Foundation for Offshore Structures
Professor S. Nallayarasu
Department of Ocean Engineering
Indian Institute of Technology, Madras
Lecture-25
Pile Load Test I

Something relevant for onshore and coastal areas, where the possibility of load testing is feasible whereas, for offshore conditions full-scale load testing is not feasible because of several constraints in any case to understand what involves such load test will be very useful so that you can see what alternatives can be worked out for offshore conditions, but in the near shore around less than 20-25 meters we have done pile Load testing but quite cumbersome quite expensive and time-consuming. So the pile Load test if you look at the design of foundation, you know there has always been a debate because of the uncertainty associated with the soil parameters.

Always it is understood that design is verified by testing to full scale at the side of the final construction. If you look at many of the international course, obviously they state that in the engineering based design is not hundred% sure so if you go back to British course or European course including Indian course specially for pile foundation you will see that every pile needs to be tested to its capacity every pile. So if you have say in a in a construction site several hundred piles, testing every one of them becomes you know elaborate as well expensive, time-consuming, it puts the whole project in a different schedule of construction activities so you select critical piles or piles that may represent actual site conditions.

So among hundred number of piles may select say 2 piles or 3 piles which may represent actually the site conditions. So normally most of the modern-day projects we take about 3 to 5% of the piles that means if you have hundred piles you do the testing of 5 piles. So you select them in randomly to distribute all around the site in such a way that you can extract information from this pile testing so that you can represent them in the design process. But by doing that what you are actually going to do is you take this so-called test parameters and then that calculate and go back to the design revisit the design and adjust the design parameters to suit the tested pile information.

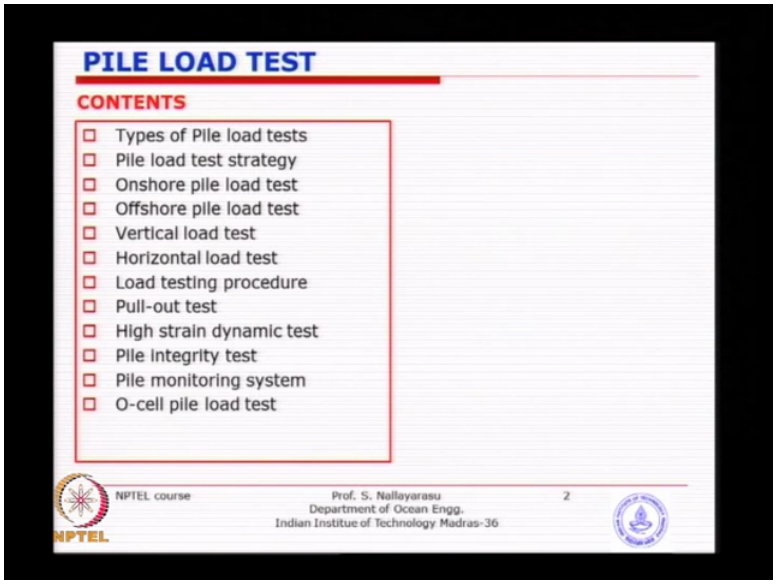
So if the tested pile is giving the design or the failure load is lower than the design load means your design parameters what you have used in your calculations are on a higher side or

vice versa. So you can go back and then adjust the parameters until that you get the design capacity versus failure load is almost close by, so this adjustment is even now many of the projects we try to do this so that in the future installation become almost reasonably correct. So that means this testing has to be done up front before the construction starts so that is the idea behind pile load testing that means you get a comfortable level of confidence which is very essential for foundation system because you cannot have an uncertainty on a foundation for structure which may actually pose a big threat.

So the pile Load test has been there for several decades for onshore and offshore projects of near coastal areas several kinds I would say. So since now you see the procedure how we want to start the project with low testing, we want to do the load tasting up front before the actual construction starts so you can say sacrificial testing that means once you do the testing of this piles, the piles will never be able to use it because you already have failed the pile to ultimate load load capacity. So that means you have a different category of testing or you can actually test the same pile which you want to use it as a part of the structure that means you cannot fail the pile but you can actually apply the loading until the load that it may get during its service.

You know so you you can see here now planning is required, what type of testing is planned for that particular site, whether you want to do a full-scale failure to load test or you want to a working load test, the test that may actually take you to the level of working load and stop then you actually construct the structural system on top of it. So this pile Load test is quite useful in a sense, so we will look at various test and the procedures available for us.

(Refer Slide Time: 4:49)



So we will be looking at both horizontal load test and vertical load test, you know we have specially the coastal areas and the berthing structures and offshore structures we have considered amount of horizontal load compared to onshore structures. And then we will look at some of the testing, some special testing by which you could actually get the similar information but then kind of empirical method, you do some testing and extract the information and prorate it to obtain the axial failure load which nowadays seems to be very economical and is quick specially the dynamic testing and some of these are commonly used.

So if you select 5% of the piles for testing using gravity method, the remaining 95% you know still uncertainty exist because if you look at a site your construction site say 1 kilometre by half kilo meter wide industrial construction and you select only 1, 2, 3 and 5, remaining 95% of the pile is distributed all along this site. Now you may conclude based on 5 piles that these remaining piles are safe we have adjusted the design, but what surety you have over the distribution of soil within a 1000 meter length, it may be very difficult decision.

So instead you go for the remainder of the pile with simplified method instead of going and putting a big weight and then measuring the displacement and strain, you do a simplified method of pro rating the capacity based on certain small scale testing which is what we used in dynamic testing and which is very useful in in many cases it proved to be... So if you do a full-scale testing and on the same pile you do a dynamic testing, compared capacity then you can actually get a very good feel how the dynamic testing is fairing with regards to the full-scale gravity testing and your design your theoretical design, you you have 3 numbers to compare and then you can come to a conclusion and then the remainder of the piles you go and do a...

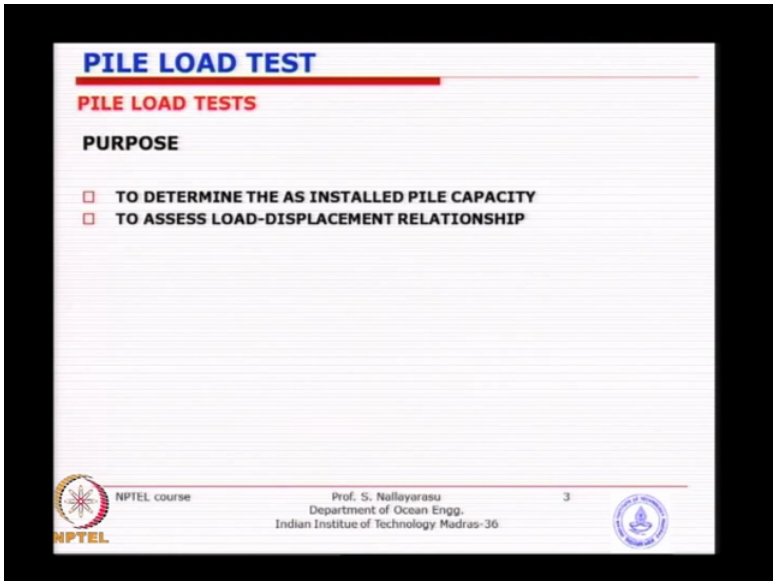
So you can see the correlation is very important from gravity testing to a dynamic testing to a engineering design then you go back and do the remainder of the pile you have only engineering design adjustment plus the dynamic testing. So this procedure is adopted in most of the large-scale projects but of course if you look at only some projects were only 5 piles, 10 piles are there and subject and dimensions of the structure is so small like 50 meter by 50 meter, the variability may not be that great so you can do only one pile test and you can leave it. And in the (())(7:34) application of such simplified methods for pile monitoring for offshore structures is very much useful like what we have learned about your medical scheme to calculate the number of blows required to drive a pile to a particular depth of penetration using a particular hammer.

You can back calculate and it is called pile monitoring system that means you will use the information during driving and then calculate what resistance it would have been offered by the soil during driving and then you just adjust it to long-term capacity using several parameters and then you can predict or at the end of driving you can say the pile would have achieved this much capacity. Now what you did avoiding here you are not going to place a big weight and try to do a measurement of displacement which is quite cumbersome especially when the pilot very large and the load is huge and that is why the pile monitoring system is one of the indirect means of getting pile capacity in offshore condition and that is what we are going to discuss at the last.

And in the recent times in the last 10 years or so another method of permanent implant of device into the pile system which is adapted for concrete piles at least. You know basically before you install the concrete pile, you would a load cell at the bottom of the you know the concrete pile itself and just cause the pile and afterwards you have a activation system, a wire will come to the ground so you can activate the hydraulics and you just push the pile against the soil resistance. And this can be done for ultimate test or it can be so this O-cell test is also employed in some of the onshore projects, bridge projects in US but very in this part of the world because it is quite expensive, you need to embark a complete load cell inside the pile itself permanently, you cannot extract them afterwards so it is just left over there.

So this O-cell is basically Osterberg cell name after the person the professor who found this method for one of the bridge project in US and it is in use for quite very useful and few projects we have used it for offshore or coastal, so we will go through each one area by little bit detail.

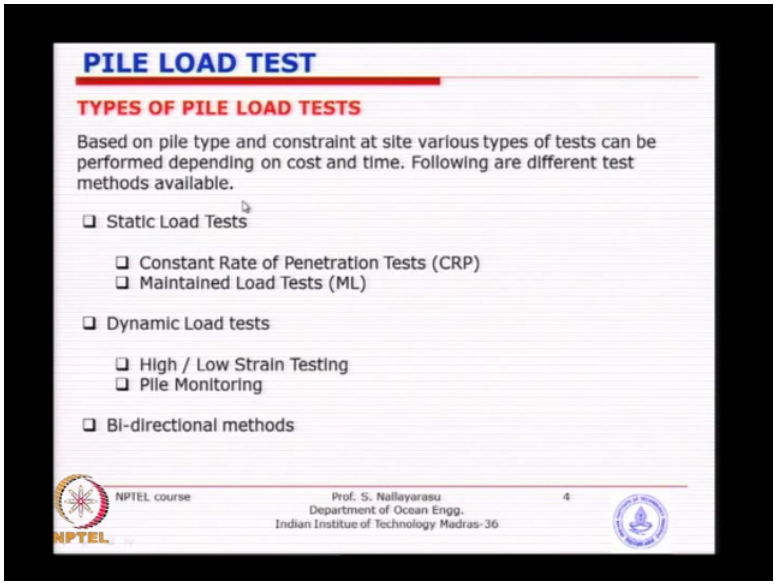
(Refer Slide Time: 10:05)



So the purpose of pile load test is to find out the install pile capacity and verify and remove the uncertainty of associated with the assessment that we have gone through during boring, taking Sample and then to laboratory test and then properties and unknown properties are calibrated using past you know information. So all those things will be removed once you have the actual capacity versus you know the displacement and to assess the load displacement basically, there is no critical information that easy to relate the capacity versus displacement. You might have already got the methodology to evaluate the capacity bearing capacity in terms of N-bearing and (())(10:49) only thing is we have assumed load displacement for you know PYTZ which may not actually hundred% represent.

A multilayer site, what you saw was basically a single soil layer giving a theoretical relationship between the capacity and the displacement, whereas when we have a multilayer soil the behaviour itself is going to be complex and the only way to get the load displacement relationship is to carry out complete load test which will be a prototype in nature, you are not doing a scale model like our laboratory. So the primary purpose is to link and assess the load displacement characteristics of a particular pile at a site.

(Refer Slide Time: 11:38)



So the test can be of in fact 3 categories, basically the one that normally carry out is the static load test, the load is static in nature and that the dynamic load test which is what we were talking about the quicker and the cheaper methods. Then we have the bidirectional method using O cell, you can actually do this way or the other way. In the static load test we have got variety of load application methods, one is the constant rate of penetration, imagine if you have the pile already installed and try to do the loading, the displacement is not under control so that means if you go by this method, whatever displacement comes you will actually note down, whereas if you actually control the displacement by changing the load according to the displacement characteristics, the rate of petition can be controlled.

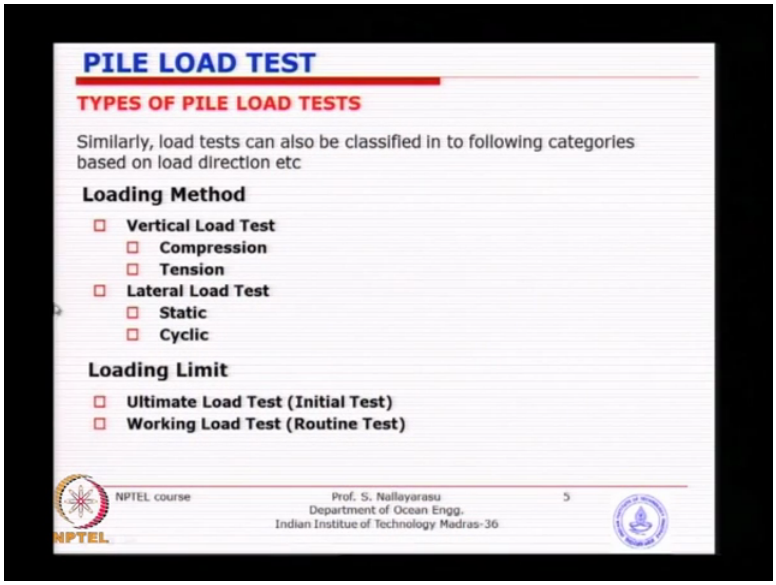
So but the first one is quite obviously very difficult to do because you have to continuously having a monetary system of displacement and adjust the loading according to the rate of penetration. Not many of the contractors have this facility because you need a feedback loop so that when the displacement increases you have to decrease the loading and it is only feasible by hydraulic means, where as normally most of the most load test you see in the field, they all just put big weights, so removal of weight is going to be very difficult. So most of the time we do maintained the load test, you put one weight, weight for several hours according to the procedure and monitor the displacement, if the displacement become constants that mean for that particular load soil has achieved its maximum possible displacement.

Then go to the next load displacement and apply the loading, wait for several hours and vice versa you remove the loading and look at any elastic rebound happening or is a plastic failure. So basically this maintained load test is commonly used in most of the projects, very rarely we go for this particular method. Dynamic load testing, we have very similar idea like you know the pile hammer, when you take a hammer and drop onto the pile and you see the stress waves travel through the pile and get reflected if the absorption is not enough and you measure the statistics of the transmitted stress waves and reflected stress waves and depending on the reflection and the transmission, you back calculate using the same principle what we were looking at the the dynamic equation and calculate that what would have been the resistance offered by the soil because this much waves has reflected back from the soil itself.

So that is indirect means, but before going and doing the actual testing at the site you may have to actually do a calibration in a known material which is easy to do and after that you can compare with the known material versus actual pile at the site, this is you got 2 types of tests, one is the high strain dynamic testing, the other one is the low strain dynamic testing; just the weight of the hammer and the low strain dynamic testing is normally preferred because for concrete piles if you do a high impact, the pile itself will actually fail.

Pile monitoring I think we will talk about it little later, it is a simple idea of using the driving information or driving records, number of blow counts and you know the duration between the blow and also sometimes you will have major stresses at the pile tip at the top and calculate back the resistance, which is also is dynamic because you are using the pile the hammer impact loading. Bidirectional method is quite useful only for the O cell testing which is you can do testing in both directions because the load cell itself is planted into the the pile foundation.

(Refer Slide Time: 15:49)



So you can do vertical load test, you can do compression, tension, I think obviously some of the piles in coastal areas for example, berthing structures, you will have compression loading and tension loading depending on the magnitude of horizontal load. So the pile needs to be tested for compression and tension as we calculate the capacity, you know pile capacity we calculate using skin friction pleasant bearing that is for compression. For tension you will have only skin friction depending on whether the pile is plugged or unplugged, you will see the internal and external. So in this case the tension testing is required for only few number of piles for example, even if you design a structure, the whole structure does not have any tension loading that you do not need to do this type of testing.

But most of the berthing structures will have tension because the gravity loading is very less and it is predominantly going to resist the horizontal loads like ship berthing structures, so you will see a huge amount of tension coming at you have to make sure that the pile has sufficient penetration to take the tension loading, it is not the whole structure will pulled off. In many cases what we normally do is, if you are unable to penetrate that much longer than you actually do a anchoring of the pile into the ground, means you will do a smaller hole we will talk about one of the days I think later, in one of the sessions about encourage piles only for tension loading which is very essential for such type of design.

Then we have also lateral test, static and cyclic and you can see here static test is going to give you certain capacity which will degrade when you apply the same loading several times because the top layer of the soil as we have learned from our PY curve, near the seabed you

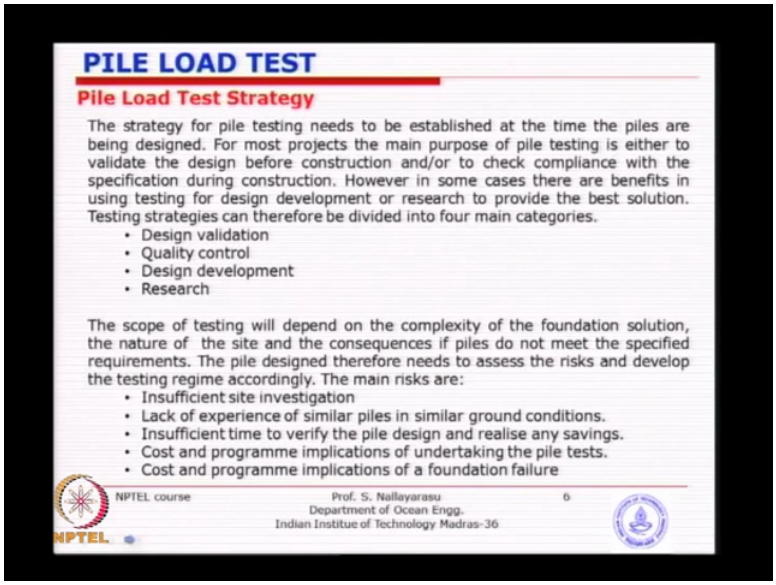
can see the soil gets disturbed quite a bit because of the repeated nature of loading and degrade the displacement or increase the displacement, degrade the capacity. So we need to see after how many cycles the capacity gets (())(17:55) that means you would see that displacement would be more.

Then we have loading limit, whether to load to the ultimate failure stage that means the pile will go into permanent deformation and the soil or you want to do a routine test by which you will not destroy the pile, you will only do a extend of maximum working load the structure may get and stop it so that the same pile can be used for permanent construction as part of the structure, so either way we can decide. Only problem is there is an uncertainty in the second one, you know you do not know what behaviour it will go through after it achieves that so-called working load limit because it can fail straight away, plastic deformation can happen or it can have a redundancy after that which will not be revealed when you do the working load test.

Whereas when you do this, you will be able to find out at what load the pile is failing then you know what is the factor of sifting because the factor of safety is defined as the ultimate load by working load or ultimate capacity by working load. So you will only be able to ascertain the factor of safety if you are able to find the ultimate load of, what you will not be ascertain that factor of safety because in the working load test you only have that level, it may actually fail after just going slightly higher than the working load, which will not give you the comfortability of the factor of safety so that is why the working load test is normally not preferred but then cost versus your factor of safety and design requirements.

You have to decide how many number of piles you want to do ultimate load test and how many you will do a working load test, but of course if the test result so large scatter then you will increase the number of piles that you do testing. If you do a 5 piles and all 5 of them are shows very reasonable matching of results and you may have actually conclude that no further testing is required but each one of them shows different results and different variations in displacement characteristics, you may actually decide to do furthermore addition to the pile testing, which again is is actually an procedure is decided by the the site representatives.

(Refer Slide Time: 20:16)



I think we have discussed, the performance is design validation, I think the primary purpose is design validation, whatever corruption you have made during your bore holes and to the design stage, you would like to validate that those assumptions are nullified so that your process of construction can go. Quality control, for sure in concrete pile is one of the biggest worry, in fact steel pile you do not have such issues but the quality control of concrete pile construction because everything goes underwater, you have to displace I think we have discussed about the construction of concrete pile, you have to displace the slurry which was poured inside by means of good quality concrete, but the quality could not be ascertained because nobody can go inside.

So when you do this kind of low strain dynamic testing, you could also assess the the concrete the honey combing structure. If the concrete is not done properly, you will see that the reflected waves will differ from the solid concrete that if you have, you can actually have uh testing of pile itself whether the pile is sound enough to reflect and transmit the waves or if the pile has got low, honey combing inside also can reveal. Similarly for steel piles, if the pile has been broken during driving and if you do this testing and it will reveal that if the stress waves are not coming, you could easily find out where is the fault so that is the idea behind this the low strain dynamic testing.

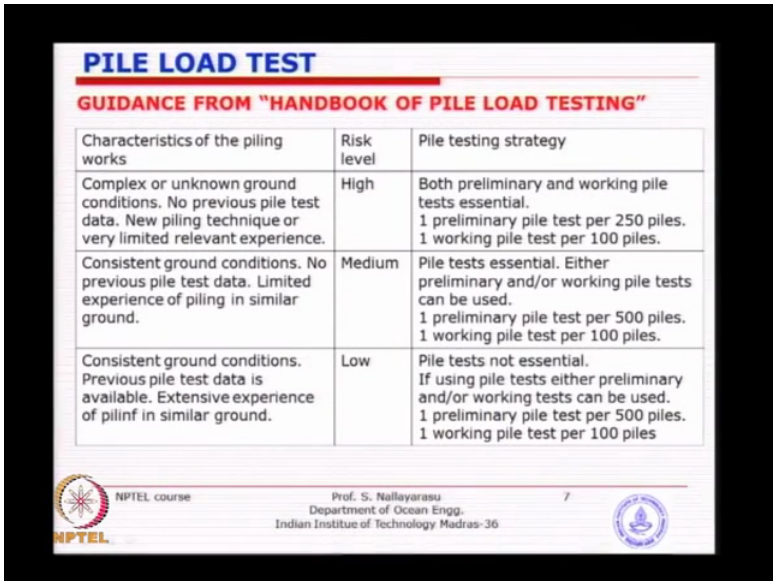
So basically quality control of the construction itself can be verified by means of carrying out cross correlation test. Sometimes you do a design development you know you basically you have a large number of some projects of thousands of piles like if you go to some of the

large-scale industrial projects, you may have several hundred piles. So you do a representative pile testing and use that information to further develop and then come up with a design procedure. In many cases if you if you look at some of the large-scale projects, they actually develop new design procedures specific to the site using the design data collected from the pile load test plus the portable information and they come up with their own design strategy and the you know you do not need to follow the standard procedure given in either any of the codes or regulations because it is proved by testing at the site so that will be done sometimes.

And in many cases always you will use it for further refinement of academic interest. I think these these are secondary but of course insufficient site investigation, normally you do not do a construction without the site investigation but then all depends on you know the the owner's intention, sometimes some government organisations may not be able to do a site investigation before the hour of contract to the contractor because of the nature of limitations they have. They may not be able to allocate funds separately for site investigation and separate for construction; it is part of the construction itself.

So what happens is, when a contractor comes to the site they have no clue what is the site so they will be doing the site investigation, so that is the time when the design becomes difficult, the design has to be evolving based on the available information but not actual site information. Many cases that happens, so you do that at that time when the project starts, you have assumed certain parameters during design and then you proceed with the construction but then do the testing 1st. Once you do the testing your assumed information verified and several other limitations on you know basically cost is one of the primary parameters, nobody wants to do testing if they can live an engineered design I think everyone will be happy, but that will not be the.

(Refer Slide Time: 24:26)



Now guidance from Handbook of pile load testing, this is just give you an idea of how to decide how many piles is good for a particular site. You know just of course this is only a guidance, it will need to be decided by the site engineer and the and the owner of course for sure depending on how much of time and money is are located for that purpose. But typically you can see the complex or very much unknown ground conditions, you know it is isolated place, no one has constructed in the vicinity so then probably you can go for a large number of

So you see here they recommended is 1 preliminary pile test per 250 piles, so that means preliminary means this pile will not be allowed to be used in the permanent construction, so you do a separate pile at an isolated location within the periphery of the the boundary where the structure is going to be built. It will not be within inside because what you do not want, you do not want to fail the soil between close vicinity of a working pile. For example, you have a pile here and just half a meter away or 1 meter away you want to construct a pile and fill it which is not very good because you cannot install another pile in the because the soil already have mobilised its full strength and failed.

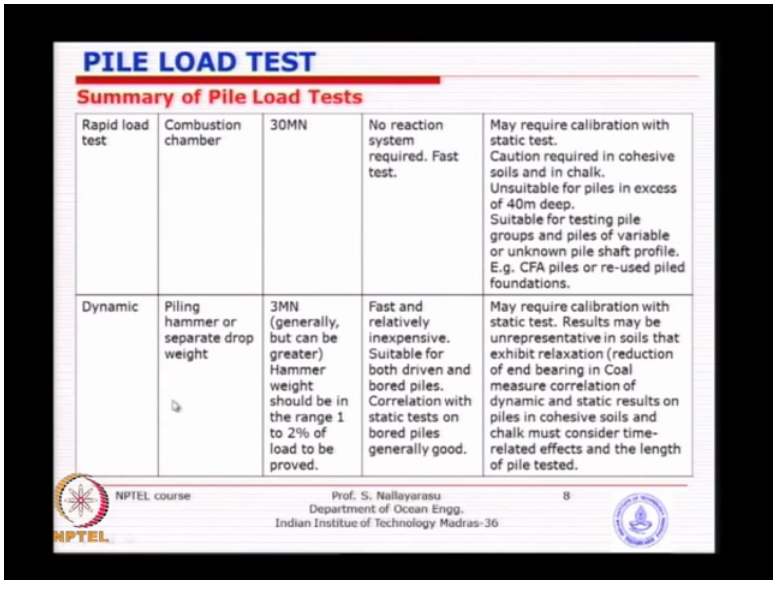
So normally you will go little bit away but not very far, you cannot do the testing several kilometres away, it does not represents the actual site conditions. So within the parameters probably representative location you will do a 1 preliminary test for 250 piles. So you can see here, it is only a guess, there is no rule book or it is not representing some kind of you know relationship, it is only a guess that it may actually give you some information plus 1 working

pile test for every hundred piles. That means among the remainder of the piles, every hundred piles you select one and then do a where the the ground conditions are very much unknown probably not very clear.

No previous pile test data is available in the site, new piling technique is used in case in that area every time they were using a concrete pile but suddenly you are going to use a test you are going to use a steel pile then it is an unknown experience, very limited information available in such cases you do this. Where as if it is the other cases, you know your risk is reduced with reasonable information then you can increase or decrease the number of piles per testing. So you see here 1 preliminary test for 500 piles which and then for very low or in fact you got plenty of data then you can also use 1 in 500, 1 in 100 or 1 in 200. In fact codes are not suggesting any of these numbers because they leave it to the you know the owners or consultants who are representing the design validation.

So normally we design something very similar like this, 1 in 250 but not very projects will have 250 piles, you know maybe 10, 20, 50, so if you do one pile that itself is good enough. So this is only a guidance which if you are representing your company for pile testing or if you are writing a specifications for pile testing, you can put that kind of number.

(Refer Slide Time: 28:00)



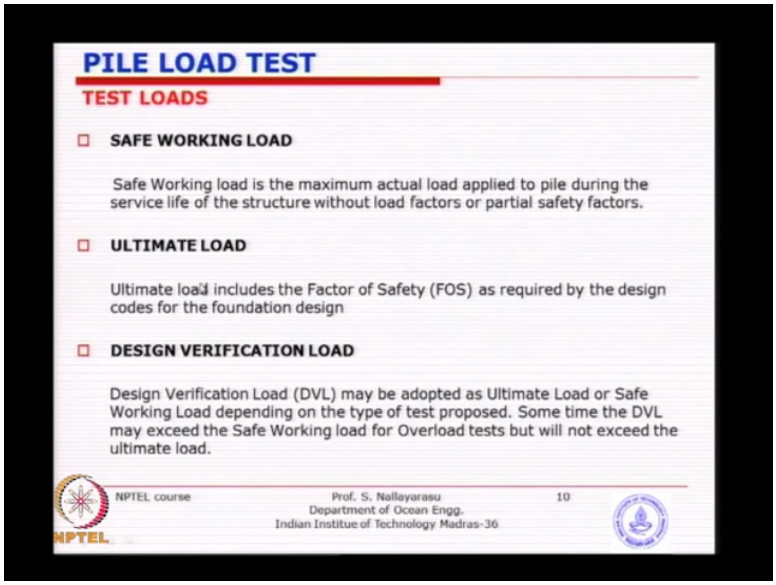
Rabbit load test versus dynamic load test, you know the kind of capacity that you expect you know 30 mega Newton is $ 3000 tonnes and what kind of hammer you will be using, just information that you can use it that much is practically possible to do the testing. So if you remember we were talking about pile capacity in offshore pile system, I think we were

talking about 20 to 30 mega Newton for each pile, which is something like this. So it is not that we cannot do, it can be done but at a very expensive system design because water depth is more and you want to design a reaction pile for such type of testing will become costlier than your jacket, so that is why we avoid.

I think we just discussed about static maintained load of test versus static penetration test or the so-called constant penetration test, you can read some of the information about the past history of, what was done the maximum load of what was achieved in the previous several years, it can be done to that much of load 3000 times. So you will see if you go around some of the the pile way construction I think MRT construction is going on. I think 6 months back so many places they were doing pile testing for the pillars the big pillars, you will see that a use platform is built and concrete blocks are stacked upon each was about 600 tonnes.

So you can see that the bulkiness of that platform to load this 600 tonnes because you calculate a 600 tonnes by either by sandbags or by concrete blocks, you will get 3 to 4 layers of concrete blocks will come.

(Refer Slide Time: 29:55)

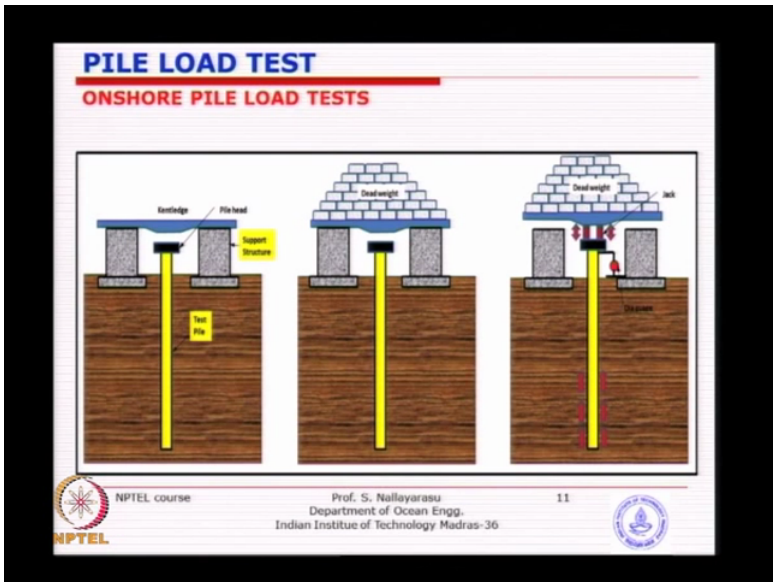


So safe working load, ultimate load and design verification load, sometimes differ from, we discussed about safe working load is a working load of the pile as per the design requirement. Ultimate load includes the factor of safety that means either 2 or 2 and half or whatever the design factor of safety as per the design code. If it is a IS code, you normally use 2 or 2 and a half, whereas API code we use 1.51 through and so this is the test load that you will apply if you do ultimate load test. Sometimes design verification load is in between these 2 we go

50% overload, instead of failing the pile we do a pile load test taking between the working load and the ultimate load, sometimes 25% higher than the working load.

Still the pile can be reused because you are not failing it, but it is slightly overloaded just to see that how the behaviour goes because if the pile fails immediately after reaching the working load after say 5 percent, the the factor of safety is not there anymore. So design verification load, it can be any one of them or it can be in between also.

(Refer Slide Time: 31:04)



A typical onshore pile load test, we will just read the methodology how it is carried out. So you can here this is a good ground condition means the ground at the surface is reasonably good. So we have a gravity based support system something like this, you construct pillars sometimes we actually use concrete blocks. You know simply put on 4 Corners, make a steel beam something like this and just you have your pile previously installed which is going to be tested and then with a prepared pile head, it could be a concrete piece or steel piece placed on top and then you start stacking up your weight because while you are stacking up because people have to go up and load it or you your Crane has to bring material and then just keep stacking up.

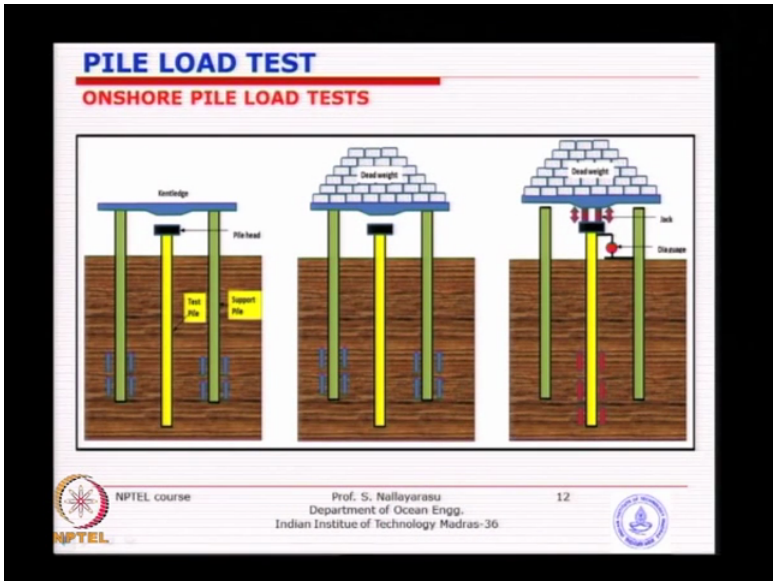
And then you will place a hydraulic jack or Jacks 1 or 4 of them, normally 4 of them is used and just jack it up. So what happens is, previously when it was loading is done at that time no load is going to the pile and safe because for a longer duration you do not want to keep this condition because it will topple or slides down to sideways you will be putting big danger on the pile itself as well as the system. So normally you have this is called Cantalage weight

distribution system, this is feasible only when the ground conditions are good number 1 and also the the distance from the pile should be sufficient enough that the load does not actually alter the soil conditions in the vicinity of the pile.

Imagine, if you do this and if the soil gets actually squeezed and get compressed, the pile capacity that you are actually going to measure is not going to be represented in the actual site condition because already the soil has been compressed and consolidated. So that is why you have to keep this support system quite away from the pile itself so you have to keep it 3 diameter to 4 diameter away so this cantalage becomes actually very large depth girders normally you will see 2 meter-3 meter girders spanning between the supports something like this you have to keep 10 meters away, if it is a 2 meter-3 meter pile so they will be away so that that influence of the reaction is not coming back to the soil.

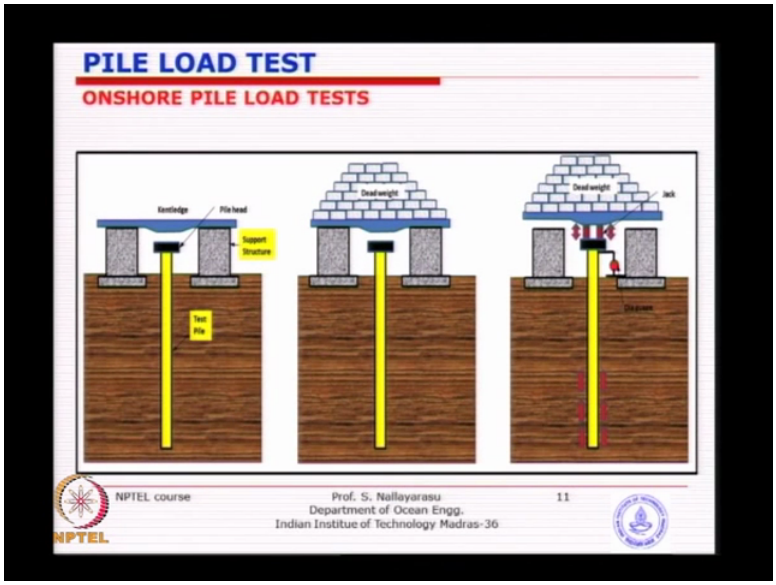
So this is a typical onshore pile load test that using you know spread footing type reaction system, so that is the idea put behind. So this test can be repeated if it is a working load test, you just load-unload load-unload but load will not be applied in one single stage normally because then you will only get one load one displacement relationship. So you actually divide the total load into say several steps, if it is a 300 times divided into say 5 or 6 steps and put 300 into say 6 steps means 50 tonnes and just look at the displacement then go to hundred tonnes, wait for some time and till the displacement becomes constant then you take the displacement reading, go and put the further loading so it is just done in steps.

(Refer Slide Time: 34:31)



And then similarly you can do a unloading, so from 300 you come to 250 and 200 and so on, so you can see whether the loading path and unloading path is same or different. If there is a plastic deformation then you will see that there is a different load path from loading to unloading, so that also can be verified. If it is a soil condition that the top surface soil is not good or it is going to distribute the load very close to the the pile that is being tested then you may actually look at installing additional piles and this is the case most of the cases it happens like this.

(Refer Slide Time: 35:14)



So install additional number of piles in and around the test pile, normally 4 number of piles are installed and you prepare a cantalage which is nothing but a just a grid of beams which will support these weights to restacking during unloading process and then when you want to do the testing you simply use the hydraulic jacks to activate and then lift it up. So you can see the difference between soft bound you know soil condition at the surface to good soil condition, the expense increases several folds.

You can see here, here just only a simple pedestal support, quick to make, easy to remove, where as when you go to this one, you can see here for one pile load test you are installing 4 number of piles so you can see the the multiplication of the time and the cost and the removal, you have to remove these piles you cannot leave them there itself unless it is isolated place. So basically the procedure is same, only the difference is depending on pile condition you will do the support reaction and cantalage (())(35:57) according to the requirement. And if you are going to do the same testing in coastal waters; 5 meter, 10 meter, 15 meter, 100 meter water depth, can we do this?

So that is where we bifurcated into a different idea, if it is a 20 meter water depth yeh, probably you can design a pile which will be directed around the other load testing pile and make a platform something like this and then construct this frame, load and unload can be done up to say 10 meter, 15 meter, 20 meter, but when you go beyond 25 meters will easily see that the diameter of the pile tested and diameter of the support frame, the diameter 0becomes too large. If you actually have to do a pile test in say jacket location 100 meter water depth because jacket is still not there because jacket will come only after you complete all your design and everything. You cannot do testing of a pile through a leg, for sure it is impossible.

So when you want to do this 100 meter water depth, imaging you may have to actually specially fabricate a jacket vertical in nature is not it something like this and keep the frame there and put the pile inside and do the testing. That means it becomes another project so that is why this pile testing is completely not feasible, so maximum pile testing I think for coastal areas people have done up to 20-25 meters maximum, beyond which you will see that the design of the system itself becomes a problem specially when you are doing so much loading coastal areas 300, 400, 500 tonnes.

But for jacket type of structure if you want to mobilise weight of 3000 tonnes which is becoming a bigger problem, so how to avoid even in coastal areas, even in land based structures, can we do testing without this weight? This is one of the very good idea so that you can avoid for example, if I go and connect this beam with this pipe so what will happen? I do not want to put the weights here so instead of using this weight as a reaction what we want to do is, we have simply weld this this beam with this pile. So what happens when you are actually putting up the hydraulic jack, the reaction will come from soil itself so that is basically the idea in the recent times no one wants to do a this this is called Dead weight method of testing.

And you can just look and eliminate the so much of weight, bringing the weight, stacking upon and removal can be removed provided these piles which were installed as a reaction pile or a support pile has sufficient pullout capacity otherwise that pile will come and you do not know whether you are measuring the this displacement of this pile or whether you are measuring the pullout of the other pile, which will become a very complicated situation so that is where some still.