Wave Hydro Dynamics
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Module No. #06
Wave Theories and Testing Facilities
Lecture No. #02
Hydrodynamic Testing Facility

Types of waves, that is we started with regular waves, looked at its characteristics, properties, the physics behind the different parameters. And then, we also went into wave loads, and structures due to regular waves, etcetera. We also looked at the wave deformation. And then, after having good amount of exposure to the behavior of regular waves, we went into understanding, what is mean by random waves their effects, and how would you generate random waves, and how experimental investigations are important? Although, you have numerical facility numerical, I mean the computer modeling etcetera, you have lot of experimental, I mean numerical modeling or the facility with numerical modeling.

But then there are several problems for which you need to look at the hydrodynamic testing facilities. In this lecture what I have been, I have tried to do is, what is meant by hydrodynamic testing facility? I will try to say, what is the purpose of doing it? And then, also I will start with the regular waves, and then go into random waves, which I have already covered, the basic aspect you already have. Then, I will focus more on the testing facilities, and after having an exposure to both of these testing facilities, then I will move on to three-dimensional waves. And once you have the understanding of three-dimensional waves, I will go into the mathematical mathematical treatment of the three dimension or mathematical representation and treatment of the three-dimensional waves.

So, this is what I am trying to, this is how I organize my lecture on this. For this, department of ocean engineering IIT madras, has been identifying as centre of excellence for the field of ocean engineering. And ever since all these facilities came, I am with the department and I grew with the department.

So, what I have decided is, I have taken the liberty of using the development of hydrodynamic testing facilities in the department of ocean engineering as a basic material, how such facilities can be developed. This will give you a feeling to the facilities. Not only that it will also help in some of you tomorrow, if some of you are taking up teaching career and then probably you are planning for your own lab etcetera. This gives a good; this can form as a good background.

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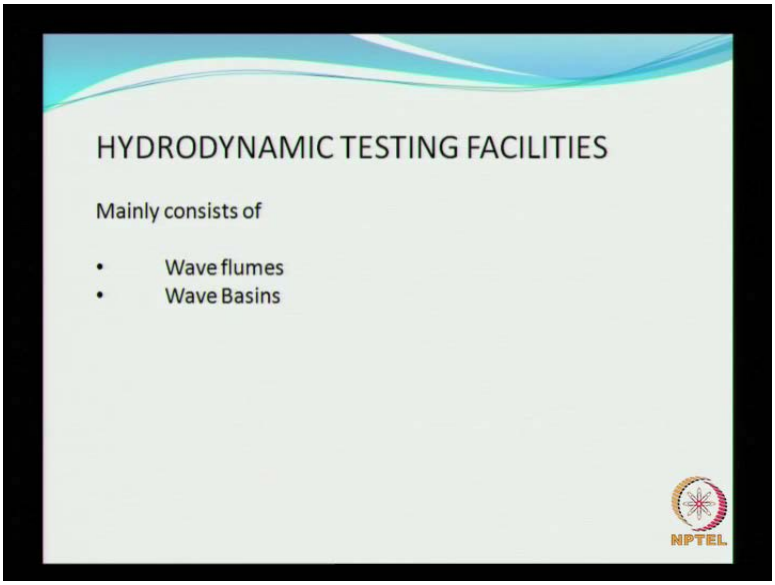

So, whatever I have seen, I show in this lecture pertains to the department of ocean engineering IIT madras. So, let me start, when you look at hydrodynamic testing facilities, concerning the stimulation ocean waves. All of you have, I am sure that some of most of you would have heard of flumes.

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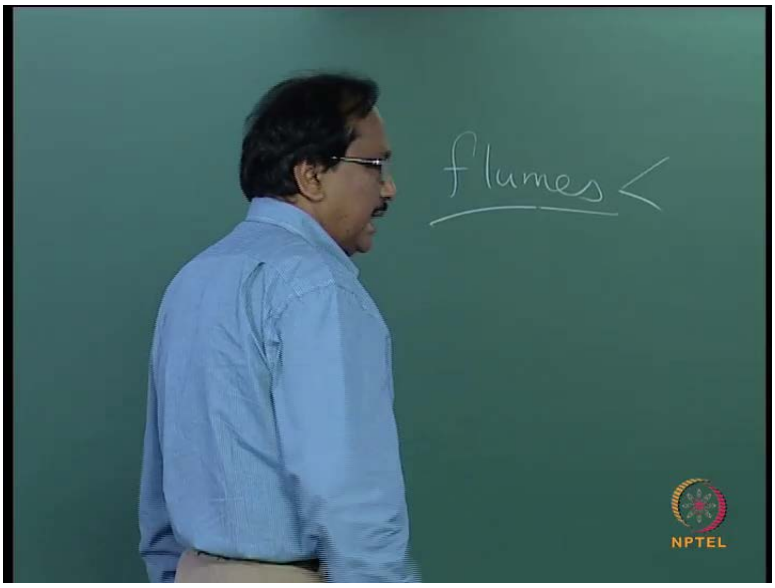

Flumes are, flumes are just facility in any classical civil engineering laboratories. So, where you all of flew to take place, measure the velocities or forces due to the flow. All these things, measurement of discharges all these since have been done and it would form as an exercise under your B Tech program or the undergraduate program. Then these wave flumes are slightly different it is also a channel. But it has a wave maker at the other end at one end and on the other end you have the absorbers.

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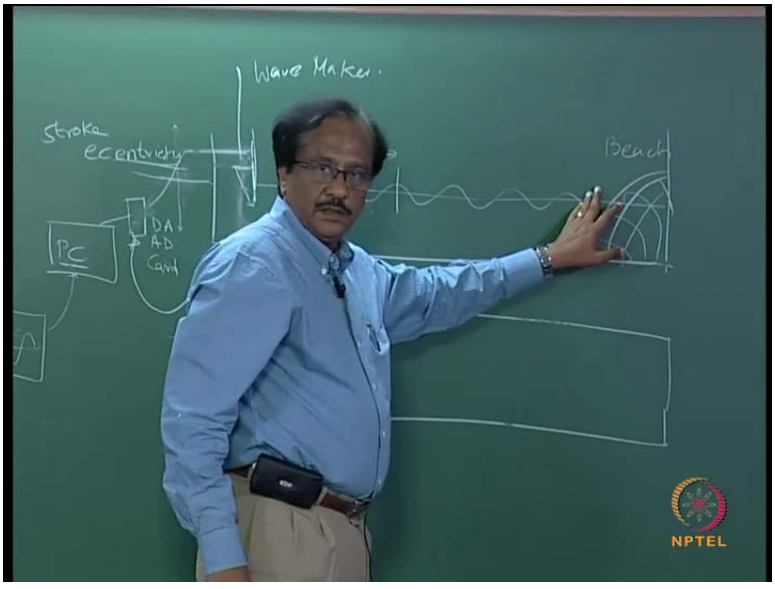

Basically, a wave flume would consist of a wave maker which is hinged to more or piston more whatever it is will come to those details later. This will be moving up and down. So, this is the water depth and this is the channel, in plan. So, your wave maker will move in this direction or it can move in upper direction, it can move in this direction or can move in this direction. Whichever direction it moves, it results in the displacement of the water surface. Depending on the movement of the wave maker, the water surface also oscillates. Hence, you have the control over the wave maker.

So, initially what they did was they use to give, simple harmonic motion in the sense this will be, if it is upward motion, up and up and down motion. This will be from mean position, it will move up to a certain level, come to this position. And go to this position and again it will go and then come. So, you see that it will be moving up and down like the pendulum or of a clock. So, it is going to generate sinusoidal waves. How I high it moves, how high it moves, this is what is called as from the mean position. This is called as eccentricity or it is also refer to as stroke.

The stroke of the wave maker would control the amplitude of the waves and how frequently it moves, how fast it moves, that controls your wave period. In the initial stages, we just had only a wave maker that was not controlled by any computer. So, we had some kind of function generator or some kind of mechanism with, through which you can control the movement of the wave maker. So, both the stroke of the wave maker, as well as the speed with which it moves, that can be controlled. But then there are some kinds of limitations but the system works.

Later, due to the rapid development in the computers, what will happen is, what has happened is? This the moment of the control moment of the wave maker can be controlled by computer. How do you do that? You can generate a signal of your designed frequency and amplitude. This is a digital signal and digital signal will be generated in the p c. And then this will be having, what is called as a card, which is AD card or DA card or AD card. That is AD is analog to digital and this is digital to analog. So, you create a digital signal and this signal is now sent through a DA card. And, the DA card will dictate the movement of the wave maker.

So, it is a pity that, some of these components were not available. And so, there was a time lag in the developments that took place in other countries compare to the real

advanced countries. But now, you see that the method has become so simple. Once this method is very clear, digital created in personal computer have a DA card, send the signal through the DA card, drive the wave maker. And there you have the waves generator at the flume and once, the waves are generated in the flume you need to measure.

So, for this what you do? The signal from this one goes to AD card. So, you have DA card to drive the wave maker, it gets the. So, you have some kind of measuring system may be a wave gauge or whatever it is, may be force transducer or a pressure sensor. Then the signal from this gets into the, through the AD card and then you acquire the signal in digital form. So, this process is clear. But then coughing there is some information which you need to do. When you are doing the acquiring of the data you need to do calibration. Calibration of your instruments to convert this oscillation in terms of millimeters or centimeters to, I mean convert the signals which you have measured in terms of volts to centimeters or millimeters later.

I will not, I will bypass that topic, because that is going to come under experimental investigations which I am not going to touch now. So, as far as now, as far as this so far said so, again I am repeating PC create the generate signal, send it through the DA card, digital to analog signal. And that signal is sent to the control system of the wave maker and the control system drives the wave maker, according to the signal it has received. Then you can generate the desired signal in the wave tank, is that clear? So, now the other important component is the beach. What is the purpose of beach? So, you have on one side beach, one side wave maker.

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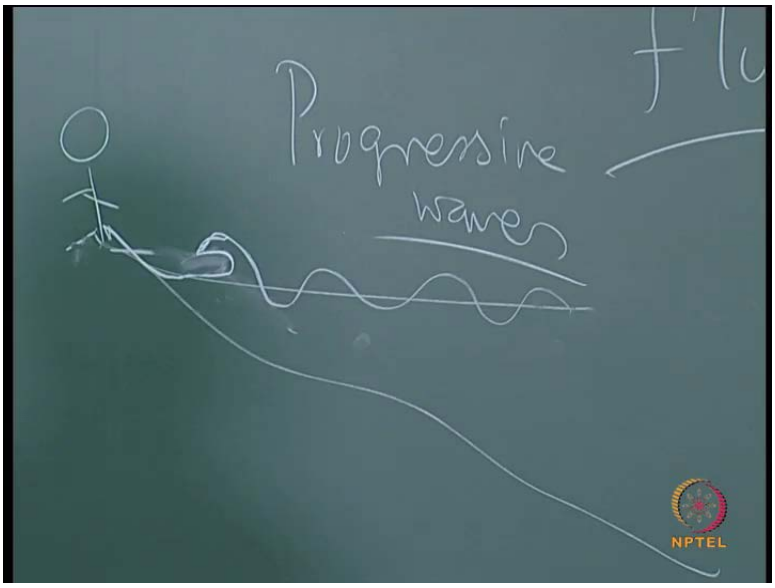

What is this for? When you go and stand on the beach, what do you see? You see the waves breaking. And then, you have a gentle up rush and you are very sure that, the wave is not going to continuously come to you. And that is the reason why you are standing here. So, every time you look, you see a new wave coming, a new wave generated, propagates and undergoes transformations, which we have seen. And, then breaks here and then you have an up rush. So, here the energy is automatically dissipated. So, these are, as I mentioned earlier, these are called progressive waves. So, in order to generate progressive waves in the lab, we have a beach which absorbs the incident wave energy that is generated by the wave maker. Remember, that the waves are constraint within two side walls.

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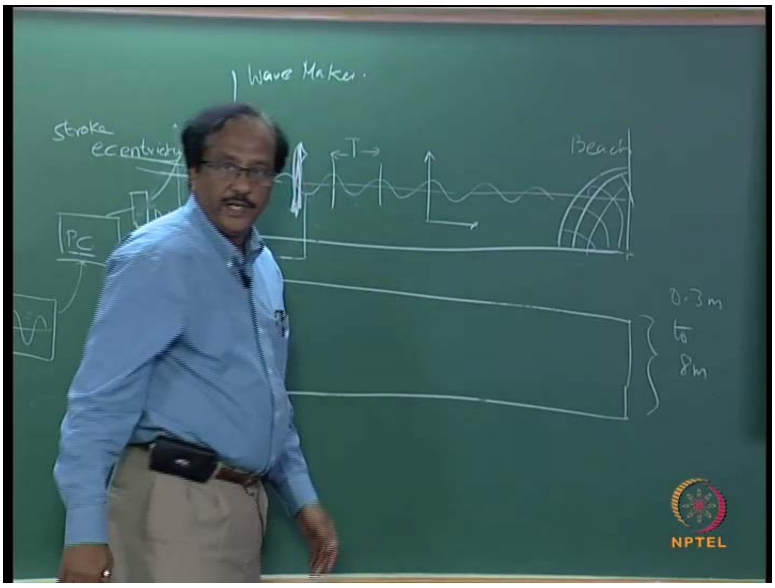

This width of the flume, can be anywhere between 0.3 meters, going all the way to 8 meters talking only about a flume. But it can be a much wider also then we call that as wave basins. I have come to wave basin before going to wave basin, when we look at the wave flume, the waves are propagating. What is a kind of flow you are going to have here? It is a two dimensional flow. There is a flow taking place in this direction, in the direction of wave propagation, plus the oscillation of the. So, there is no flow in the direction normal to the board or normal to the flume walls. So, this is what, this is how a flume would look like but then, we will try to understand other details, as we go.

When we are talking about how the hydrodynamic testing facilities were developed step by step? So that, that gives a better clear understanding. Now, what is a wave basin? In the flume, you see that the length of the flume is much longer, much much longer many times that of the width of the flume. So, basically a flume is going to be available to you to generate unidirectional waves. Unidirectional waves, what does that mean? It means that, the waves are approaching the test area from only one direction. So, when you are standing near the coast, the directional wave you will see that it is very well defined in most of the cases. Because it reaches you, reaches the coast after undergoing all kinds of transformation.

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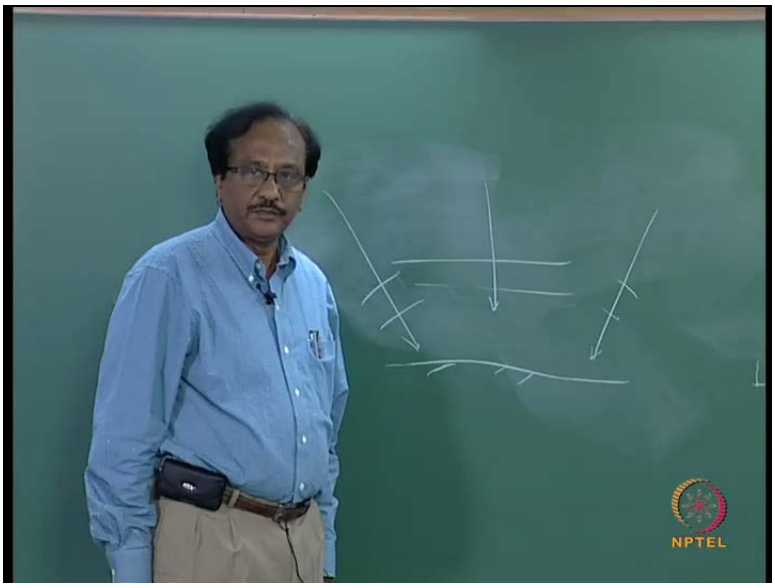

You will see, when the waves are reaching the shoreline, it will be more or less, normal or it can come like this or it can come like this. So, here in the direction is well defined, if come if it comes like this we say normal angle of incidence. When it comes like this at an angle it says it is termed as oblique wave of wave angle incidence, oblique waves.

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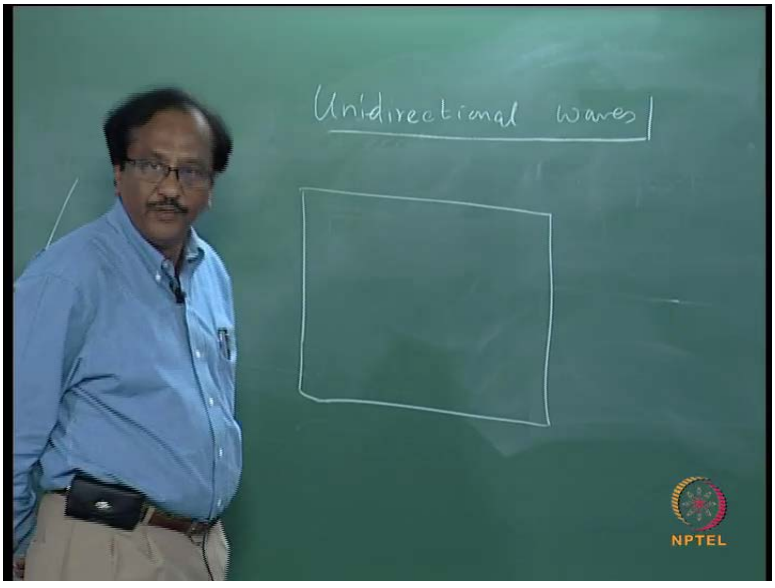

In the case of basin, so in the case of wave flumes, remember that you can generate only direction unidirectional waves. But in the case of basins you can achieve this, the size of the basin is either both sides same or one side longer than the other but it is comparative.

It is not like the flume. So, the idea is you can generate a variety of waves, not just unidirectional waves. So, that means this would certainly fulfill all the requirements for investigating wave structure interaction problems in the ocean.

But naturally, when you have all kinds of facilities available in a testing facility, naturally it has to be very expensive not only for insulation but also for maintenance. And sometimes, it becomes having such it kind it might become too ambitious, when you start planning for installing a wave basin. Once you installed the wave basin then comes the problem of maintenance also.

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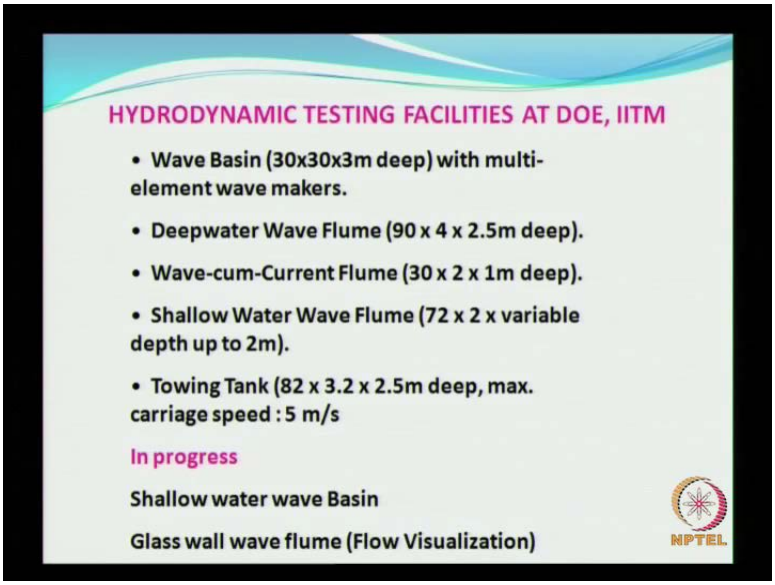

So, I will just go with, what are the requirements and what forces us to (No audio from 20:00 to 20:10) the facilities. Hydrodynamic testing facilities in the department of ocean engineering IIT madras or a wave basin 30 meters, 30 meters cross section and 3 meters deep, with multi-element wave makers. I will explain that later. First let me discuss, let me list all the facilities. Next is a deep water wave flume, 90 meters long 4 meters wide and 2.5 meters deep. So, when I say 3 meters, that is the water depth and when I say 2.5 meters, it is also the water depth not the flume height depth. Then, wave wave-cum-current flume, this is 30 meters by 2 meters wide 30 meters long and it is 1 meter deep as I said. But that is the water depth in you we usually use.

But the water depth can vary from about 0.3 meters to about 1 to 1.2 meters etcetera, around or 0.2 meters we can still manage. And then, we have a shallow water wave

flume where it is the length is 72 meters, width is 2 meters. But the water depth can be varied from point as low as 0.3 meters and as high as 2 meters. Then, we also have a towing tank facility which is used for some resistance test for ship models, propellers etcetera which I will not be covering that topic much. But this is one of the important facilities we have. Then, we also have shallow water basin here, it is written as in progress. But we have just completed the shallow water wave basin and then, the glass wall flume which is with flow visualizes, flow is visualization.

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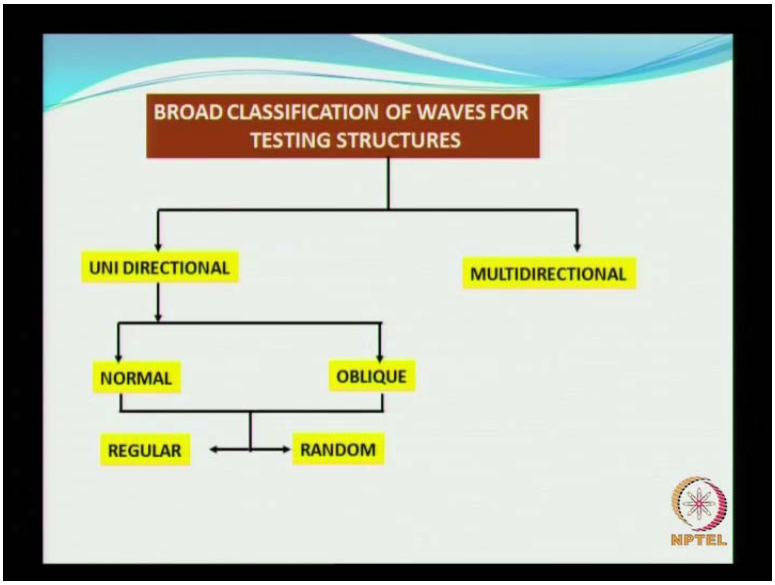

So, I will cover one by one. But before I cover some of these facilities, let us examine the broad classification of four waves that are adopted for testing of structures. Broadly, it can be classified as unidirectional and multidirectional waves. Unidirectional I have just said, the waves approaching your test location from one direction. Multidirectional is the waves approaching your test location from different directions. Unidirectional, you can either have normal wave angle of incidence which I just now explained or oblique wave or of attack. Again, under this category you can either generate regular waves or random waves. There are some reasons, why you have to generate test regular waves? Why you need to do with random waves? Why you need to resort to multidirectional waves?

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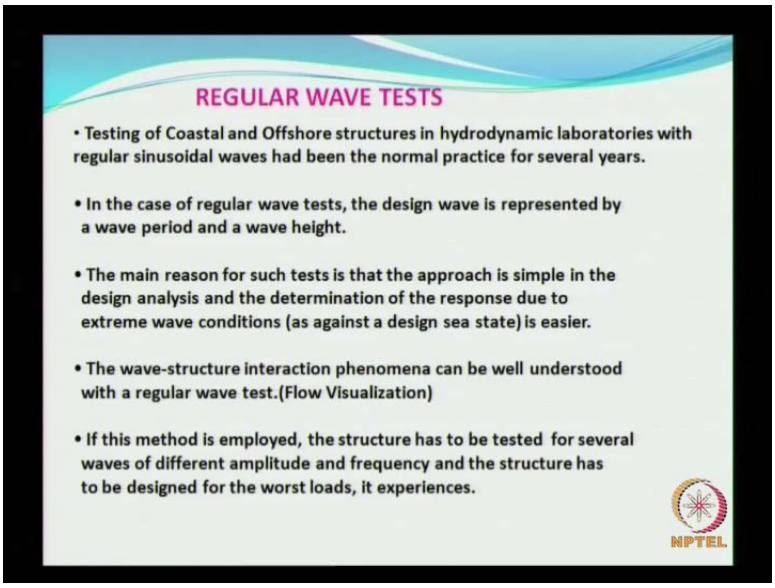

First if you want to understand something about the basic physics of regular waves, or if you are just starting your studies. Or you want to just set up a lab, the best way of understanding the basic physics is through regular waves. Testing of costal and offshore structures in hydrodynamic laboratories with regular sinusoidal waves, as being the normal practice for several years. For the simple reason that the physics behind, then such problems can be very easily understood. Because we are going to deal with only one wave. When I say one wave, it means it is a combination of a particular, a pair of wave height and wave period.

In case of regular wave test, the design wave is represented by a wave period and an associated wave height. The main reason for such test is that the approach is simple in the design analysis. And the determination of the response due to extreme wave conditions, such as design sea state, is easier. Be it a fixed structure or a floating structure, if you want to look at floating structure, you can find out the frequency response. For different frequencies, how does it respond? How high it goes? How much it moves forward? How much it moves in the lateral direction? If it is and if you are talking about a freely floating body also, how much it can drift? All these information can be understood.

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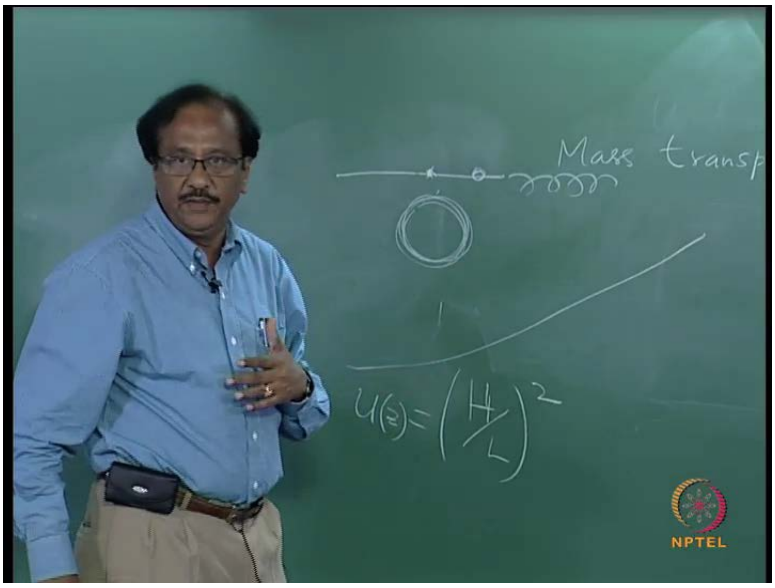

For example, when we are talking about mass transport velocity, you remember, we were discussing about mass transport velocity (No audio from 25:30 tO 25:39). We also said that, when we took, when we look at the basic wave hydrodynamics, we said that it is moving in elliptic. I mean circular orbits and the particle if you are floating, if some particle is floating, it will remain in the surface, at that particular location. But that was not true; you know that was not true. Because if you have a particle here that is subjected to an oscillatory motion, you see that it is getting transported in the direction of wave propagation.

When it is moving in the direction of wave propagation, we also found that it is going to be a function of H L square. And we also, knew that mass transport velocity will be varying as you go down, along the water along the water depth. Now, can you easily can you try to use some simple technique to understand this physics. So, if you have a floating object subjected to regular wave you use a steeper wave, flatter wave. And then try to find out how fast or how slow it moves near the surface. It is a simple experiment can easily understand, you cannot straightaway jump into such problem using the random wave.

So, if you want to understand such kind of information, the best way of doing it is with a regular wave and more. So, if you want to look this only an example. If you want to look at the design sea state, then corresponding wave height and wave period are supposed to

be used to measure the forces pressures exerted on the structures. The wave structure interaction phenomena can well be understood with regular wave test. Whatever I have explained here if you have some kind of seeds or some kind of flow visualization technique. And if you have a flume, if you have a flume with the side walls full of glass that will help you to observe the flow behavior.

How? Including this movement of all these things are based on simple linear theory what we have seen. But if you want to believe on and if you want to have feeling to all those things apart from the mathematical aspect, you can jump into a system. If you have a flow visualization technique, you can visualize everything and that has to be done only for a regular wave. That is only an example. But there can be a number of serious research works, involved in flow visualization technique. There are several complicated problems and testing the structure with flow visualization and that too with regular wave is going quite handy.

If this method is employed the structure has to be tested for several hours to several waves of different frequently amplitude and frequency and the structure has to be designed for worst load it experiences. That is true. One simple term, problem here is why when regular wave test and one more thing is very very simple, straight forward. There is absolutely no complication in using a regular wave maker also; even the working also is very simple. So, the last question if this method is adopted now, you have to subject the structure for several combinations of wave height and wave period, in order to find out for which of the combination it might have some problems.

So, the testing takes time. Testing certainly takes time, but nevertheless it gives lot of information as stated through earlier points. So, if you ask me, regular wave test is it necessary or not? Definitely it is necessary; it is very useful as I have said earlier.

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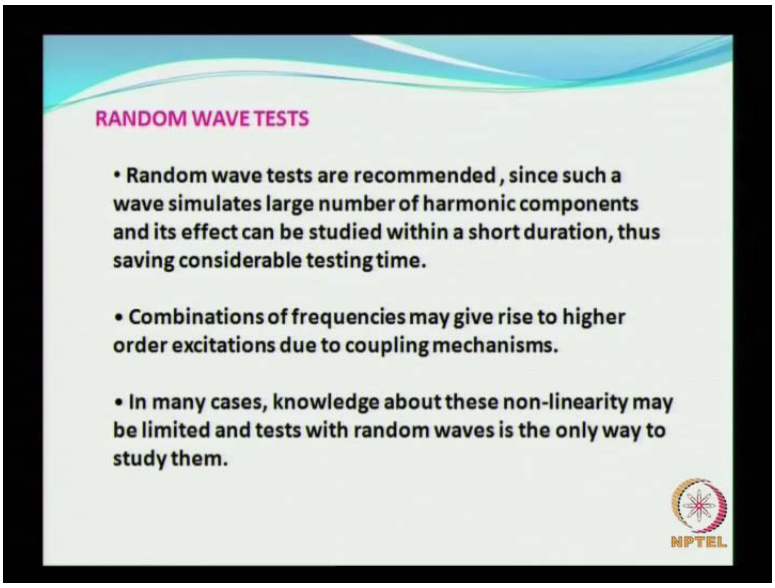

Now, random wave test. Why are we talking about random wave test? Random wave test are recommended, since, such a wave simulates large number of harmonic components and its effect can be studied within a short duration. So, thus saving considerable testing time, this is also very true.

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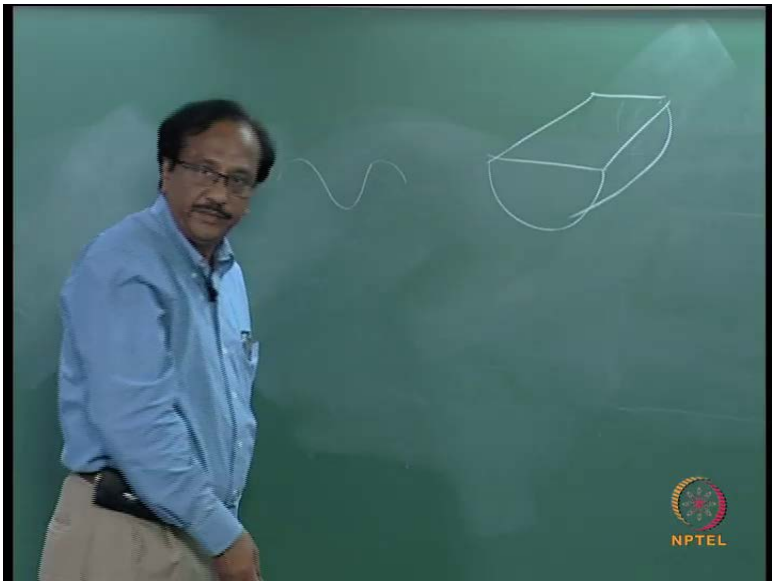

So, when you have a regular wave like this, you have a body for example, and it is going to oscillate. For example, I am talking only about heave motion, heave motion is just

going move and moving up and down. And I want to find out, how the heave response looks like?

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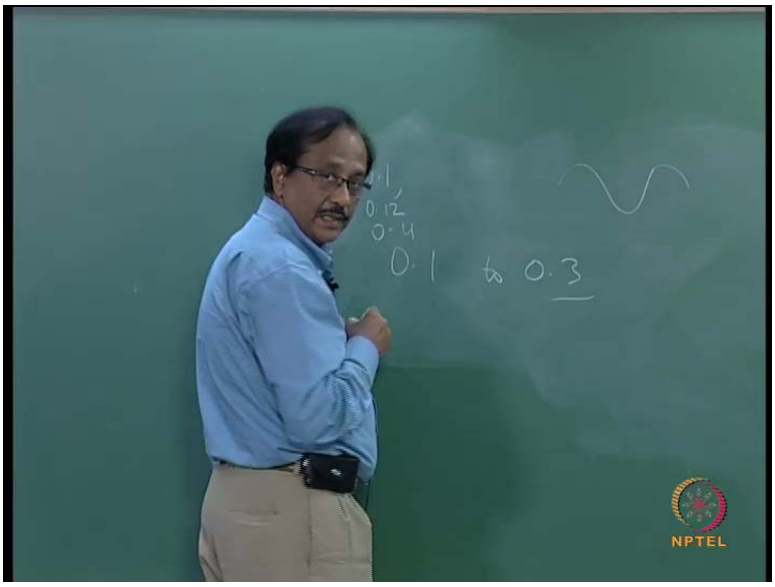

If I do not have a facility to generate random waves, what I have to do is, I have to so for example, I have to check for about a range of frequencies 0.3, some range of frequencies. Then, I have to check for 0.1, then 0.12, 0.14 like this. For complete range of frequencies, I have to check, how much is the heave for a given wave amplitude?

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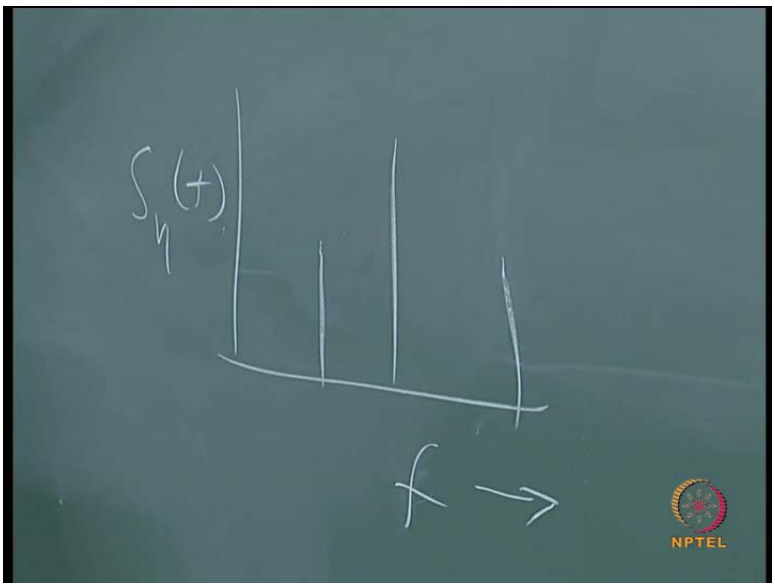

Then, I can get some kind of a frequency response, frequency the spectrum. Where in, on the x axis I will have frequency, on the y axis I have spectral density for example, or heave response function.

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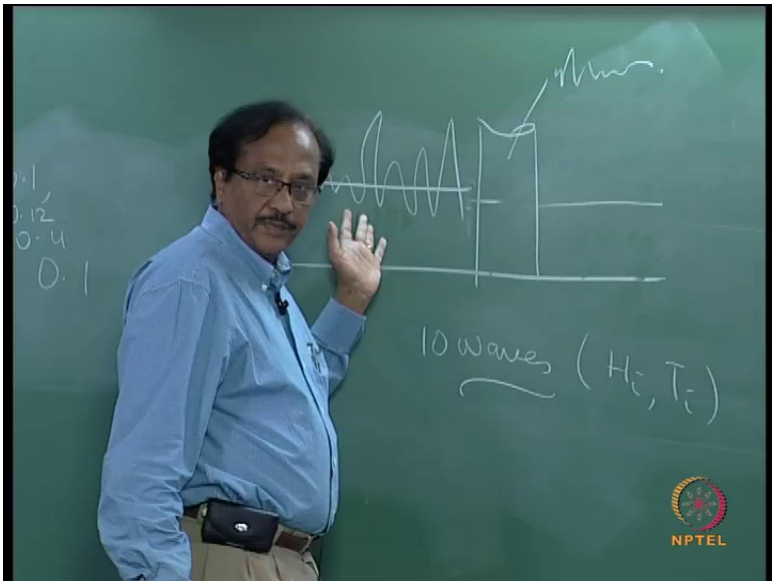

Suppose, if you are looking at a structure which is fixed and you are trying to measure the force (No audio from 32:41 to 32:51). So, for each frequency I will try to get the, for each frequency and amplitude, I will get force. So, each wave you have to subject this at least to 10 waves of a particular wave height and wave period. So, when I have about 10 frequencies, 10 discrete frequencies, suppose I have 10 discrete frequencies to cover the range of frequencies which I am suppose to test. Then in that case, for each of the frequency associated with a wave height, I need to generate at least 10 waves.

Then, you can imagine the number of hours that you put in for the measuring, for the measurement and also for the analysis and coming out with the presentation of the results. But when you look at the random waves, what does that do? Instead of regular wave, I can tune my wave maker in such a way it covers the range of frequencies which I have which I am interested. And then, I generate and then I get the force time history. Then, I subjected both, to the spectral analysis as I have said earlier.

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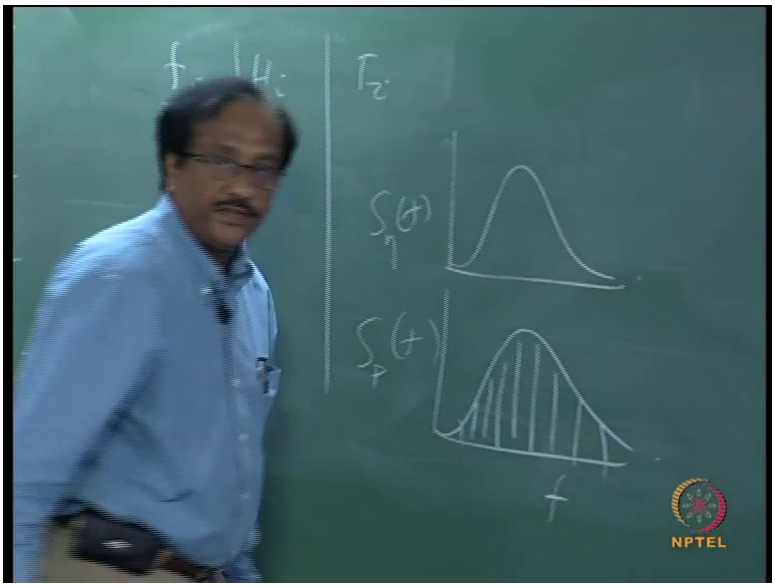

So, I can have the force the eta of f and the force. So, in that way I will get how the force varies with different frequencies. And this kind of test, it does not take much time hardly few minutes, what you have spent may be few hours a number of hours, you can achieve it in few minutes. Another thing is analysis is also very quite straight forward. For this only thing is, you need a costlier wave maker that will have the facility of generating random waves. Combinations of frequencies may give rise to higher order excitation due to coupling mechanism.

So, this is an observation which you can see when you are testing with random waves. Because there can be a particular periodicity which can be contributing more towards the excitation or the force. In many cases, knowledge about these nonlinearities may be limited and test with random waves is the only way to study. So, random waves but we are talking only, we are we have been talking only about unidirectional regular and random waves, have that in mind. In the case of random wave test, the design wave environment considers a wave spectrum.

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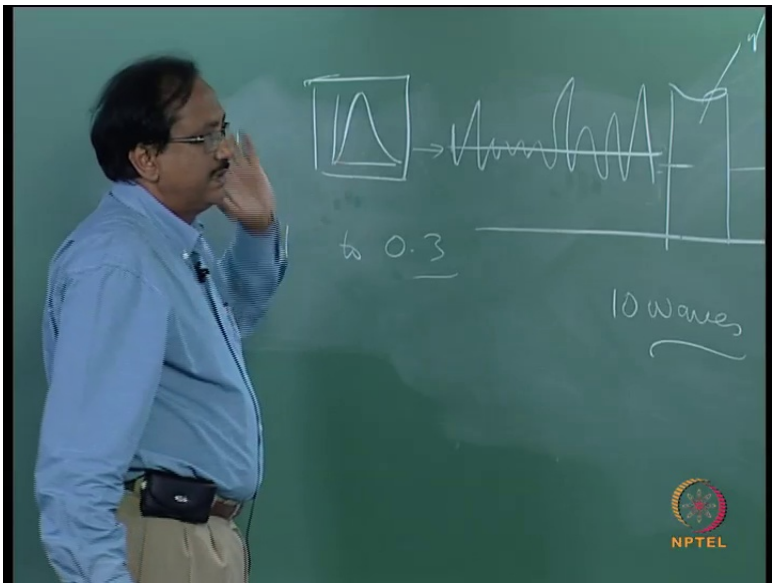

Because in the earlier class I have said, how do you simulate this? In fact you simulate this, from a known spectrum. This comes from a spectrum.

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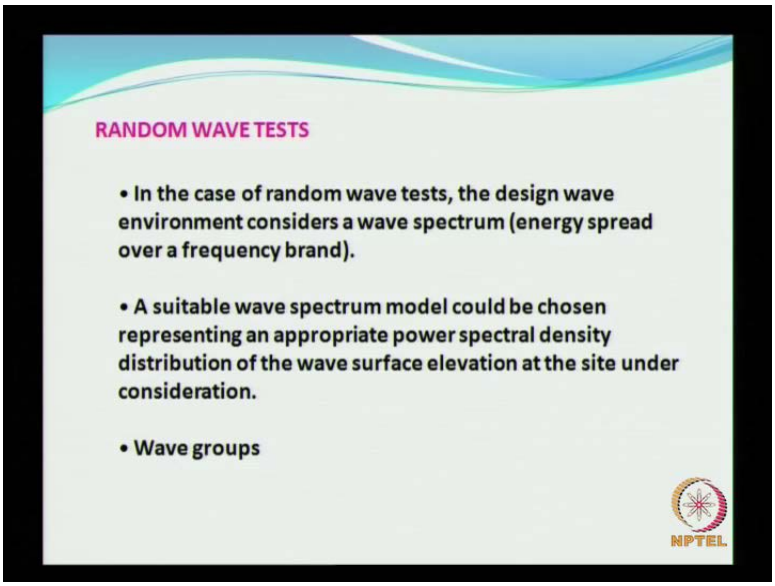

So, energy spread over a frequency brand that is what I have written here. The suitable wave spectrum model could be chosen representing an appropriate power spectral density distribution of water surface elevation at the site under consideration. This is also, I have just explained in the previous class, where this actually we considered. That is, how it has to be considered? Etcetera like, you have the standard spectrum from

which you simulate the wave elevation of pre defined spectral characteristics, from which you can measure the forces exerted on the structure. The last one is the wave group that is another kind of there is other kinds of waves also. For example, freak waves.

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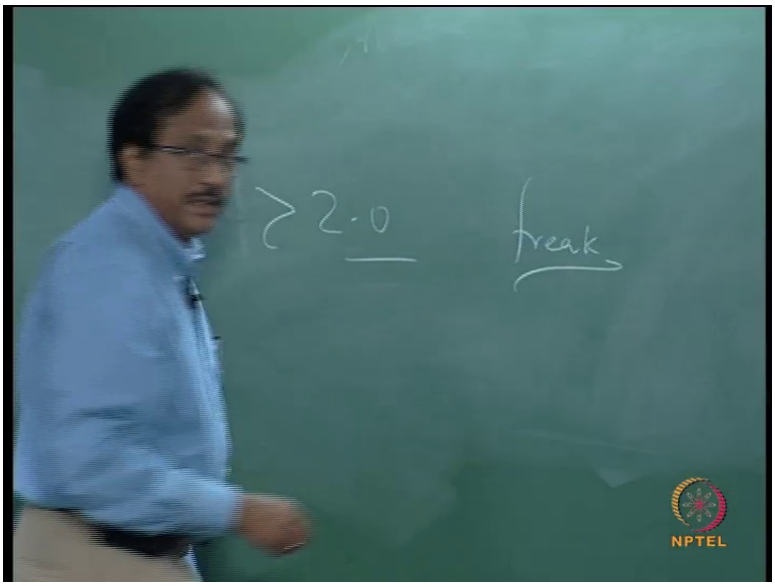

When you had, H max divided by H S, I said it will be ranging between 1 to 2. Remember? That is based on the Rayleigh distribution. Suppose, if H by x is greater than 2.0, then we call it as freak waves. Freak waves can create the capsizing of vessels. So, you need to be very careful with this kind of. So, the facility the random wave, the kind of random wave facility can also, facilitate the testing structures with freak waves.

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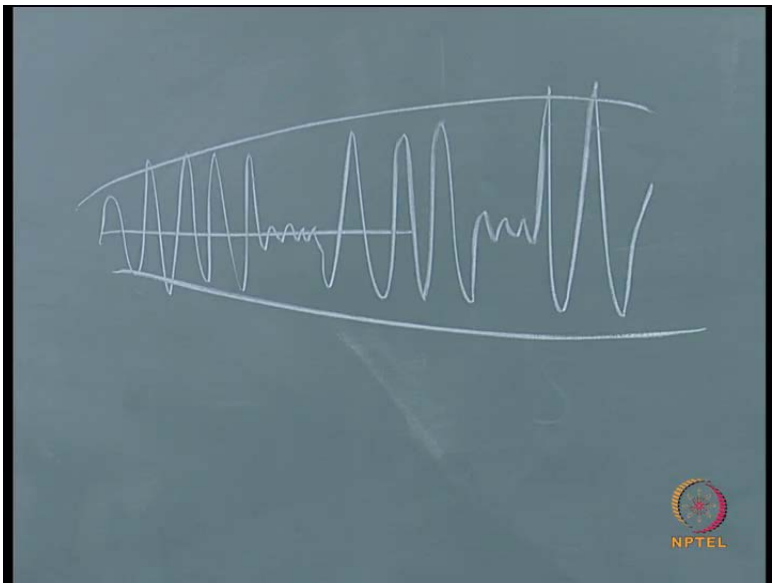

Then wave groups, these are, so it moves as a group wave group. What will happen?

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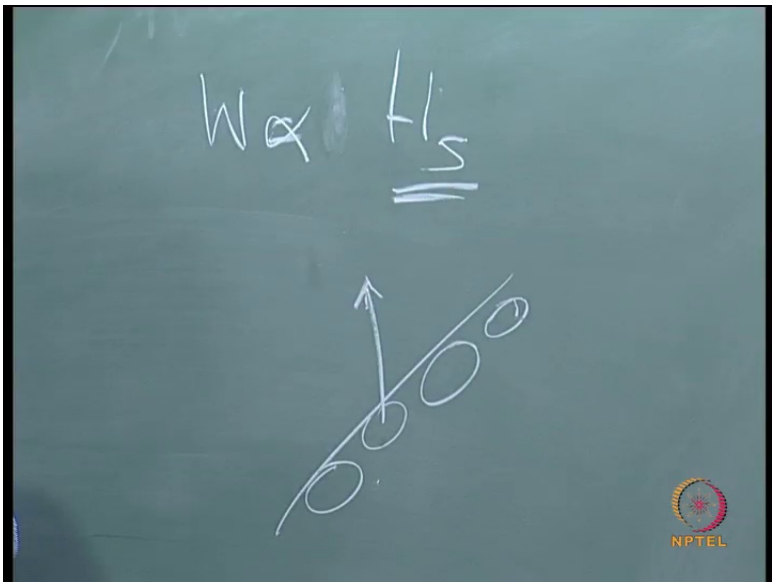

The effect of wave groups is, suppose, if you are designing a rubble mound structure. The weight of the individual stone is based on weight of the stone is directly proportional to H s. So, assume that you have designed the stone and there may not be a problem, if wave height is slightly exceeding even the H s, once in a while it does not matter. But very frequently it exceeds the significant wave height. Then, what will happen? That is

called as wave groups. It keeps on the wave height is greater than the design significant wave height. But it goes, hits, goes, hits at very short intervals, it keeps on hitting.

Then the stone gets dislodged. These are called as wave groups. Such kind of waves can also be tested, when you have this kind of random wave testing facility. Now, we move on to testing of structures with multidirectional waves. So, far we have seen this moving in this direction in normal wave, normal direction. But what is this three dimensional waves?

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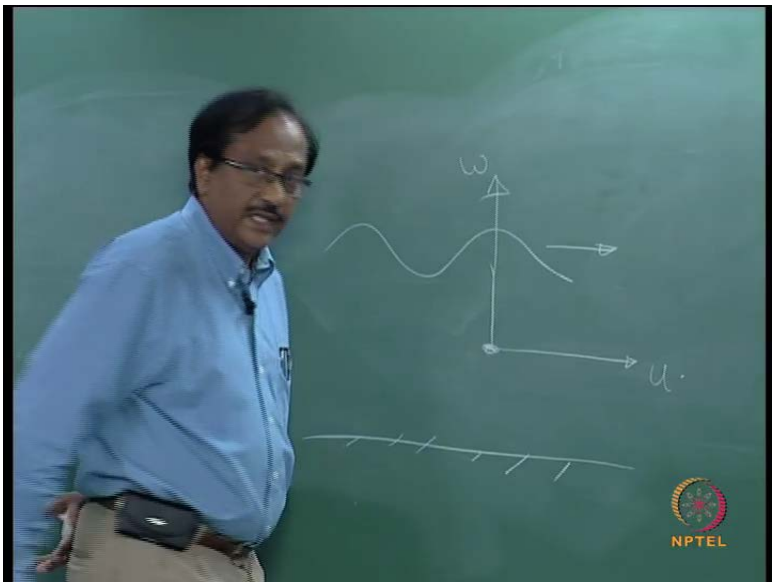

I said when the waves move in this direction, you have orbital velocity in this direction in the vertical direction and in the direction of wave propagation. This is the wave propagation and this is what we have used in our linear wave theory. What did we do? We decided we assume that the velocity in the direction normal to the board is 0; we can call it as Transverse velocity.

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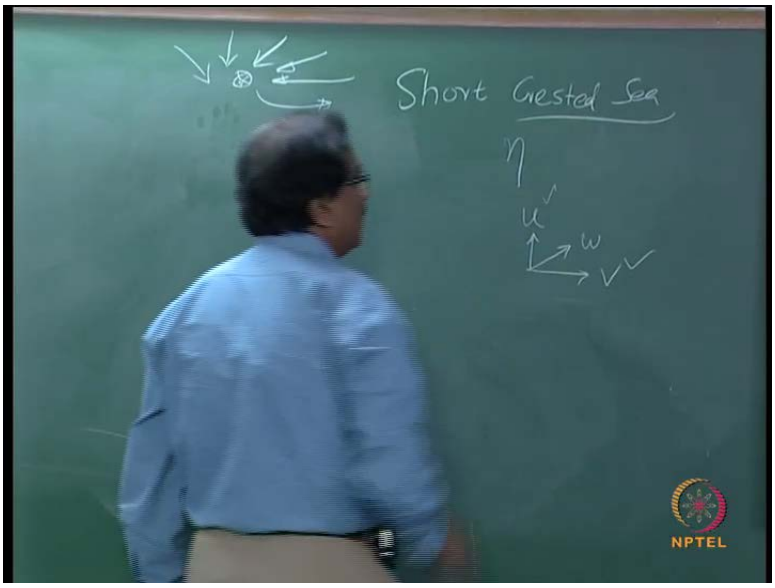

You take an open ocean. Somewhere in the deep ocean, the waves are supposed to reach from different direction. It will come from different direction and if you have a facility to measure eta and the three velocities u, w and v, v is the transverse velocity normal to the board. Then, if you measure in the deep waters, you will see that u and v are almost of same value or comparable. That means, that is an indication that, waves are coming from different direction at that location. So, this kind of a situation is also termed as short crested sea wave, short crested sea or multidirectional waves. How can you simulate such kind of a wave in a flume? It cannot be done. Because there has to be motion normal to the board also.

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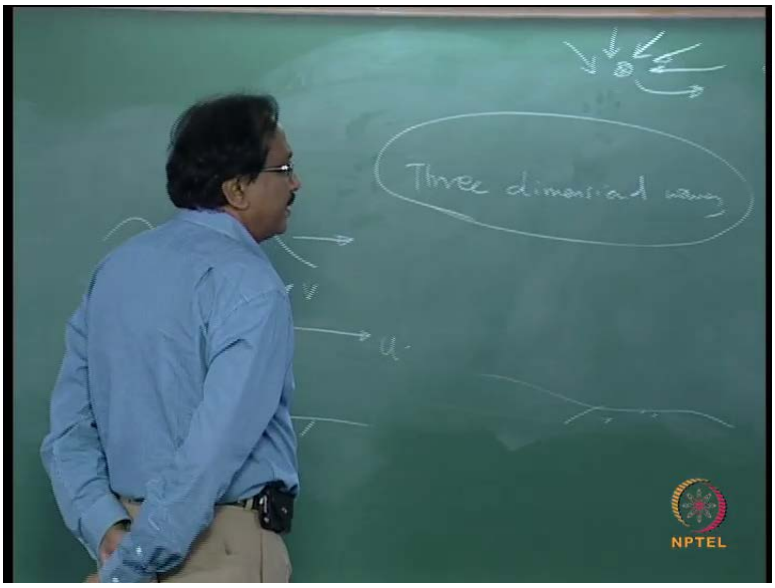

And, that is why we resort to three dimensional waves or short crested waves. Now, you know which is closer to reality Real Ocean. Naturally, the three dimensional waves are close to the real ocean. So, now what you are suppose, what we have been seeing step by step? We started with regular waves? What is the purpose of regular waves? Then, what is the purpose of random waves? And then, we are slowly going into the reality that is closer to the real ocean waves. But how did this originate, the importance of the three dimensional waves?

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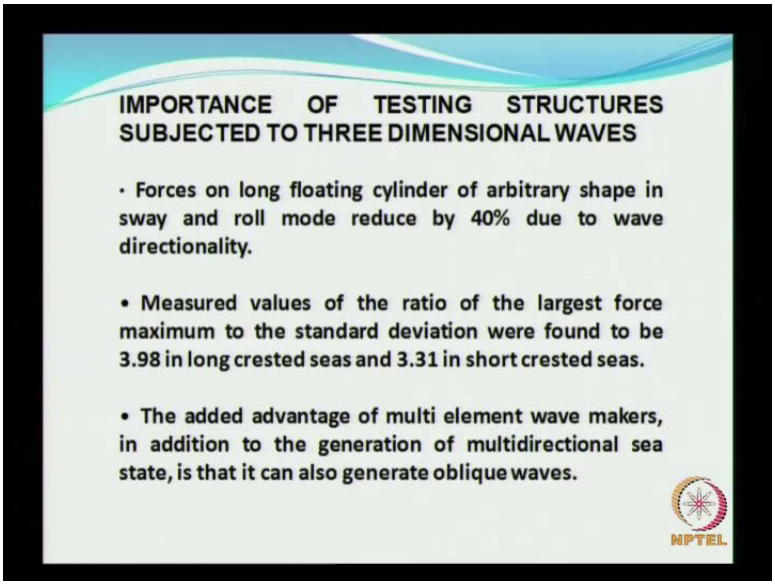

They found that forces on long floating cylinder of arbitrary shape, in sway and roll mode. You have motions in the, we have three linear motions and three rotational motions. So, in the case of roll and sway, they reduce by about 40 percent due to wave directionality. For example, if you consider the motion in this direction alone, you are over estimating the force. So by considering, if you are considering this structure to be experiencing to be exposed to the action of three dimensional waves. Then, you need to know how it would respond in three dimensional waves compare to the two dimensional waves? Because three dimensional waves when you test you will easily find, that the forces may be much less compare to that in two dimensional waves.

On the assumption that in the two dimensional waves, you assume that the forces in the two dimensional waves, what will happen? If you are considering a square cylinder or rectangular cylinder when it is moving like this, it is going to be dependent on the width and it is normal angle of incidence. Now, if it is moving in this direction naturally your force is going to be less. So, that is what the first point says in terms of long floating structure cylindrical structure of arbitrary shape in the sway and roll mode reduce by about 40 percent. Measured values of ratio of largest force maximum to standard deviation were found to be that is largest wave force that is the force maximum divided by your standard deviation.

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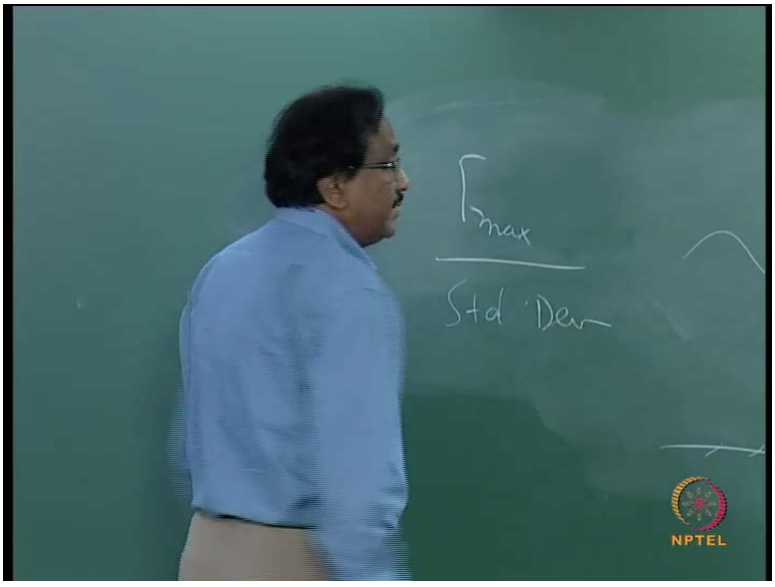

It was found to be higher in the long crested waves. Where long crested wave means the two dimensional waves, short crested waves means three dimensional waves. So, this is something like 3.9 or close to 4. Whereas, in short crested waves it is, it was found to be 3.0, all these things are proved. The added advantage of multidirectional, multi element wave makers in addition to the generation of multidirectional sea state, it can also generate oblique waves. So, this will facilitate the testing of structures.

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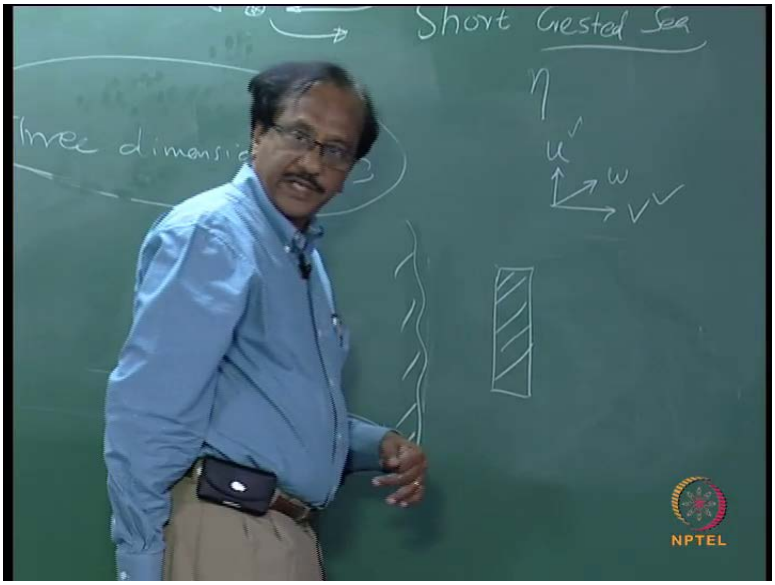

Suppose, if you have, you want a structure which is floating, I am showing it in plan. So, you want to put a structure in plan. See now, if you do not know how to calculate the forces and you want to do it through the experiments, then what will happen? If you have only a flume, you can generate only the normal wave angle of incidents. But if you have a basin, then, I can allow the waves to penetrate form different directions. So, we have seen some few points earlier.

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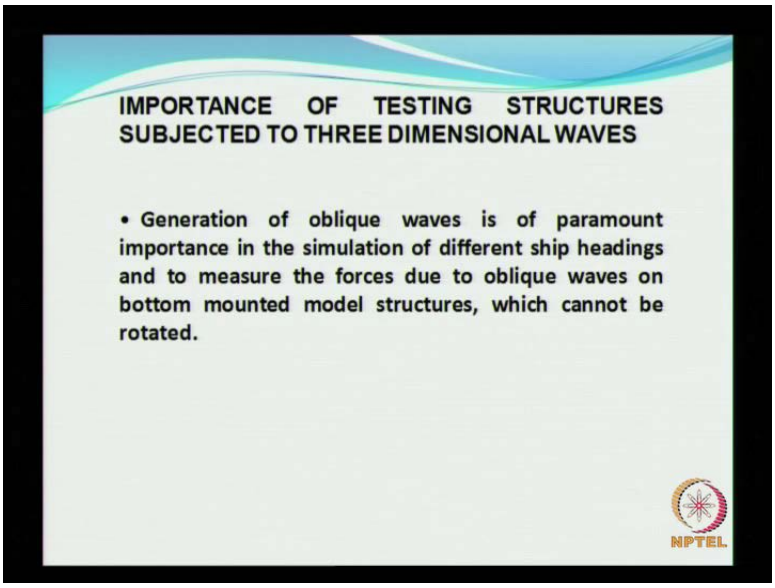

Then in continuing the oblique wave, generation of oblique waves is of paramount importance in the simulation of different ship headings. And also to measure the forces due to oblique waves on bottom mounted structures and in which case the bottom structures, bottom mounted structures cannot be rotated.

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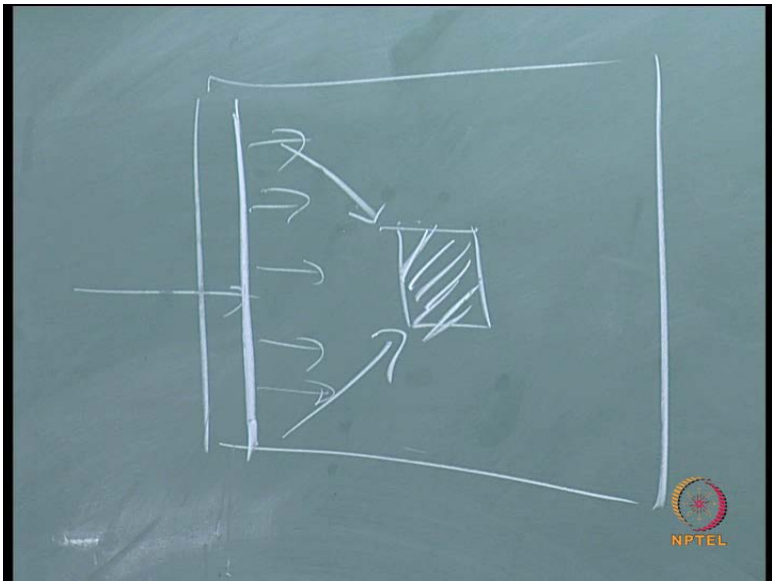

One way of testing the oblique waves is, that you have a basin you have a basin and you have a wave maker. This is not; I am not talking about multi element wave maker. It is a simple unidirectional it can generate only unidirectional waves. For example, then in that

case, I have a structure here and I want to test the structure for different oblique waves. Then, I can simply rotate the structure. So, not with the, so wave maker will still be generating only, regular or random unidirectional waves. But then, we cover the problem of oblique waves by rotating the structure.

But in certain cases, it may not be possible to rotate the structure and in which case, this becomes very handy. If the wave maker itself can be controlled in a control room, where in it is only kind of software, with which you need to work. Then, your model can still be fixed intact as shown here. And then only with the controlling of the wave maker you will be able to generate waves moving in this direction or in this direction. I am talking only about oblique waves here; in addition to the directional waves is something different. But here oblique waves this can be done. See the purpose and why we need to test, have wave maker? If you have a wave maker that can simulate the oblique waves, then it becomes quite a handy. That is what I am trying to stress.

So, I am sure that, this would have given you some information about regular waves, random waves, multidirectional waves, oblique waves, oblique random waves, oblique regular waves. So, there is variety of waves, wave groups, freak waves, etcetera. So, I will just continue with the, with the facilities that are available in our department. How they were developed? Or how many years it got developed? And what is its status as of now? So, this is this will be illustrated with some of the video clips etcetera, some of the standard explanation, some of the important test which we have done. A few test I will just project. So that, that gives you an idea about what is all about.