Port and Harbour Structures
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Module No 07
Lecture 37: Mooring Dolphin at KPT

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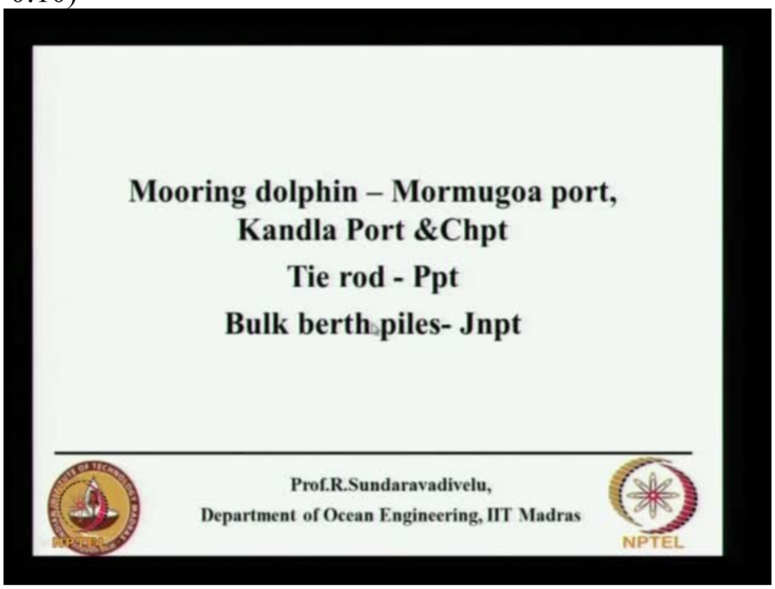

In last class, we discussed about the integrity tests, what we have to carry out but if there is a damage to port structure, mainly this damage is due to the ships which are not going in their own path. It deviates, loses control and hit, generally Mooring Dolphins, it hit and afterwards, there will be some damage to the piles, 1 or 2 piles but we have to do some integrity tests to carry out the response, mainly the frequency response that we have done for 3 projects which I will explain.

The next study is, we provide tie rod, is one of the supporting member and we have measured the tie rod poreses just to see what we have considered analytically is what is being realised. This is done at Paradeep Port trust. Then, while doing construction for a bulk berth in Jawaharlal Nehru Port trust, some of the piles have failed due to wave action, some of them have got tilted. So to find out the reason, we have done some studies.

The 1st study is due to a ship hitting the Dolphin because it has lost control. 2nd is to study the forces experimentally on a tie rod and compared with analytical studies. The 3rd one is the failure of some of the piles during a cyclonic conditions.

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1st we will see Mormugoa Port. This shows the aerial view of the Mormugoa Port. We have very small breakwater here. This is called as a seminatural harbour. There are some hills which are protecting the Harbor basin. Here, we have one floating dry dock. This is one set of berths, this is another set of berths and here we are seeing 3 Dolphins. One more Dolphin is there on further this side.

When the vessels are coming and the berth is not free, in that case, they will anchor the vessels for a small period of time, small period means maybe a day or sometimes even 2. Waiting outside, they will be anchoring their vessels here. Once the berth is free, then the vessel will come and berth and take loading or unloading. See, when one of the vessels was trying to go out like this, it has gone and hit one of the Dolphins here and it has undergone some damage. So we normally do one study that is called as frequency response study. I will explain about that.

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These are called as Bullards which are used to tie the vessel what you are seeing here. This is a tugboat which is controlling the vessel because when the vessel is entering the harbour, you will be not be having any, the engine will be stopped. So the vessel will only push the, the tug only will push the vessel. So these are tied together. This is how the Mooring Dolphins are used to tie the vessel. For example, if there is a vessel here, it will be tied between this point and this point.

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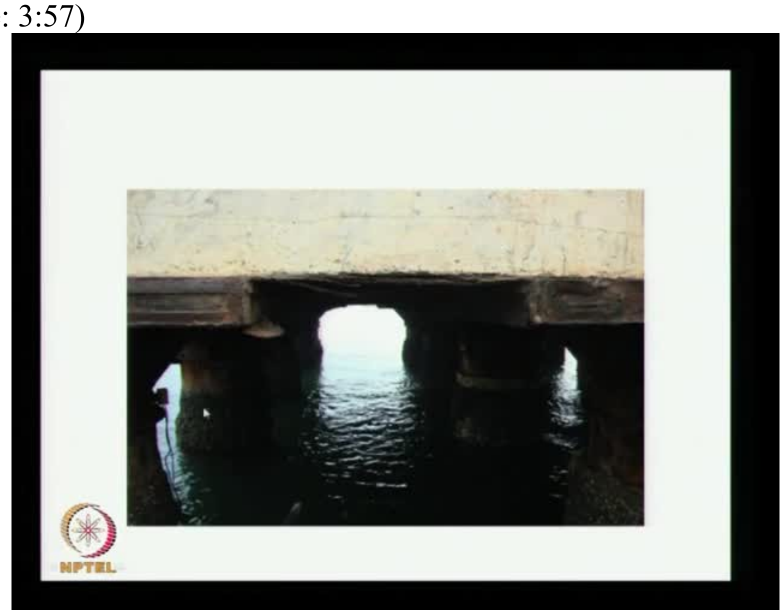

These Dolphins generally have a RCC deck and they will be supported on piles. You can see some discolouration here. This is the biofolling which takes place. They use a liner but liner is getting corroded. The circle you are seeing. This is one side of the Dolphin which is not damaged.

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If you see the other side, it has got completely damaged. The steel framework has gone down, some of the reinforcement which is coming from the deck to the pile has got bent and there will be a discontinuity of the reinforcement.

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For this type of study what we use is a tugboat. These tugboats are used to hit the Dolphin like this so that the Dolphin undergoes certain oscillations and we measure the oscillations.

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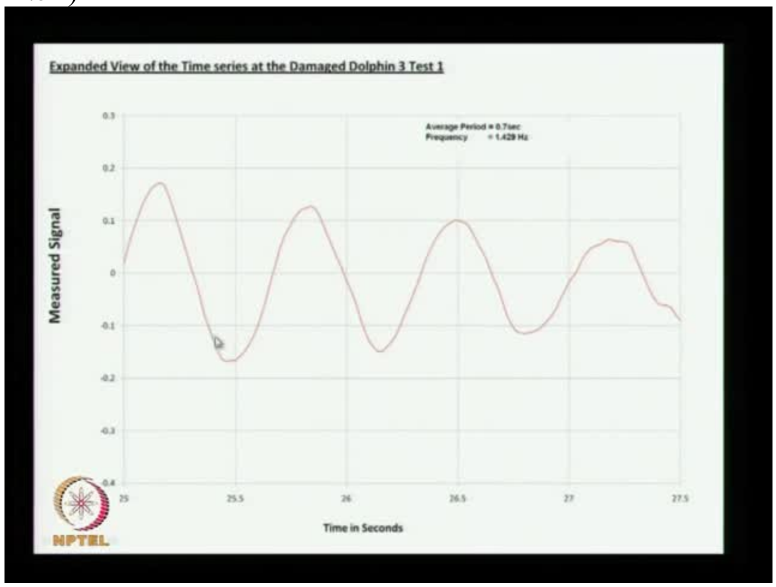

So this is one-time series of oscillation which is measured. So again we use a acceleration pickup to get the timeseries. Then we have a amplifier, then a recorder. What we are measuring in the X axis is the time in seconds, Y axis is the measured signal, generally in volts or you can convert the volts in acceleration in meter per second square also. So once the Dolphin is hit by the tugboat and the tugboat goes away, then the Dolphin oscillates.

That oscillation is picked up by the signal and it dies down after certain period of cycles. Maybe after 10 cycles or 15 cycles. From this crest to this crest, is one cycle. This is called as trough, this trough or this trough is another cycle. So this is one cycle. We had, we have taken the measurement, study signal after 25 seconds after the tug has hit and it is, it is a 3 wave variation test. So after the tug has hit, we are measuring it.

This is one of the Dolphin which has got damaged. This is the test number 1. We repeat the test. At least 3 test we carry out. We are measuring the frequency, that is 1.4 to 9 hertz and the period is 0.7 hertz. How to calculate is, the time taken between these 2 successive crest is 0.7 seconds. So what we do is we, there are this is one cycle, this is 2nd cycle, this is 3rd cycle.

So for 3 cycles, you find out what is the time taken, divided by 3, then it will give the natural period of the system. So from this point is 26.5, this point may be 27.2, difference 27.2 minus 26.5 is 0.7 seconds. 1 by 0.7 is this hertz. This is the 1st test which we have carried out.

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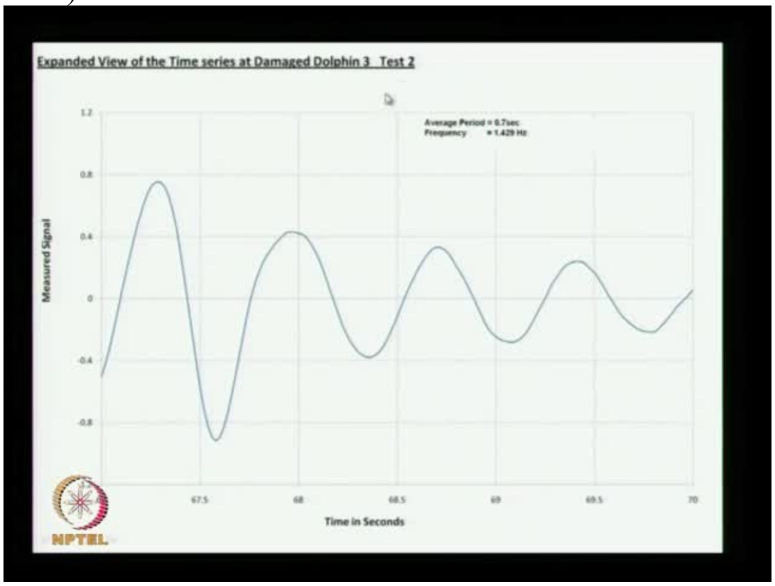

Again we repeat the test. When we did the 2nd test also, we get the different type of signal but the period is nearly the same. The acceleration levels were higher. If we see the previous slide, it was only 0.7 whereas here it is 0.8. The accelerations are ed very high compared to the previous test but the period remains almost the same. This is for the damaged Dolphin. What will be the frequency for the undamaged Dolphin?

Professor-Student conversation starts

Professor: What will be the frequency for the undamaged Dolphin? Will it be more than this or less than this? Question is clear no? We have measured the frequency. The frequency will be more or less for a undamaged Dolphin? So you do not know the answer. So I will tell you the background to this. So if you see here, there are a number of Dolphins, or Dolphins, one of the Dolphin has got damaged, the other Dolphin is undamaged.

Both are identical because they are designed for the same forces. So now we have to find out what happens to the frequency for which we should 1st find out what is the equation of motion.

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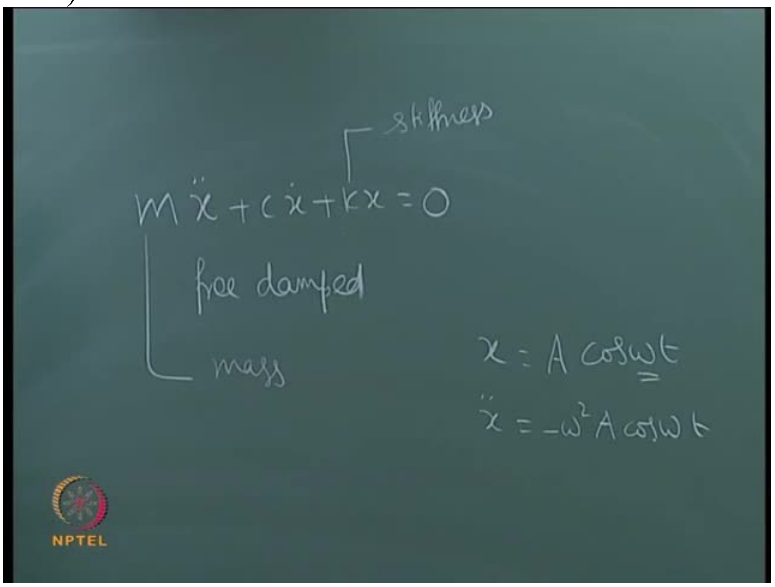

This is called as free vibration, free damped vibration equation. What is M?

<u>Professor-Student conversation starts</u>

Professor: What is M?

Student: M is the mass.

Professor: What is K?

Student: Spring constant.

Professor: What is it?

Student: Spring stiffness.

<u>Professor-Student conversation ends</u>

Stiffness. You can write X is equal to some constant A into sine or cos omega T where omega is the frequency. So X double dot will be minus omega square A cos omega T. If you do the differentiation, X dot will be omega A sine omega T and X double dot will be minus omega square A cos omega T right? So if you substitute this in this expression, assuming the damping is 0, in the damping term.

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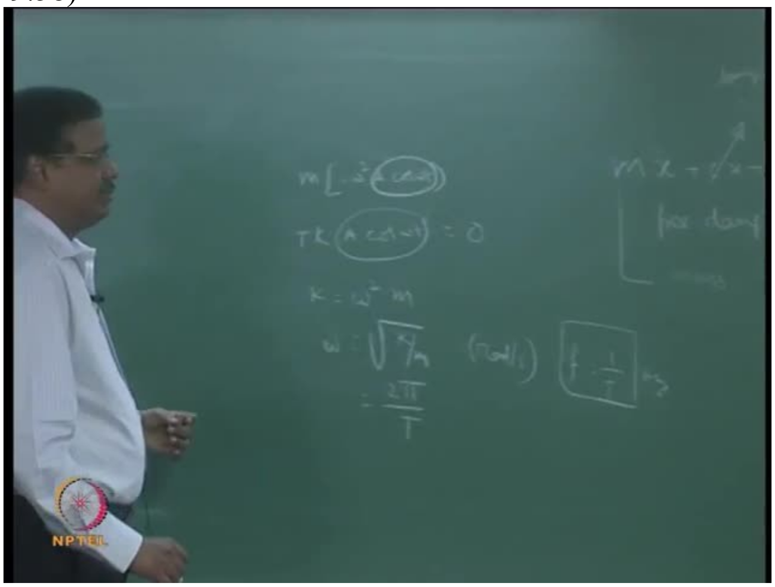

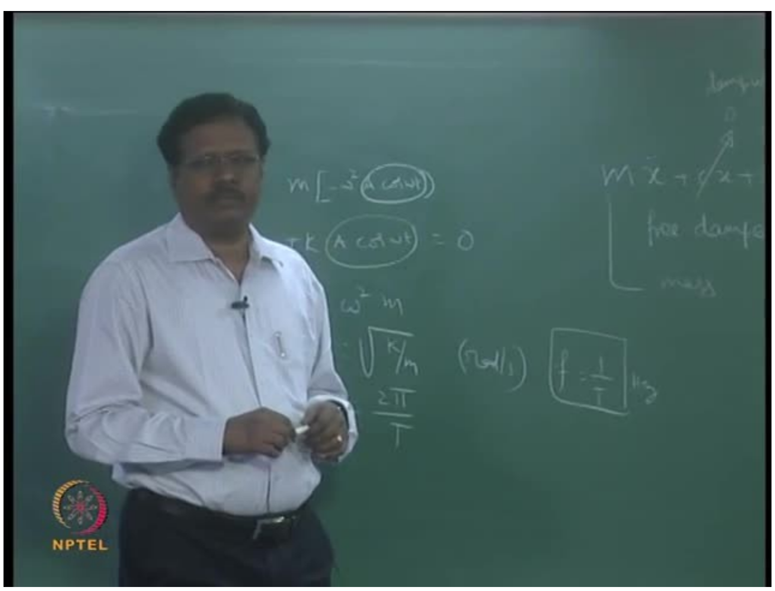

But damping exists in our analysis, but assuming it to be 0, then we will have the equation, M into minus omega square A cos omega T plus KA cos omega T equal to 0. So this A cos omega T, when A cos omega T, so we can remove that, so what we will get is K is equal to omega square M, omega square is equal to root of, omega is equal to root of K by M where K is the stiffness, M is the mass. The unit for omega is radians per second.

This omega is nothing but 2 pi by T, this is a natural period. F is equal to nothing but 1 by T. This F is given in hertz, T is given in seconds. This is clear to you? For a free vibration of any structure, this is damped, you will have 3 times. 1st is a inertial terms, 2nd is a damping term, 3rd one is the stiffness term. So this gives the M into acceleration, C into velocity, K into deflection which is equal to 0.

If we assume C is 0, then the equation is MX double dot plus KX equal to 0, X equal to, you can write A cos omega T or A sine omega T. X double dot will become minus omega square A cos omega T, you substitute in this equation, find out omega square is equal to K by M and omega is equal to root of K by M. Period if you want, once omega is known, T is equal to 2 pi by omega. Once T is known, F is equal to 1 by T. Okay?

This is T is called as the natural period of the system, 1st mode of vibration.

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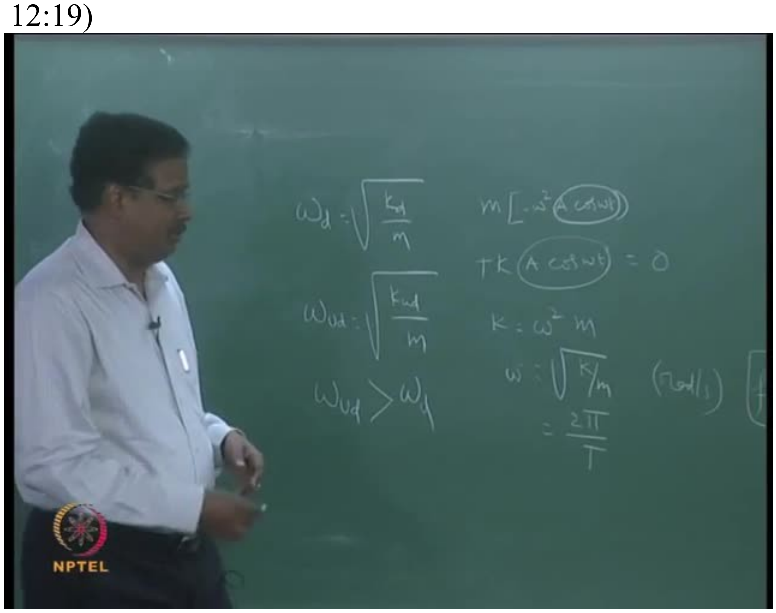

This omega when you talk, it will have damaged, that is equal to root of KD by M. Omega undamaged will be equal to root of K undamaged by M. I am putting the mass same because mass will be the same for the both, damaged and undamaged Dolphin.

Professor-Student conversation starts

Professor: What happens to the stiffness? Which stiffness will be more?

Student: undamaged.

Professor: Hmm?

Student: Undamaged stiffness.

Professor-Student conversation ends

Undamaged stiffness will be higher. So then what happens to the frequency? Undamaged will be more than the damaged. So omega of undamaged should be more than omega of damaged. So now we will see whether we are getting that or not okay.

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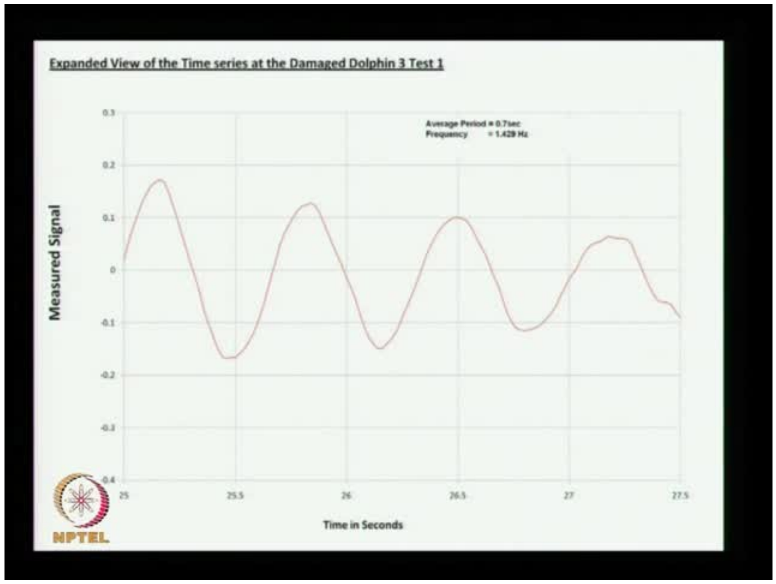

We have fortunately 2 Dolphins. So this is for the damaged Dolphin. Frequency is 1.429 This is for the damaged Dolphin. For undamaged Dolphin, the frequency should be higher. Right? This is for the undamaged Dolphin. You can see, the frequency is 1.923 hertz. Right? This is higher. Period will be lower because the stiffness of the undamaged Dolphin is higher, this is one, we have given the, Dolphin has 4 faces.

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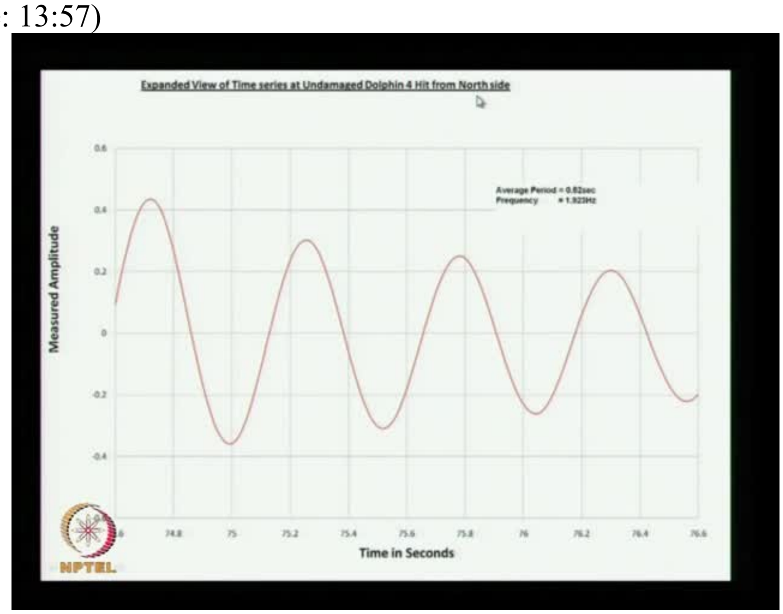

This is from the northside.

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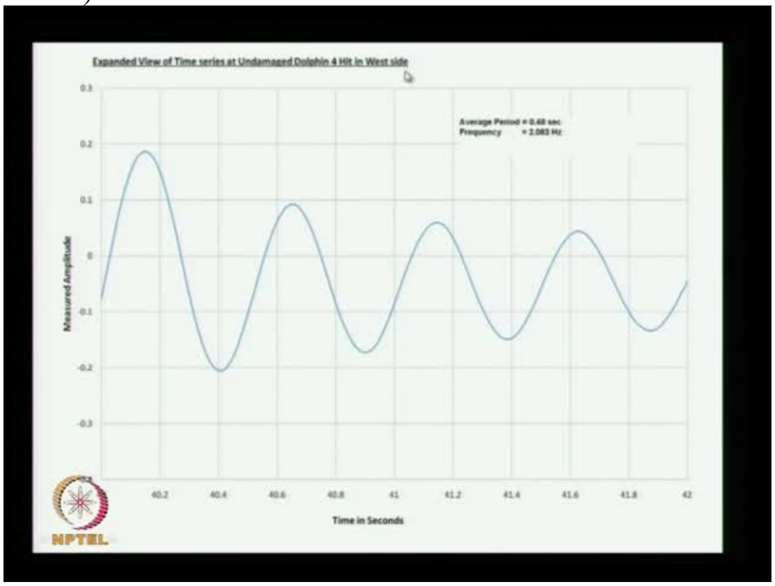

Results

S No	Description		Average Period	Frequency
1	Damaged Dolphin 3	Test 1	0.7 seconds	1.429 Hz
2	Damaged Dolphin 3	Test 2	0.7 seconds	1.429 Hz
3	Undamaged Dolphin 4	Test 1	0.48 seconds	2.083 Hz
4	Undamaged Dolphin 4	Test 2	0.52 seconds	1.923 Hz

\This is from the west side. There is a small difference here for the Dolphin, that is undamaged Dolphin. This is 2.083. So we have a table which shows the Dolphin number 3 is damaged, Dolphin number 4 is undamaged. We have done 2 test, one each Dolphin. Damaged Dolphin, the frequency is lower, undamaged Dolphin, the frequency is higher because undamaged Dolphin, the stiffness will be very high.

Right? This is what we have measured. Now what we are going to do is, we are going to repair this dolphin, then we will take again the measurement. At that time, the damaged Dolphin should be close to the undamaged Dolphin. Then we can say the structure is in good condition. Right? The stiffness what we are talking is the lateral stiffness. That is the 1st mode of vibration.

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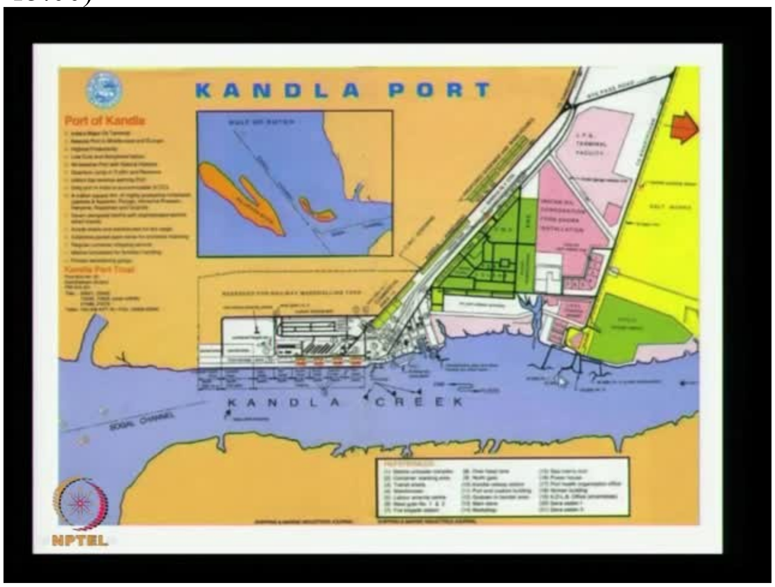

Now we will go to next structure, that is the Kandla Port. So this is the Gulf of Kutch and if we enter like this through this showgirl channel, this is the showgirl channel if we enter, this is the Kandla Creek. Here we have a lot of berths. One stretch, a very long berth, this is about a 2 km long berth that is there. Then these are the oil is, that is 1, 2, 3 and 4. When the vessel was just like the previous case, here also, when the vessel is entering the channel, if the berth is not ready, they were mooring the vessel somewhere here on its own ship mooring.

And when it was trying to go out to berth at some berth, it had gone and hit one of the Dolphin here. Right? This Dolphin it has hit when it was trying to go out. So we will see a video.

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You are seeing the Dolphin in a very bad condition. What are the damages in the stalls the stalls and? What happened to this pile? It is completely damaged. You are seeing a lot of water going now. This is the tidal creek where the water is going out. Normally, the Dolphin height is very high because the tidal range in Kandla is more than 4 m. So because of that region, the top-level is very high.

They have done some repair because of corrosion, that is why it is going like this. Here the piles are both vertical as well as inclined piles. The ship has come and hit this pile directly. That pile is again damaged, it has fallen down after some time and here also, there is some damage. So for this type of damage, you see the current speed, how much it is coming. The current velocity which is coming near the pile if you see, there is lot of water that is taking place.

Since there is so much damage to the structure, we didn't do any frequency tests. Very clear that the damage is very high and we cannot repair the structure simply. We have to put some additional piles all around and then strengthen the structure. But we didn't do any study for that. Okay.

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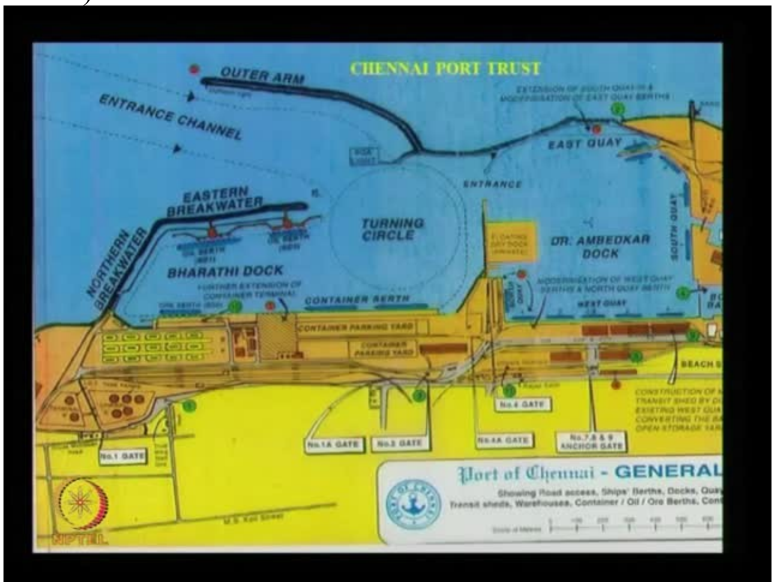

The 3rd one is, in Chennai port, so we have 3 docks here, one is called the Jawahar dock, somewhere here, next is called as Ambedkar dock, inside here, then we have a dock called as the Bharathi dock. This is breakwater, Eastern breakwater, northern breakwater and this is your southern breakwater and this is your outer arm. The ship is coming through the entrance channel and then there is a turning circle.

When one of the vessel was trying to go out like this, it has to go out like this. So when the vessel was trying to go out like this, it has lost the control and had gone and hit this Dolphin. One of the reason it has hit the Dolphin is this is very close to the entrance channel. So it has come and hit the Dolphin and there was some damage. This has happened more than maybe 15 years or 16 years back.

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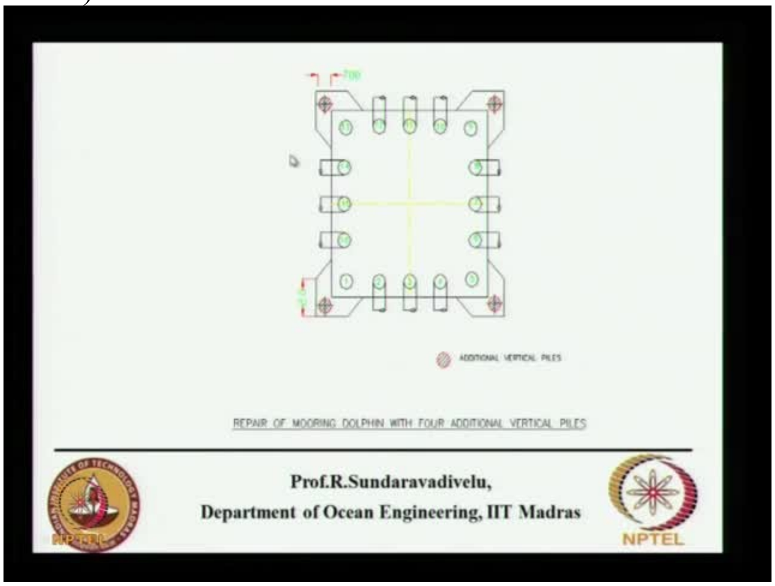

So this is how the Dolphin is. We have 4 corner vertical piles. Then we have racker piles, inclined piles, 3 in each face. One of the pile, vertical pile has got damaged. I will show you it the photograph in the next slide. In order to repair this pile, we found that it is better to put additional 4 piles and integrate with the deck system so that the new dolphin after the 4 piles, it will be in good condition.

Actually, they didn't repair this Dolphin what we have suggested. What they have done is this Dolphin was damaged, they put one more Dolphin. There were 2 dolphins here, one Dolphin here and one Dolphin here. They put one more Dolphin here and then they used it for purpose. They didn't want to repair because the shipping agency will give the money for constructing a new dolphin. So they gone in for that construction of new dolphin.

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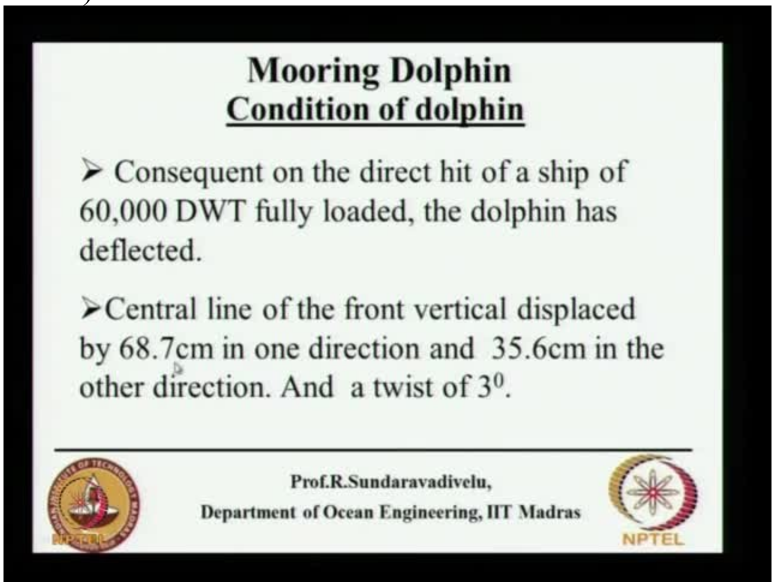

Normally the ship size is defined by deadweight tonnage the ship 60,000 DWT. And we can visibly see the deflection of the Dolphin. So the Central line has deflected by about 687 mm in one direction and 356 mm in the other direction. There is a twist of the dolphins, that is the top surface of the Dolphin has got twisted by about 3 degrees.

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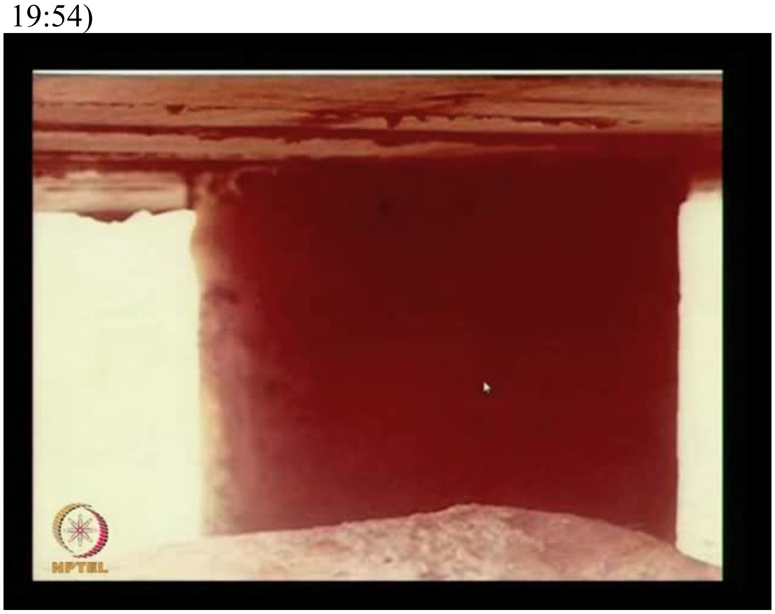

There is no visible damage what we have seen in the earlier slides and all because the Dolphin is very strong. Do you notice any damage in this, any problem in this pile? This is the pile, this is the deck system. Are you noticing anything?

Professor-Student conversation starts

Professor: Hmm?

Student: (no reply).

Professor: Nothing you are noticing. What is this? This is a bulge. That means there is a buckling of the steel liner. You are able to see the bulge no? There is a bulge here in both the directions, only for a small distance. This bulge is mainly due to buckling of the liner plate. If we remove this, you will see some crushing of concrete inside.

Professor-Student conversation ends.

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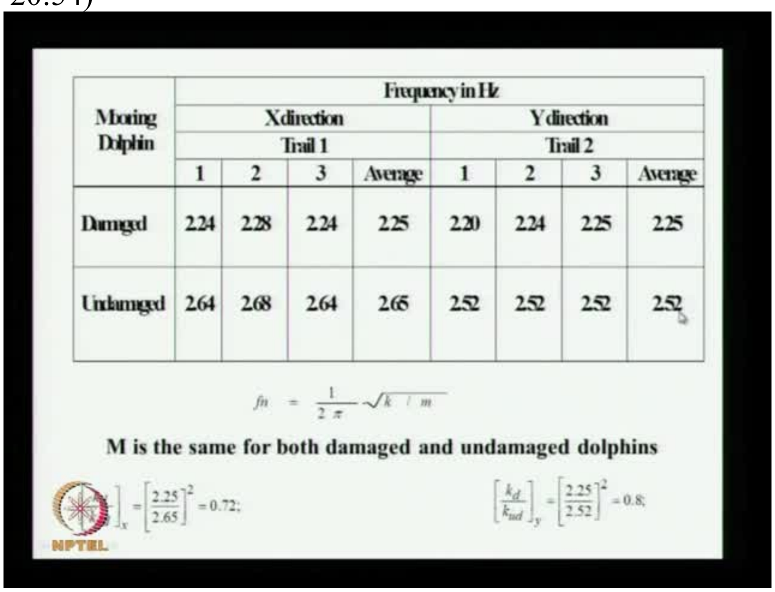

Here also we have done the damaged and undamaged Dolphin, both X and Y direction. We have done 3 trials in X direction and trials, 3 times in the Y direction. We have got average 2.25 for damage . For undamaged, 2.65 in one direction and 2.52 in another direction. I don't know this is a coincidence or otherwise. Damaged Dolphin, in both the directions generally we get the same results.

Failure also I have shown, same results we are getting in two directions whereas undamaged Dolphin there is small change where some soil will be different and things like that. So here also, the undamaged Dolphin, the thickness is high, so the frequency is higher here. So if you want to find out the ratio between the stiffness of the undamaged to damaged Dolphin, it is the ratio of the frequency and this gives about 72 percent in one direction and 80 percent in the other direction.

So you can also quantify what is the reduction in stiffness. Reduction in stiffness is square of the frequency ratios. So here it is 72 percent, another is 80 percent. This is required to reduce the stiffness when you do the reanalysis. Suppose one pile which is buckled, that pile will give the stiffness days only 70 percent and redo the analysis and when you do the analysis also we get the frequency and that also should match.

Then when we put 4 piles, then this damaged Dolphin, the stiffness will increase and the frequency also should increase to 2.65. That we have seen and it has become all right. But they have gone for some other work.

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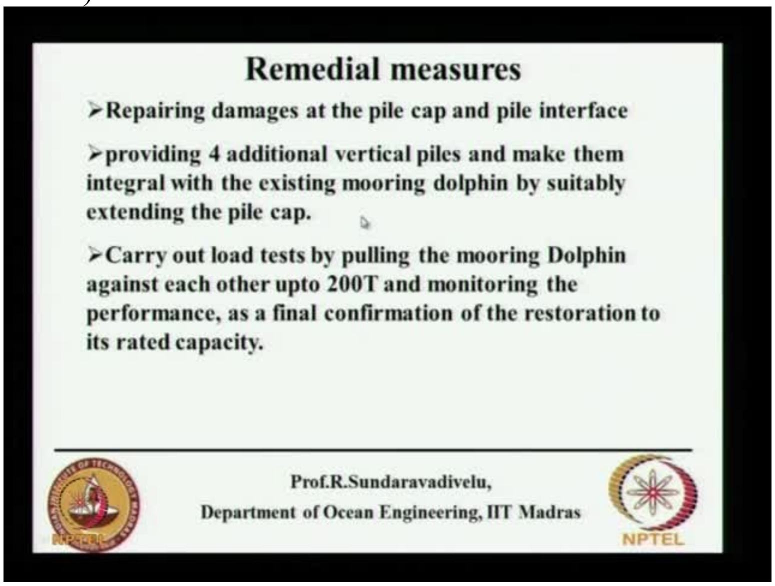

So we have to repair the damages at pile cap and pile interface, provide for additional piles and we have to make them integral with the existing Dolphin by suitably extending the pile cap. And again we have to carry out load tests by pulling the mood in Dolphin against each other up to 200 tonnes, it is designed for a mooring pull of 200 tonnes. So we have to apply this load and monitor the performance as a final confirmation of the restoration to its rated capacity.

These are the sequence we have told but they did not do it. They built another Dolphin. Since the insurance company is paying the money, they have done. But that cost will be at least 10 times more than the repair costs if you want to repair.

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Now this again, giving in detail, opening of the joint between the concrete piles and the deck slab, treatment of the corner pile exhibiting compression bulge, falling and cracking of concrete in the corners of the deck slab and the top surface, the level was not there. Because it has got tilted so you have to level it.

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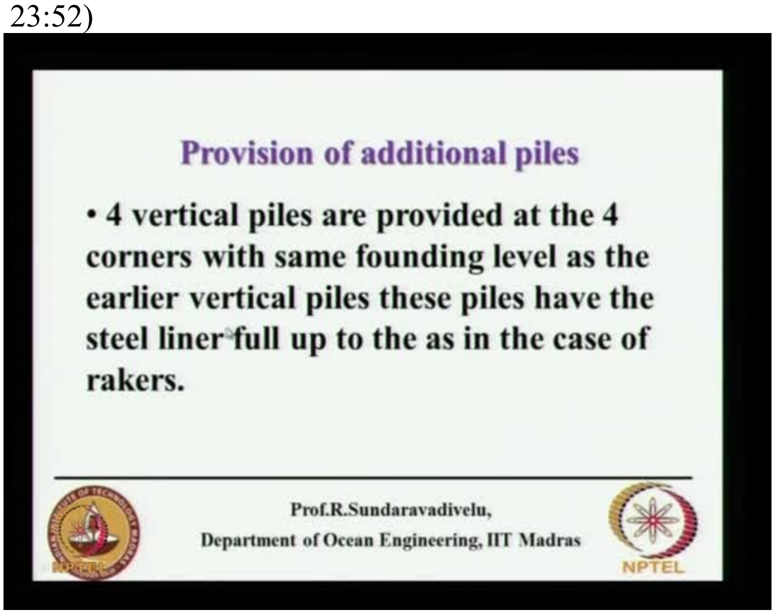

And we provide 4 additional piles, then connect them and we provide the same founding level as the earlier vertical piles and we want to also provide steel liner up to the bottom like raker. See earlier what they have done is, the raker pile for construction purpose, the liner will go up to the founding level. There is a borehole will collapse for a raker pile if the liner is not there whereas vertical pile, they have stopped. So that is why, there is some damage which is observed. So we thought we will take the liner right up to the founding level.

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This is a layout of Paradip port. Here we have what is known as the 2 breakwaters, the entrance channel. This is called as a lagoon harbour. What is shown in dark blue colour is a proposal what they want to do in faces. This is existing. They have iron ore berth and again there is another berth for iron ore transport. This is called as a general cargo berth. So this general cargo berth we have done some tie-rod measurement which I will explain.

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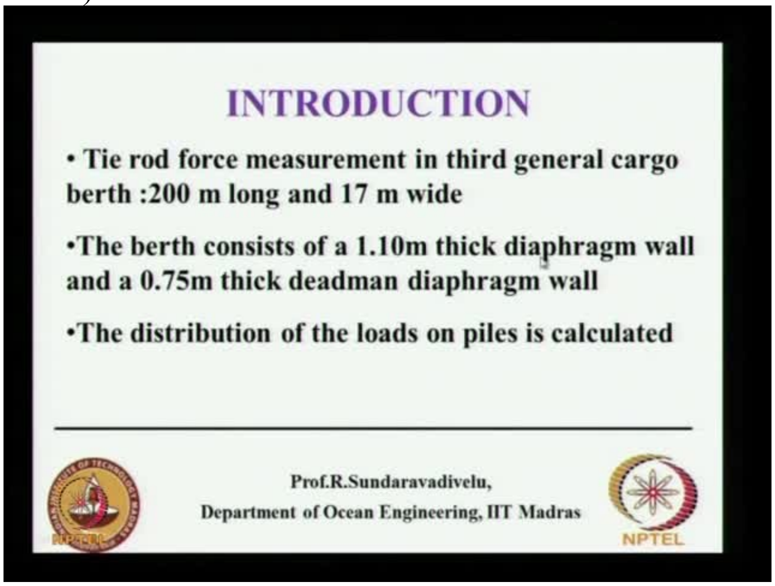

This berth is about 200 metre long and 17 metre wide. This consists of a die from wall which is about 1.1 metre thick and there is a deadman die from wall which is 0.75 metre thick. We want to find out what will be the load distribution between the piles and the diaphragm wall.

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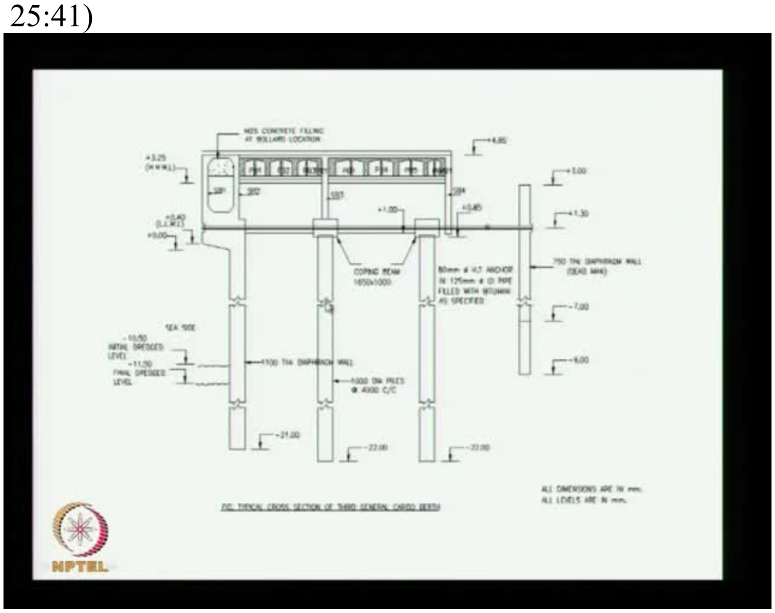

This shows the layout of the structure. This is called as the front diaphragm wall. We have two rows of piles, we have a deadman diaphragm wall. This deadman diaphragm wall is connected to the main diaphragm wall by a tie rod. When we have very deep main beam, these piles are at a very 4 metres centre to centre in lateral direction. So every 4 metre, we have this main beam. On top of the diaphragm wall, we have what is known as the coping beam.

Here we place the fender and here be provided the Bullard and here we put some pre-cast launch hold beams over which we put the slaps. The deadman diaphragm wall, the main diaphragm wall are connected by a tie rod. This tie rod diameter is 80 mm and this is kept inside a GI pipe which is 125 millimetre diameter. The gap between the GI pipe and anchor rod is filled with bitumen so that the corrosion effect is not there in the tie rod.

The thickness of the main diaphragm wall is 1100 millimetres, thickness of the, this is called as a deadman diaphragm wall is 750 mm. Here, we are seeing some cut in the cut shown in this drawing, this is to show that this is not drawn to scale. Actually, this length of the tie rod is much more than what it is shown. The deadman diaphragm wall is not so close. It is far away from this. To cover it in the drawing, we are showing it like this. Right?

The top-level is 4.85. Deadman diaphragm wall starts from plus 3, it goes up to minus 9 whereas the main diaphragm wall, the cut-off level is 00, from there it goes down up to minus 21. The construction procedure is like this. We will have the soil filled on both the sides, they construct the structure, then they start dredging. This is how they do the construction procedure. This is not done in the open sea. It is done in the land surface.

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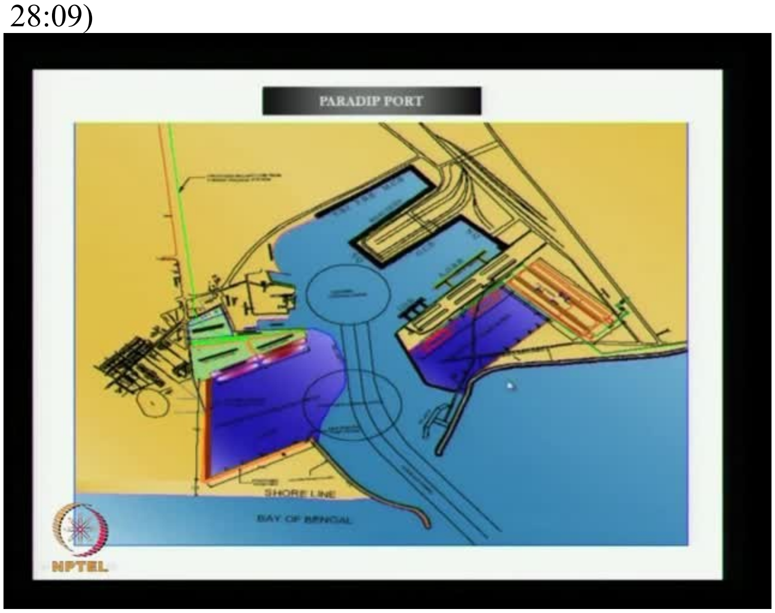

Lagoon harbour means, this is called as the lagoon harbour. The whole area is a land mass. Now this area is a land mass. So what they do is, they do the construction, then they remove the soil by dredging. Same way here also, they build the structure, then they removed the soil by dredging. That is what they have done. Clear no? This, the conversion procedure.

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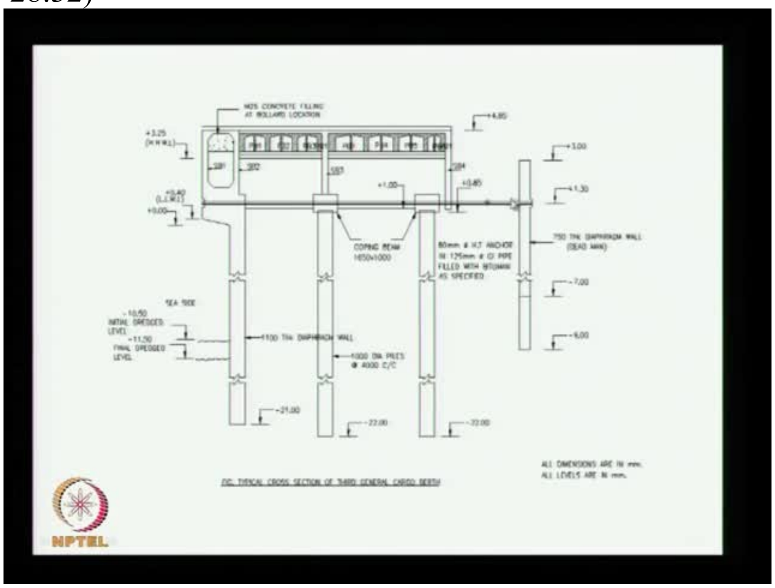

Now there are piles connected to this by a main beam. The deadman wall is connected by a tie rod to the deadman diaphragm wall. When you are removing the soil from here to here as you go here, initially they do up to minus 7.5 and finally to minus 11.5. As they are dredging the soil, what will happen to the main diaphragm wall?

Diaphragm wall will deflect. Now the diaphragm wall is going to deflect, the tie rod will bring it back to the position, it will take the tension and through the tension, it has to pull this deadman wall also. So they assumed about 60 tons or 600 kilonewton is the force in the tie rod. But when we saw this structure, since the pile is very large diameter pile, 1000 mm dia, we have told them that this is a seethis 600 kilonewton will not be mobilised on the tie rod.

The load will be shared between the deadman wall as well as the pile. Is it clear to you? They assume there will not be any load on the pile, lateral load. All the load, they assumed it will go to the deadman wall. That is why we decided to do some measurement on the tie rod forces. The objective is clear to you? We are assuming that the whole lateral load due to the pressure will go to the deadman wall.

But actually, it will be shared between the pile as well as the deadman wall. We want to find out how much is the sharing. This measurement has been published in one of the journal, American Society of Civil Engineering, general law of waterways port and harbour engineering.

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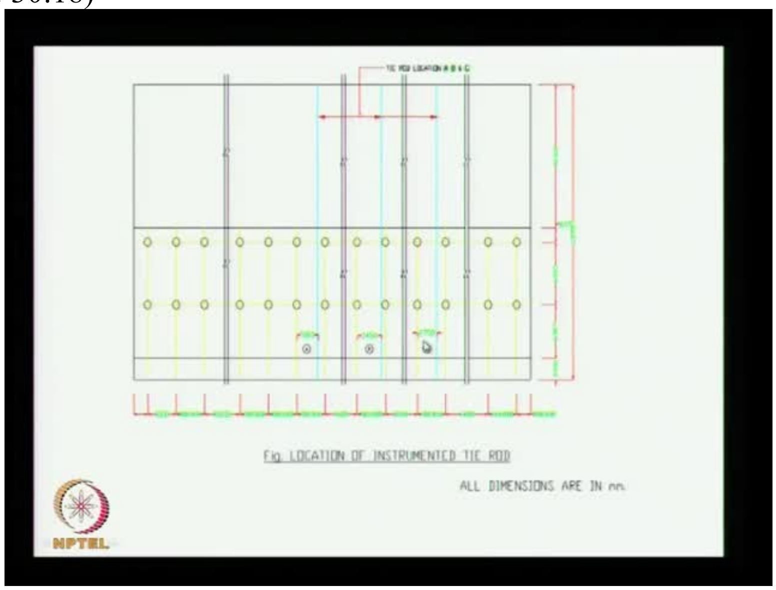

These tie rods are provided at closer intervals and these are the piles which are at 4 metres centre to centre. This main diaphragm wall is somewhere here, deadman diaphragm wall is somewhere at this end. And at 3 locations, we have measured the these are the 3 rods which are subjected to some measurement.

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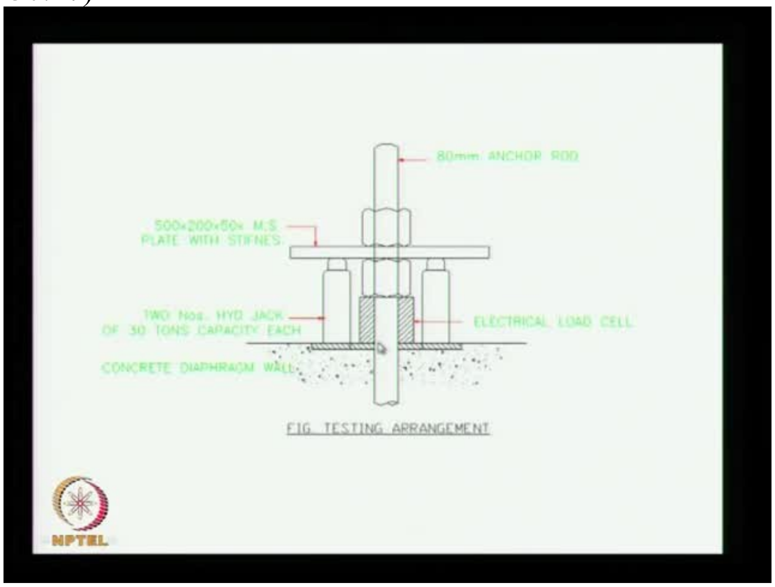

So at the end of the tie rod what we have done is, we have put some load cell which will measure the tension in the tie rod. It is a same gauge type. Then we have 2 nuts which are connected to this. What we do is, we put two hydraulic s, each of 30 tonne capacity because this is designed for 60 tonnes of tie force. So these are the 2 s which are given as 30 tonne capacity.

So what we do is, we just apply the load of 30 tons each. We will apply such a way that till the tie rod becomes loose, we will apply the load so that we will get the initial reading. Then we will release the so that we will get initial reading and final reading because dredging will take place after 6 months or 8 months after the construction is over. That time we should read the initial reading and the final reading.

To get the initial reading, we will transfer the load from the tie rod to the and then again transferred the load from the to the tie rod. That is why this arrangement is made. You cannot take the initial reading and then did the final reading after 6 months. Because this place will be filled with water, that initial reading and this reading will not be the same.

Is it clear? You cannot take the initial reading today and come back after 6 months and take the final reading. You will not get the reading properly. So for that reason, we have made this arrangement.

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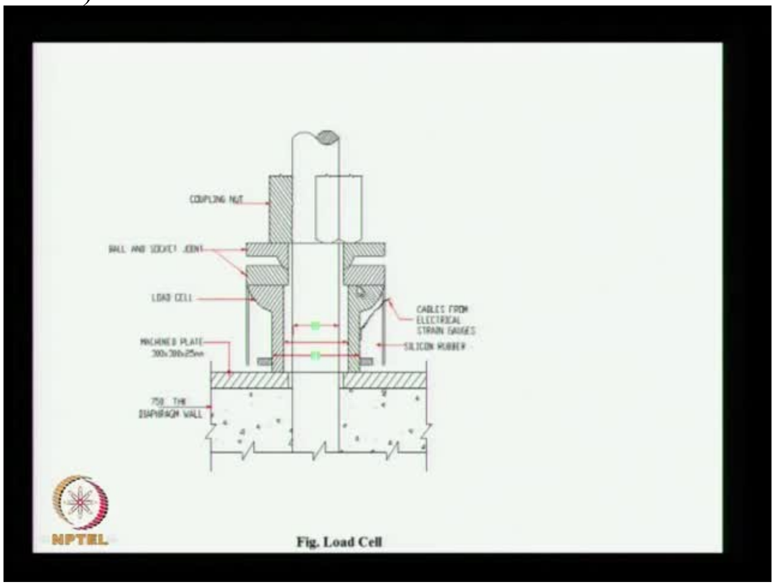

So here you can see the details of the load cell. To have a concentric load transfer, we have made this balance at its joints also so the load will be transferred here. These are the coupling nuts, this is a tie rod which is coming from the 750 thick diaphragm wall. There is a machine plate here so that this from this we can take the.

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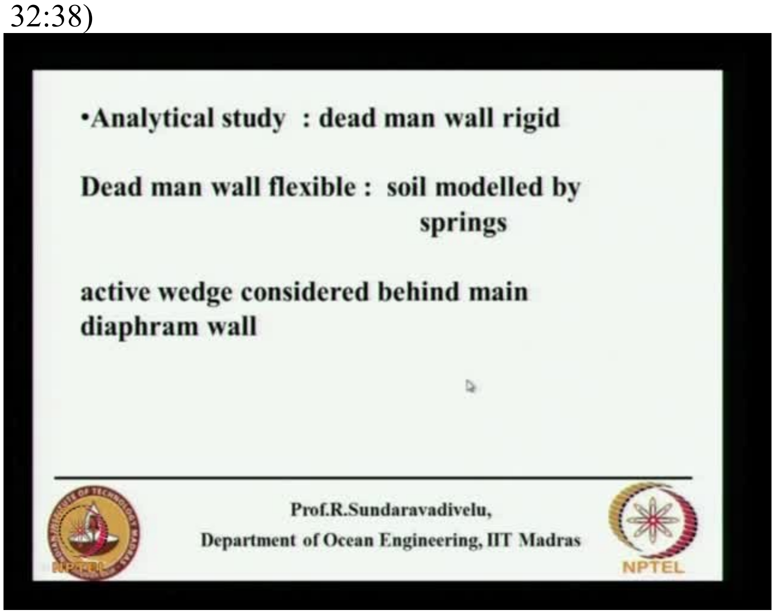

Then what we did is, we carried out two studies, analytical study. In one study we assumed, the deadman diaphragm wall is not deflecting, that is it is rigid. Another study, we assumed that the deadman wall is flexible. That means, the deadman wall also will deflect. That is modelled by springs. And again we consider the active wedge behind the main diaphragm wall to do the analysis.

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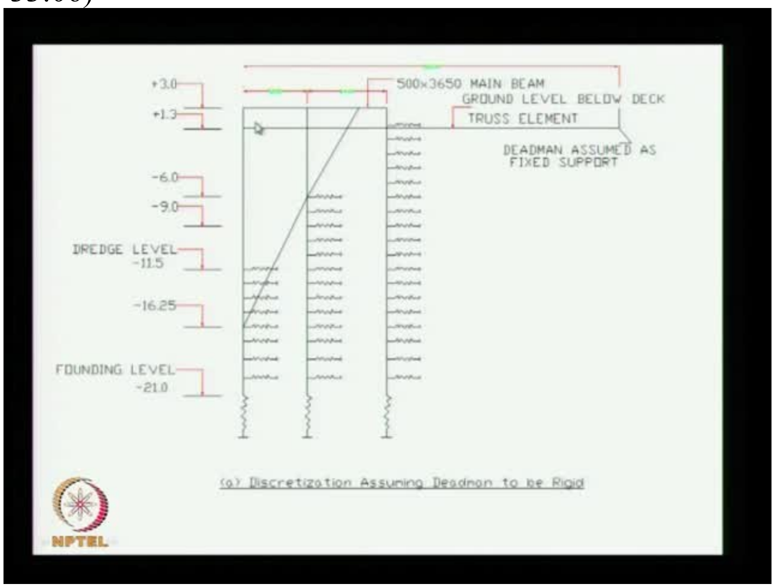

So we will see the discretization here. This is the finite element analysis which is carried out. This is your main diaphragm wall, 1st row pile, 2nd row pile. Here we have the deadman wall. This Deadman wall is assumed to be fixed in one analysis. This is the central line of the beam, plus 3 months is the level of the tie rod, plus 1.3.

This beam is very deep, the depth of the beam is 500 x 3650 millimetre. 3650 millimetre means it is height of this room, 3.65 metre. That is the depth of the beam. That is why we said, this beam will transfer the load to the piles also. I was talking about the active wedge. This is the active wedge behind the main diaphragm wall. So when you have an active wedge behind the main diaphragm wall, the Spring will start somewhere from here only.

Here, the Spring may have to start actually this active wedge is drawn here to take only this and there are some possibilities some forces will transfer here just about this point. But we can take from 16.25 also. This this is a point of research, where you have to take this active wedge line from here. It can be either taken from the dredge line or it can be taken from the point of (()) (34:36) or one third distance between the dredge level to founding level.

So that is why I have marked the line. If you take the active wedge line from here from the dredge level, then you can assume the springs like this and the spring will go slightly more. These are the springs.

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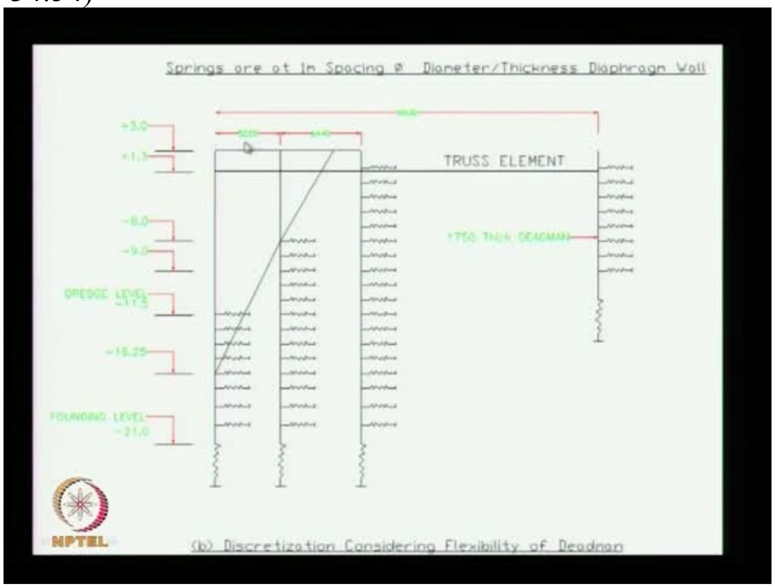

The next slide, you will see that we have put the Deadman wall here and then we have modelled this by truss element. The distance and between the main wall and the Deadman wall is about 30 metres. This is also calculated because there should not be a line of a influence between the Deadman wall and the main wall. That is why we have done this.

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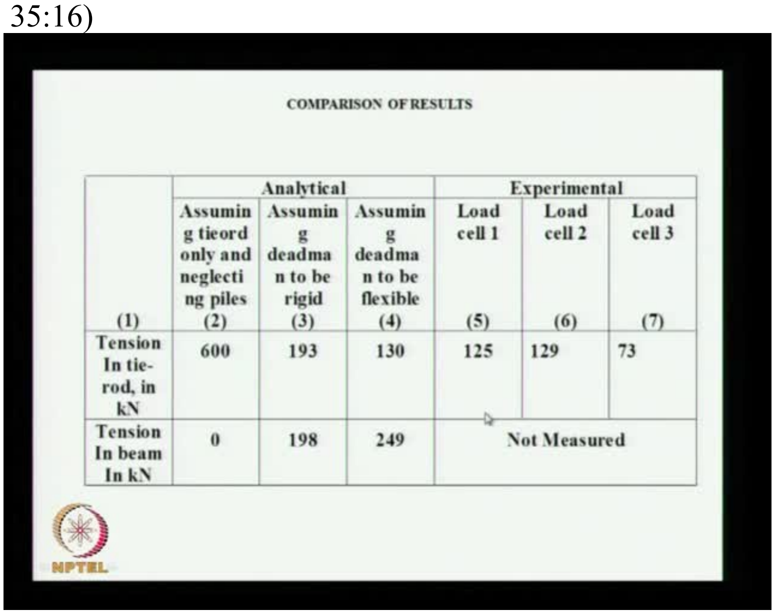

COMPARISON OF RESULTS

	Analytical			Experimental		
(1)	Assuming tieord only and neglecting piles (2)	Assuming deadman to be rigid (3)	Assuming deadman to be flexible (4)	Load cell 1 (5)	Load cell 2 (6)	Load cell 3 (7)
Tension In tie-rod, in kN	600	193	130	125	129	73
Tension In beam In kN	0	198	249	Not Measured		

Now we can see the comparison of results. We were expecting around 600 kilonewton. That is what is shown in the analytical design which is done originally assuming that tie rod only takes the lateral force neglecting the piles. The tie rod will take 600 kilonewton and the beam should take about 0 kilonewton. This is what is originally assumed. But finally when you measure, there are 3 tie rods which are measured.

The load taken by them is 125, 129 and 73. Only one fifth, one seventh of the load what it is supposed to take. And we did not measure what is the load on the beam because it is not possible to measure the load on the beam. The measured only the tie rod. And we have done two analysis. One is assuming the Deadman wall to be rigid, another is assuming the Deadman wall to be flexible.

So this flexible 130 kilonewton compares well with the measured values. That is, the Deadman wall is not assumed to remain rigid. It will also deflect along with that. Then the beams here, it is taking 249 kilonewtons, that means, the sum of these 2 is about 370 whereas we assume its rigidity is very close to 400 but what is originally assumed is 600.

That is the air pressure, root air pressure the load transferred to the tie rod is assumed as 600 kilonewton whereas actually the lateral force transferred is only about 400 kilonewton to the that Ben diaphragm wall is rigidand it is close to 370 kilonewton if it is assumed to be flexible. Okay, this analysis is what is carried out but you can actually infer this result by doing a very simple analysis.

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So we do in 2nd year or 3rd year or civil engineering course what is known as a consistent deformation method. I will not go into this detail. You can refer some studies and some textbook and see that. But somewhat similar to this, we can have this. Suppose, this is very important. There is a tie rod. When the force is 0, the elongation will be 0.

When there is no tensile force in the tie rod, the elongation will be 0. Suppose the force is 600 kilonewton, what will be the elevation?

Professor-Student conversation starts

Professor: There is a tie rod which is subjected to a tensile force of 600 kilonewton, what will be the elongation? What is the formula to calculate the elongation?

Student: PL by AE.

Professor: PL by AE. so PL by AE.

Professor-Student conversation ends

What is P here? P is 600, L is 30 metre, A is the area of the tie rod, E is Young's modulus of steel material. Area of the tie dod is pi D Square by 4, thy metre of the tile is 80 millimetres, 8 0 millimetre, L is 30 metre, so we can substitute in consistent units and find out what is the elongation required. Okay? But the holes, all the structures are connected. The diaphragm wall, the main beam, the piles, they are all interconnected. Tie rod is connected to the main diaphragm wall and Deadman diaphragm wall.

When this is elongating for 600 kilonewton, I do not know the value. Suppose this is going by about 60 millimetre let us say, then what happens is, when the main wall moves, beam also moves by 60 millimetre, the pile also will move by 60 millimetre. So the pile when it has to move by 60 millimetre, suppose there is a pile and you want to pull it for 60 millimetre, then you have to apply a lot of force.

That is what is transferred. That 249 kilonewton going by the beam is because the beam has to pull the pile also. That is how the load share takes place. Is it clear? The elongation of the tie rod plus the displacement of elongation of the tie rod should be equal to the displacement of the beams because of subjected load at the top. These 2 should match. Then only the load transfer will take place.

So because the displacement is to be same, you have to find out for the will displacement, what will be the elongation in the tie rod. For the same displacement, you can find out what is the load on the pile.

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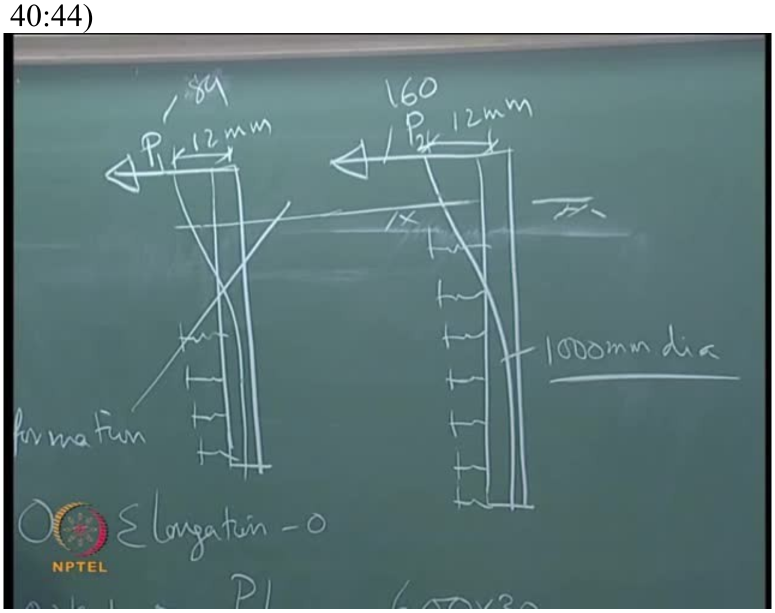

Suppose there is a pile here, the last row of pile, the bed level is here, the founding level is here, and this is pulled by some force P. There is some soil here which is resisting this. So the deflection of the pile which is 1000 MM millimetre dia can be calculated by doing a beam on elastic foundation theory. You can find out how much load is required deflect this by this will go like this. This deflection let us say about 12 millimetre, the elongation also 12 millimetre will be the same okay?

There are 2 piles. This is the last row of piles. There is another pile here but this is on the active wedge. This spring is here like this and here also you apply the load P but here also, this has to deflect by the same elongation of 12 mm. But this 1st row of pile load and 2nd row of pile load will not be the same.

Which will be more, P1 or P2? We have the 1st pile is in the active wedge. Deflection should be the same. 1st pile also should deform by 12 millimetre, 2nd pile also should deform by 12 millimetre, the tie rod should also deform by 12 millimetre, all of them will have the same deformation. Right? For 12 millimetre elongation the load taken by the tie rod can be calculated, P is equal to AE delta by delta L by L.

The other calculation is difficult that is for the pile. But the question what I am asking is, the beam is transferring 249 kilonewton. This 249 kilonewton will be shared by the 1st row of pile and 2nd row of pile.

Professor-Student conversation starts

Professor: Will it be equal? Hmm? Yes or no?

Student: No.

Professor: No. Which will take more load?

Student: 1st pile.

Professor: 1st pile or 2nd pile?

Student: 1st pile

Professor: Hmm?

Student: 1st pile.

Professor: That is wrong.

Student: P2 will take most.

Professor: P2 will take more.

Student: Because the active wedge moves away from it.

Professor: There is no active wedge for this. The spring is right from the bed level. There is an active wedge. There is no resistance for the pile here.

Professor-Student conversation ends

So 249 kilonewton, this P1 may take 119 or maybe 89 I will put. This will take about 160. Because this pile is having a lot of stiffness because the support is right from the bed level. Whereas this support is much below the bed level. So if you want, you need small smaller load than this to deflect it by 12 millimetres because this is thefree cantiliver line. Whereas thefree cantiliver length is only very small for this. So this is how you have to have some analysis of loads that are taking place but you can really get the details when you do analysis and get this information.

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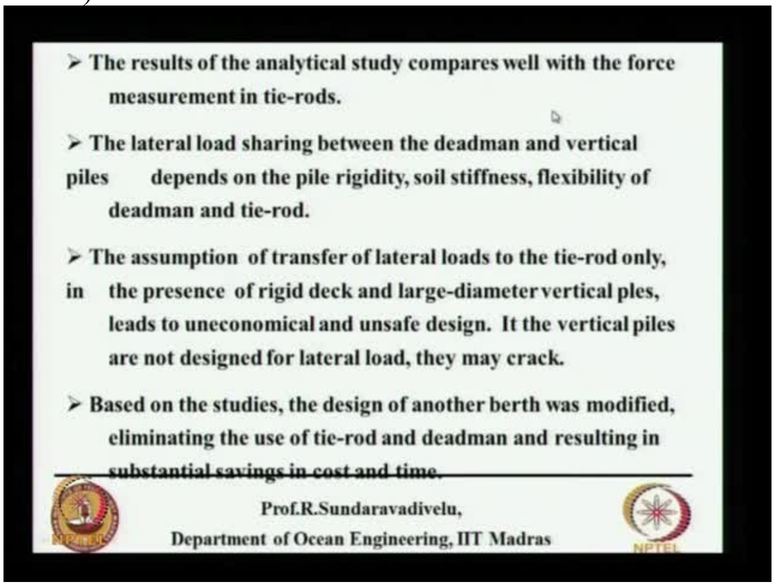

The results of the study compares well with the force measurement. The lateral load sharing between the deadman and vertical piles, this depends on the pile rigidity, soil stiffness, flexibility of deadman and tie rod. The assumption of transfer of lateral loads to the tie rod only in the presence of rigid deck and large diameter vertical piles leads to this is very important, it leads to uneconomical as well as unsafe design. Uneconomical means you are designing the tie rod for 600 kilonewton whereas it is taking only one fourth of that value, less than one fourth.

That means you are putting more tie rods. Instead of putting tie rods at one and a half Centre to Centre, they can put even at 4 metres Centre to Centre. That means this number of tie rods can be reduced. Similarly, the Deadman diaphragm wall also design can be reduced. This is more important, that is unsafe. Which is unsafe? We are assuming the pile is not taking the load.

If we assume the pile is not taking the load, pile will crack. Because you are not designing it for bending moment and reinforcement you are not providing, then the whether you design the pile for lateral load or not, the pile is taking the load. It will crack. But actually they have put over design, both pile as well as tie rod. It is not cracking. Whatever minimum reinforcement you provided, 0.8 percent it is found to be sufficient to take this load.

We have talked about 249 kilonewton, right? Actually we have tested a single pile for 450 kilonewton. It has taken the load. The capacity of the single pile, 1000 mm dia is about 450 kilonewton. Both the pile put together only is 250 kilonewton here. These are vertical piles, they have designed only for vertical loads. If they are not designing for lateral load, they may crack. Once they crack, the reinforcement will get corroded and failure will take place.

So what is the inference this? Based on the studies, we have designed another berth which was modified, we have completely eliminated the tie rod. We have removed the deadman also. We provided only one more row of pile. So at that time, the cost saving was about 20 percent another advantage is when you want to put the Deadman wall, you want to put the tie rod, it takes more time also. Time is money.

So we have saved the construction period from 24 months to 18 months because we did not have to provide the Deadman diaphragm wall as well as the tie rod. Instead we have to put one more row of pile. With that we are able to have substantial savings in cost and time. Time is money because 18 months you complete the berth and start operations. That six-month period, you can collect a lot of revenue also. That is how it becomes very essential to have the to save the time.

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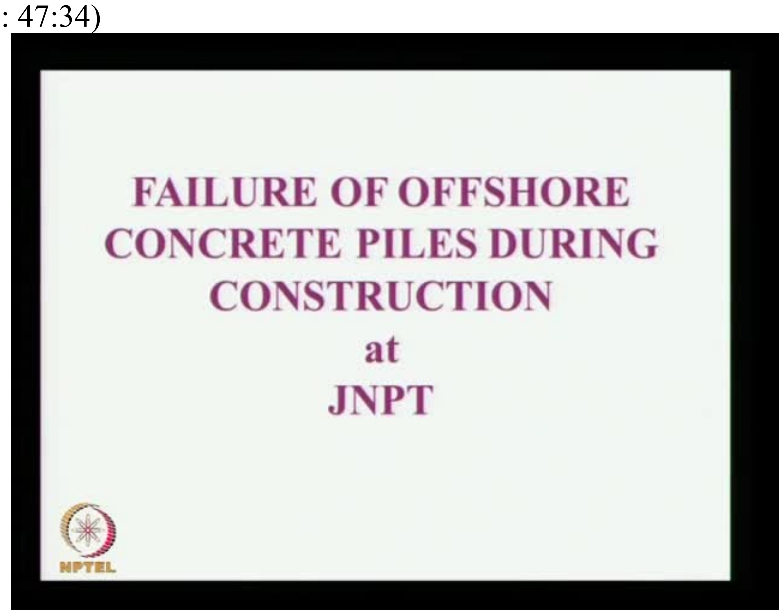

This is very interesting failure what we are going to see, this is normally not expected, that is failure of the piles during construction. Many structures which are failing, they are failing during construction period because of faulty design or construction. So I have shown in the 1st case study,damage to the Dolphin. This damage has taken place because of accident. Accident means the ship is not going through its own path.

It loses control or the captain is drunk. He is not piloting the vessel properly. The tugboat, he is not using properly. It is an accident. That accident can happen any time. Because of that accident, the force coming onto the structure is more than the designed force, because of that it fails. Because the structure is subjected to a force more than the designed force. That can happen any time.

Whereas if there is a fault in the design, or fault in the construction, and in 99.9 percent, the failure take place just during construction or slightly after construction is completed, 1 or 2 months after construction is completed. This is what is happening. So you should be very careful during construction and if there is no failure taking place during construction or just after construction, mostly the structure will be very stable. There may not be any failure to the structure. Most of the cases.

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This happened at Jawaharlal Nehru port trust. This is one of the most modern port in India. This was then somewhere in between 86 to 90. This is the biggest container terminal as on today in India. This is handling about 4 million TEU, that is 20 foot equivalent units, 4 million TEU. It is a of the here and here and here this cargo share is about 70 percent of Indian container terminal is in Jawaharlal Nehru port trust.

This is during construction of the bulk berth but subsequently this bulk berth also is now converted into a container berth. You see here, there are a lot of floating equipments. There is no access to the land. These are the piles which are driven. Then they put the concrete deck. These are the liners which are driven by another vessel. So the construction is like this. There is one floating barge here doing the deck construction.

There are some support vessels to transfer the cement and concrete. There is another floating barge with the crane facility to drive the liner. The liner is driven by one floating barge, the concreting is done by another floating barge. They are continuously driving the liners here like this. Right? About 50 percent of the liners are concreted, 50 percents of liners are driven.

On one particular day, some of the liners have fallen down. And some of the concreted piles somewhere here which is not connected with the deck, here it is connected with the deck, that is also fallen down. It is during construction, the construction company has told that we will do the we will whatever liner has got tilted, we will remove it and read it. The pile which is fallen down also, they said they will remove the pile. It has fallen down, completely fallen down and they will replace it.

But the administration is worried whether the piles which are already driven with the concrete deck which has not fallen, whether it is intact or otherwise? They also want to know why some piles have fallen down, some piles have got tilted. Liner tilting or liner falling, they are not very much worried. There are 2 concrete piles which have completely got damaged. So they want to know know the reason. So here, it is much more difficult to find out the reason.

So we have to do 3 different types of studies. This is very important. Whenever somebody wants to design any structure, if he is an expert in structural engineering, that alone is not sufficient. We have 3 disciplines which are very important whenever you do the design of structures.

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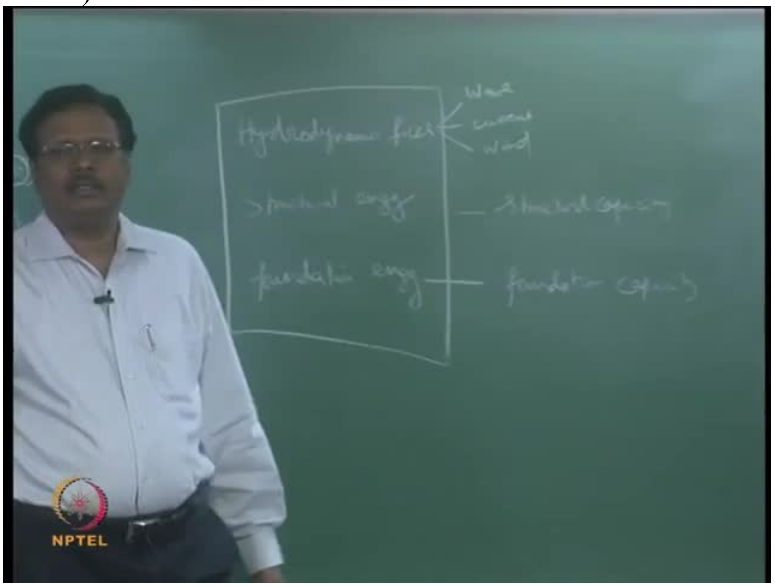

One is, you have to estimate the forces on the structure. This is hydrodynamic forces. Then we need the structural engineering to find out how the forces are transferred to the pile. Then we also need the foundation engineering. This port and harbour structures itself is a specialised field. And we should study these 3 aspects. One is, what is the force coming onto the structure due to hydrodynamic forces? These forces can be due to wave, this can be due to current, this also can be due to wind.

And this may act alone or this may act together. This may act in 2 different directions also. Suppose you I will assume that this water bottle is the pile. Wave can come from this side, current can come from this side and wind can come from another side. So these 3 can be from different directions. That is also there. And water level varies. Okay? Water level varies with reference to the tide. That also will change.

Then this structural engineering, this this is not sufficient if we know what will be the capacity of the structure. How many days are required for a concrete to obtain the strength? Hmm? Suppose we say M 30. M 30 means what?

Professor-Student conversation starts

Professor: What is meant by M 30?

Student: 130.

Professor: Hmm?

Student: 130 days.

Professor: 130 day. What is M 30?

Student: Grade of concrete.

Student: Compressive strength.

Professor: Grade of concrete. What is 30?

Student: Characteristic of compressive strength.

Professor: Compressive strength of what?

Student: Concrete.

Professor: Concrete means what concrete?

Student: (())(54:57).

Professor: Characteristic will come later. Compressive strength of what?

Student: Hardened concrete, sir.

Professor: Hmm?

Student: Hardened concrete.

Professor: Hardened concrete of what size? Hmm? What size? You have to take the cube.

Student: (())(55:12)

Professor: yes.

Professor-Student conversation ends

We have to take a cube of 150 by 150 by 150. In US, they take a cylinder. This is the characteristic compressive strength of a cube after 28 days of strength. Okay? This is called as the compressive strength. Characteristic comes because of the standard deviation and I will not go into detail. That is after 28 days, the strength will be M 30. That is what we assume for the design purpose.

Professor-Student conversation starts

Professor: What happens to the strength of concrete after one year? Will it be more or less?

Student: It will be more.

Professor: After 5 years?

Student: (no reply)

Professor: Generally after one year, the strength increases to 20 percent. Afterwards, it remains almost constant. It does not increase further but if there is some chemical attack or some chloride attack, the concrete strength will come down. Right? Age factor is there. 28 days, if you have M 30, after one year, you may have 36 kilopascals, 36 megapascals.

Professor-Student conversation ends

M30 compressive strength of concrete cube is equal to 30 megapascal. But this failure of the pile has taken place before 28 days, not after 28 days. That means you should know the behaviour of the concrete from 0 to 28 days. So in structural engineering, we always do the design after 28 days. That is not sufficient. We should know the behaviour from 0 to 28 days. Then this foundation engineering, generally it is the, there are 2 capacity of the pile.

One is the structural capacity, another is the foundation capacity. See when you apply a lateral load on the pile, the structural failure takes place. The concrete and reinforcement will fail. Foundation capacity failing means the soil will yield and the pile will fall down. Concrete will be intact. Is it clear? The lateral load what you are applying to a pile, it will be transferred to the soil if the structural capacity of the pile is adequate.

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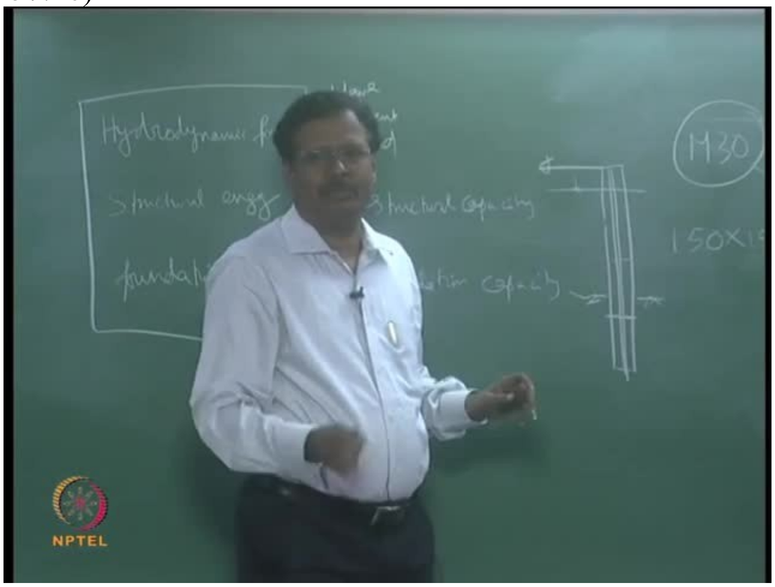

If the foundation capacity is not adequate, suppose there is a pile, it is a freestanding pile. This is your bed level, this is your water level. you apply a load like this. Suppose you put the pile only here, you stop the pile here, there is no sufficient embedment depth. Then the whole pile will fall down because of inadequate soil capacity. Suppose you put the pile very small, very small diameter pile. Instead of 1000 mm, you put 150 mm and apply the load the pile will somewhere crack like this and pile will fall down. It is it clear?

Structural failure means the pile concrete will fail and foundation failure means the pile whole pile will fall down because we did not provide sufficient embedment depth. This is your embedment depth. In this particular case, both the failures are observed. Foundation failure also is there, structural failure also is there.

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This is the place which is from where we take all these barges and other things. So I am sitting here (laughs) and I am observing the 2 piles which have fallen down. These are the 2 parties which have fallen down. This is a liner, this is the concrete. Some of the piles were bent like this, and here, there is no bending in the reinforcement. It remains the same.

But some of them have got snapped. You have seen the failure? This is a combination of both structural and foundation failure. Structural failure means it has cracked here. That is why there is a structural failure. Foundation failure means, the cause for the structural failure is due to foundation failure which I will explain later.

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You can see a close up view of these piles how it has bent and how the concrete has got damaged.

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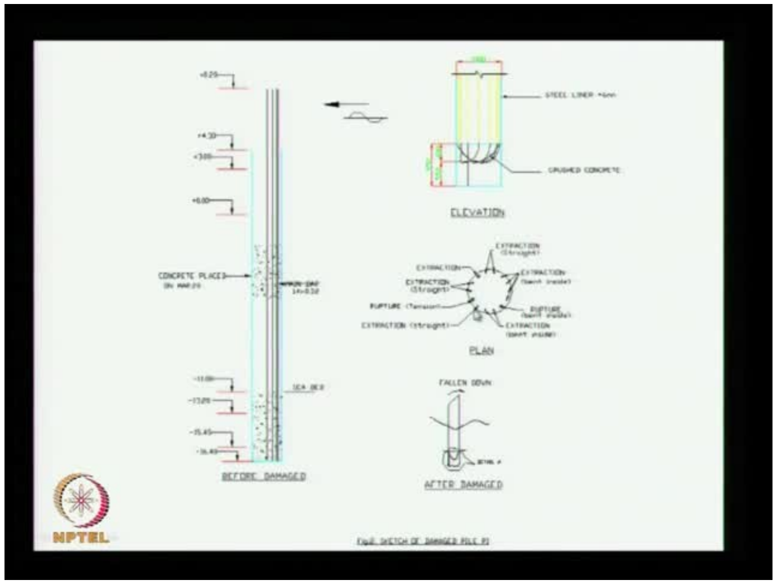

So this is how the failure has taken place. Here we have marked, there is extraction of the reinforcement. It is straight here. This is bent here. This also bent and here there is an extraction, there is a straight rupture, there is a straight pile here, there is a tension rupture here. That means, this side of the pile is subjected to tension, this side is subjected to compression. At the founding level, the surface of the concrete is something like this.

With this, the pile has fallen down and below this, it is still in the foundation itself. It is in the soil itself. Some portion has fallen down, still some portion of the pile is below.

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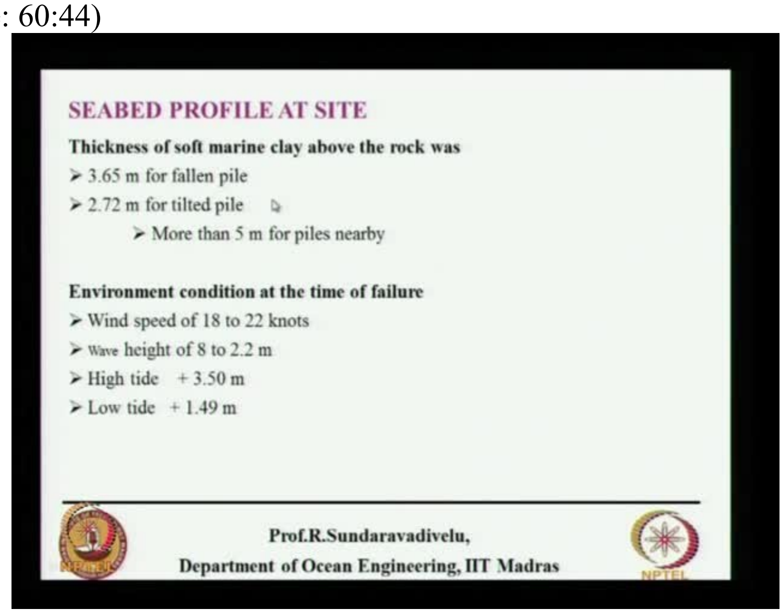

This thickness of soft marine clay, there are some piles which have fallen down, some pile which has not fallen down. You have to find out the reason why some of them have fallen down, some of them have not fallen down. This is mainly based on your soil profile.

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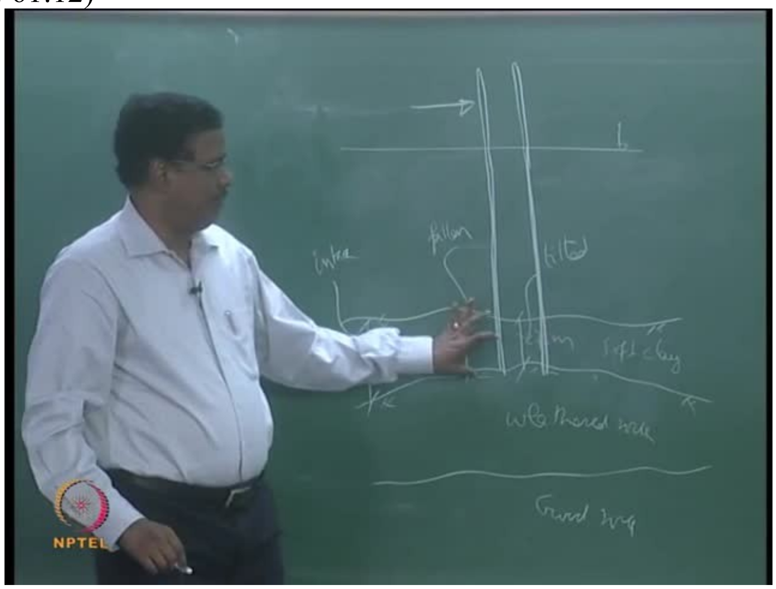

This water level is this. Your bed level is something like this. Then we have some level going like this. This is soft clay. Then we have weathered rock. Then it goes like the then we may have a good rock like this. So this depth are places where the piles have fallen down. This is about this depth I will take. This is about 3.65 metres where the concrete pile has fallen down. Where the liners have got tilted, is about 2.72 metres.

Where there is no failure that has taken place, it is greater than 5 metre. So here the piles have fallen, here the piles have got tilted, here the piles are intact. What normally they do is, they put a liner, they stop the liner just they when they touch the rock. After which, they will not take the liner into the rock. So when there is a load, this liner is right up to the top.

So when there is a load acting on this, if this embedment depth is not sufficient due to the load because we have 3 stages of structural behaviour of pile.

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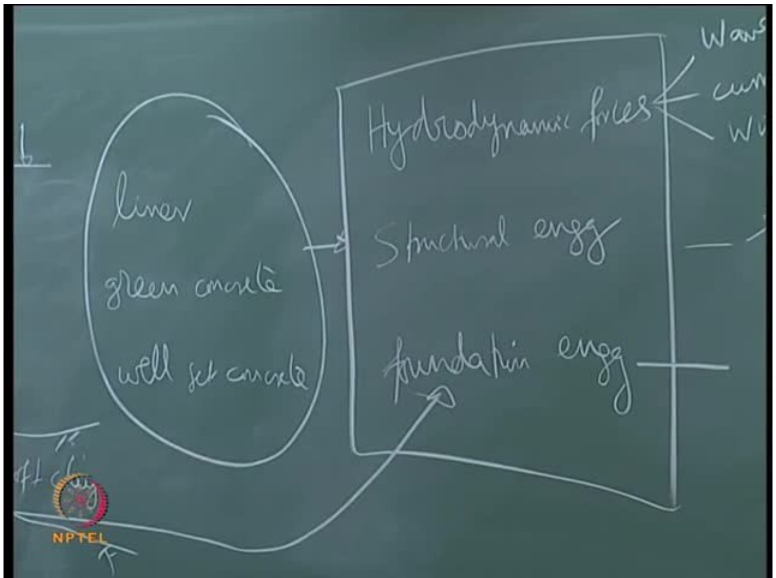

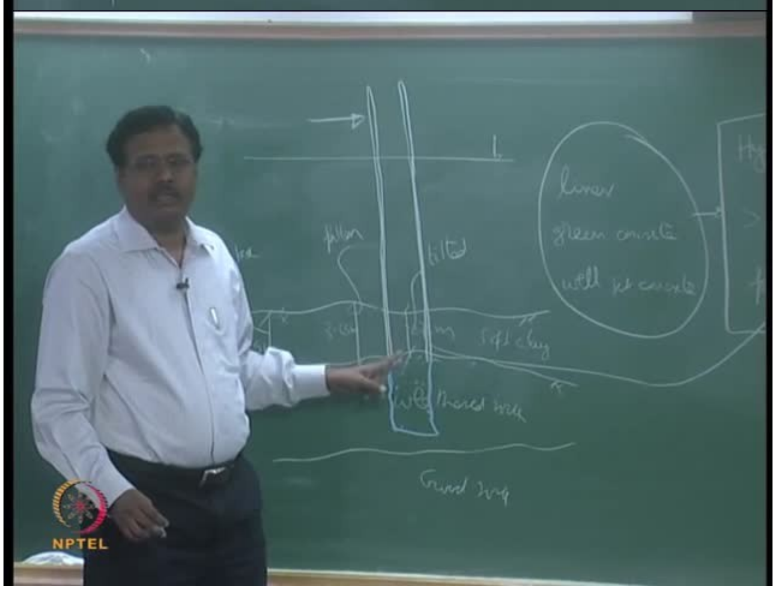

The 1st stage is only liner, another is green concrete, the 3rd one is well set concrete. So this is your cultural behaviour, this embedment depth is your foundation capacity. So we have 3 cases here. Only liner when there is no concrete inside, embedment depth is smaller, liner will tilt. Then you have a green concrete. It has not attained its strength. Green concrete means you have the concrete going below this level. It will go sufficient depth.

If this concrete what is going inside if it has attained well set, this pile will not fail. Before it is attaining the strength and still it is in the green concrete stage, then it may fail. Sometimes even if the depth is not sufficient what they have provided, we have found even well set concrete will fail. So the 1st thing, what is this hydrodynamic forces? So that only has to be estimated.

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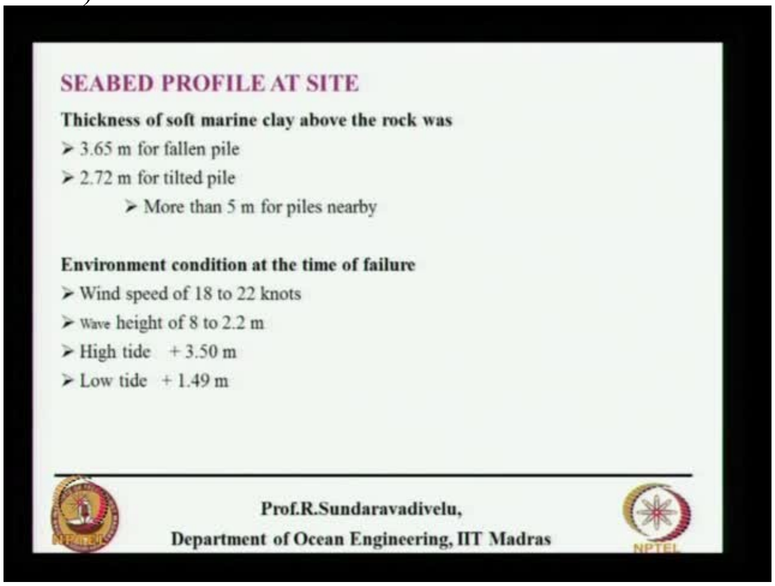

On that particular day, the wind speed was 18 to 22 knots, wave height is there is a typing mistake, it is 0.8 to 2.2 metres, high tide is plus 3.5, low tide is 1.49. Normally, we do not assume about 2.2 metres for the design purpose. The wave height is significantly higher. But there are certain possibilities which they could have done to avoid the failure.

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One of them is when you construct this liner like this, they should embrace the liner at the top. Suppose there are 4 rows of piles, the cross-section and number of rows in the lateral direction, they have to connect the pile in both the directions. In that case, it will not act like a single cantilever pile. That if they have done, the failure could have been avoided because only during construction phase we found that design is insufficient because of the liner capacity not sufficient and the foundation capacity also being not sufficient. They did not do that.

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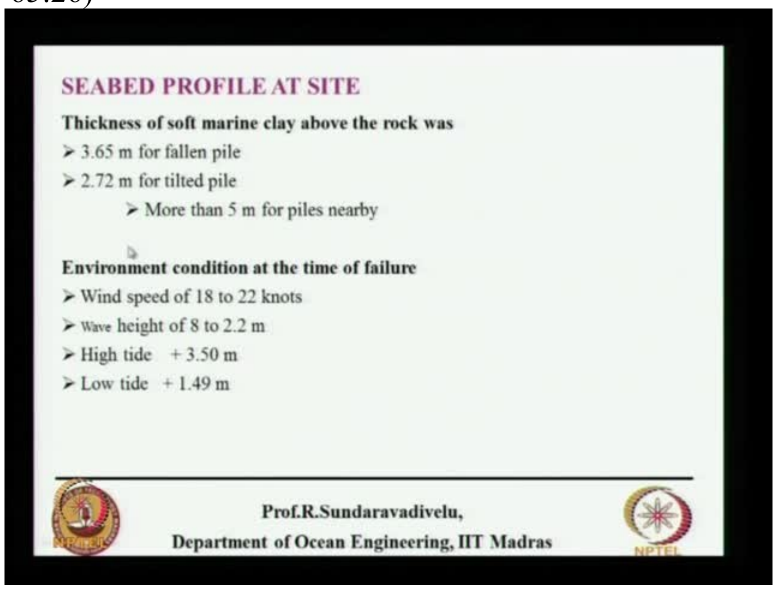

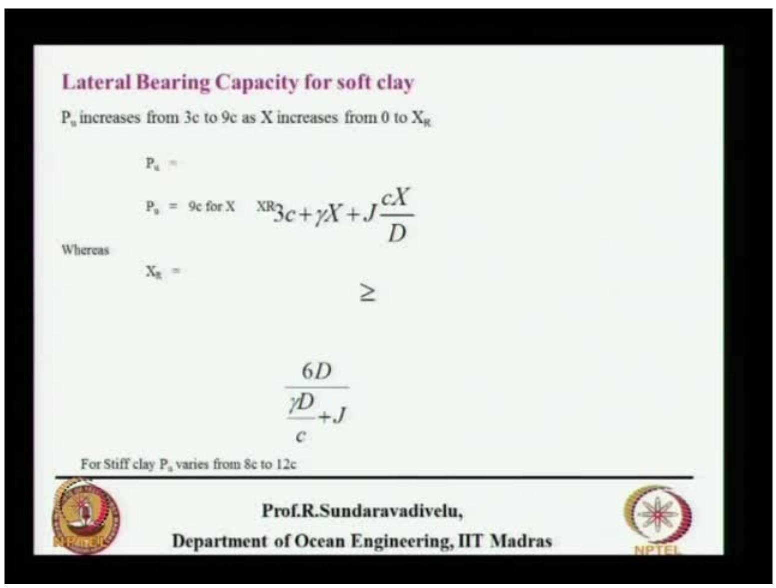

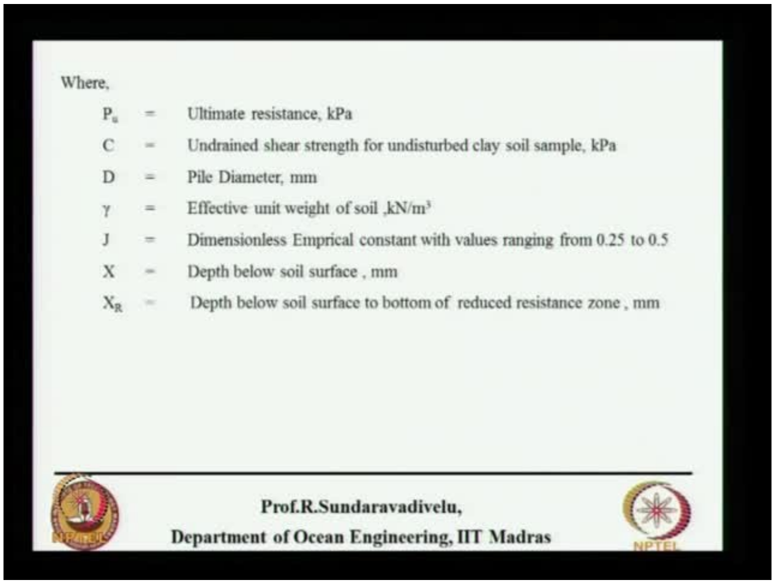

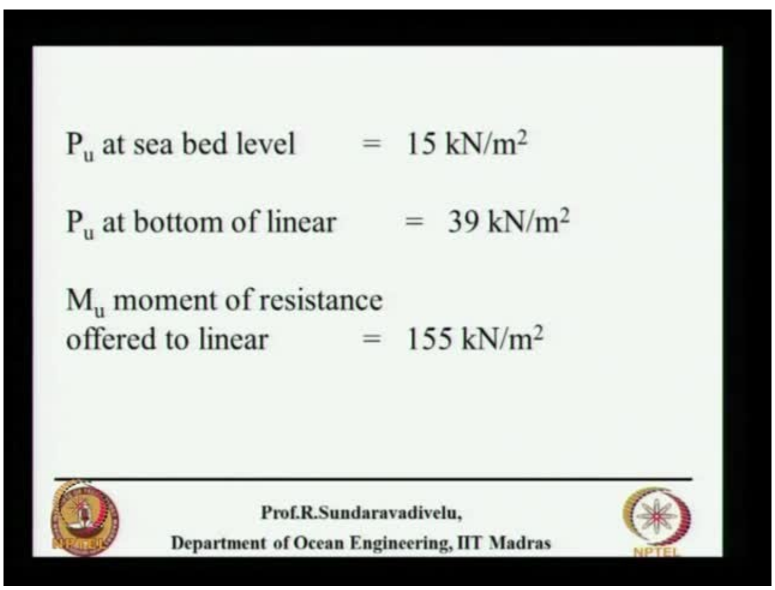

So we have to estimate the force due to this accurately assuming the direction of the current as I explained earlier. Then they have to estimate the lateral capacity of the soft clay. Then they also have to estimate, this is how they have to estimate at sea bed level, at bottom of the liner, what is the moment of resistance, all these things they have to calculate.

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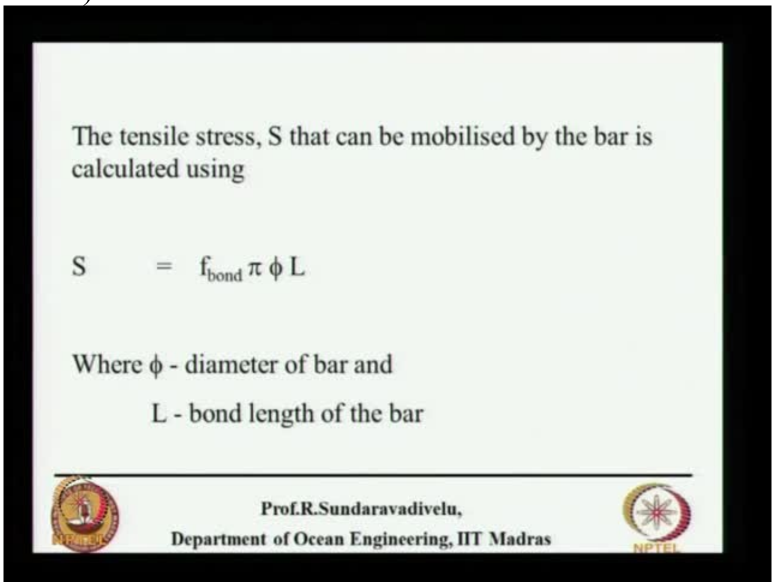

Similarly they have to find out the bars as you have seen in the photograph. Some of them have come out of the concrete. That failure is because there is no adequate bond between the reinforcement bar and the concrete. The failure is not any other type of failure. It is mainly the reinforcement is not having adequate bond strength with the concrete because the concrete is green. So we can use this expression to calculate the bond strength.

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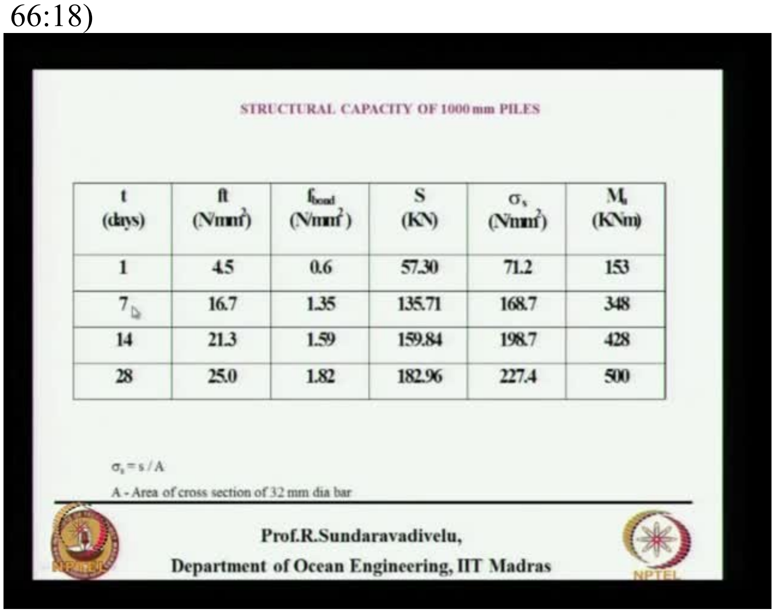
STRUCTURAL CAPACITY OF 1000 mm PILES

t (days)	ft (N/mm^2)	f_{bond} (N/mm^2)	S (KN)	σ_s (N/mm^2)	M_u (KNm)
1	4.5	0.6	57.30	71.2	153
7	16.7	1.35	135.71	168.7	348
14	21.3	1.59	159.84	198.7	428
28	25.0	1.82	182.96	227.4	500

$\sigma_s = s / A$

A - Area of cross section of 32 mm dia bar

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So this is how we calculate for 1 day, 7 day, 14 day, and 28 day, what will be the bond strength? What will be the moment of resistance in kilonewton meter? So 153, 348, 428 and 500.

Actually,on 28 days, some of the piles are having adequate capacity against the load what is happening. But between 1 and 14 days, the capacity is less. So this is what you have to calculate.

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NATURAL FREQUENCY OF PILES

Sl.No	Particulars of the pile	Period in secs.		Frequency (Average) in H_z	
		Parallel to the berth	Perpendicular to the berth	Parallel to the berth	Perpen-dicular to the berth
1	1200 mm diameter pile (braced parallel to the berth)	0.47 0.47 0.51 0.52	0.66 0.65 0.69	2.03	1.49
2	1200 mm diameter pile (unbraced)	0.85 0.82 0.80	0.85 0.77 0.77	1.22	1.25

Then again we have to calculate the natural frequency which I have told earlier. See subsequent to the failure, we asked them to brace all the piles. So they have braced the piles parallel to the berth, not perpendicular to the berth. Then parallel to the berth, we have higher frequency where stiffness is higher. Omega is equal to root of K by M. Perpendicular to the berth, the frequency was lower.

This is for a larger diameter pile, this is one 1200 pile which is unbraced, so here Omega is equal to root of K by M the stiffness is small because it is unbraced. Here, frequency is higher because it is braced. Even if it is braced in the parallel direction, perpendicular direction it has some effect whereas if it is not braced in both the directions, the frequency is much smaller compared to this.

Only one half of this bracing. So you see the effect of bracing. If you brace it, the frequency increases. That much stiffness it is giving.

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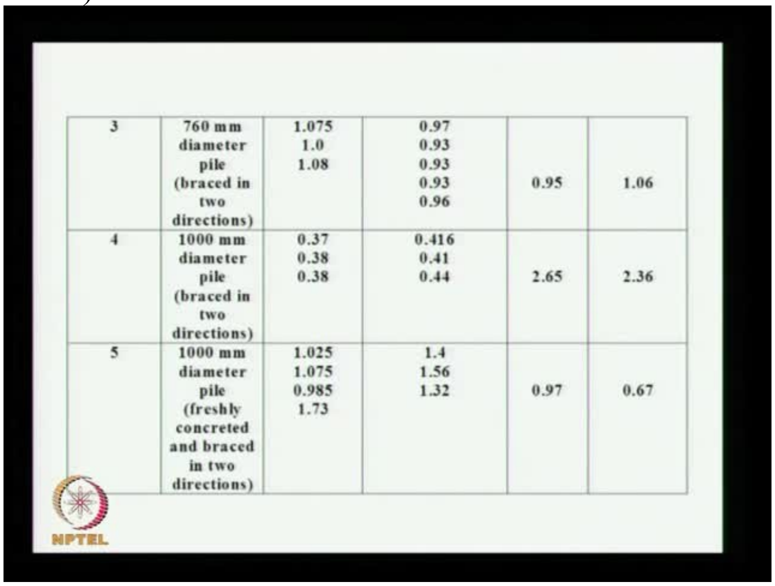

3	760 mm diameter pile (braced in two directions)	1.075 1.0 1.08	0.97 0.93 0.93 0.93 0.96	0.95	1.06
4	1000 mm diameter pile (braced in two directions)	0.37 0.38 0.38	0.416 0.41 0.44	2.65	2.36
5	1000 mm diameter pile (freshly concreted and braced in two directions)	1.025 1.075 0.985 1.73	1.4 1.56 1.32	0.97	0.67

This is a smaller diameter pile braced in both the directions very close to 1 hertz and this is braced in 2 directions, 2.65, this increases because of the diameter. 760 diameter, thickness will be smaller compared to 1000 diameter. When it is freshly concreted thickness will be lower. You see this 1000 mm diameter pile. These are all braced, this 1000 mm diameter and 1000 mm diameter, both are braced but this is with fresh concrete whereas it is well set.

So when the concrete is fresh, the frequency is lower. The inference is, when it is well set, the frequency is almost 2 and a half times that of not well set.

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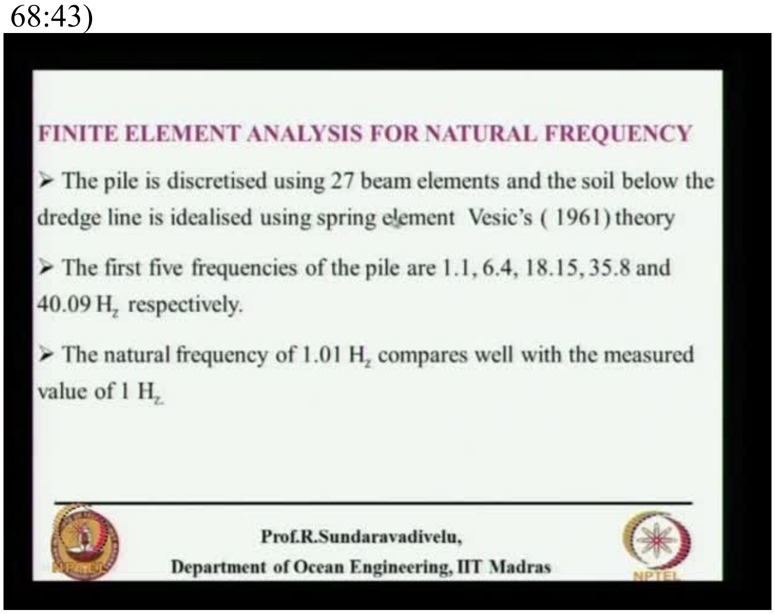

So we have done an analysis also using spring element and found out the 1st 5 frequencies. And whatever for this particular pile, what we have obtained by analysis is same as the measured frequency.

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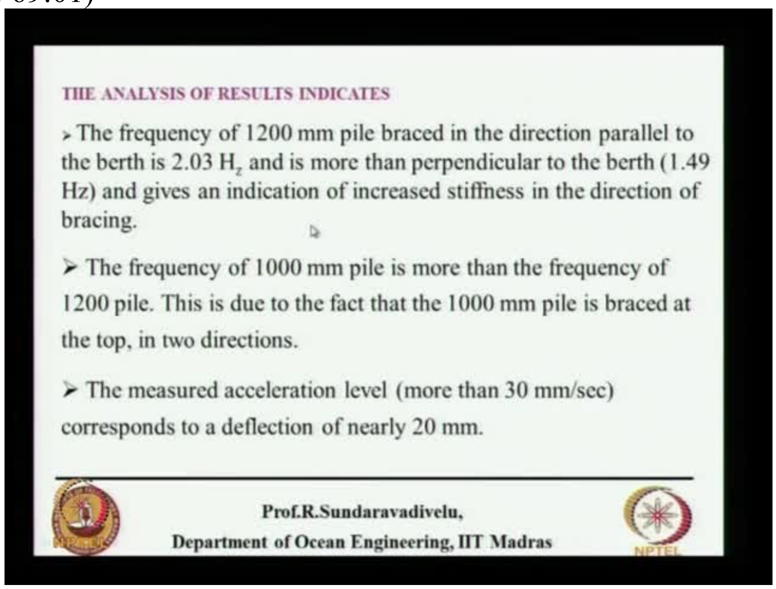

So the inference again I will tell, the 1200 mm pile braced in the direction parallel to the berth is 2.03 hertz and is more than perpendicular to the berth 1.49 hertz and gives an indication of increased stiffness in the direction of bracing. The 2nd conclusion, I will leave it because…

The 3rd one is the measured acceleration level is more than 30 millimetre per second, this corresponds to a deflection of nearly 20 mm. Last class I said, if we integrate acceleration to velocity and velocity to deflection, we have got the deflection of nearly 20 millimetre. This is not by pulling with tugboats and all. The 1st slide I said, we push the tug and all. Here, we did not do anything.

For making the measurement, whatever waves are there at that time, maybe half a metre or 1 metre, that is giving sufficient sensitivity to the accelerometers to measure. Even at that stage, this deflection is 20 millimetre, not due to any pulling or pushing. It is just natural environment gives so much of deflection.

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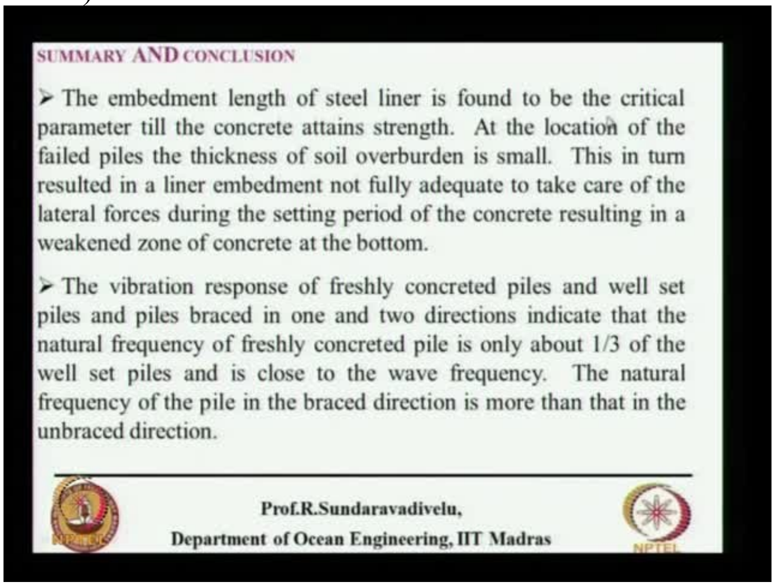

The conclusion. The embedment length of steel liner is found to be the critical parameter till the concrete attains the strength. Once the concrete attains the strength, full length of the embedment below the seabed level can be taken. Till such time, only the liner embedment is required. At the location of the failed piles, both tilted and fallen, the thickness of soil overburden is very small. If we see that the rock is coming very close to the bed, we always have a impression that it is very good.

Actually, it is not good for this type of construction because the embedment depth of liner becomes smaller and it fails. This in turn resulted in liner embedment not fully adequate to take care of the lateral forces during the setting period of the concrete resulting in a weakened zone of concrete at the bottom. So when this adequacy is not there, the green concrete is subjected to lot of oscillation and it fails. The vibration response of freshly concreted piles and well set piles and piles based in 1 and 2 direction indicate that the natural frequency of the freshly concreted piles is only about one third of the well set piles and is close to the wave frequency.

This is another thing which we have found. So when the freshly concreted piles because the mass is more, Omega is equal to root of K by M. Mass is more, the frequency also comes down. Because of this reason, the frequency is only one third of the well set piles and this frequency is very close to the wave frequency. That means you will have lot of resonance. The natural frequencies of pile in the braced direction is more than that in the unbraced direction.

So that shows the effectiveness of the bracing.

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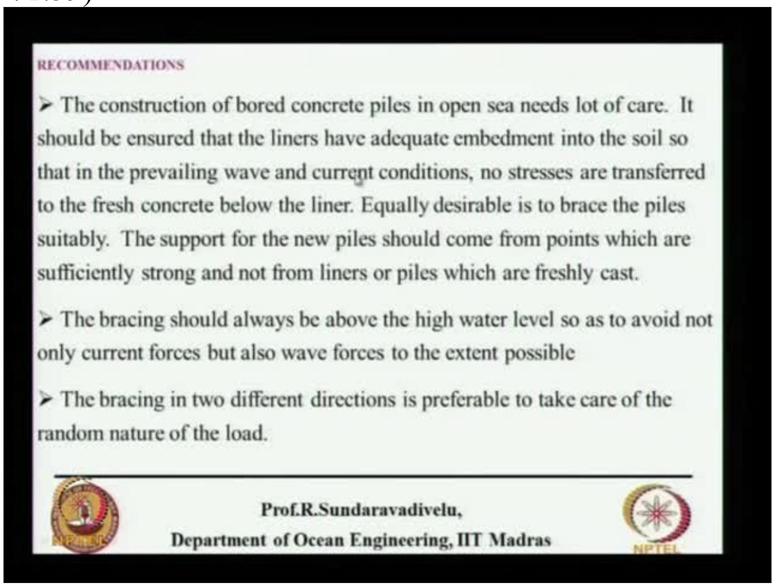

So this type of piles in open sea, it needs a lot of care. It should be ensured that the liners have adequate embedment into the soil so that in the prevailing wave and current condition, no stresses are transferred to the fresh concrete below the liner. Equally desirable is to brace the piles suitably. The support for the new piles should come from points which are sufficiently strong and not from liners or piles which are freshly cast. So when you want to brace, you do not brace with another pile which is also fresh.

You should brace it with a pile which is already strong. The bracing should always be the above the high water level so as to avoid not only current forces but also wave force to the extent possible. Which level you have to put the bracing. You should not put it very close the low water level. It should be above the high water level. Otherwise what happens is, this wave and current forces act on the bracing, that also is transferred.

And the bracing in two different direction is preferable to take care of the random nature of the load. The base and current can come from any direction. So it is better to provide the bracing in both the directions.

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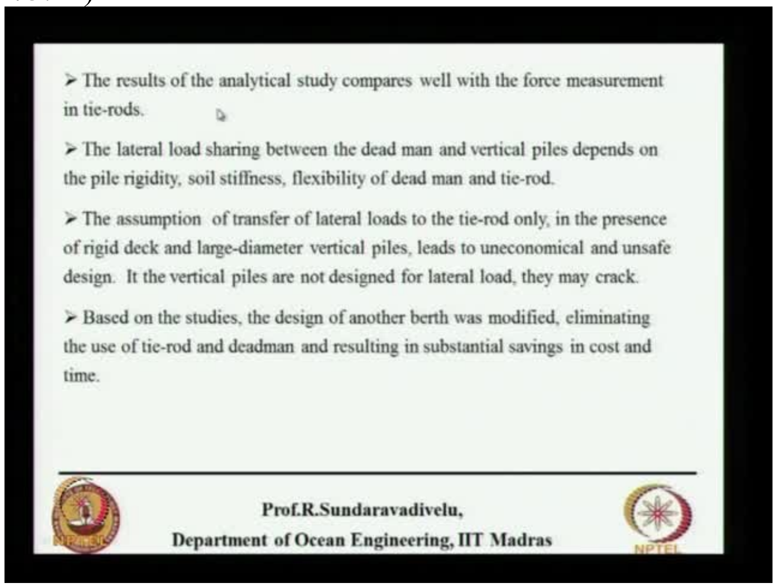

So our analytical study compares well with the force measurement. I think this is for some other okay with this we will close this lecture, thank you.