Wave Hydro Dynamics

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Module No. # 06

Wave Theories and Testing Facilities

Lecture No. # 03

Hydrodynamic Testing Facility at IITM

Today, we will look at the developments of hydrodynamic testing facilities in IIT Madras, that is in the department of ocean engineering.

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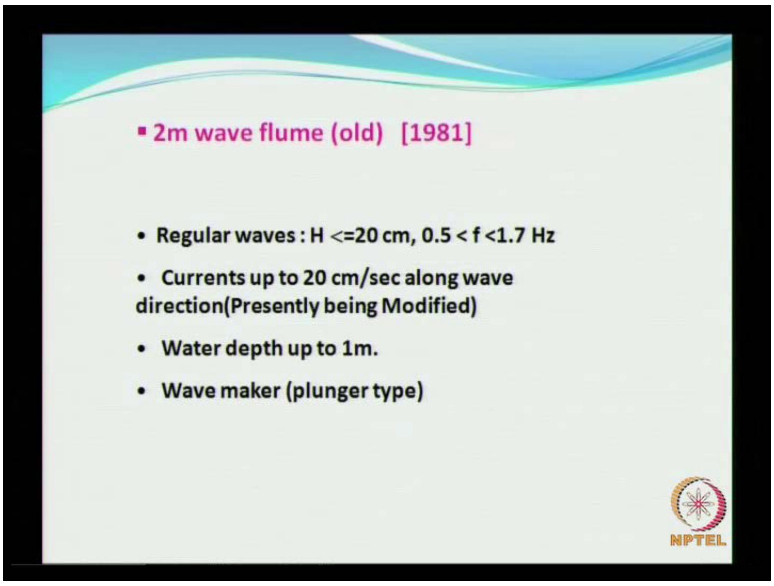

So, I will initially we had a 2 meter wide wave flume 30 meter wide; and the depth of the flume was 3.5 meters, with a wave maker on one end; a simple plunger type wave maker which can move up and down; and based on which it can generate waves height up to about 20 centimeters; and the frequency was ranging between frequency of the waves that could be generated in the flume varied between 0.5 and 1.7 Hertz.

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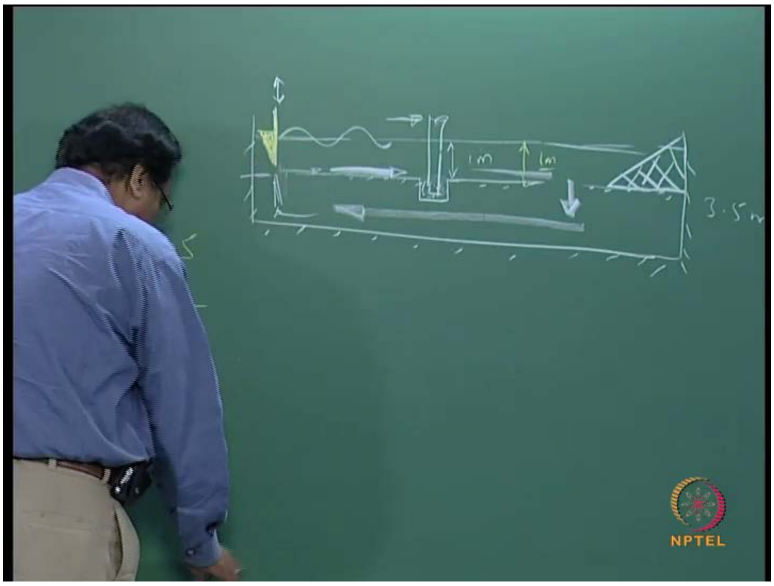

So, later you will see that we we will see the cross section of the flume, wherein under since the flame is was three and a half meter long deep. What we decided was to have a false bottom, and so that the water depth now in this case will be around one meter say. So, this bottom of the flume will serve as a reservoir for you have a suction pipe; the water will be sucked in with a motor and the delivery will take place here.

So, the wave maker here will be moving up and down to generate the waves. Now this is going to be your new false spot. So what will happen, the current will be generated in the direction of wave propagation. In addition, you also have a deep pit here that is filled with soil, sand, etcetera, so that if one is interested in doing some tests with a structure may be a pile, soil structure interaction or may be is cover under a structure etcetera, plus your wave all this thing can be done in this tank.

In addition to the combined the loads due to the combined effect of waves and currents on the structure. So, this was the concept, so of course, we had a wave observer on the other end. So, this current this will be acting as a sink so this is going to serve as a reservoir. Now, you have understood, how a flume has been converted; initially that was planned for generating ocean waves alone in the laboratory has been converted to a current interactive facility. But initially, when we had the limitation of your wave maker is fixed in the sense, the frequency of the wave that can be generated is fixed, because of the characteristics of the plunger.

But you know that d by L is the parameter, which controls the characteristics of the wave or the classification of the waves, for example, it is less than 0.05 you say shallow water waves and in between 0.05 and 0.005 and intermediate waters, and then if you say 0.5 you say it is deep water waves, in such a facility you can still consider. You will be in a position to generate both deep water waves as well as the intermediate water waves without much of a problem it more although, you will be covering mostly this range be still be able to reach this limit for a certain combination of the water depth and because in this case the water depth was is more or less fixed as 1m, it is almost a constant water depth. But the facility you cannot have all the things in one facility. To start with to begin this was a better way, this could generate only the regular waves, no random waves.

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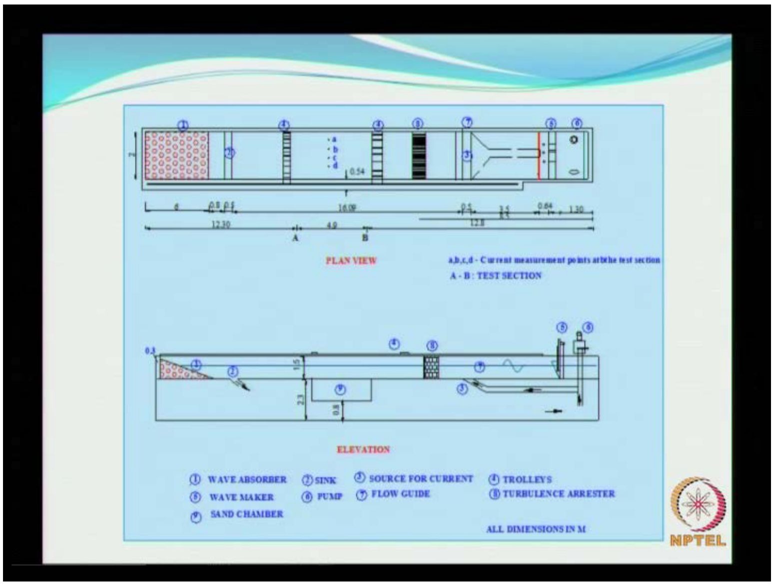

So, what I have explained here is shown here, so you see that this is a reservoir, this whole thing is the reservoir, this is the original bottom of the flume the whole thing, and this is the side walls, and this is the pump for generating the current, so you have the delivery pipe, so which juts the water inside the water inside the flume and this is the water depth so you see the waves moving. And you have you have the plunger here going up and down. So this is a screen to an order to stream lines the propagation of waves; and then here is the pit which I was mentioning, and then this is the place where you have the sink. This is the sink for the reservoir. So you have a circulation system for the currents.

So the top one is the plan, so you have the screen here then you have a diffuser for this for the currents, so that you have a some kind of a uniformly distributed current although it is quite difficult to achieve. But still we can sort of a obtain a reasonably current, and then this is quite this was quite useful for calculating I mean for a carrying out all the tests with the wave, soil structure interaction. As I said earlier it is only a plunger which used to move up and down.

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This was the earlier flume, where please remember that this was installed as earlier as 81, and this was the first facility wherein we could get some exposure to the feeling of generation, and also generation of a regular waves, and also trying to understand the how to carry out the experiments with regular waves. So these are some of the tests done carried out, where you see that there is a test that is being taken that is being conducted to verify the stability of a rubble mound breakwater, here the ship motion studies are being carried out, and this is another flume, which was…

Then later after a few years in mid nineties, what was decided is this had to be removed, because we wanted to test structures subjected to random waves also. Since, we have gained enough experience with handling regular waves, we wanted to remove this and have a random wave maker I mean, so this was a wave maker which was installed in mid 90s that can generate that can generate both regular and random waves. Here you see some flume studies, so here the structure is placed wherein the forces are being measured on a pile, a large diameter pile; and here again similar kind of study is being carried out.

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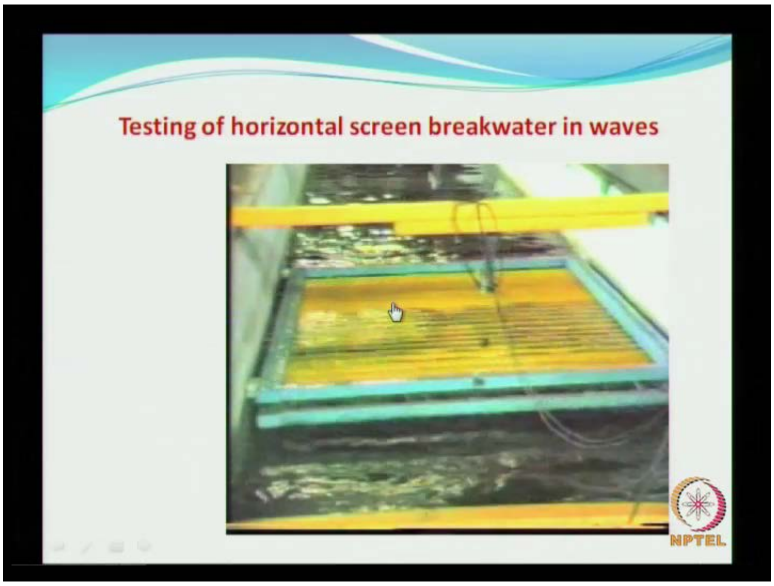

So, this is another test that is being carried out, wherein the test involves the characteristics of a floating breakwater, wherein the waves are moving in this direction, it is anchored but what we are trying to measure is the mooring forces on the on mooring lines, the forces on the mooring line and also see look at the floating breakwater, which is formed by pipes. The reason is when you have pipes here, you have a porosity being created, and this is going to allow the waves to penetrate through the porosity thereby dissipating the energy. Floating breakwaters are useful mostly, when we want to create a calm area in the ocean for carrying out a specific task for over a short duration of time.

So, this was a study at this, here we use what is called as a pulley system to measure the motions of the structure as well as use load cell for measuring the forces on the mooring line. I will not go into the details of these studies but such studies have been carried out using this flume.

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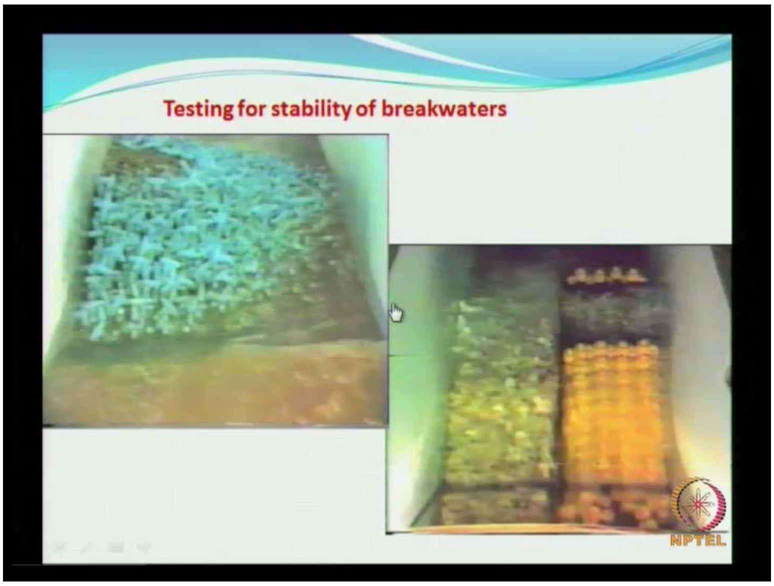

Yet on another study here, you see that this is a study that has been carried out for measuring or assessing the stability of the head of a breakwater.

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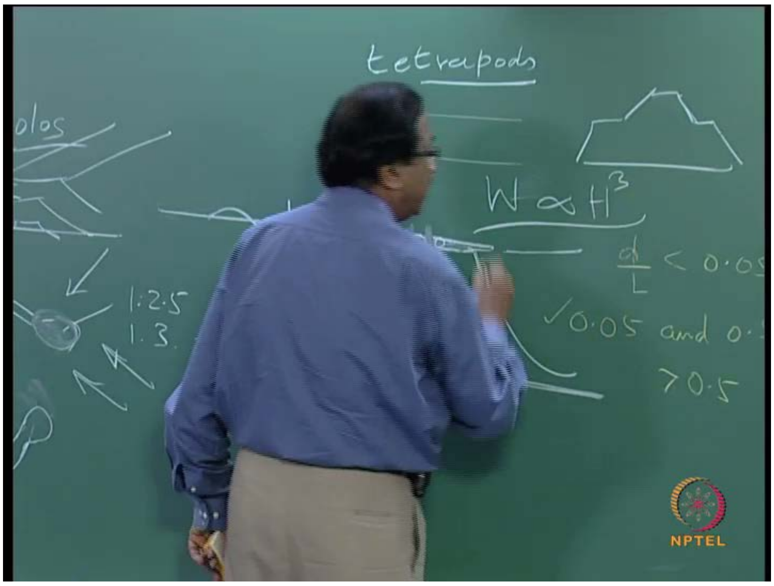

When I say breakwater, the breakwater is a structure that is built for creating artificial harbors. So, you have a it is usually a trapezoidal in section, I am jutting into the ocean, so if you have a shore line; you can have a breakwaters like this, so here the head of the breakwater is slightly flatter so in cross section this is how it would look, but this slope is the trapezoidal section. This may be for 1.5 to 1 is to 2, whereas this one will be slightly flatter, because this portion is being subjected by waves of different directions. So, usually when you want to test the stability of the structure of this nature, we test the front portion of this whereas and also the head portion.

What you have seen just now is the head portion of the breakwater, and on the right side, test are going on with typical blocks. This is what is called as a thin frastam concrete block as you see and the other side on the left side on this side, you see the tertapods. Please check for all these terminologies used in the net or you have to refer to some other lecture material, pertaining to coastal engineering or port and harbor structures etcetera. So, here this structure, this armour layer was dolos that was adopted and now, so you look at this; so this is what would reveal, when it is continuously subjected to the ocean waves.

And if the stones do not, if the armour layer is not quite it does not have the power or interlocking capacity and if one stone gives way the whole armour direction collapse. So, such information so this can be done only through physical model test and you cannot really go in for numerical models, for such informations and because these weight of these stones are proportional to weight of these armour blocks or is proportional to the weight of the proportional to H cube, that is H is the wave height. It is all governed by empirical relationships. So, even though you decide you although you have a formula to derive to estimate the weight of the stone but still you need to verify it in laboratory investigations. So, you can see this movie so, that will give you a clear indication as to the usefulness of physical models and the kind of facilities which we need to verify them. This is very important in the field of coastal engineering, port and harbor engineering as well as offshore structures etcetera.

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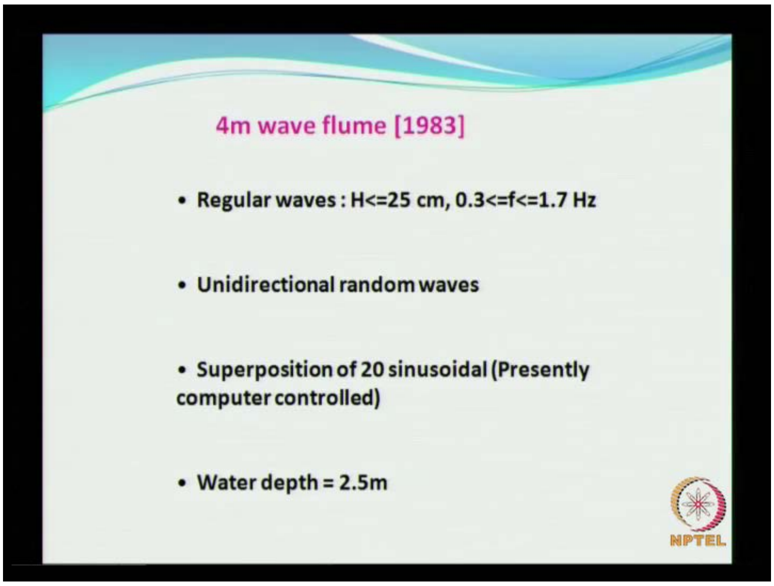

Now, the 4m wave flume, this is 4 meter wide wave flume; it can generate regular waves up to about 25 centimeters, then the frequency range is similar to that of the older flume wave maker and it can generate only unidirectional random waves. You can generate of course, when I say random waves it is also it also includes regular waves.

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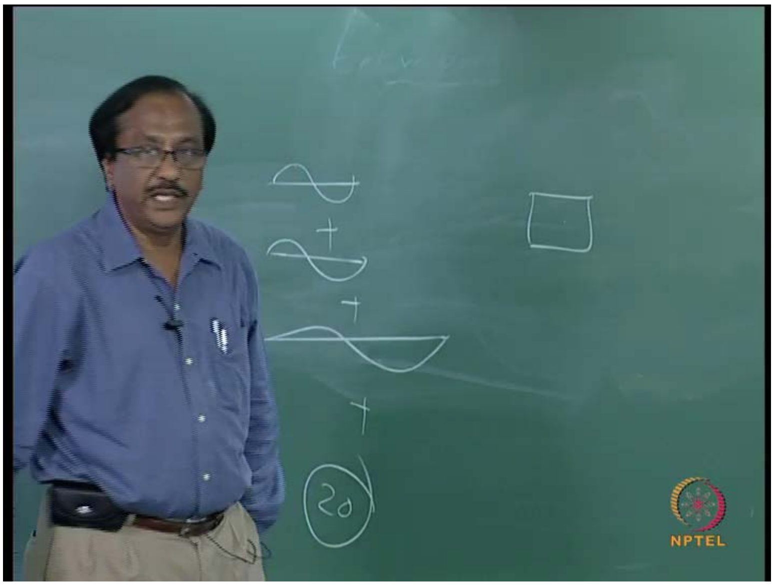

Initially we had a control system that used to be controlling that it will have only the superposition of the facility of superposing 20 sinusoidal components, so only 20 such components. But later it was replaced by computer controlled system, which I had explained earlier that is, I have already told you about the simulation of how do you simulate the random waves. So, the simple; same procedure is used here; so that the wave maker can be controlled by the computer here the water depth is around 2.5 meter.

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These are some of the tests that has been carried out. So, you look up the wave flume, this is now 90 meters long. So, you see the wave maker here four meters wide, and you have 2 meter deep. So, this is the view these two are the view of the flume and here you see a tension leg platform being subjected Tension leg platform.

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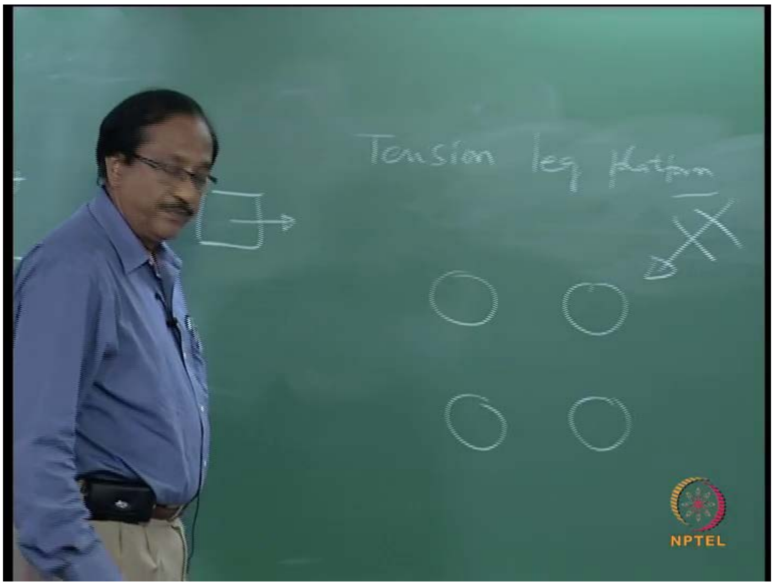

Earlier I said all these facilities are used for structures related coast engineering port and harbor structure, port and harbor engineering as well as ocean engineering that is the port the deep ocean engineering, deep waters you see here tension leg platform that is being subjected to waves to measure its motion response. So, here you see that the interference between structures that is because when you have structures, which are supported on piles in the ocean.

So, when the waves are coming or approaching the structure if you do not have this three piles or two piles any neighboring piles, the force exerted on this structure will be quite different, when it is isolated compared to when it is in the midst of a neighboring cylinder. So, this requires some amount of experimental work as well as theoretical work, even if you do some numerical work, you still have to validate your numerical work. So, we do so we have this kind of experiments being done.

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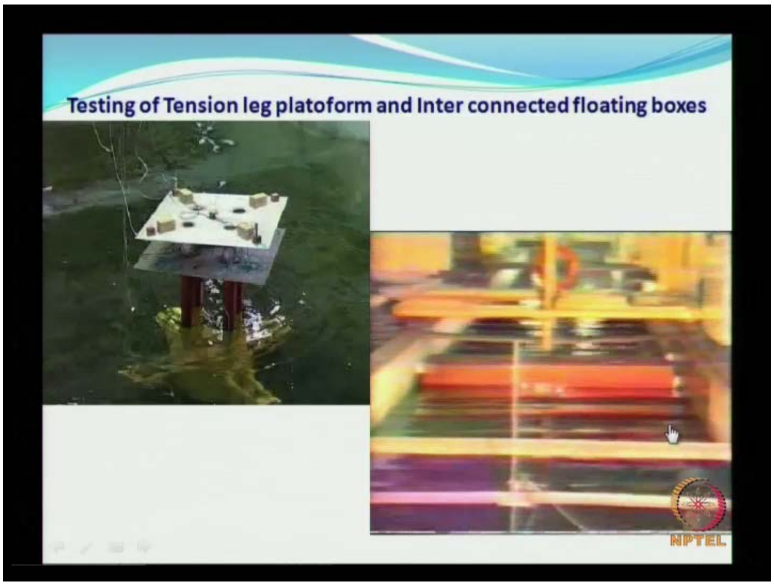

So, this is the experiment that is being carried out on the motion responses on a trim, on a tension leg platform. I will not go into the details again. So, this is a just I want to show you some of the typical test. So, here you see that the waves are almost quite steep. So, it is on the verge of breaking; and here we have a trim connected, inter connected floating trim boxes, so it is inter connected.

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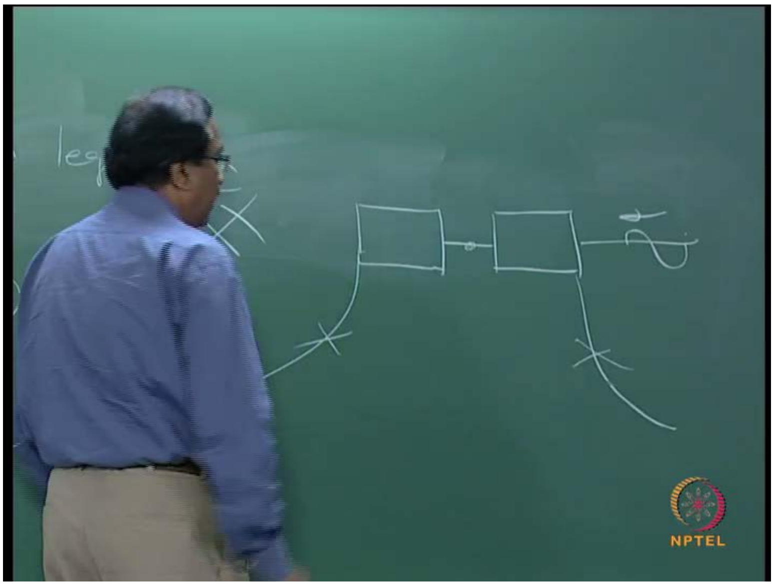

So, you have the waves moving in this direction. So, how they respond to the waves, so you see the inter connection done here. So, we also measure the forces acting on the joint, the forces acting on the mooring lines and also the motion response of the structure.

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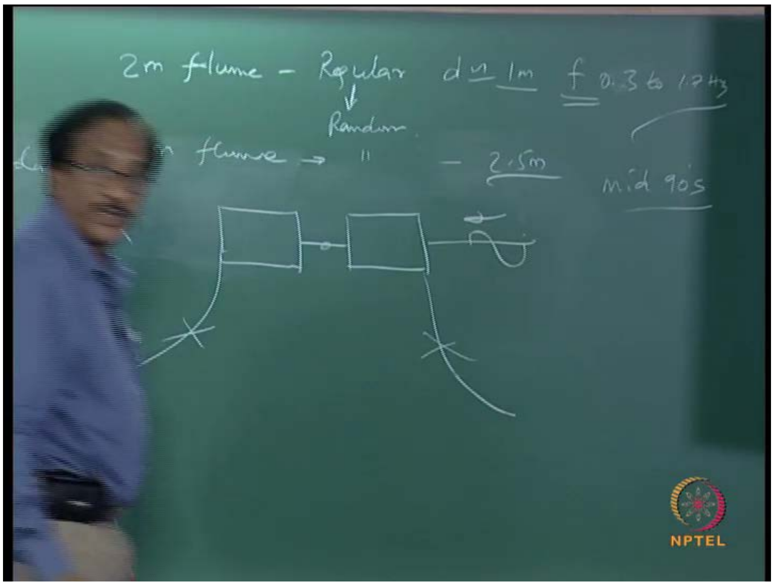

So, we had a narrow flume, which we thought of having it for flow visualization, but that was removed later, because we had a some minor problems. Then if you look at all the facilities; earlier the 2 meter flume we saw that it had only regular waves 2 meter wide flume having only regular waves, but mostly with a water depth of approximately one meter, and your frequency range was limited as we have seen earlier. As we have seen in the case of a so it was 0.321, 0.57 both wave both the wave makers 0.3 to 1.7Hertz. So, then this was upgraded to random waves as I have explained later. Then later we also had the 4m wide wave flume capable of generating regular random waves, but here in we had one meter water depth, but then here we had 2 meter water depth 2.5 meter water depth. So, thus we were able to cover regular and random waves in two different water depths 1 meter and 2.5.

So, this was the status around mid 90s at that point of time, there was a need felt that we need to now move on to directional waves - number one; number two - we also need a facility to cater to the port industries, port and structures related to coastal engineering.

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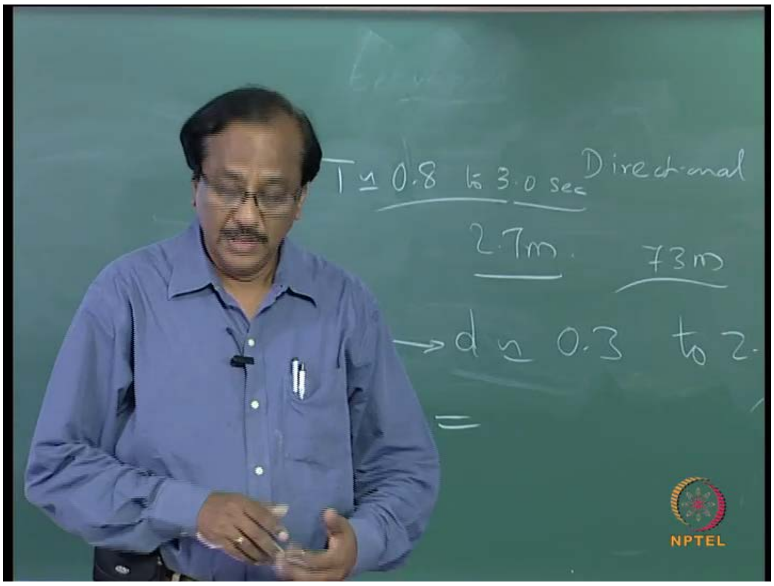

So, in that way, we wanted one is directional waves; and regular waves, regular are random waves, but with a wide variation of water depth. So that then in that case, we will achieve all that is required for a laboratory, which can be called as world class. So, this realizing this, we have 2 meter, 2.7 meter deep wave flume 73 meter long and 2 meter wide. The advantage of this is it can work for water depths 0.3 to 2 meters. so, water depths can be varied from 0.3 to 2 meter wave.

So, and your frequency range in this case, I will say that the wave period can be ranged ranging anywhere between in fact you can go up to three seconds, in fact we can go beyond this also. So you see that initially we had a plunger, which was having only a no computer controlled, then it was switched over to computer controlled. Similarly, the 4 meter flume also did not have a computer controlled machine the wave maker it was only a function I mean, a sinusoidal superposition function generator, and then it was switched over to the computer controlled wave maker. The wave maker was started we started operating the wave maker through a computer.

Then when we went in to this, by that time you see that there is a rapid development in a computer. So, all the systems beyond mid 90s, where all the wave makers were being controlled through computers. So, here most of these things, we used to cover only d by L greater than 0.5, and d by L between point zero point mostly I would say 0.05 to 0.5. But we had a wide option for doing a test with deep waters, but then what about the shallow waters and that is why we have this. So with this kind of a facility you can d cover, a wide range including the shallow water waves. So, the wave maker here can operate both in piston mode as well as in the hinged mode.

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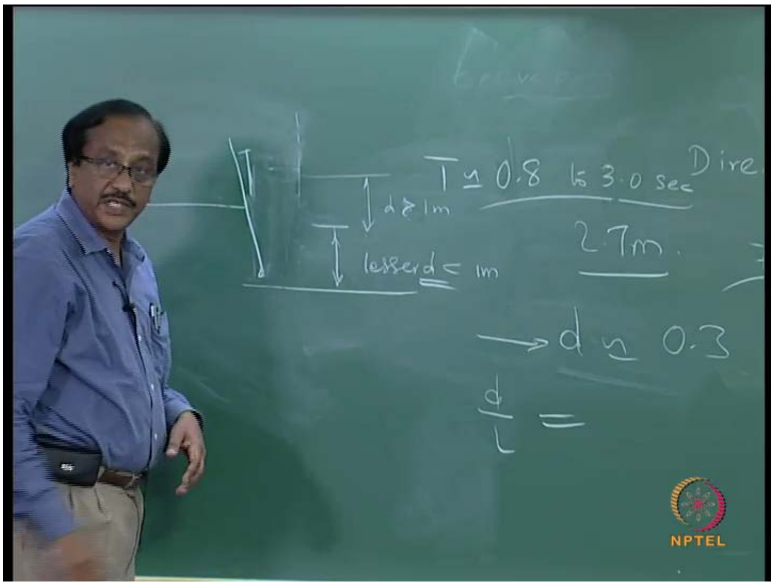

When I said piston mode, the whole wave maker, the whole wave maker will move uniform, the whole wave maker will be moving as a piston in the piston mode. And this is in the case of a lesser water depth; lesser water depth; for water depth it is less than 1 meter for water depth greater than one meter this will be oscillating as a hinged mode; it will be flat mode understand; one is the piston mode and the other one is the flat mode. So, some of these aspects, I had already discussed, when I showed you about this with web page, where we looked at the orbital moments as well as the wave maker theory.

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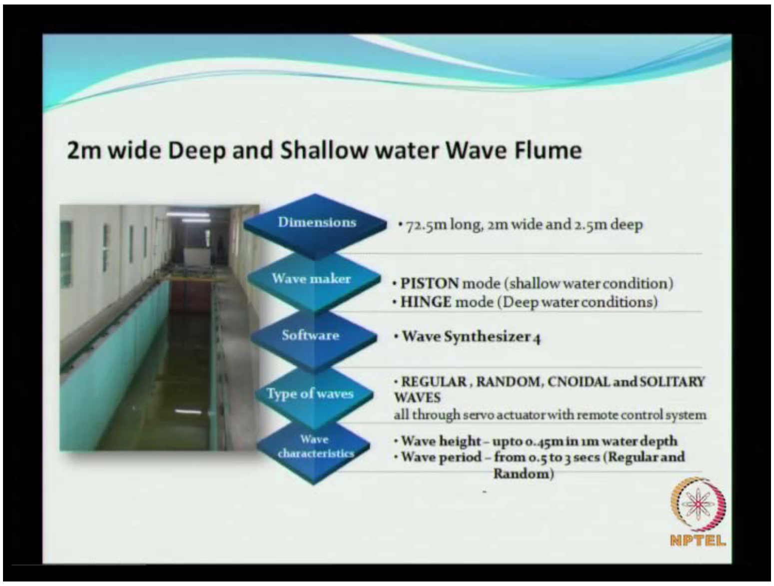

So, as I have indicated the dimensions are given here, it can be moving as a piston mode and hinge mode, and the wave maker is controlled by a soft ware which is referred to as wave synthesizer. So, the types of waves that could be generated by this wave maker is regular sign of a regular random cnoidal waves as well as solitary waves. So, please refer to the lecture on finite amplitude waves, wherein the aspects of cnoidal theory and solitary theory has been covered. So, here the wave height can go up to about 0.4 I mean, 45 centimeter, but we do not reach that limit, we restrict ourselves to about 0.3 meter, then the wave period can vary between 0.5 to 3 seconds.

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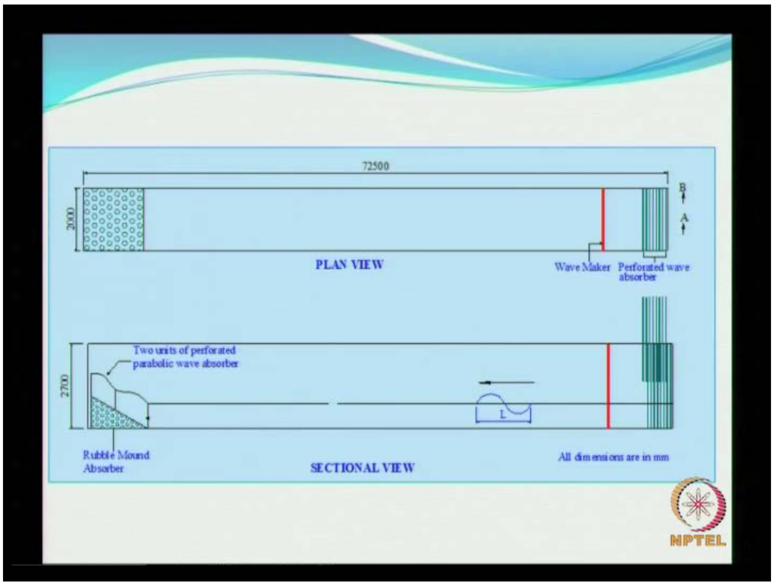

So, this is the plan view. So, this quite simple; we do not have any current generation facility has to have to had in the old two meter flume. So, we refer to this as a new 2 meter flume, which is having a better facility.

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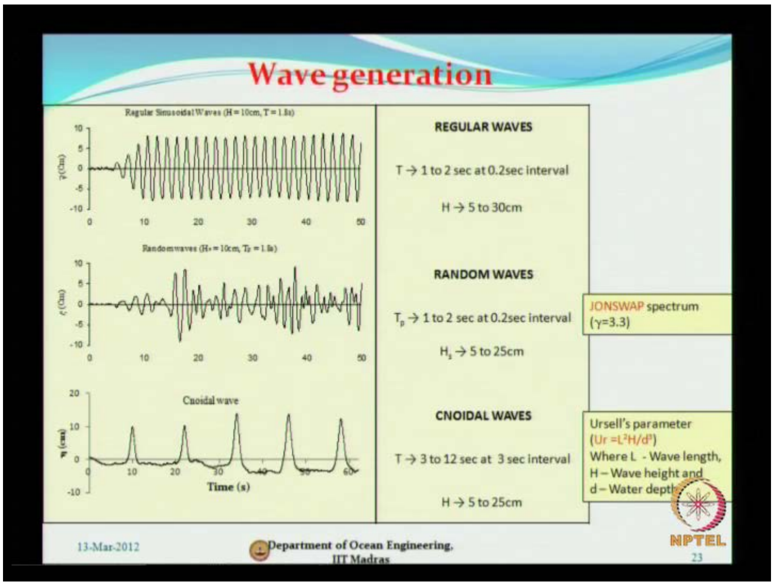

So, some of the types of waves that could be generated using this wave maker are shown here. So, we have recently carried out some tests where in the top one shows the waves waves; that is the regular waves the characteristic of which is indicated here. And then the random waves the random wave is a the second one the middle one, with a the particular wave period as of here the wave period the peak period is 1.8 seconds, and the wave height is approximately 10 centimeters, then the bottom one is the cnoidal waves; these are a special type of waves wherein the crest is very sharp, and you have a very flat base.

And it also sometimes some researchers feel that, it can be equally said to be some people they say some researchers they say that cnoidal or solitary waves will have the characteristics more or less similar to that of a tsunami. And that is the reason after the 2004 tsunami, this generation of a solitary waves and it is action on structures have become more and more popular.

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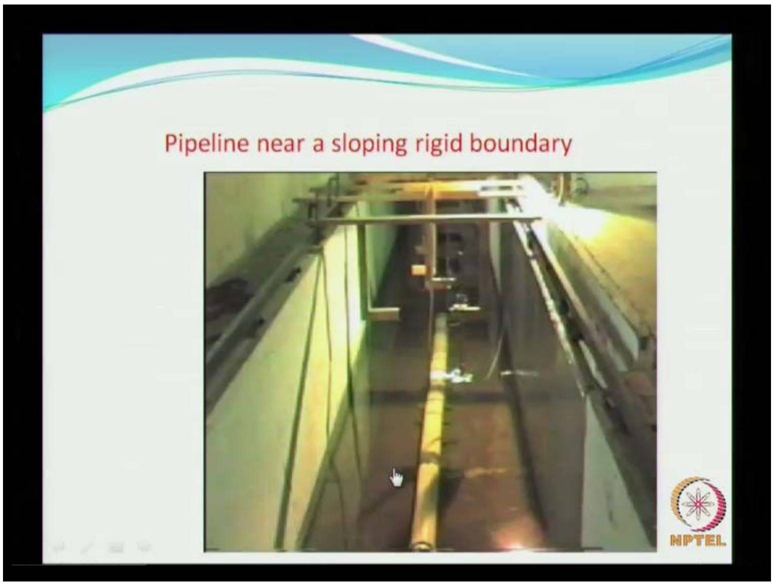

So, these are some of the typical experiments wherein here, you have inclined cylinders being tested in the flume, and you have you have a intake well large diameter well. And now here is a typical movie, I mean a clip - a video clip of a what is being done that is here you have a sloping bottom or a sloping sea bed, you have a sloping sea bed over which a pipeline is placed. And the pipeline is fixed with a pressure since as around the circumference of the pipe, and wherein due to the progressive waves hitting the structure you will be able to measure the pressures around the pipe.

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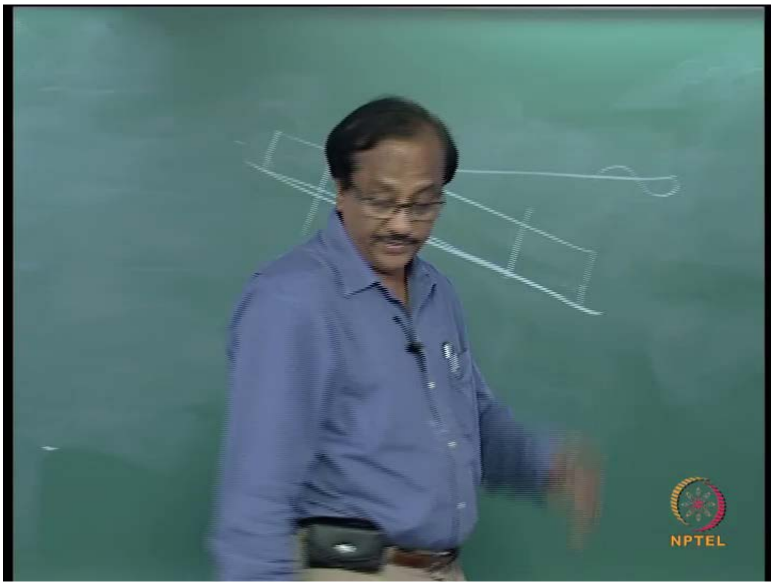

So, this is a very common structure this is a very common structure, either it is resting on the bed or you can have a small gap between the bed and the pipeline. And it may be anchored at locations, and then you have the waves. So, there is common problem and so this addressed through experimental investigations in one of this in the new flume.

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So, these are some of the tests that have been done in this particular flume pertaining to harbor structures. That is the different as I said earlier we have different size, different shapes of stones for breakwaters; that are used as a are armour layers cubes, then you have tetrapods, accropods, dolos and also the core loc etcetera. And all these things having tested in the laboratory in this particular wave flume. There are certain other experiments wherein you have vertical you have a floating breakwater with pipes. Now, you have a vertical breakwater with pipes in between, so you see the holes the gap between the pipe pipes, but behind it you have a structure a vertical structure, a vertical wall when you have a vertical wall the pressures exerted by the vertical walls are high.

Because of this the cover can go up, the forces exerted on the vertical wall can be higher. So, in order to reduce all these things you have a porous structure in front of an existing structure or in front of a structure which is in distress. So, that this structure can the wave stream can act as a kind, some kind of a relief structure for the original structure. So, this is kind of a study which has been carried out.

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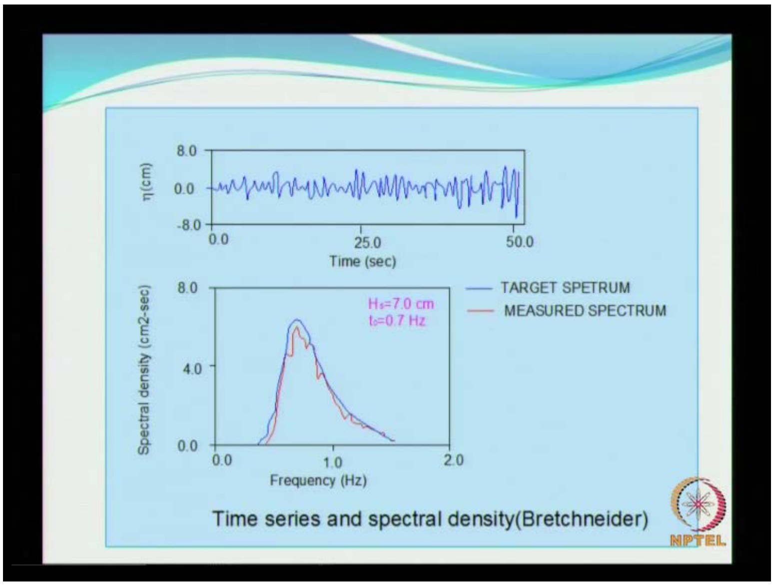

Now, in all these things please refer to the lecture on the random waves wherein I have mentioned about the target spectrum, and the source measure spectrum. So, when you want a particular when you want a time histories to follow time histories of pre defined spectral characters need to be generated in a wave flume, we need to generate the target spectrum; this is the target spectrum in this case. And then we drew this signal through the wave maker as I have said earlier I do not want to go into it again and again. So, then you measure the spectrum in the flume, and try to compare the target and the measured until compared until you are really satisfied. There is a way to alter the signal, so that you keep doing the process until you come to the type of spectrum you would like to have in the tank.

For this purpose, you should refer to the book by goda which gives us some basic information about how to tune your wave maker in order to arrive at the characteristics or the waves in the flume that you would like to have.

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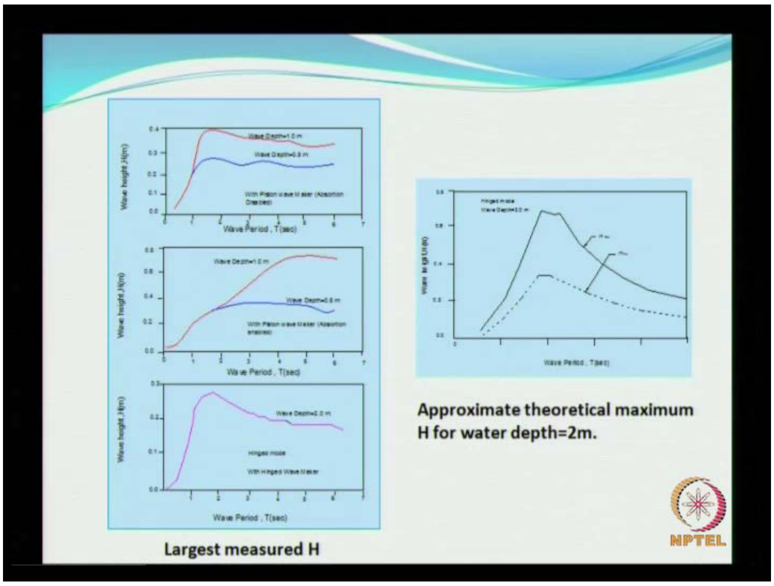

So, before this continuing with the 2 meter wave flume, we also have what is called as the maximum wave height; that could be generated in the tank in the flume is limited by your wave period.

So, as you see if the wave period is longer, I mean if the wave period is higher you see that the wave the wave height that could be generated will be higher. So as you as you see here, it is around 6.7 meters here. For example, in the case of red one is for 1 meter water depth, and the blue one is for about 0.5 meter. So, this can easily this is a solution where in you can get this information, what is the wave the maximum wave height; that could be generated this based on the critical wave steepness. So, but we restrict we do not go this is what is called as the theoretical wave height, that could be achieved, but we normally do not go to the level we just restrict our wave maker.

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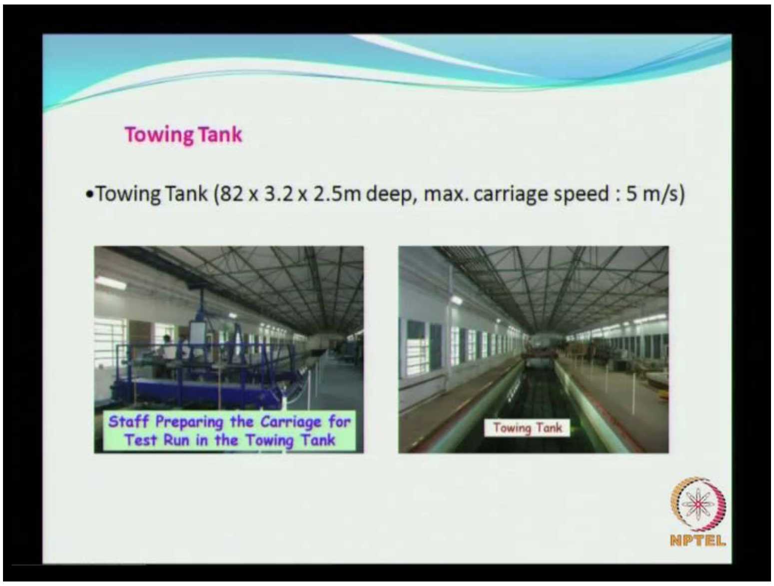

So, this is something to do with the theoretical spectra which I will not cover this; there is in addition to the wave flumes we also have what is called as a towing tank as we have as I have mentioned earlier basically to the dimensions are given here. Basically to measure the resistance of the ship motion - ship models, and other related test related mostly related to (( )) engineering.

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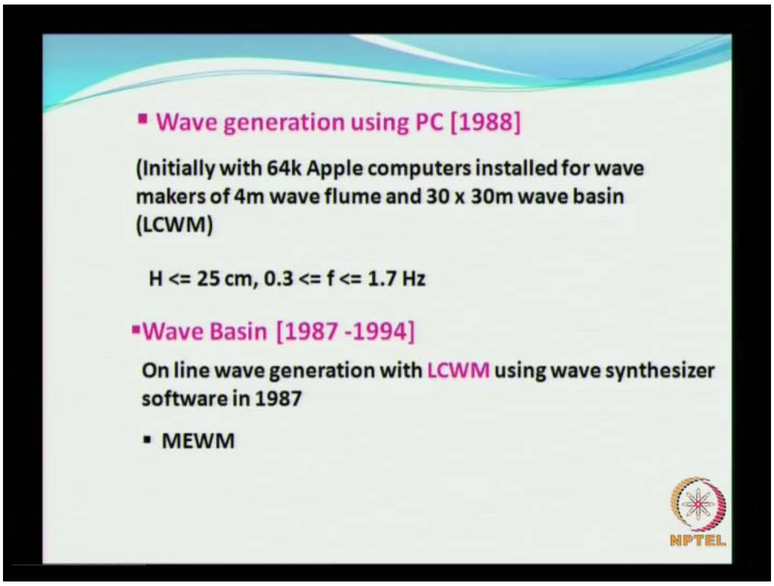

So, some of these informations are not needed, but significant wave in progress was in mid 90s where we have the wave basin, as I said earlier all that we have covered was pertaining to unidirectional waves. And as I said earlier we went in for a multidirectional waves in the mid of ninety. So that was the final phase in the wave evaluation of wave energy technology the wave generation technology.

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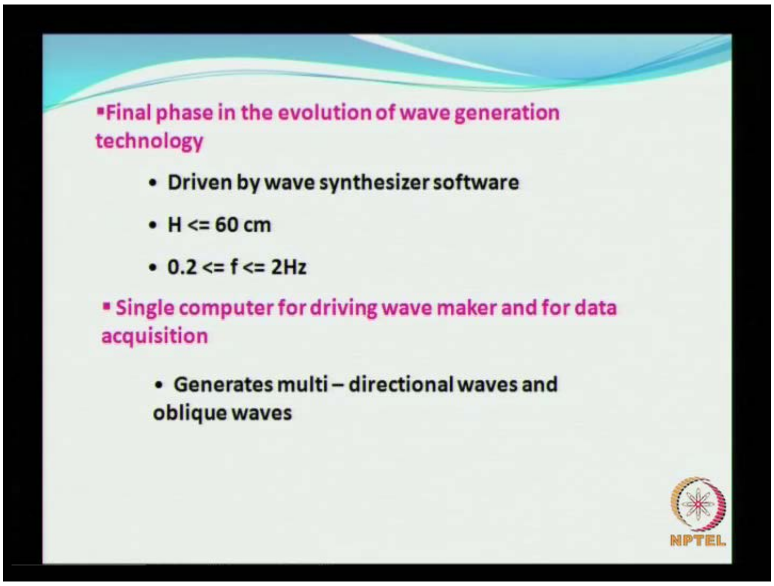

So, we had a single computer that could drive the wave maker, and the same computer could be used for data acquisition. So, the frequency etcetera or frequency range would be the wave height could be generated etcetera are given.

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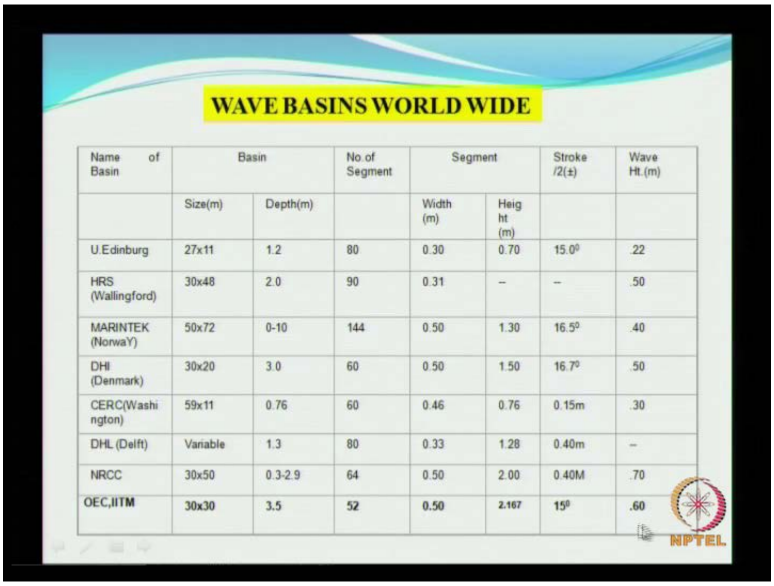

Name of Basin	Basin		No.of Segment	Segment		Stroke /2(±)	Wave Ht.(m)
	Size(m)	Depth(m)		Width (m)	Height (m)		
U.Edinburg	27x11	1.2	80	0.30	0.70	15.0^0	.22
HRS (Wallingford)	30x48	2.0	90	0.31	--	--	.50
MARINTEK (NorwaY)	50x72	0-10	144	0.50	1.30	16.5^0	.40
DHI (Denmark)	30x20	3.0	60	0.50	1.50	16.7^0	.50
CERC(Washington)	59x11	0.76	60	0.46	0.76	0.15m	.30
DHL (Delft)	Variable	1.3	80	0.33	1.28	0.40m	--
NRCC	30x50	0.3-2.9	64	0.50	2.00	0.40M	.70
OEC,IITM	30x30	3.5	52	0.50	2.167	15^0	.60

But before we go into that, let us have a brief look at the type of wave basins that are available in the world. But this is not a completely updated list, partially updated list, so you can see the size of the basin and the basin in our department; that is department of ocean engineering is 30 by 30 meters. 3 meter, 3.0 meters wave height when you want to generate a multi directional waves.

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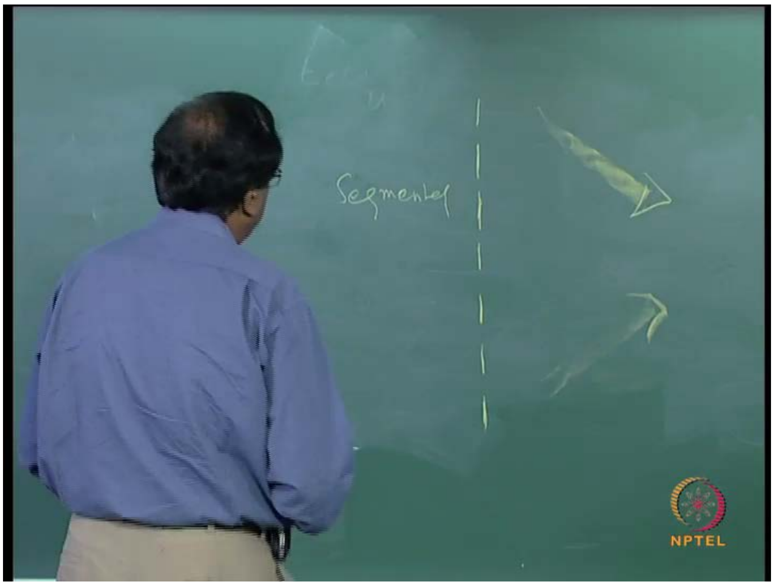

It cannot it is possible only when you half number of wave makers, it is not possible to have a generate a directional waves with a single wave maker. You need to have a number of wave makers to generate the directional waves. As I said earlier that what is meant by directional waves to some extent, I introduce you to the subject; the mathematical concept will be coming later. But now you see that with this kind of a facility you can generate I have already said you can generate the oblique waves or the waves coming from different directions. And when you want to do that waves with a different amplitude, and frequency approaching from different directions at a particular location. And you need the multi element wave maker is also called as segmented wave maker are snake type wave maker, because it starts moving like a snake when you set it to in motion for generating a directional waves.

So, this number of segments are also given here some of the width of the segment all this information stroke which is needed for generating the kind of wave height you would like to have. So, look at the stroke we have comparable wave height, that could be achieved in the basin that is 0.6 meters.

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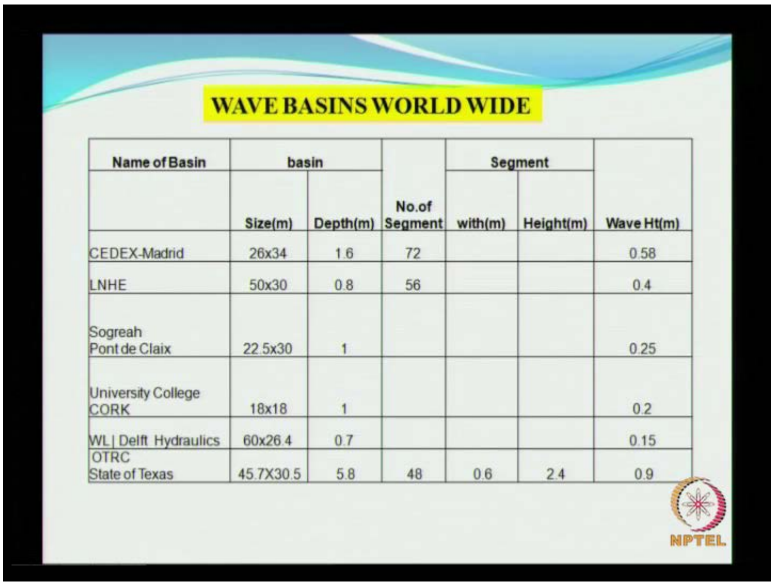

Name of Basin	basin		No.of Segment	Segment		Wave Ht(m)
	Size(m)	Depth(m)		with(m)	Height(m)	
CEDEX-Madrid	26x34	1.6	72			0.58
LNHE	50x30	0.8	56			0.4
Sogreah Pont de Claix	22.5x30	1				0.25
University College CORK	18x18	1				0.2
WL | Delft Hydraulics	60x26.4	0.7				0.15
OTRC State of Texas	45.7X30.5	5.8	48	0.6	2.4	0.9

And there are other wave makers there are some more wave makers which has recently been installed at Dalian universities in China, and the few more universities that are available where they have the wave basins. Installation is very expensive as well as the maintenance of wave basin in very expensive.

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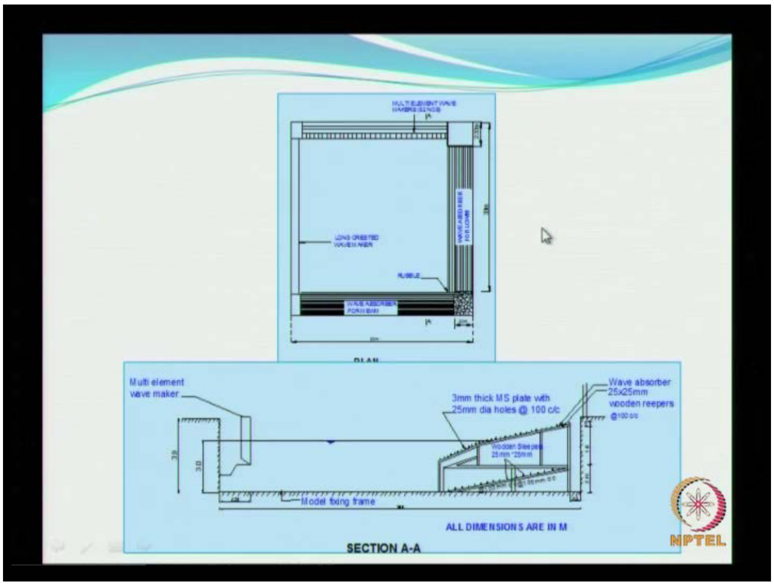

So, this is the view of a wave basin in the department of ocean engineering where in so the you see that there is one wave maker which is the long crested wave maker here on the left, this is the long crested wave maker; that is this size is 30 meters by 30 meters water depth is 3 meters. The LCM - L C W M that is the long crested wave maker can move as a single unit as a as a single unit, and it does not have any direction. So, it can generate long crested waves moving in one direction with it can be both regular as well as random.

And then on the other end we have segmented breakwater I mean segmented wave makers where in it can move with its own frequencies, and amplitudes which can be controlled by the computer. On the other end on both the sides when you want to operate this, this will be forming as the wave observer, because you need to generate only progressive waves as mentioned earlier or in the other way when you want to generate the random I mean the oblique waves or three dimensional waves. You need the wave maker this side as well as this side.

In fact, so it is better to avoid waves being generated in this direction, because this is a vertical wave maker that can generate you can have reflected waves. So, normally it is not it is not preferred we do not generate waves approaching in this direction, but we can always generate waves moving in this direction, because these two wave makers can care take care of the absorption.

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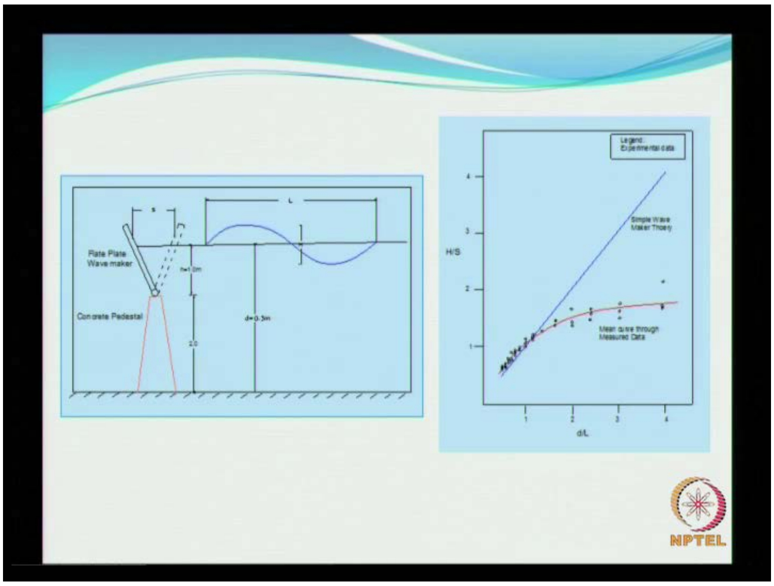

It is mounted on a pedestal here, it is 2.2 meters from the floor. And then you have 2 meters from the floor, and then you have the wave maker here moving that can be moved, and then you can generate the waves. And these are the information concerning the maximum wave height that is this is the simple wave maker theory, that can that gives you the wave height that can be generated by the wave maker theoretically.

But what you can achieve is shown here based on the test we have conducted, this is what we can really achieve.

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And this is the views different views of the wave basin. This is only one of its kind in India, and we have carried out very interesting projects both international, and national projects in this facility. Now, you see the operation of the L C W M that is the long crested wave maker, wherein it is generating only long crested waves. So, you have already seen the waves generating in the flume. Now, you can see the waves long crested waves generating in the tank, and that is propagating in presence of a floating body the motions of which is being measured. I let it go, because that gives you. So, that is about the long crested wave maker and this probably is what is saw was random waves, and probably now it is something like the it is random wave that is being generated.

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And then we just move on to the multi element wave maker. Now, you see that all the single units of 52 in number, the number of units are moving in unison that is as a single piece. So, generating long crested waves, that is what can be generated with the long crested wave maker; it is the same model that is being tested here.

So, now it is generating oblique waves. So, you see the wave it is moving. So, you see the waves moving in this direction with a oblique wave of angle of attack. And it also can generate their three-dimensional waves, which is quite straight forward; all these things are controlled by software which is house in the control room. So, the same computer is used for acquiring the data from the measurements. So, the same computer can be used for all these things, so that is about the wave generation path.

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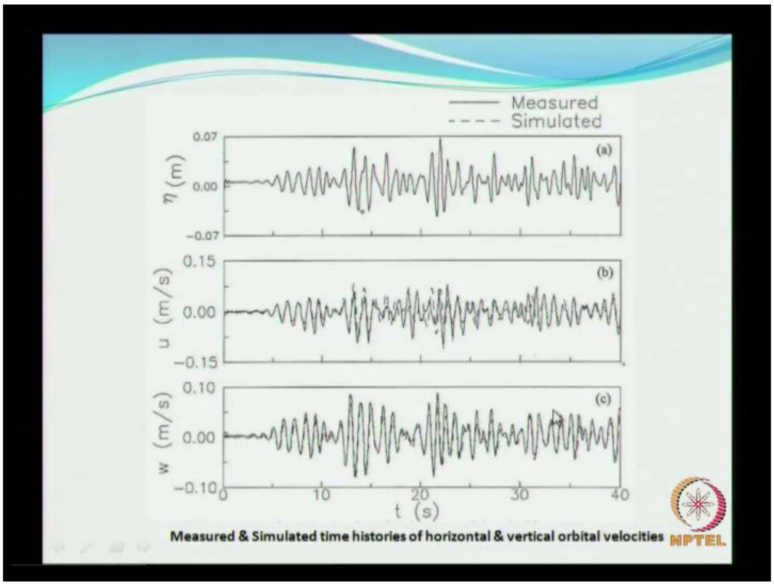

So, here in this is a typical result which we have got obtained from the wave tank test, this is the simulated wave for which you have measured and simulated particle velocity in the horizontal direction, and in the vertical direction just to prove that your measurements and the simulations.

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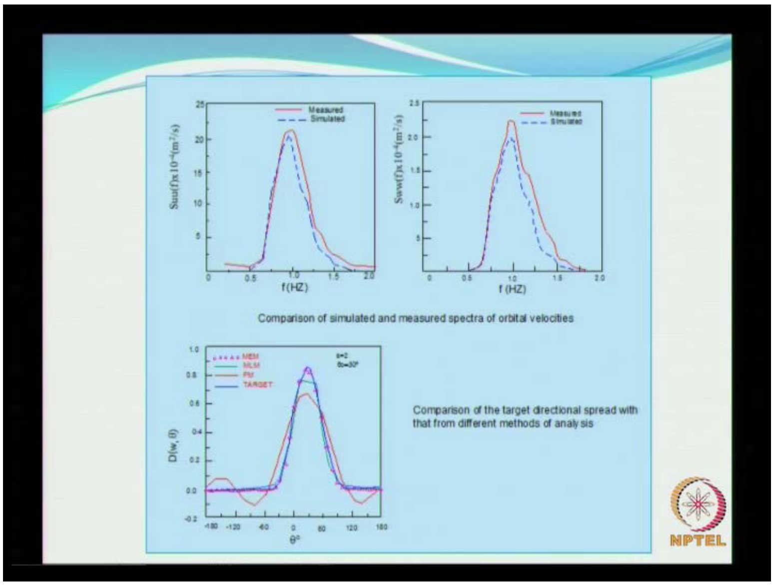

And then these are showing some of the typical comparison between the measured and the simulated target spectrum. I think this is for the orbital velocity for the same time histories, which we saw the comparison between the measured, and the simulated orbital velocities and below you have the comparison of the and measured directional spread which I will discuss about the directional spread when I go into the aspects of directional waves.

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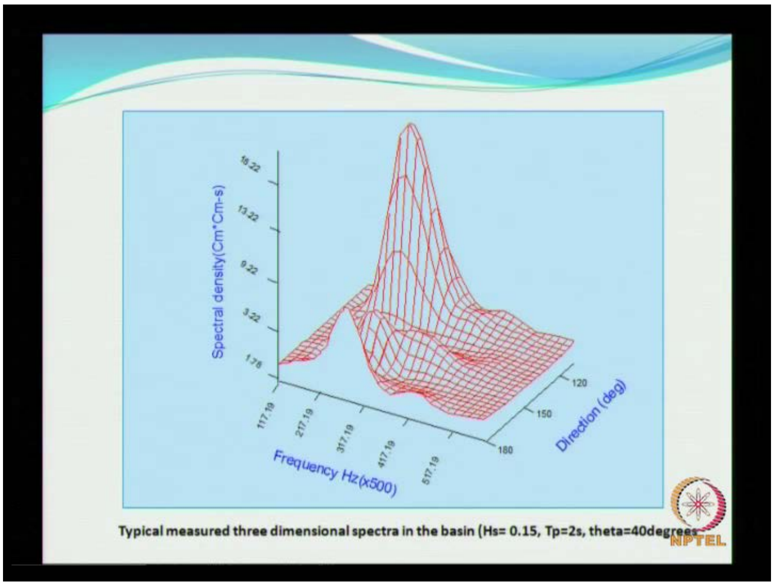

This is a typical directional spectrum which we have measured. So, you see that this is the energy distribution, this is the spectral density which you know and this is the energy, and as a function of frequency, and also as a function of direction. So, if you take one direction you get one spectrum or if you take one frequency you will get the distribution of energy as a function of direction. So, that is what it gives the directional spread.

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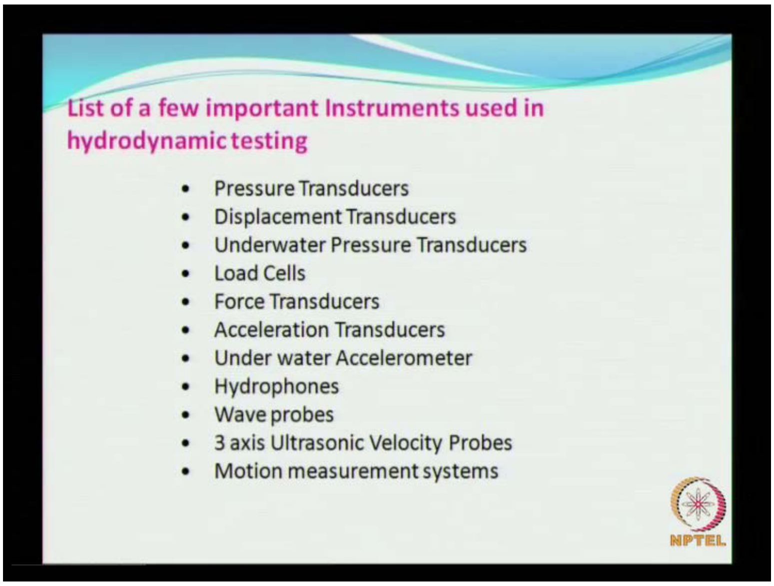

Apart from the hydrodynamic testing facility to enable all the test we need a host of a equipments, I have listed few of them pressure sensors displacement transducers, underwater pressure sensors, load cells, force transducers, acceleration accelerometers, then under water accelerometer, then hydrophones wave gazes, velocity probes motion measurement system and the it goes on the list goes on I have just listed a few.

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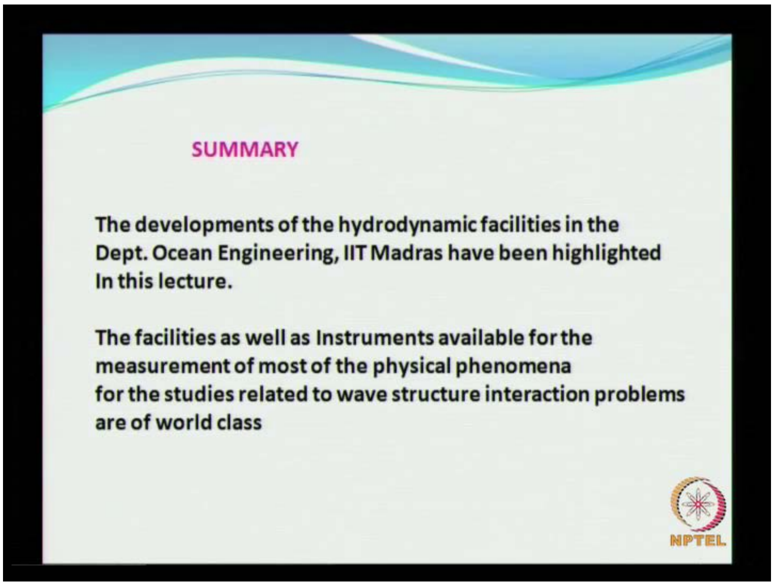

So, in this lecture what I have just summaries the development of hydrodynamic testing facilities in the department of ocean engineering I I T Madras, and then the facilities that are also needed and data available in our department to carry out studies related to wave structure interaction problems.

So, now that you have seen the regular waves, random waves etcetera. Now, we you have fairly a good understanding or at least you have, I mean a kind of an exposure to the three dimensional waves. In the next class we will try to look into the mathematical aspects of the three-dimensional waves, and then we will go in there.