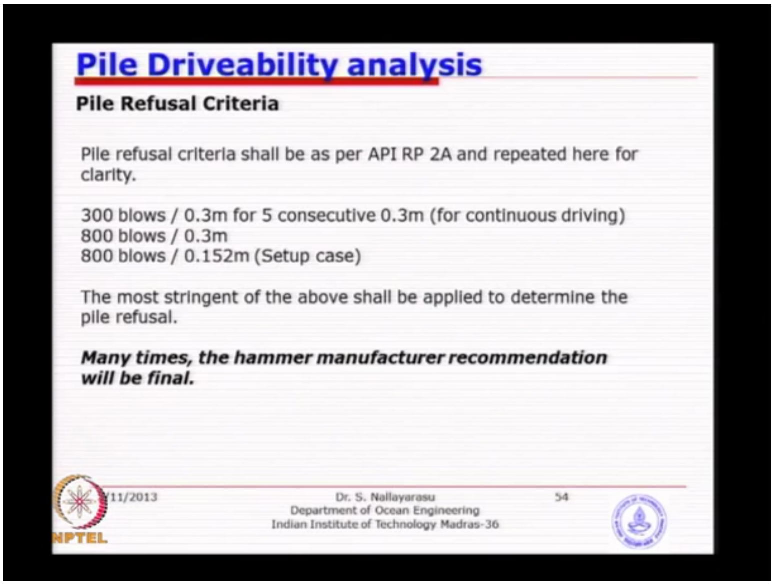

So when do we stop we keep hammering and then this is one of the important decision making information because we just can't keep doing that until the pile fails or soil fails. Either one of them should fail, isn't it? Or the hammer break down so basically we need to set and keep in our mind that what will be an acceptable situation.

So that we can decide because this is not theoretical paper work it is actually practice at field so something needs to be given to the hammer operator. He should know when I should stop and he may not be an engineer so that is why you have to put it in terms of number of blows rather than stresses because he cannot understand. So what we are looking at there is a difficulty in making this decision.

You take a bigger hammer the same soil you can drive with lower blow count. If you take a smaller hammer the same soil, same pile you will take larger number of blows to even drive or even to stop you know go through a smaller penetration. So all depends on right selection, so what is right selection? Basically that is what the driveability is all about. You have to establish the relationship between the energy of the hammer that you have selected and the number of blows that you find out.

Ultimately it should not be a too big hammer that even at 90 meter penetration only few blows its going down which is not a good, so ultimately the set value the last few blows you should have a minimum that means at design penetration for example your design penetration is 90 meter that is where you want to achieve full capacity at that time when you reach that 90 meter penetration you're penetration per blow should be minimum.

Which what we were looking at uh one inch or two inch for example for one blow you have acceptable criteria of say one inch, 300 blows it could be large number which you need to find out what is your design criteria for a particular type of facility for example if it is a residential building under that full capacity you don't want that large amount of penetration to happen so 1 inch, 2 inch you set.

So the hammer should be selected in such a way that after doing the analysis at the end of particular driving for that penetration. Your 0.3 meter for five consecutive 0.3 meter is basically 300 blows and suppose to happen five consecutive time that means 1500 blows and again point 3 so your set value if you calculate point 3 divided by 1500 it is a very-very nominal value less than what we were talking about .

So that means this is the type of analysis when you are reaching this and you select a hammer according to this that means the hammer is appropriately selected that means you stop. This suppose to happen at the time when you reach your final penetration. Now suppose if this happens earlier than say your design penetration is 90 meter but this happens at 15 meter,20 meter that means is actually early (())(18:15) your hammer selected was not sufficient enough or your expected resistance to driving is unexpectedly higher than what you are estimated.

So either one of them has happened so that is basically the idea so the blow count given by API this criteria is just spelled out in the code but several times hammer manufacturer also have a say we depending on what type of hammer they use the efficiency but ultimately code prevails as a final criteria so 300 blows for point 3 meter for five consecutive point 3 meter.

So you will just monitor 1,2,3,4 and then that means consistently for one and a half meter of driving through you expected a very hard driving. So it is not that just 300 blows one segment you get point 3 meter and then after that it becomes little bit easy don't stop. Means there is a local behavior that means there could be small bolder or it could be a small or thin layer of sand offering such resistance does not mean that the pile has achieved its refusal.

So that is where you are looking at point 3 meter for 300 blows with five consecutive so you will just need to just look at the records. You don't actually need to even you know seriously look at so many numbers because while driving itself the operators will know whether they have reaches such type of layers basically the flow of the pile downwards.

The next criteria is 800 blows for point 3 meter for example first one if you look at is , is actually consecutive you are not mixing up but whereas if you look at the past 800 blows or or past point 3 meter penetration what has happened? You know even if 1.5 meter has not penetrated but within this local range itself if you look at the blow is exceeding 300 but below 800 so you can look at such criteria also for continuous driving.

And for setup case for example this is both of them is applied for driving continuously but in case where you restart for example if we decide to stop the pile at that time after achieving 50 meter something has happened you want to change hammer because you had first segment is only that much so I want to put a second segment so if you happened to calculate or decide your lengths based on some idea but happened to be at this place you restart.

Two things have happened the soil above 50 meter already have setup because you have given a gap and also the soil at that restart location is so hard so when you restart you definitely expect a slightly increased resistance and that is a time you apply slightly different criteria so you reduce your 0.3 to 0.15 with 800 blows. So this is normally not used for continuous driving.

Setup case we even allows slightly increased number of blows for point 3 meter that means is half of the penetration so that is the idea of API. So when you exceed this at any time you suppose to stop that means few things would have gone wrong. Hammer selection incorrect, soil understanding is incorrect, or you know basically the estimated blows during your driveability analysis is incorrectly model.

So you must stop and investigate and then progress further if it is prematurely stopped. For example according to your calculation you wanted to go 90 meter as your penetration.

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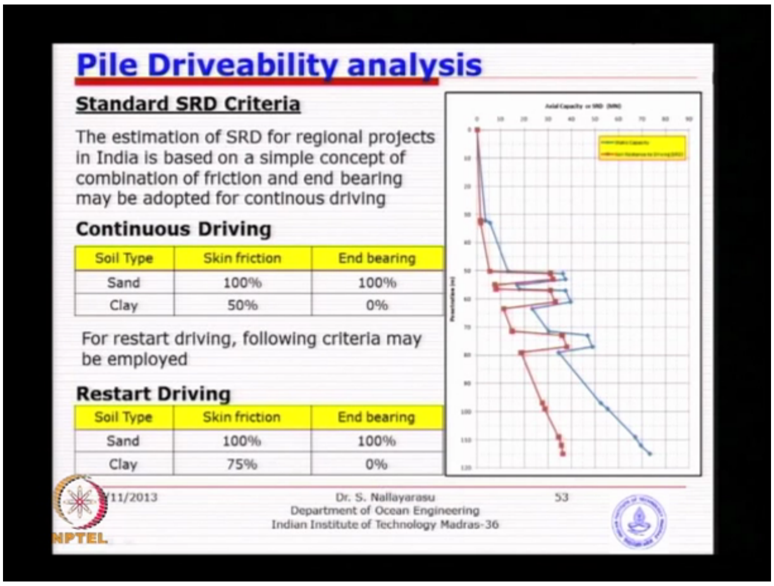

But when you reach 75 meters the blow count exceeds 800 for 0.3meter you stop. Now you could come to a conclusion that pile has achieved greater resistance than what I thought because I am unable to drive.

During driveability analysis I have predicted that for full capacity the blow count is less than 800 but during raw actual driving is unable to go through blow counts are increasing. You could actually say that but it maybe not true because you have selected a smaller hammer. Smaller hammer will definitely come with larger blow count but does not mean that the pile has achieved or pile has got sufficient capacity.

Because you're theoretical calculation require 90 meter penetration to achieve full capacity according to your design. Now when you stop at this place you see here what has happened if you just draw a vertical line down here at that point it so happened to be a very big bulb of sand layer got good capacity, you stop there but then whether the pile has stopped because of a sand layer here or because of incorrect selection of hammer you will not know.

Unless you analyze the data and that is it maybe happening at this point but still blow counts are higher. So that is why we have to find out what is the cause of the, many cases what happens is premature refusal means they are not worried about the pile driving itself we are now worried about the what capacity has achieved by the pile whether we can install or whether the jacket and structures could serve the purpose for which it is designed.

Because if you have suspicion on full capacity the jacket may not be put to used, you may actually abandoned, so if you are not able to drive either you should try to drive by making assessment or bringing a bigger hammer or other methods of making sure that the pile reaches its final penetration because we have no other tool to assure that the pile has achieved full capacity. So premature refusal means is a big worry and concern.

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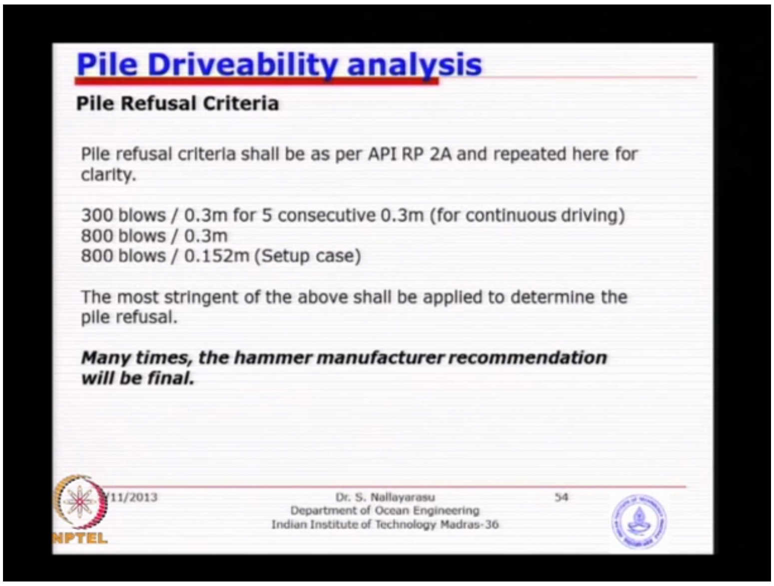

Because we cannot validate the refusal means capacity is achieved such relationship is not at all directly feasible offcourse in the recent days there are several methods of calculating back the capacity based on blow counts. Because now you see here you go back to the methodology what we have described this so called wave equation analysis. What we are giving as a input to the program?

We are giving as a input to the program as a pile information, soil information and hammer information and we try to calculate the number of blows required for each time you drive. Now what if you supply the number of blows soil information but then I can calculate back the soil resistance during driving and then I multiply by a factor of the long term capacity factor described by some of this people from a short term driving capacity to a long term capacity.

So this we called it pile monitoring which I think we will talk about it little later. How do we get the pile capacity from driving records so the forward calculation is driveability analysis backward calculation is pile monitoring and pile capacity evaluation from driving records. Sometimes quite useful sometimes is little bit tricky because the calculation of this multiplication factor from short term to long term see originally we were calculating from long term to short term now from short term to long term.

This factors play a major role because again it depends on the type of soil type of you know the granular structure of the material which is again subjective. So talking about pile monitoring and pile back calculation is not going to be a 100 % automatic because you are not doing pile testing. If it is a pile testing is 100 % sure that the test capacity is same as the capacity of the soil.

Whereas this one is just only a half way between you are using some installation information but also you are using some (())(26:19)so pile refusal criteria has to be employed in every project but offcourse hammer manufacturers input also required sometime they actually multiply with their own factors higher or lower but will be in the order of magnitude of similar kind.

See one such program which I was talking about the wave equation is employed is, is GRL this each GRL is each one I think globe ross and another person's name three name they setup this company and of the only program available in the industry which does exactly like what we were talking about the time scheme the by finite difference method as well as all the methods employed by whatever I have presented in the class is very similar as this originated from one of the university professor and then taken by this industry group.

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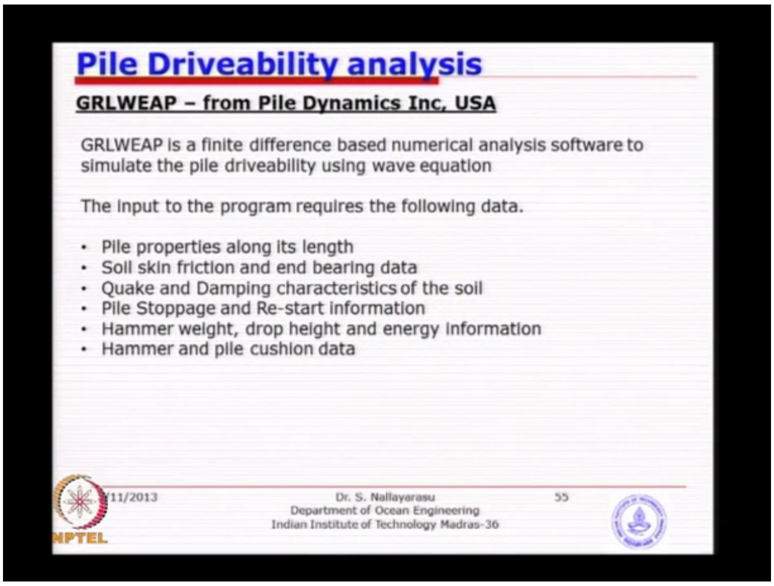

Now this is one of the biggest group all over the world providing services for driveability. So what you require as a input is the pile property for sure you need to have the length pile property along the length soil skin friction and N bearing data and the dynamic characteristics which is quake and damping, pile stopping ,restart timing you know you should know where you’re when you’re stopping, you have to decide.

When is the best time to stop so that I don’t get the increase resistance so you will decide that Pile stoppage and restart information hammer and associated weight and its drop height which will give you the energy requirement. Then hammer and pile cushion protection if you actually planned to provide which will actually absorb some amount of energy and reduce the stresses on the pile. So this are some of the information normally you require for any analysis to be carried out using this.

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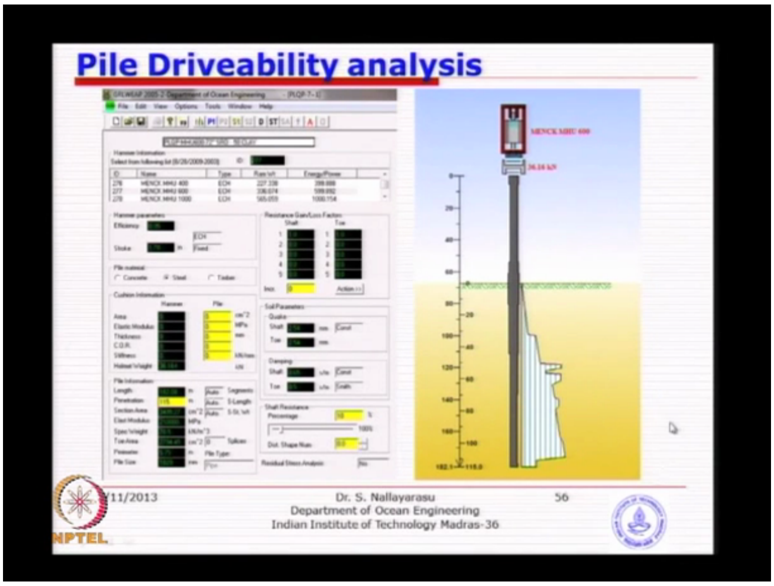

The program will be looking something like this. We will see one of the days whether we can do some exercise but I think you may practice during your recess time. So basically you can see here is a very simple computer program the program shows what you have modeled here.

You see on the right hand side this is the pile and that is the hammer that is the water depth and you can see here the hatch given on the side is the resistance offered by the soil very similar to your pile capacity curve what you normally have understood. So the increased resistance and local packets of increased resistance of soil by sand and then go like this. So basically that is that gives you along the depth of penetration from the seabed all the way down to that pile termination. So all this can be simulated so once you put every information right what you will get.

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Pile Driveability analysis

SOIL RESISTANCE TO DRIVING (SRD)

Diameter 1.829 m
Wall Thickness 0.05 m
Perimeter 5.75 m
Area 2.63 m^2

Soil Type	Depth	Layer Thickness	Skin Friction: Unit Skin Friction - Graph	Skin Friction: Limiting value	Skin Friction: GRL Input	End Bearing: Unit End Bearing-Graph	End Bearing: Limiting Value	End Bearing: End Bearing	End Bearing: GRL Input	Quake: Skin	Quake: Toe	Damping: Skin	Damping: Toe
	m	m	kPa	kPa		kPa	kPa	kN		mm	mm	sec/m	sec/m
CLAY	0.00		0.00		0.00	0.00		0.0	0.0	2.54	2.54	0.656	0.033
CLAY	32.20	32.20	30.00		22.50	250.00		656.8	0.0	2.54	2.54	0.656	0.033
CLAY	33.00	0.80	66.00		49.50	900.00		2364.6	0.0	2.54	2.54	0.656	0.033
CLAY	50.20	17.20	89.00		66.75	900.00		2364.6	0.0	2.54	2.54	0.656	0.033
SAND	51.00	0.80	96.00	95.70	96.00	9600.00	**9600.00**	25222.5	25222.5	2.54	2.54	0.164	0.492
SAND	53.00	2.00	96.00	95.70	96.00	9600.00	**9600.00**	25222.5	25222.5	2.54	2.54	0.164	0.492
CLAY	55.00	2.00	116.00		87.00	1300.00		3415.5	0.0	2.54	2.54	0.656	0.033
CLAY	56.50	1.50	118.00		88.50	1300.00		3415.5	0.0	2.54	2.54	0.656	0.033
SAND	57.00	0.50	93.00	92.80	93.00	8640.00	**8640.00**	22700.3	22700.3	2.54	2.54	0.164	0.492
SAND	61.00	4.00	93.00	92.80	93.00	8640.00	**8640.00**	22700.3	22700.3	2.54	2.54	0.164	0.492
CLAY	63.50	2.50	146.00		109.50	1800.00		4729.2	0.0	2.54	2.54	0.656	0.033
CLAY	71.50	8.00	158.00		118.50	1800.00		4729.2	0.0	2.54	2.54	0.656	0.033
SAND	73.00	1.50	89.00	89.90	89.00	7680.00	**7680.00**	20178.0	20178.0	2.54	2.54	0.164	0.492
SAND	77.00	4.00	89.00	89.90	89.00	7680.00	**7680.00**	20178.0	20178.0	2.54	2.54	0.164	0.492
CLAY	79.00	2.00	164.00		123.00	1650.00		4335.1	0.0	2.54	2.54	0.656	0.033
CLAY	97.00	18.00	184.00		138.00	1650.00		4335.1	0.0	2.54	2.54	0.656	0.033
CLAY	99.00	2.00	198.00		148.50	1900.00		4992.0	0.0	2.54	2.54	0.656	0.033
CLAY	109.00	10.00	209.00		156.75	1900.00		4992.0	0.0	2.54	2.54	0.656	0.033
CLAY	112.00	3.00	70.00		52.50	1900.00		4992.0	0.0	2.54	2.54	0.656	0.033
CLAY	115.00	3.00	70.00		52.50	2900.00		7619.3	0.0	2.54	2.54	0.656	0.033

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This is the calculation for the input into this program so what this program is expecting is thickness of the layers the layer locations and skin friction values which you could calculate using alpha or beta method you know because pile diameter is input so the program will calculate what is the total resistance.

As well as the N bearing and the dynamic and this quack characteristic everything needs to be input in line by line for each of the layer change from clay sand and whatever.

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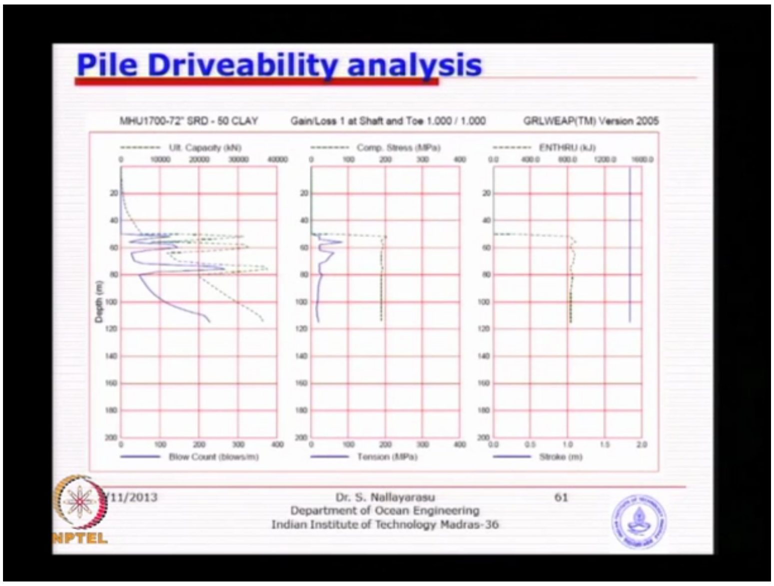

So what you will normally see from the computer output is something like this. You can see here on the first picture is the capacity versus depth which is regenerated from your input values of the depth of pile and the skin friction values and the N bearing values so you can see here in the blue color is the blow count and the dotted green color is the capacity. So you can see here there are three short location of increased resistance because some maybe sand layer which you can see from your n layer here and thick sand layer here about. So basically you can see here in this regenerated capacity or resistance to driving and also see the blue color which is the blow count.

You should read this axis for blow count and that axis for capacity. So you have to be little bit careful there. And then you can see here whenever you just try to overcome the resistance of a sand layer you have the number of blows increasing from, so initially you have only less than maybe 20, 20 blow counts or 50 blow counts then suddenly blow counts increasing and you can see here blow count almost reached 250 to just overcome the resistance offered by this third sand layer.

And after that the blow counts have come down and then again increasing so at the end of reaching almost 110 meter penetration the blow count is almost 300 somewhere around. So this blow count is per meter of penetration you have to little bit cautious you have to convert to 0.3 meter instead. So that is the information that you arrive you obtain from this type of program continuous driving and then also stresses induced during the driving you can see this tension stress this is the compressive stress.

So can see here this tensile stress is because of reflection the partial energy coming out but mostly you will see that compressive stress will be substantially you can see because of the impact force 200 mega Pascal is the type of stress that you get for that particular hammer so the hammer is 1700 kilo newton meter is the type of hammer placed there. So this is the idea of this program what you want to get is this information so now from here you can decide whether the pile is able to go through to the final penetration or not.

The last picture what you see here is the is the energy transfer and the stroke so you can see here the stroke is around one meter the energy is about. So this hammer you though if you are using 1700 hammer we don't want to use at the full stroke because if I go to full stroke it maybe over stressed or not required because my blow counts are within limits so they are operating at only 60 % energy.

So you can see 800 kilo Joule or kilo newton meter that means this information is also very-very useful because you can actually without changing the hammer you can change the rate of energy transfer by just simply adjusting the stroke level that means you will reduce the energy going to the hammer itself which is possible by simple means.

So that is something that if you see a very high stress you can suddenly reduce the, you have a bigger hammer but then I will operate at a lower efficiency so that the blow count can be reasonable and the stresses are also within limits.