Foundation for Offshore Structures
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Module 1
Lecture 18
Pile Driveability Analysis 1

So let look at the Driveability consideration for the hollow section piles, predominantly we will be looking at tubular hollow sections for Offshore Structures. So Driveability means there are three things, you know basically the ability of the hammer to drive the pile to the target penetration without damaging neither the hammer nor the pile that is what the idea behind. So we need to size the hammer to be selected from outside market what hammer we should supposed to buy or hire so that when we go offshore we are able to achieve the target of driving the pile and not damaging the.

In many cases what happen you under predict and you go offshore, you are unable to drive the pile or pile is stopped half way through the requirement you know you have already learned about designing piles for certain penetration so that you get a capacity. So the platform is having sufficient margin of safety as per the course. Now if you are unable to achieve that particular penetration as per your design what happens is platform cannot be used because that was the minimum requirement and there is no way that you are going to re-establish that the pile capacity is sufficient because I got a refusal earlier that means the soil is better, but it does not mean exactly that because soil can be better or the hammer capacity could be lower than what you expected or the soil characteristic at the time of driving your understanding is incorrect that means you are over predicted or under predicted their capacities at the time of driving.

So that is when this analysis becomes very critical because it might actually make the whole project unusable you take a hammer you go offshore and you are unable to drive and there is no remedy because the next time that you want to come and drive you will be too late because everything is time bound. If the platform cannot be installed in this particular month in that year you cannot install because the next month will be not permitted because of the sea state will be worse than the particular period.

And if it is next year is a year delay which will have a serious impact on the contractor as well as the production because the oil could not be produced in that year one year later it may be that particular field becomes almost no use, it might become too expensive. They have lost so much of money because they have invested so much of money to produce oil now but you are telling them you only produce next year so that whole process becomes problematic.

So that is why pile Driveability become one of the contractual issue that your prediction becomes very very important.

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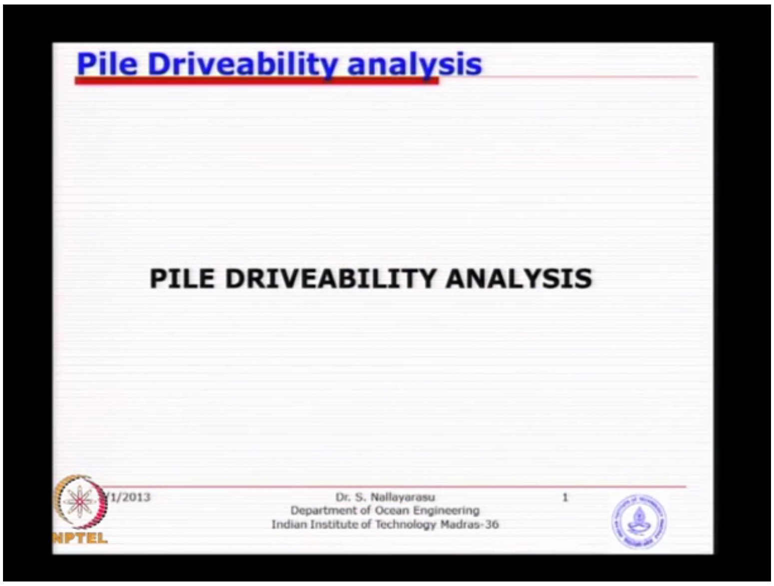

So this contains several parts of course you need to have a good understanding of soil, good understanding of the pile and the overall system behaviour. So we are just going to look at one by one over the next may be 5, 6 classes basic understanding of the system, hammer, pile as well as the soil behaviour at the time of driving and somehow we have to simulate it numerically in a computer program so that you can predict the effort required to drive, ultimately what we require is what is the effort required so that you can estimate the effort in terms of a you know like impact energy then you can select a suitable hammer and take it offshore.

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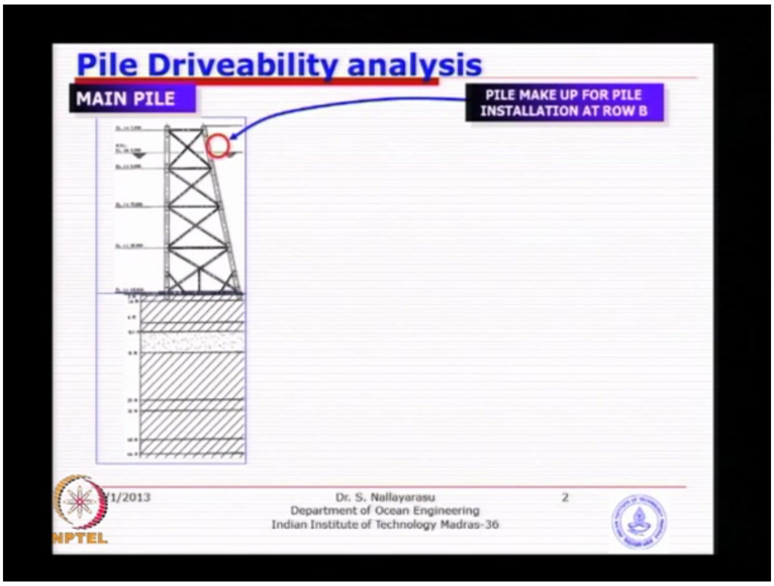

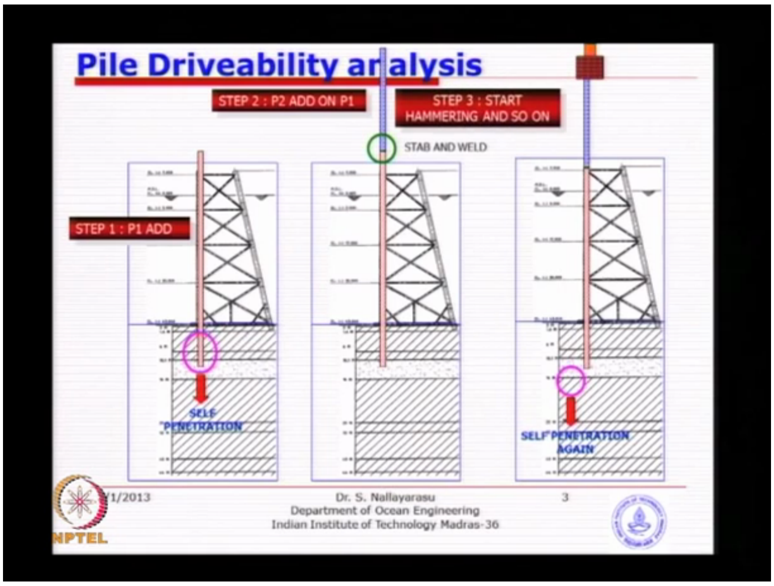

A typical driving system I think which I have shown you some pictures yesterday. So basically the main pile will be of first one is to insert a segment into the leg which is what we were discussing yesterday, some portion of it must be sticking up so that you can place the second segment and that means at this time it must have been stable because the capacity coming from the soil and the pile weight is equal after cutting the stopper, I think the stopper is the most important parameter here, if there is no stopper and if the soil is having weaker it might actually disappear or in some cases if you are very (())(4:22) that I do not need a stopper because I know very well the soil at the top is very very strong, may be not a clay sandy material then you can go just without stopper. So the pile is placed, pile is not going anywhere but that assessment has to be done carefully.

So now the main question is how do we select the first segment, you know if it is very deep for example the soft clay is extended very long, if you are not able to handle. For example for first 30 meter there is a very soft clay and when you insert the pile the pile is not stopping it is keep on going. So if the water depth is 100 meters and the pile required 30 meters to reach a good soil so 130 meter when you take a 130 meter it is not feasible, so you may actually divide into two 65, 65.

So the first one when you insert you will have a stopper and then you take the second 65 meter weld it and then release the stopper and then it will go. So there is a lot of manipulation is to be done that is what you need to understand that second thing where do you want the pile to stop is a very important criteria. For example you stop at a place where it is a sand typically.

Now if that is a sand you take 6 to 8 hours to go and weld another piece of pile, when you restart driving or start driving first time you may encounter a larger resistance to overcome. Once you overcome the initial resistance then it becomes dynamic friction, then automatically driving. So the restart driving very very important that where you want the pile to stop either at the starting time or at the intermediate time so needs to be very careful.

So the length of the pile needs to be adjusted in such a way that it does not stop at a layer that you do not want, predominantly we do not want to stop at a sand layer because restart driving will become really troublesome. So basically the pile driving is a sequence of activities, it can take any direction depending on what you have decided. So the stabbing and welding, so how it is done you can imagine it is about 30 meter high, this the second piece what we have brought in, how do we hold it together.

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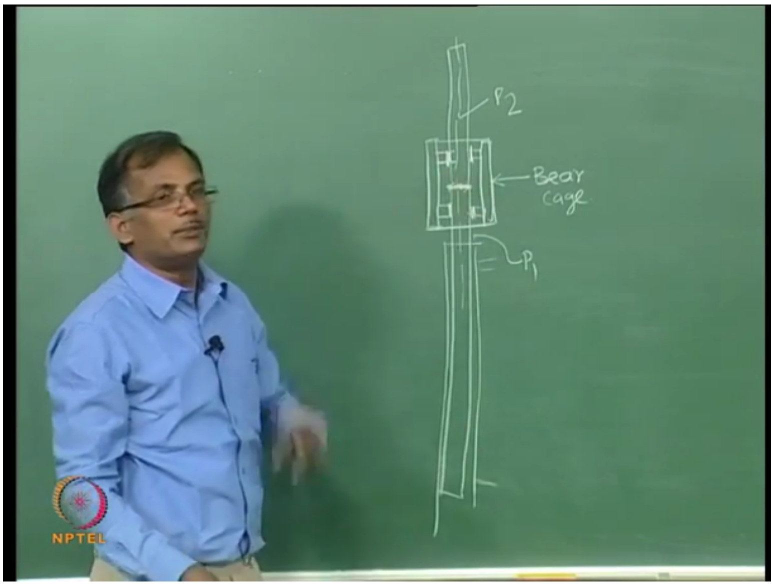

So normally what we do is we use a terminology called bear cage. So you have a pile like this and that is your jacket, leg and then you place this pile you will have hydraulic jacks attached to, so this is completely a system, this is a interface, this is called bearing cage it will look like a cage, actually it will be a circular system with 4 cylinders at least and there will be gripping here.

So this P2 segment and the P1 segments are held together in an alignment we want because we want a vertical alignment it will maintain, somebody will go and do this welding once the welding is done this machine can be taken off into two pieces basically it will be bolted connection. Once you establish that connection and it is stable then you can go around do the welding of two tubulars together and remove that connection every time when you have to do it you can see how much time it will take, you have to take such a machine assemble it inside, outside the pile and then make a hydraulic activation so that they are held together and then start welding. So it takes about 3 to 4 hours or even more than that.

So then you start driving this the next segment once you reach this pile becomes in this place because it is reaching downwards then you go back to the procedure what you are doing, remove the hammer, bring back another segment, bring back your bearing cage and start welding, remove the gauge, put the hammer back, start driving so that you have to repeat.

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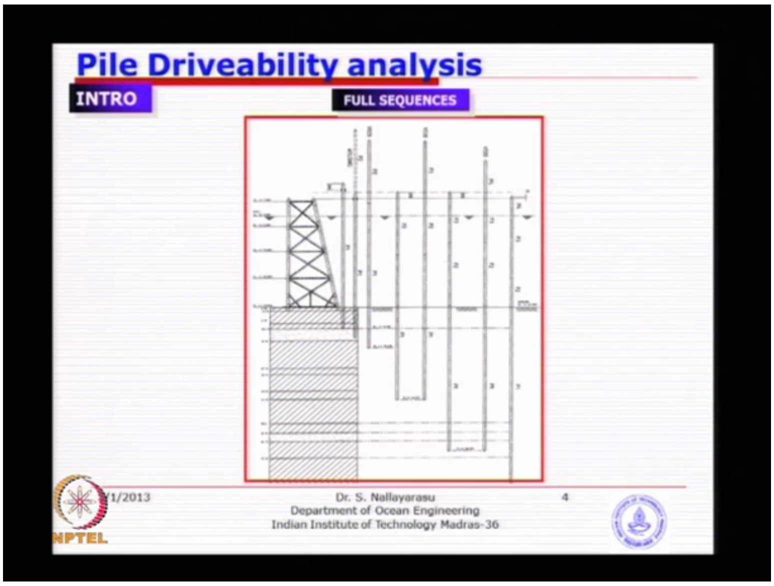

And that is what we were seeing in the yesterday sketch what I was showing in different form that the sequence of driving needs to be understood what you want to do and how much time it takes.

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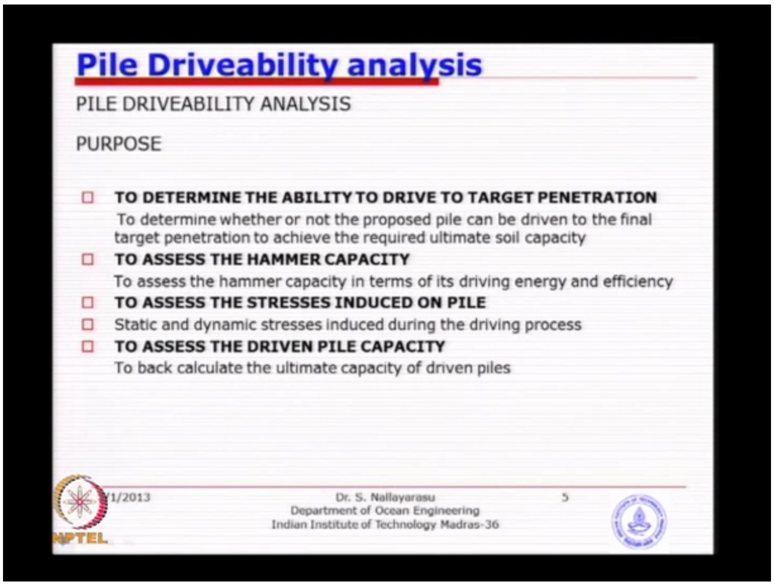

So now the purpose of Driveability I think is several fold which I have already explained, the ability to drive to target penetration. One of the important aspect I think in the first class I have explained the difference between offshore, onshore and coastal. In onshore and coastal areas our design is based on testing whereas as the offshore the design is based on engineering, I think that demarcation you should keep it in mind that there is no way of evaluation of pile capacity after installation, whereas in onshore and coastal areas we have amble opportunity and variety of methods.

You could actually install a pile, make a pile load test and make sure that you know what load capacity it can carry you might actually go around in several construction sites on bridges and highways in Chennai itself, you will see big pile load test is going on, you know they will have a dead weight put on the pile and wait for the load displacement behaviour to achieve load, unload activities will take several days and just you will see a relationship of displacement versus the load and you are actually testing the prototype pile with the prototype soil and there is nothing else you could do, all your engineering becomes of no use because you have tested the pile in reality.

So such things are possible in onshore definitely 100 percent, coastal may be yes, no depending on water depth sometimes we do sometimes we cannot do because if the water depth is becoming larger doing testing up coastal areas also becoming problem but definitely for offshore we will not be able to do testing because the reaction frame cannot be constructed, the main problem is reaction frame.

So that is why we have to rely highly on the theoretical capacity predicted by you based on the engineered properties of the soil and that is the end. So that means our design has to achieve that penetration that you have decided and the pile has to reach there at least that much and that is the only surety that we are concluding that the pile has got sufficient capacity.

So that is why we have to make sure that the system that we derived and we take it to offshore should have sufficient capacity and energy that the pile can be driven to the target. So to assist the hammer capacity means the effort required to be evaluated. Stresses induced on the pile during driving needs to be kept under control, so what can be done? Listen we have got ideas to divide the pile according to our so called flexibility and that means we can control the stresses to some extent, you know if we do not want 100 meters sticking up because the bending stresses are very very large, so I can divide into 5 segments, each 20 meter so the bending stresses can be reduced.

I also have control over what hammer I want to use it for driving I do not want to bring in a biggest hammer in the world and then place it there, is it not. So you can bring in a hammer suitable to drive your pile to the target penetration and that is what we want to evaluate. But with that itself if the pile is having over stress you can possibly change the diameter, or change the wall thickness, or change the material of the construction like steel you might use a mild steel you can go for a high strength steel or ultra-high strength steel, so that the tensile stress values are higher so you do not need to worry about failure.

So basically the assessment of stresses is for to make sure that you selected the pile is suitable. The last one is also very important since we could not do any more testing because of water depth, because of the capacity, because we may require thousand tons of capacity we cannot do a testing. For example most of the onshore systems you may have 100 tons, 200 ton capacity normally you might have seen in the pile load test, they construct a frame on top of the pile and place lot of sand backs I think if we go around, either a sand back or concrete blocks big big concrete blocks they will place it we call it dead weight load testing exactly simulate.

Now imagine if I have to get 1000 ton weight offshore to do a pile testing, it is going to be a big challenge, taking the material there bringing back, forget alone the reaction frame and all that. So that is why we may also require a methodology based on pile driving effort. For example you assist your required hammer for pile driving (())(13:58) energy impact energy, you go offshore, you drive and during the driving if the pile is going down very slowly.

For example instead of half a meter per say 200 blows, 300 blows it goes only by 2 inches, 3 inches that means your resistance of the soil is higher than what you expected something similar which we can characterize. The number of blows required achieve at certain penetration will give an indication that the soil is behaving or soil is actually better than or weaker than what you estimated using bore well material, you know you have taken a bore well you have done laboratory testing and you have got some understanding but actually when I go to site and then drive soil behaves slightly different, it could either be due to the hammer is insufficient, or hammer is bigger or it could be really the soil is better than early understanding, so several things can be there.

Now using the pile driving records we call it pile driving records means the displacement versus the effort that you have put in, you can come up with an idea that I can calculate back what capacity would have been there in the pile or what would have been the resistance at the time of driving can be calculated we call it the back calculated capacity. There are several methods devised in the literature which is quite useful.

So that is why when you are driving it is obviously better that you make a record of the number of times that you blow the hammer number one, how much it goes down by each time and also the stresses on the pile tip you can place transducers, you can either place displacement transducers or strain cages at the top to measure the stresses at least at the top of the pile because which includes the incoming stress from hammer as well as the reflected stress from soil.

So you can also measure that values then we device the idea to calculate the capacity backwards also possible, though we cannot do a real time testing, we could at least achieve some capacity calculation based on the site records. So that is one of the possibility that we will derive some equations to do that exercise because we cannot anyway do the pile testing, that is why this pile driveability analysis become a most critical part of the whole offshore project because this can turn the project in any direction.

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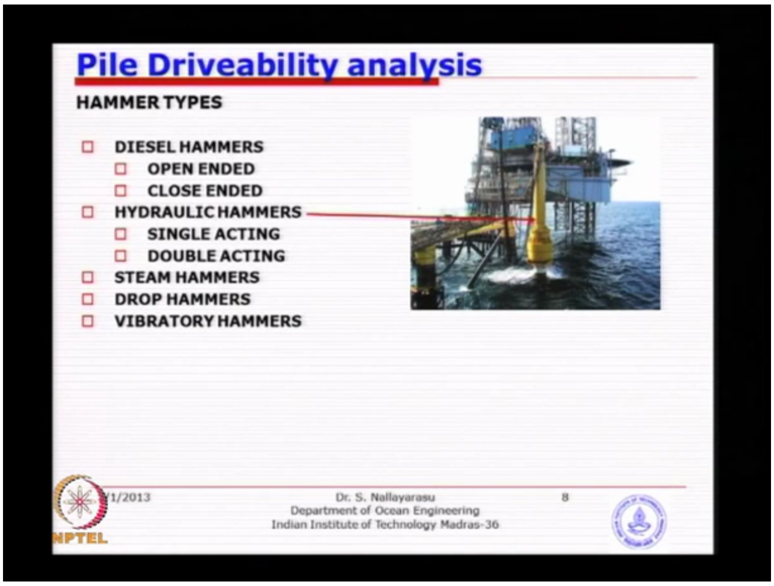

Now in olden days we use to have pile driving formulas I think if you have studied foundation engineering they might have thought you in classes soil mechanics or foundation classes, pile driving formula is nothing but a empirical formula derived from fundamental basics of input energy, energy absorbed you know. So you rely on these two principles how much energy is coming from external and how much energy is absorbed by the soil pile system and strike a balance and see whether you have excess energy and how much the pile is going down.

That use to be a I think even now most of the onshore projects people are using that only, nobody is doing such sophisticated pile driving analysis which is not definitely required because in onshore projects people are not worried too much, if the pile does not go does not matter, I can put another pile nearby or I can actually do many many alternatives. So that is why pile driving is not a very critical situation in coastal and (offshore) onshore projects and not due attention is given to such kind of things what we are discussing here because a lots of lots of alternatives.

So before going to pile driving formula actually I was looking at hammers which I think we will just quickly browse through various types of hammers which in fact I have already introduced to you one is diesel hammers, steam hammers and then the hydraulic hammers. Basic principle of working is similar except that the driving fluid is different. For example if you take a diesel is a typical diesel engine which has got (())(18:19) so that it can actually rotate which will translate into a linear motion.

The linear motion will up lift up and down your cylinder and the piston and basically the movement will drive energy by lifting a heavy weight which is we call it RAM and just lift it up and leave it down. So instead of diesel engine if you use hydraulic fluid to push this cylinder up and down basically pressurised fluid and which is hydraulic hammer instead you can actually use a steam normally nowadays nobody is using because the capacities are quite smaller, steam engines are almost not used in the industry, except in very very few isolated cases, not only in pile driving elsewhere, you know we use to have steam engines for even railways nowadays I think slowly becoming obsolete.

Drop hammers manual drop hammers in a simply (())(19:17) using chain and pulley block or either using mechanical devices or just allow it to freely drop by gravity you know simply and then there are sometimes we use vibratory hammers of smaller size because once you go for these kind of drop hammers you know the weight will be very large as I mentioned earlier in some cases if you are unable to place the hammer because of its weight bending stresses are going to be larger than you bring in a vibratory hammer put it on top and just vibrate and the pile might actually goes slowly down until such length that you can actually remove this and place the bigger hammer. So that is the idea behind vibratory hammer is basically to vibrate and see whether the pile goes down without much effort.

So these are various types I think most of the time for offshore applications we use hydraulic hammer for several reasons is easy to handle number one, compact in size and efficiency is very good comparing diesel engine or steam engine efficiency is very very high in fact sometimes it go to 0.95 as the efficiency and breakdown is very very less. For example if we take a diesel hammer several times it breaks down and one of the problem is the replacement become a problem.

For example onshore today one hammer breaks down we can bring in another hammer tomorrow, whereas offshore once breakdown the project is almost gone because the next time that we can bring the hammer will be next few weeks which will not be tolerable. So that is why even if it is main pile driving many times we use hydraulic hammers.

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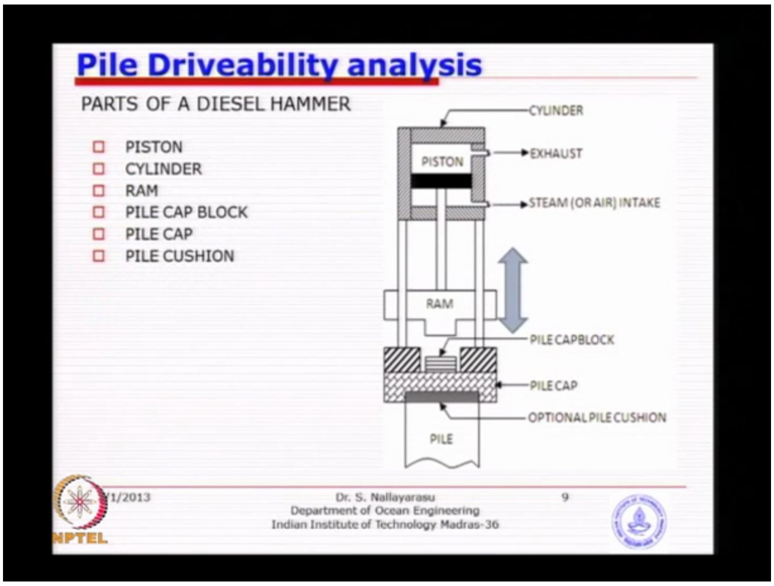

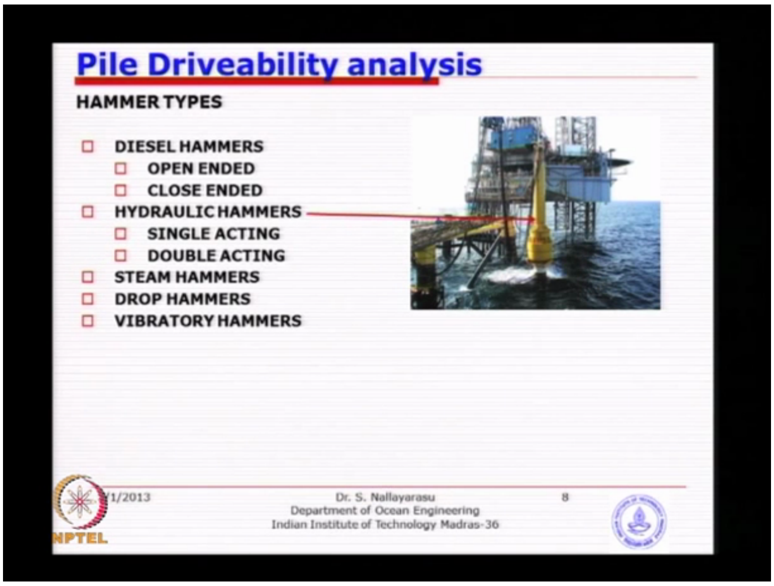

Typical hammer will be something like this various parts you could see there one piston, a RAM is attached to the bottom which is the weight which makes the fall times the weight becomes the energy you know so the heavier up the weight of the RAM the more energy imparted on to the pile and you have the housing and you have the exhaust and so this is typically a diesel type of hammer basically the (())(21:27) is happening inside the chamber there and just go up down.

You also see some of the components basically an interface between the RAM and the pile, we do not actually want to strike the pile directly because you may actually damage the edge of the pile wall because the next time you bring in another pile to be welded if substantial damage is done to the pile you may actually have to cut and resurface it edge preparation will take a lot of time of course still even otherwise if you damage the larger portion of the pile which is not very good and that is why we need to place a pile cap which is just nothing but a piece of metal which will be placed but it should be held in position so that it does not jump.

And you will have a cap block on which the RAM will strike, so that there is a potential direct contact of RAM with the pile is avoided, many times we use cushion you see here at this between the pile cap and the pile itself, you might see in many places. So the material that can observe reasonable amount of energy but not too much because if it absorb too much of energy then the transmitted energy to the pile will become too less. So normally we use wire meshes or soft wood as placed on top of this pile so that it does not damage the pile edges or pile wall thickness.

So you can see here is a very simple idea that we want this RAM to go up and come down either by gravity means or by double acting forced means. So that is why we call it single acting, double acting is nothing but go up, down up by the machine by the effort and release it by gravity is a single acting or you can just do like a engine from a car it goes both ways under the effort either way.

So that is the idea behind how a pile is being made to go down is striking from top and the energy is transmitted, some energy is lossed at the pile cap and pile cushion and the reminding energy is going to the pile and pile transmits the energy to the soil and that energy is absorbed by work done internally in the soil material by means of displacement, once you break the bound between the pile and the soil pile goes down. So that is basically some energy absorption and the remainder energy comes back if it is unable to absorb that means at the time of refusal you will see you strike no energy is getting transmitted, pile is not going down and the energy will go up reflected that is what we want to find out when it is happening and basically under what situation it will happen.

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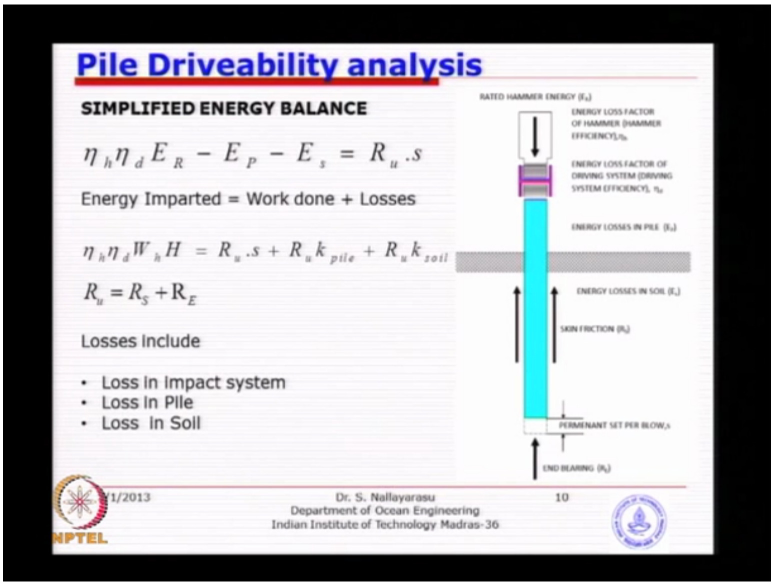

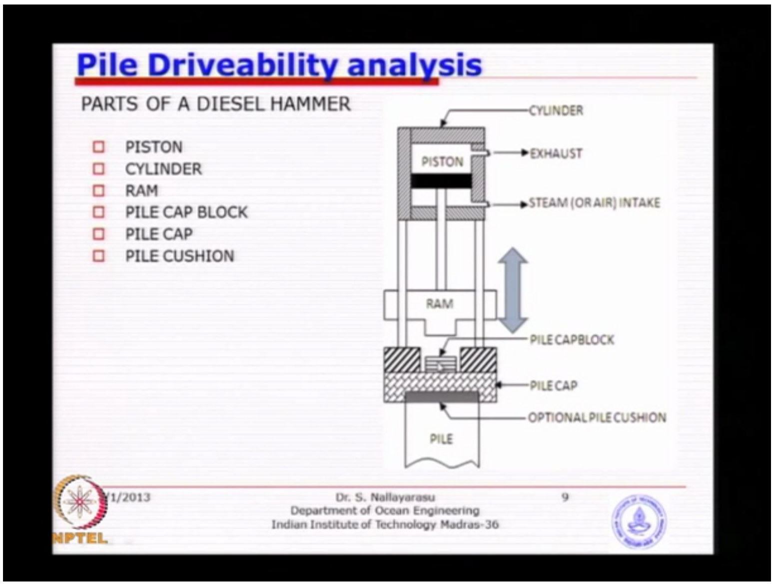

So the energy balance is something that we need to just understand the whole idea. So you see from this right hand side picture what you can see here is the pile and that is the hammer system, we have some kind of interface between the pile and the hammer and when we strike from the top at a particular energy of impact that means the weight times the height of fall will give you the energy.

And some energy is lossed in here some energy is also lossed in the pile itself because the pile will get compression it is not because you apply a axial load to a steel material for sure axial displacement will happen, strain will happen. So some energy but that will be very small because the pile is so large diameter and wall thickness and it will be too smaller compression will happen.

Then after that it goes to the soil and basically because of the soil failure or displacement pile goes done. So that led displacement will be permanent, you know basically it goes down means unless you pull the pile out it not going to come out. So that settlement sometime we call it set in earlier terminology, you can call is displacement which we are looking at permanent deformation of soil which is going to happen.

So if you look at this energy balance the amount of resistance coming from the soil times the displacement that has happened is the internal work done by the material there and the external energy imparted from the system is on the left side, every time when you strike after going down by few millimetres the pile and the soil has to come to a final equilibrium that will only happen on the external energy to internal work done is equal, otherwise suppose if the pushing is higher it will jump up is it not that means the resistance is too much so basically that will never happen because the pile will always be.

So what we have writing down here the eta h is the hammer efficiency, what is hammer efficiency? You have for example diesel hammer so much of let us the engine supposed to work in 100 percent efficiency supposed to produce this much of rate of energy if and if it is not able to operate because of losses within the machine normally for diesel engine not more than 60 percent, 70 percent will not allow that much is the efficiency of the diesel engine, whereas the hydraulic machine can actually go for as much as 95 percent but sometimes we use 90 percent.

So the hammer efficiency and the next one is the driving system efficiency which is nothing but hammer plus the pile head interface you have pile cushion, you have cap block and you have anvil sometime we call it anvil I do not know whether in this we call it sometime anvil you have a if you go to a black smithy shop you will have a anvil very similar you have a large metal piece placed on top of the cap so that when you strike that takes the immediate impact force but ultimately transmit the energy downwards.

So there is a loss of energy by 5 percent, by 10 percent in that system so we call it driving system loss or driving system efficiency so we can take it 0.9, 0.8 depending on the type of hammer. So multiplied by the energy or rated energy of original manufacturer what he has rated for (())(28:27) height and this weight theoretically you calculate the energy in terms of joules or in terms of kilo newton meter minus the energy loss in the pile itself because of compression and basically energy absorption in the soil should be equal to the work done internally which is the resistance given by the soil multiplied by how much of the set value which is nothing but your displacement.

This was actually the starting point of almost all empirical formulas developed by various literature in the past from 1940's people have been using this idea which we call it simplified pile driving formula or sometime we call it dynamic pile driving formula, engineering news formula I think basically a several formulas have been in the use I do not think we need to go much detail there because we will not be using that for offshore applications basically you will see equations of this kind this is where the energy imparted is work done plus losses. So that is the idea behind, you can rewrite this in many forms and that is where you will see that those many formulas.

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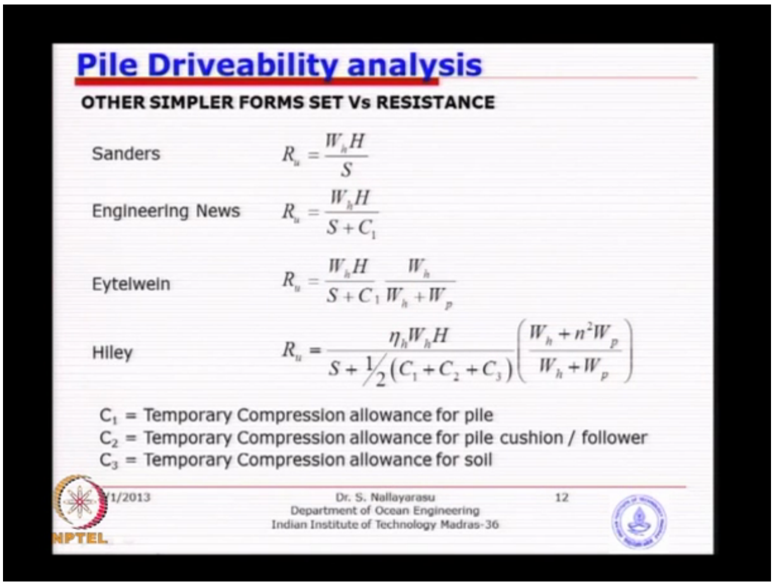

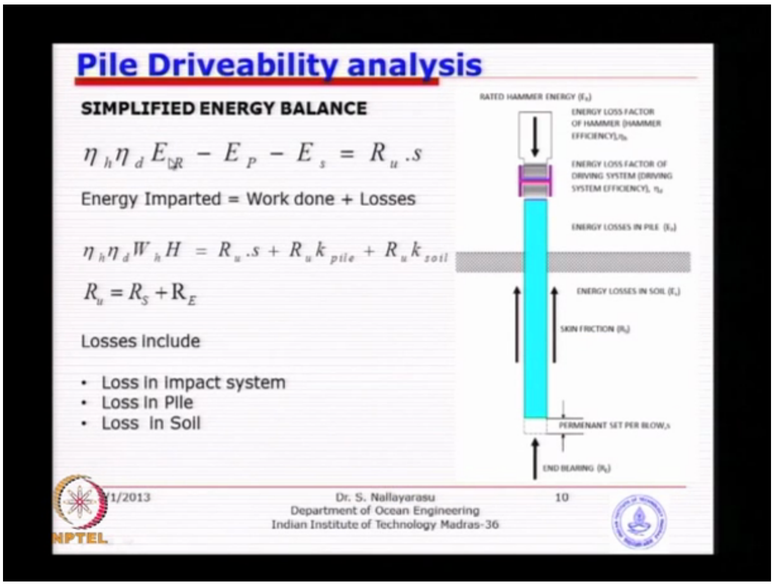

In fact I have summarized one of the formula I think oh in fact everything is summarized here various people who have actually proposed using this formula what we are trying to find out is what is the resistance that is going to be offered by the soil or vice versa, what will be the value of S when I should stop the piling, you know ultimately most of the piling in onshore we want to determine a criteria I keep on driving when the penetration becomes too small should I stop or I should still keep driving because the design is based on say X meters 20 meter design you drive but at the last 1 meter if the penetration is very slow every blow you are only getting say 1 mm that means the soil is almost reaching or the depth of penetration at that location the soil is very good.

So basically that is what we want calculate back because we know both of them and we know what is the capacity theoretically you have calculated from your calculations of bearing capacity for the pile. So you can determine you can just use this reverse you bring down here. So I will stop driving when the set value becomes say 1 inch, every time when I drive it blow set value is 1 is that means I have achieved the value of R u which I predicted using engineered calculations.

So that is the idea behind you know all these dynamic pile driving formula of course you will see various modifications a little bit of trying to adjust this parameters but basic fundamental idea behind is if you take R u times S in this side and W times H is this is the imparted energy with no loss, you know basically nothing is reduced and that is the internal work done and that if you go back here that is the idea behind if you do remove everything ultimately that formula proposed by (())(31:43) will come.

So dynamic pile driving formula is still quite useful in that sense you know you can easily understand you do not need to look at so many complicated systems. So when you come down to the second one you see here R u time S is well understood but R u times k pile what is k pile is a spring stiffness, is it not because steel material within elastic limit it behaves like a spring, one you remove the load what will happen it may comeback unless if it has gone beyond the elastic limit where permanent compression may happen.

So now you see if the stresses in the piles are beyond your yield so there will be certain elastic compression there will be some plastic compression which is not very good. So normally we limit the stresses less than the yield value. Similarly if you look at the last term R u times the k of soil which I think we have discussed about spring stiffness value of the soil linear, nonlinear.

So you can convert a nonlinear problem into a linear problem that is what we are going to do because if you have a nonlinear behaviour the driveability prediction becomes very very complicated. So what we are going to do is instead of nonlinear we are going to take a linear spring conservatively so that we have a linear system to solve so we can program this whole equation into a computer and then we can start doing every blow we can monitor how much it goes down, so that is the idea behind.

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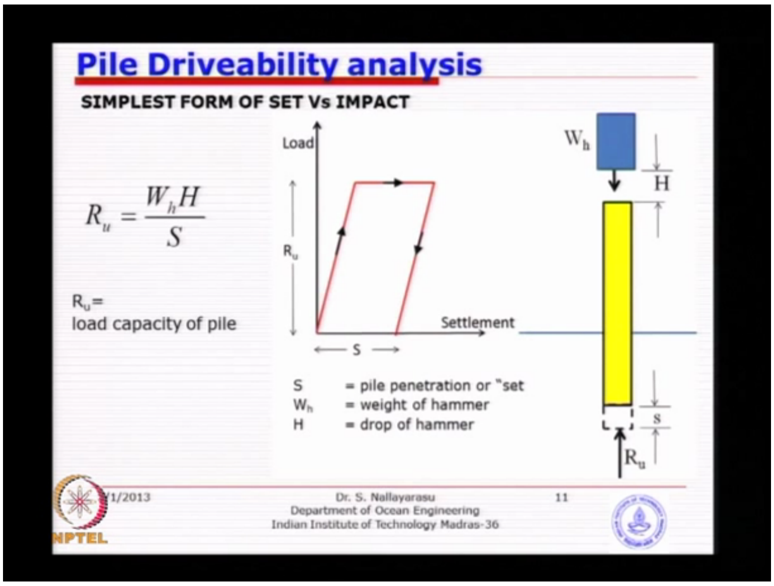

So if you look at this set versus impact in this picture you could see that idea of what sander was proposing set times R u is the internal work done, W times H is your the work done or the energy imparted from the external system and you see here when you are striking down it goes some amount and if the soil is deformed or if the soil is failed then you will have a plastic deformation once the load is removed for example the hammer goes up on after striking when the hammer goes up you will see that you will try to come back but not to the same 0 situation because plastic deformation of soil has happened.

So that is what the primary model that we are going to use, there will be a plastic deformation of the soil while you strike. If you really still want to work within the limit of elastic that means pile cannot be driven you have to break the bond between the soil and the pile as well as the bottom the soil has to get plastic deformation then only the pile will go down. If it is not feasible that means pile could not be driven or either the hammer is small or the soil is stronger.

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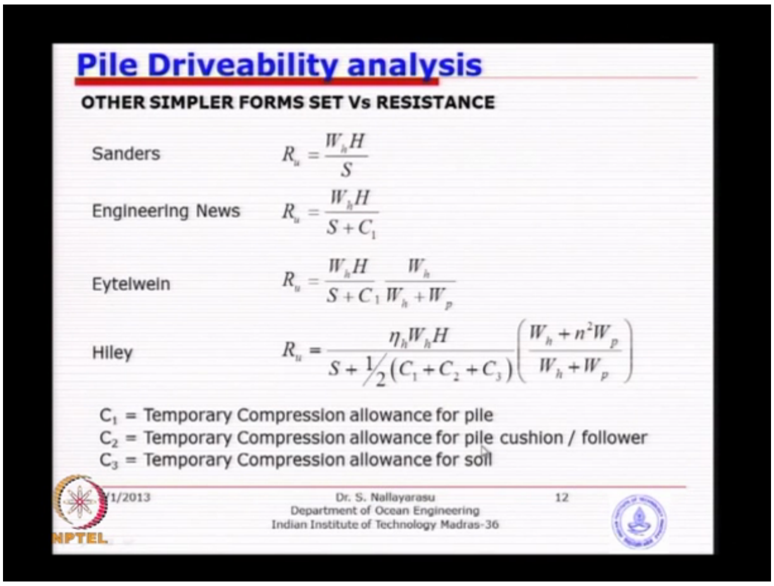

This dynamic formula first one is very similar to what we discussed, second one is you see here only one addition is given at the bottom, this S is the deformation or the set plus C 1 is the temporary compression of the pile which is elastic. As you know very well we do not want to allow the pile to go beyond elastic limit. So that means after you remove the hammer up that elastic deformation will come back.

So it is only a temporary compression of the pile which is also doing some work. So that is why they wanted to take into account. Similarly you see here the temporary compression of pile cushion which is placed at the top of the the pile also is considered into effect, all these things are too small if you actually look at the magnitude. Temporary compression allowance for soil in case where your hammer energy is so small that you are unable to break the soil bond it actually comes back. That means you are working within the elastic region of the soil spring.

So those things are added to this formula, the most famous one was actually engineering news formula mostly people use in earlier days like 70’s but there is actually a modified engineering news formula.

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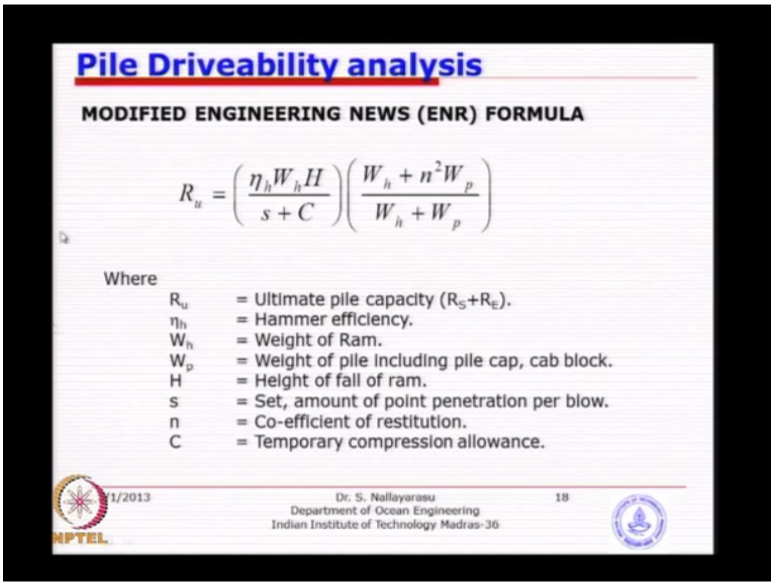

I think hopefully I have I do not whether I have it, so this is the original form was W h times H multiplied by hammer efficiency like what we are using nowadays and divided by set value and basically the compression value of the file and multiplied by so called the hammer weight ratio. So W h is your hammer weight n is the co-efficient of restitution of the material that we placed between the hammer and the pile. In this case normally we use timber or wire like steel wires has a higher percent of restitution absorbed and weight of pile. This is just to make sure that imagine you have a big pile but I bring in a smaller hammer. The sheer size and the inertia of the pile will not be allowing the hammer to strike down because the hammer is so small that it will not go.

So that is why this has been taken into account in the modified engineering news formula we call it ENR and many times people use this. So for a given size and weight of the pile you should have a reasonable hammer size. So that is why it is almost very close to if you do this calculations when you do a computerized wave calculation like what we are going to do the results are reasonable close.

So this engineering news formula became quite famous because of the parameters that it is considering taking into account the relative size of pile and the hammer and co-efficient of restitution of the material of interface between pile and hammer and then also efficiency of hammer and the parameter which is S. So how do we determine whether the pile can be driven or not using this formula is very simple when you design a residential building you know basically we say that pile foundation or shallow foundation we limit the displacement criteria.

For example 1 inch maximum vertical displacement is 1 inch. Now based on 1 inch when you reach the ultimate capacity because that is what we redesign any foundation system at ultimate capacity the maximum displacement should not be more than 1 inch. So if you have set the value of 1 inch as your acceptable criteria under maximum ultimate loading. So what you want to do is use your hammer properties just make sure you go back here put down your ultimate capacity what is the value of set that you are getting if it is less than 1 inch then the selected hammer is suitable.

Suppose if you select a hammer so big that the s values are larger than that is not going to be acceptable, so you have to bring down the hammer for a particular capacity you do not need such a big hammer because for same pile same soil different hammer will produce different results. So that is where this simplified formula became very useful because it only just you need only 5 minutes to do this calculation, whereas the one that we are going to learn it takes several days and several weeks to model and of course it has got its own advantages and disadvantages.