Foundation for Offshore Structures
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Module 1
Lecture 16
Pile Installation 1

So what we are going to see today is slightly different topic pile installation. So far what we have done is the basics and also the pile penetration calculation for minimum required for vertical load as well as the horizontal load. So both of them we have just learned about doing some theoretical calculation based on soil strength parameters and application of (())(0:34). Now what we will look at this what happens before that, before that we are trying to install the pile unlike shallow depth piles where the stresses induced during installation will be smaller.

In case of this offshore jacket structure you have length of the pile is longer, diameter is bigger and the resistance offered by the soil because of the deeper penetration is going to be larger. Primary reason is we do not distribute the loads to many piles in offshore system we have a focused four corners, you have four piles, eight piles but also deeper in length and the capacity I think the order of magnitude what we were last time I think was discussing about few hundred tons in onshore versus few thousand ton in offshore.

I think the first class I was explaining about it, 300 tons in onshore structures most of the piles will be in that kind of order. The capacity transferred from super structure to substructure, whereas in offshore structures you will see that each pile carry (1000) 2000 tons. So its order of magnitude is almost tenfold. So when you have so much of resistance to be offered by the soil for capacity you also going to face the same problem during driving itself because the more the capacity is that required for final condition that much of resistance have to be overcome during driving the pile into the soil.

So that is where you are going to have a serious problem, we need to look at what happens to the pile when you are driving the pile to a depth of 100 meters over to overcome a resistance of say 20 mega newton whether the pile will get stressed beyond their acceptable limits. Second thing is whether you can actually drive the pile or not, because you are just going to hammer it is not that you are going to drill a hole and then put the pile, you are going to

hammer it by mechanical devices so whether the mechanical device that you have selected has sufficient energy or the effort or the capacity to drive.

So we need to look at some theoretical basis because after going to the site you cannot decide I will bring another machine tomorrow there is no such feasibility available for offshore systems it is not like approachable places. So you have to predetermine what will be the size of machine required or the hammer required then you take it to the offshore and you should be able to 99 percent or 100 percent should be able to drive if there is a failure rate it will be very small.

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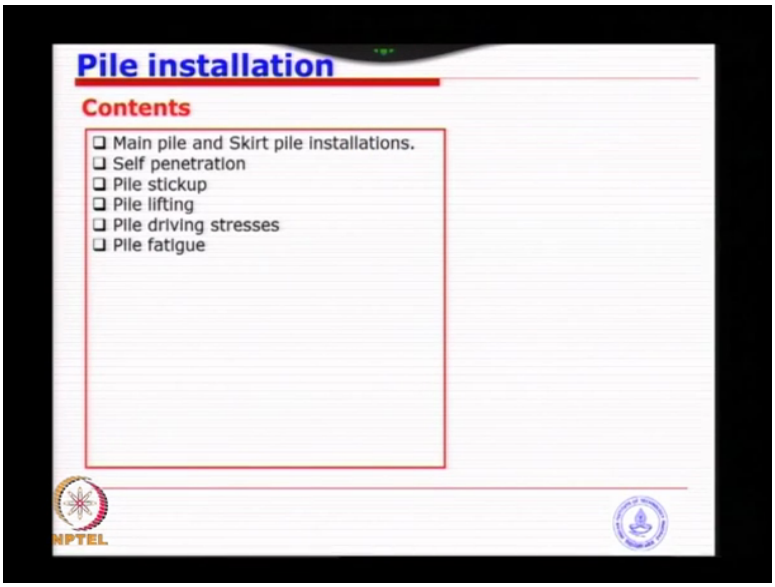

So that is the planning we are going to just look at various aspects of pile installation and associated issues. So the first one let us understanding how the piles are installed for both main pile and skirt pile and then we will look at various other aspects like when you place a pile into a jacket slot like if it is a main pile you will insert through the main leg hope I think all of you have some idea we have already discussed in the introduction time when you insert the pile the pile will go down on its own weight because it has got certain weight such passes through the initial soil layers which is very soft like first 10 meters, 15 meters, 20 meters or in some cases as big as 30 meters very soft clay will be there.

So once you place the pile just like this because of its own weight it is just going to go down that is called a the penetration by its weight self-penetration and then after that sequences of you know driving you take a hammer and place it on top when you just hammer it. If the pile sticking up above seabed is too long is going to be having a buckling problem because its

length is very long, diameter is too small in fact that problem will be there even before because when you are lifting up from the barge you are going to take the pile and make it vertical or that time itself you will be having a slenderness problem you might have studied in your mechanics and design course.

The larger the length it is going to be slender the allowable stress will be smaller once the allowable stress is smaller you are going to have a design issues. So we need to see whether we should make 100 meter single piece or we want to divide the pile into say 20 meters each 5 pieces then it is comfortable to take one by one and put it on top but then it involves field welding you have 5 pieces take first piece then put it inside, bring the second piece and put it on top and do the welding each time when you do welding it takes several hours.

So that means you are having extended time duration at the offshore. So you have to desire whether I want to break the pile into 4 pieces or 5 pieces which will save half day, so that is there this this installation things play a major role and then also stresses during driving you need to calculate so that piles are not damaged during driving itself. So these aspects are as important as what we did earlier for calculation of length and diameter and all that.

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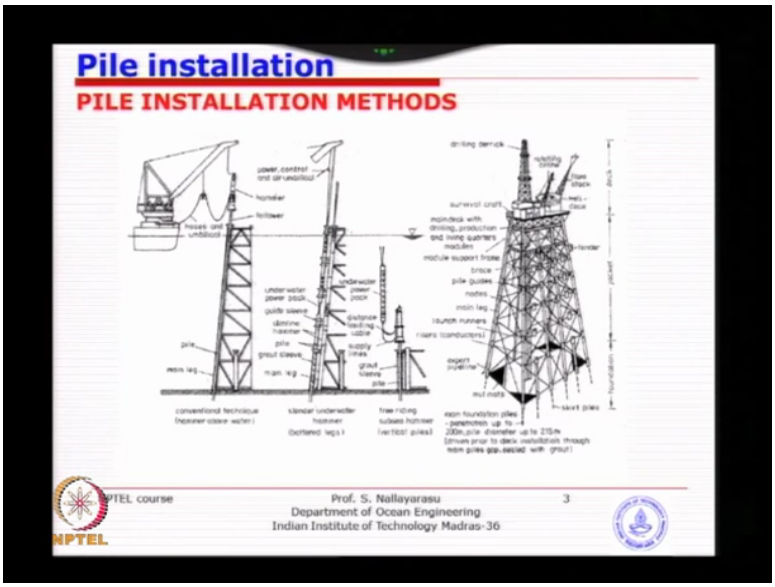

So typically if you see this picture if it is a main pile, pile is put through the annulus of the or the hallow portion of the leg and just inserted inside you have already predetermined what should be the gap available between the pile and the leg. So typically we give about 1 and a half inch I think we discussed about this the larger the gap is better but larger is not too good also for design purposes we discussed about low transfer.

So typically 1 and a half inches sometimes 2 inches very rarely will be given so that we insert the pile it goes through into the seabed and then the self-penetration happens due to its own weight it goes down and if it is longer than the expected self-penetration plus the (width) length of the jacket. So you need to predetermine the length of the pile for the first one which we call it initial segment should be longer than the jacket length plus self-penetration otherwise what will happen once the pile goes inside the jacket it is invisible. So nobody is going to go inside and then take the pile backwards.

So you need to calculate the pile length in such a way that you estimate the penetration into the soil x meters, you know the length of the jacket is y meters plus you need to see the pile little bit longer say 5 meters, 10 meters and this is what normally happens you do this estimate you find out the strength of the soil here, you have been given a bore well report I think now by this time you already have an idea what is the strength and undrained shear strength is available or angle of internal friction using that values and using the weight of pile you can find out when the pile will stop because you know how to calculate the bearing capacity for tubular pile section.

Now if we use the conventional bearing capacity method you always try to underestimate the capacity because you want to be cautious is it not normally you take the strength you only take the minimum strength you do not take the higher strength for capacity calculation. So if you do that what happens in your calculation you are under predicting the length of penetration because of its weight but in reality when you go to field you put the pile your prediction was 5 meter but actually it goes by 15 meters the pile will disappear and is basically you have a bigger problem to retrieve the pile which is very very difficult.

So that is why for such type of problem you need to over predict your self-penetration that means you will have a upper bound solution you will have a lower bound solution, you can use a stronger soil find out what is the penetration which will be minimum you can also assume the soil is weaker same material but you can have a two sides of the story then you determine what should be the height required because either way if you actually assume too much of penetration or the softer soil and if it so happen that it does not happen in the field and too much of length will be sticking out and you cannot put your hammer there because the pile will fail.

So you have a difficult problem to solve that is why we need to find out each of this category we need to find out upper bound side, lower bound side and make a decision calculated risk

take certain height and make the length of the pile because once you bring the length of the pile you cannot modify (())(9:18) you cannot go and cut because each time you cut it takes a lot of time.

So the main pile the first segment is most troublesome some to find out what is the minimum length and it depends on the water depth if the water depth is 100 meters for example the jacket length will become 120 meter. So the length of the pile is going to be minimum 130 meters, so now you can think whether we need to go for a main pile for such places the answer will be no because you have 100 meters of pile going inside the leg which is almost a waste instead if you go for a skirt pile you can save all of them. So that is why the deeper water depth nobody goes for main pile.

So this main pile installation once you have one of the pile inserted and driven to that level almost 2 meter or so slightly above the jacket level then you bring you remove the hammer their hammer will be taken back to the barge, bring the second pile section put it on top of it and do the welding. Now imagine how it can be done so you should just think about how anybody can go into (())(10:30) and who will hold the pile and how the welding will be done.

So we need a specialized devices to hold the two piles together we have device called a bear cage which will be at two hydraulic system one will be attached to the top pile, another one will be attached to the bottom section with hydraulic systems together which also will have a gap in which you can do the welding, so that alignment of the piles can be maintained at the same time somebody can weld it after that loosen the hydraulic jacks the hydraulic jacks can be taken off.

So such devices are required you cannot just hold it on by crane the crane will be moving back and forth. So that is why normally main piles are not really preferred because it involves a lot of offshore work you need to do preparation of that every time the activities are something like this remove the hammer, put the bear cage, put the pile section do the welding, remove the bear cage and put back the hammer.

So each activity will takes 2, 3 hours so may be a day will be wasted. After that once you put the hammer backwards and drive it once the top of the pile comes to this point again remove the hammer repeat the procedure until all sections are added and finally you achieved the final penetration to the target level what you calculated by capacity requirement. So main pile installation is slightly tedious but one thing you should notice all the time the machines are

above water, so what you have seen just now nothing is done under water, everything is above water visible.

So you do not need to go down under water conditions that is a great advantage because diving is not involved, whereas if you go to the last one you can see here the hammer has gone under water. In this case we have a vertical skirt pile and we got a single section no welding is involved straight away you insert into the sleeve and the hammer goes when you started here and you just drive drive and goes under water also the hammer goes below.

So you can see the equipment requirement for this and this is completely different. So you can see here this machine can be a simple diesel engine which is very simple so it the engine can just pick up the weight and drop whereas here diesel engine will not work because it is under water condition so we may have to look for hydraulic system where it will do exactly same job but hydraulic machinery.

So as long as you do not have a hydraulic system you cannot think of going for a skirt pile of this kind. So what we do is skirt pile of this similar kind but on the side I think we have seen these three pictures earlier on when we look at three different scenarios. Here the hammer will still be above but then what happens the portion between this and this will be a removal piece which we insert it for only driving then remove it later on.

So all these pile installation schemes we will just look at one by one in detail. So there are three cases one is main pile, this is vertical skirt pile, inclined skirt pile.

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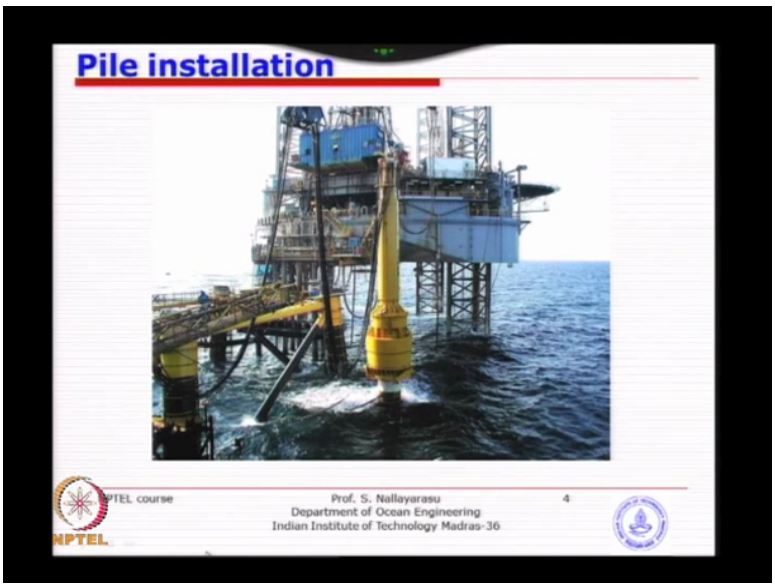

This is basically one of the project where vertical skirt pile was installed. So you can see here the jacket is very far from the pile itself because when you look at the jacket batter 1 in 8 or 1 in 7 the skirt pile will be located reasonably away from the top of the jacket somewhere here. So you can see here (())(14:13) almost 10 meter, so that is why you cannot provide support for the vertical skirt pile, the hammer will be supported on top of the pile itself.

So imagine when we were doing a driving if it is 100 meter sticking out initial stage put a hammer of 100 tons and you have sea state, wave conditions and the current. The pile is going to isolate like a cantilever. So the stresses due to wave, current and the deflected shape you put the hammer on top of it will cause the huge bending and that needs to be mostly governing the design. So the diameter has to be bigger and the thickness have to be larger.

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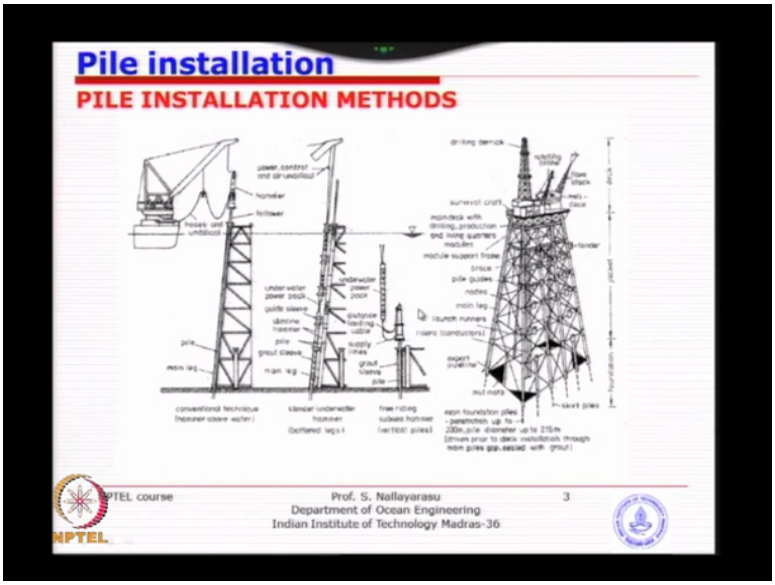

And that is what the challenges of installing such type of skirt pile and that is why when you install a vertical skirt pile you will require a minimum diameter of say 2 meters, 2 and a half meters. Whereas in these cases you do not have that problem because anyway you are going to cut the pile into several sections and start put one by one and drive.

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You can see this particular picture is a 4 legged jacket, what you see is 4 piles are just put on top of this jacket the reason is very simple. For example if I want to drive 4 piles, I take first pile 1 and drive, remove the hammer because every activity is involving crane, crane is the one that is taking the pile or taking the hammer. So every time when you want to change the hammer on pile it takes 3 to 6 hours.

So instead what these people have done just put the piles all of them on time and take the hammer and just go around drive. So instead of placing it under deck, so this is something that what has happened actually now the whole weight of the 4 piles needs to be supported on jacket. Now what will happen see this is quite high almost you will see that one more depth of jacket or length of the jacket.

So unless the stability of the system is designed properly the whole jacket will fall down, in fact this one is only at this moment it is like this the next moment it will disappear into water because the design was not done properly. We have a video probably one of the days I will show you that at that instant of time after the 4th pile was placed it is still standing in few seconds later the just whole jacket together with pile just went down into water because the stability of the system because at this time no pile has been driven it is only just standing there.

So that is why the sequencing to economized driving time does not mean that you can place anywhere you have to calculate when you actually place the first pile centre of gravity is shifting towards one side, when you place the opposite pile centre of gravity goes back and

vice versa. So, all 4 piles when you place weight increases and centre of gravity is somewhere and you must make sure that the whole system is having vertical stability, horizontal stability and overturning stability. So you have to calculate which we will be doing at the later stage of the course where you will be looking at that.

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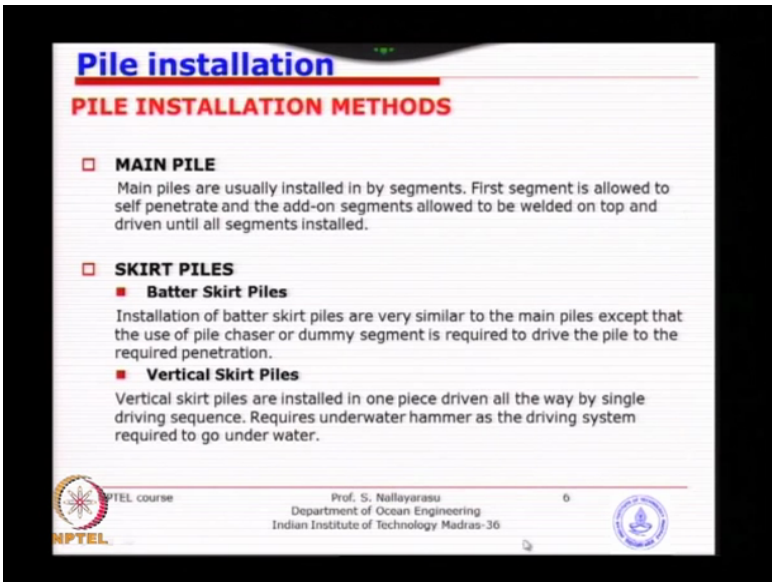

So main pile, skirt pile I think we have introduced earlier on in the design course I think but in any case main pile is installed through the main leg of the jacket by segmented construction first length will be slightly longer as I mentioned it should have been calculated based on the length of the jacket plus self-penetration plus amount of sticking up required for us to drive.

Skirt piles has batter skirt pile as well as vertical skirt pile, I think some pictures will be there we will see that pictures.

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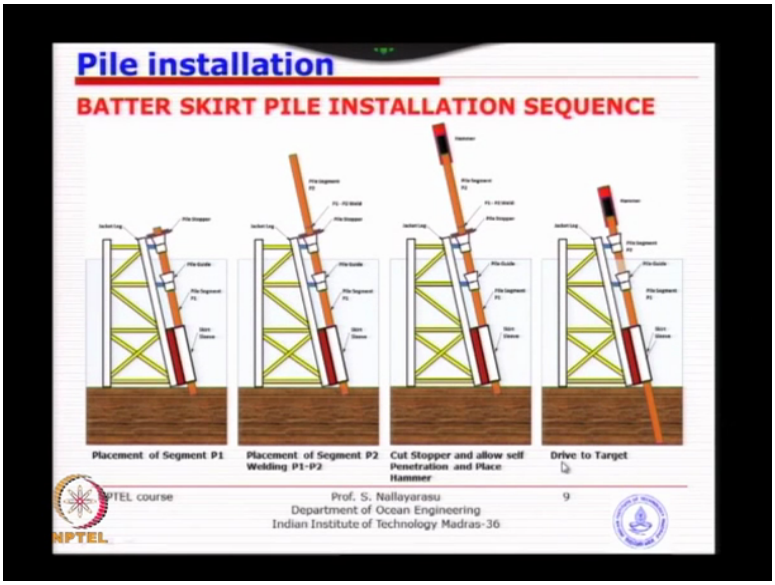

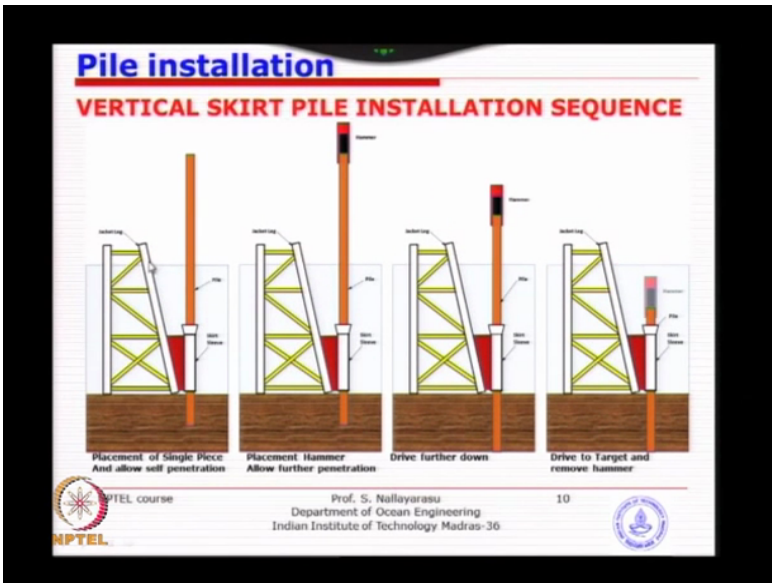

So main pile I do not think you need any explanation but the skirt pile you see here in this case the skirt height is limited to bottom so that you do not need to insert the pile all the way from bottom to top which is going to be a waste of material and driving time. So you see here the first segment is inserted into the this sleeve and the guides the one great advantage of this the pile is always laterally supported here and laterally supported here and also supported here.

So the length of unsupported section is limited so your slenderness ratio will be lower the design stresses will be lower. Whereas if you make this whole pile like this you make it one segment make the pile as a vertical skirt pile, what happens the length of unsupported section is very large number one, subjected to a large lateral forces coming from wave and current

and once it is deflected the picture does not show once it is deflected horizontally like this, then you place the hammer the eccentricity causing moment because of the weight of the hammer and that deflected shape of the pile could be very large.

So that will be the issue of vertical skirt pile versus inclined skirt pile many time people prefer this because this is under our control of supports, supports could be provided you could ask why we cannot provide support here.

That is what I showed in the first picture that the distance between the jacket and this could be 10 to 15 meter is as much as if you remember the other course where we were looking at the jacket batter the distance is very large 10 meters, 15 meters. So providing support will be additional construction time somewhere here and normally we do not recommend because that will be a more offshore work.

So that is why you see here the pictures will give you an idea how the piles are installed. So the first segment is driven for example if the length of the sticking up is say 10 meter you plan it that way, I want 10 meter above and bring the hammer drive 10 meter down as soon as you reach the top for example 2 meters above then you stop and then you bring the second section.

But when you actually plan this way should be designed in such a way that the length is just sufficient if it becomes too long for example one of the water depth is 60 meters, or 70 meters still go for main pile 70 plus self-penetration of 10 meter and sticking up 10 meter it becomes 90 meter 90 meter is a long section to be lifted up. So what normally people do is you see here something called pile stopper you weld a small piece of steel and when the pile is going inside still the pile will be stopped from going down any further.

Otherwise what happens if you do not have this pile will disappear because of its own weight and there is very little resistance from the top layer of the soil pile will go inside and that is the end of this project because you cannot retrieve the pile if it has gone inside is very hard anybody to go enter unless you have a hydraulic devices which can be lowered and then expanded and lifted up but many times very very hard.

So that is why pile disappearance is many times has happened in the past because of under prediction or over prediction of the lengths required. So normally we have a stopper here so that the pile does not go after that you bring in the second segment do the welding make sure that this length is having sufficiently with regards to stresses that means it should not be too

long and it should not be too short and after the welding is over you cut this basically pile will go down and you have sufficient length it will not disappear that means this pile will stop somewhere here. Then you bring in the hammer because of the placement of the hammer weight itself even before you start driving the pile will start going down because the weight of the hammer is in the order of 100 tons, 200 tons, 300 tons depending on the size of the hammer.

So once you place 100 ton weight at the top even before the hammer starts to drive because of the weight of the hammer itself pile will start going down very easily and once you reach closer for example if you have reached 1 meter, 2 meter you better do not drive, stop take the hammer out bring in another segment if it is stopping earlier on for example another 10 meter is there then it is safe enough to drive and initially you should drive with a lower energy requirement you do not know what will be the the strength of the soil initially.

So you should start driving slowly means the number of blow count is lower, energy is lower that means the height of fall is going to be smaller you plan in such a way that, once you drive that and then you bring it again you added another section put the hammer back. So this sequence should continue until you exhausted all the segments you already have reached the required penetration in to the ground then you can finish that pile then go to the next pile and next pile.

That is the normal sequence you do one, two, three opposite corner do the third one and the fourth one. But you saw that photography what I just now showed you instead of putting 1 they put 4 and that too its longer enough so that the hammer will come and it just drive one by one and just go away. If we have designed for such scenario we call it pile driving sequencing it is no harm in doing that because this particular sequence of so called series sequence one by one will take three days whereas the other one may take actually two days or one and a half days that means we can save a lot of time and money but all that require is design.

So the vertical skirt pile is very similar except that it is only a single piece you can see form here this is a penetration into the soil and the remainder is sticking up as soon as you pushes an immediately you will see this pile is assaulting laterally and then place the hammer, start driving and the hammer will go under water.

So this diesel hammer or steam hammers or mechanical devices cannot work what you need to have is hydraulic system that means the hydraulic umbilicals will go from from here to the barge itself because the barge only will have the hydraulic power pack which will contain pressurized oil, I think hope you understand what is hydraulic power pack if you go down to our laboratory every machine got hydraulic power pack every one of them is operated by hydraulic any under water conditions neither the diesel nor the electric engines will work because of the housing problem. So mostly you will use hydraulic pressurized system.

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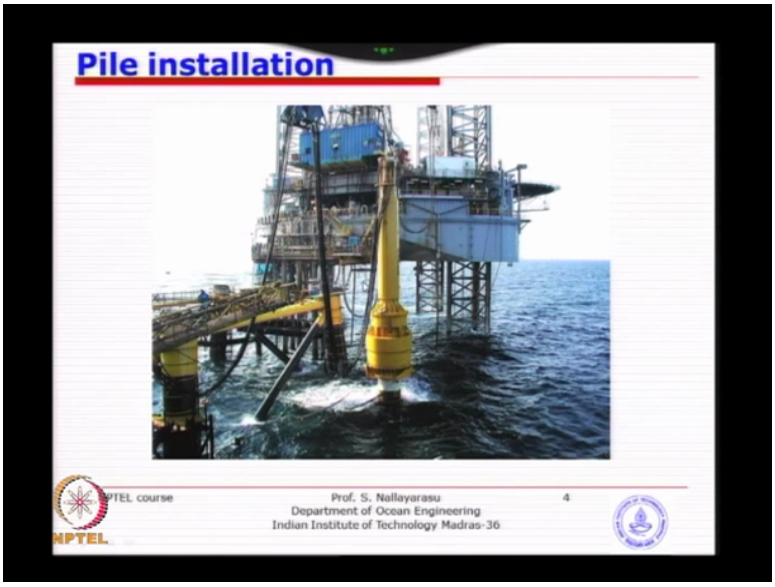

So you will have connection between this to the barge which is supporting the hammer itself which is what you will see if you go back to this you can see here several numbers of hoses going down to the barge, barge is actually at the background. So which will actually send the pressurized fluid which will make the annual hammer to lift it up and drop it, hammer is nothing but a heavyweight steel which needs to push up and down we have several types of hammers which we will see later part.

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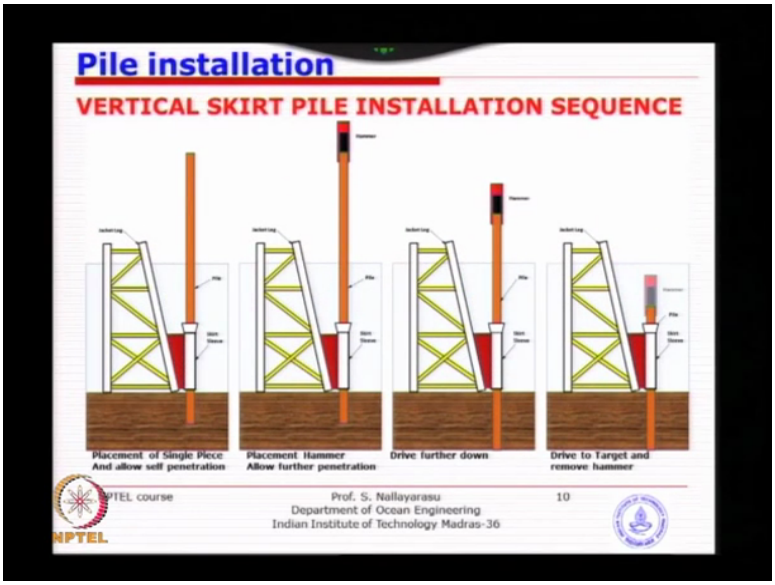

So basic idea is driving skirt pile vertical is faster but subsequently you need to make the design properly so that the pile is safer, imagine during the driving for example this pile you are driving pile got damaged here means either you find a localized bolder some rocks you have done a borehole at centre of the platform normally I think I have explained last time and you start driving the pile at the corner you have a localized rock big one and start driving and just hammer it you might be thinking some hard driving but actually the pile is starting to crumble because there is a very large bolder in in few cases it has happened like this the hammer foreman was just keep driving and was coming slightly lower penetration then normally he was thinking that it is just a hard driving.

So keep driving the pile was folding inwards because there was a rock there and ultimately after certain stage it has become a piece of metal at this particular point which no further driving was possible. Then later it was found that the pile has back to (())(27:56) they have sent some devices to look at that pile tip and it was just not feasible to try. So such condition arises there is no way that you can remedy the jacket has to be abandoned, the project is gone.

So that is why you have to see the criticality of borehole investigation making decisions to use a particular hammer and monitoring the driving time very important. After making all the effort to bring the jacket and if the pile has failed during driving you have just no remedy and that is the situation. So that is why pile driving becomes one of the most critical part of the whole project, in few cases it has actually become like that two of the piles just could not drive any further and premature refusal as well as buckling atleast premature refusal you can do some remedy but if the pile has actually buckled at the bottom and just you cannot do

anything because the cost of removing the pile and relocating the jacket will be higher than building a new jacket and building a new platform.

So that is what is the implication of incorrect design in pile design as well as the driving considerations.

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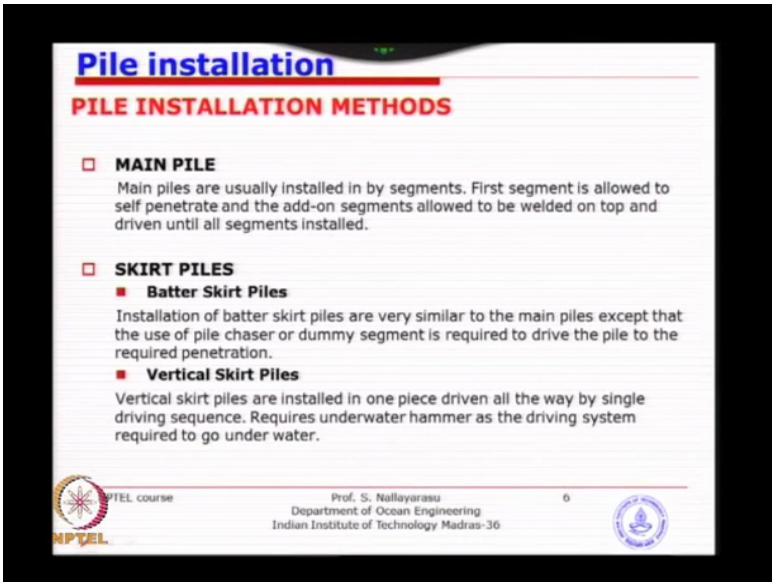

So let us go back to here so main pile, skirt pile I think by this time you have a clear understanding of how it is going to be installed vertical versus batter, the reason why we cannot provide support and provide support in the batter piles.

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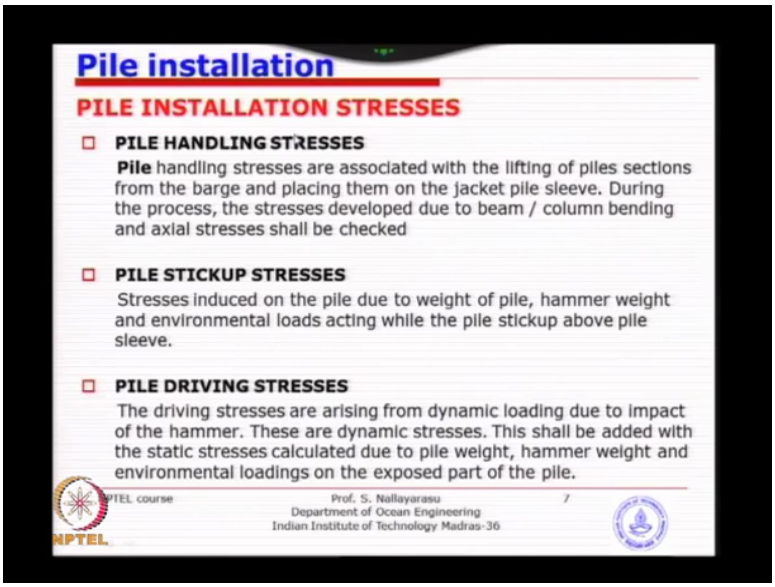

So what we are looking at is the pile handling stresses, now you can see the main pile will be smaller segment, skirt pile will be one big length imagine if I have to lift 100 meters of length of pile in one lift just take it like this, you can simply calculate the length to diameter ratio I think in the design course we have discussed about length to diameter ratio of tubular sections, order of magnitude if it is 100, 1 meter pile 100 meter long surely it does not work you do not even need to think about any calculation at all, 1 in 50, 2 meter diameter 100 meter long also very difficult.

So 1 in 10, 1 in 15, 1 in 20 so imagine 100 meter long you need to make a 4 meter diameter pile which will never be possible. So that is where you need to see where we are. So pile handling stresses is also important and it will govern the diameter and the length. So during lifting what is the stresses coming.

Pile stickup stresses which is what we were discussing just now whatever the force is sticking up and due to its own weight plus the hammer weight plus the environmental loading due to wave, current and to some extent wind because if the pile is sticking up you see this picture so much of length is sticking up and if it is a gust wind coming for sure it will get into horizontal loading due to wind which will cause stresses at that level because that is where it is going into the sleeve portion.

So pile stickup stresses, pile handling stresses of course they occur at different time because pile handling is the starting after that once you place the pile inside pile handling stresses disappears as long as they are within the elastic limit they are going to disappear. Then you have a pile stickup stresses which is going to occur when you place it and put the hammer but

once you start driving you are going to have stickup stresses as well as the stresses due to hammering.

So you may have to combine this and this depending on what is the amount of stickup stress at the time of driving every time step, so this we have to so how do we calculate the pile driving stresses we need to look at the load transfer from hammer. So you take one hammer I think you might be able to easily understand if you take a hand held hammer weight of some amount and the drop height of say x meters.

So energy transferred to the pile top is known because the energy is nothing but weight times the height of fall once you know the energy because this is being a impact loading you can convert that impact loading into a equal and static loading normally we take a dynamic factor of say two, two and a half, three depending on the type of material. So you can find out what is the force transmitted to the top of the pile at the instant of striking then it is going to travel through the steel material along the length of the pile some will be lost in the steel itself as the material of friction and then some will be lost at the interface between the pile and the soil because soil is going to absorb as a cushioning effect and that is what happens you know in railway tracks why you put lot of granular material it will absorb more energy during such kind of activities vibration.

So you can see here soil is going to definitely absorb depending on what type of soil whether it is a rock, for example take a nail and strike against a hard rock what will happen? The rock will not absorb any energy, to absorb energy what you require? You require settlement, you need to have the material get compressed, if you have a very hard rock what will happen the pile will jump upwards because there is no absorption there.

If it is a soft material and the material gets compressed then the energy is absorbed the remaining energy will reflect back. For example you have a sandy material you start driving what will happen is the amount of energy imparted into the pile system from the hammer will travel though the pile, some amount will be absorbed by the soil, the remainder will get reflected backwards and travel backwards to the pile top.

Now if that reflected energy is more what will happen? It will go and impact back into the hammer itself and that is why you see many times hammer fails because you keep hammering very fast before the energy is dissipated and that is why we have to set the the hammering time from one blow to next one as sufficient gap has to be given. So that the

energy is dissipated and then you start driving again not just greedy enough to drive quickly but you actually damage the hammer and then comeback.

So basically this driving stresses are due to the fall of the weight on top of the pile to transfer dynamic energy and then drive the pile downwards at that time it is not anymore a static stress of course you can do a simplified equal and static method like convert the energy into equal and static load of with a factor of two or three and calculate the stresses. But in reality the pile material transfer the dynamic impact force as a stress wave travels through the length of the pile which we are going to see the theoretical side of the pile driving later on.

But that stresses could be considerably larger than just take the weight of the hammer and divide it by the area you will get smaller stress because that impact will cause a larger amount of stress and the stress will not be uniform through the length of the pile it all depends on what is the type of material and stress they have travels downwards and then reflects backwards.

So at particular point you will see a compressive stress while the stress wave is travelling downwards while the stress wave is travelling backwards during reflection you will see the pile subjected to tensile stresses and that is why when you are actually taking a small nail driving against the hard wall what will happen? The nail will start coming backwards because it is unable to absorb the energy into the hard material. So this driving stresses are as important as the stickup stresses and must be handled carefully.

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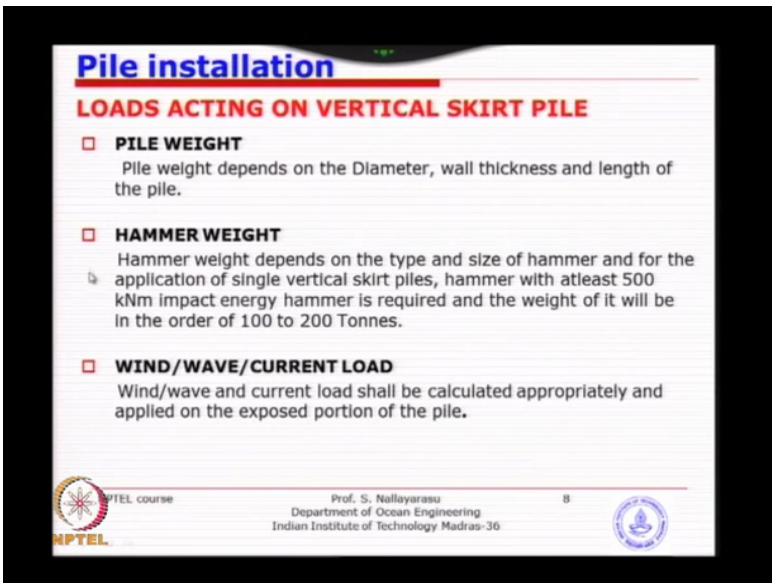

So what are the loads acting on the pile? Basically it is pile weight itself. For example if we have a vertical skirt pile nothing to worry because hopefully there is no external environmental conditions making the pile to tilt if the pile is vertical then its axial load of the pile, is not it. But if you have a inclined main pile or skirt pile so what happens is the weight of the pile is not anymore an axial load it actually makes it to have a bending movement at the point of support.

So you need to be very careful of finding out where is the centre of gravity of the portion of the pile sticking above and that much of bending moment will be applied on the support point. Hammer weight for sure not a small number to be ignored and if it is a small hammer anyway you cannot drive.

For example if you are driving onshore pile system may be you have a 10, 10 hammer, 20, 10 hammer smaller penetration, smaller diameter piles, whereas we have very large penetration and the diameters are very big you will have the hammer you could see. If you go back to this picture this diameter is almost 3 meter, so you can see the size itself is very large, the length will be above 20 meter the hammer size from here all the way down to the (())(37:29) level from here it is almost 20 meter.

So you could see that the weight could be comfortably larger and once you place the hammer it all depends on whether it is a vertical pile or a inclined pile. If it is a inclined pile and that weight is going to be creating large bending moment. And we have wave, wind and current loads depending on for a main pile you really have no worries because the pile has gone inside the leg itself.

So it is not at all subjected to any environmental conditions except sticking portion some wind load will be there, whereas for skirt piles either it is a main the inclined skirt pile or the vertical skirt pile you will have some amount of load from wave and current. But for the vertical skirt pile is more vulnerable because of the cantilever in nature no supports are provided.