Wave hydrodynamics

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Module No. # 02

Wave Motion and Linear wave Theory

Lecture No. # 01

Introduction

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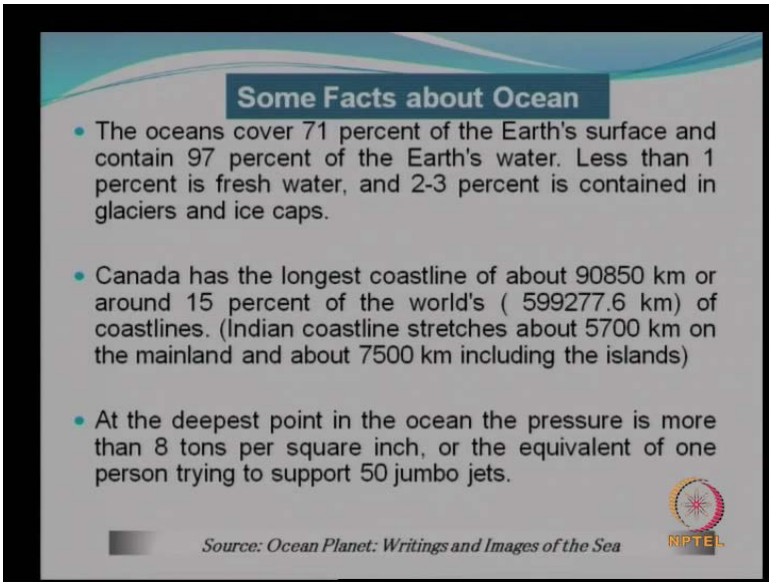

So, we will get started with the course on wave hydrodynamics. And before getting into this subject which is of great topical interest particularly, after the recent tsunami etcetera. Let us look into some of the facts about ocean. The oceans cover 71 percent of the Earth’s surface and contain 97 percent of the Earth’s water. Less than 1 percent is fresh water and about 2-3 percent is contained in glaciers and ice caps. For your information, Canada has the longest coast line of about 91000 kilometers or 15 percent of the world’s coast lines. Indian coast line stretches about 5700 kilometers on the mainland and about 7500 kilometers including the islands. Some of these points are quite fascinating, at the deepest point in the ocean the pressure is more than 8 tons per square inch, which is equivalent to one person trying to support 50 jumbo jets.

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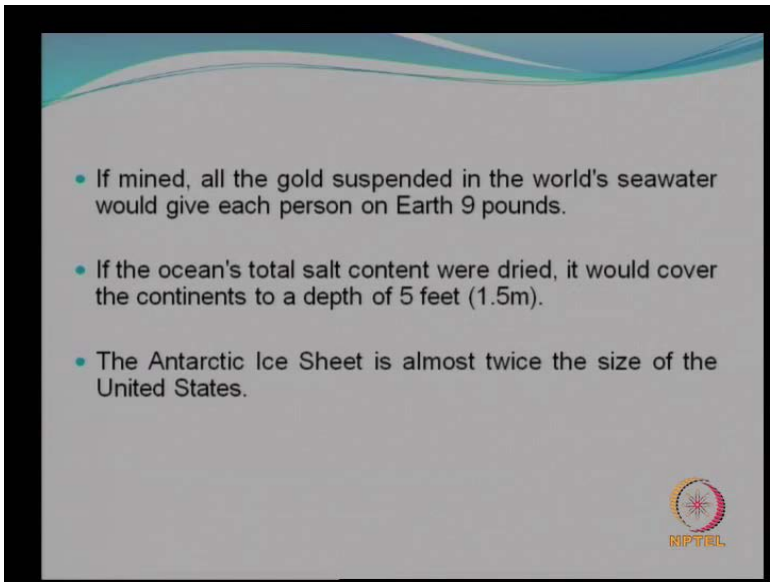

This is taken from the ocean planet. If mined, all the gold suspended in the world's seawater would give each person on Earth about 9 pounds. If the ocean's total salt content were dried, it would cover the continents to a depth of about 1.5 meters. So, the Antarctic sheet is almost twice the size of the United States, this gives you kind of a overview about the environment, we are going to discuss about and why are we talking about wave hydrodynamics.

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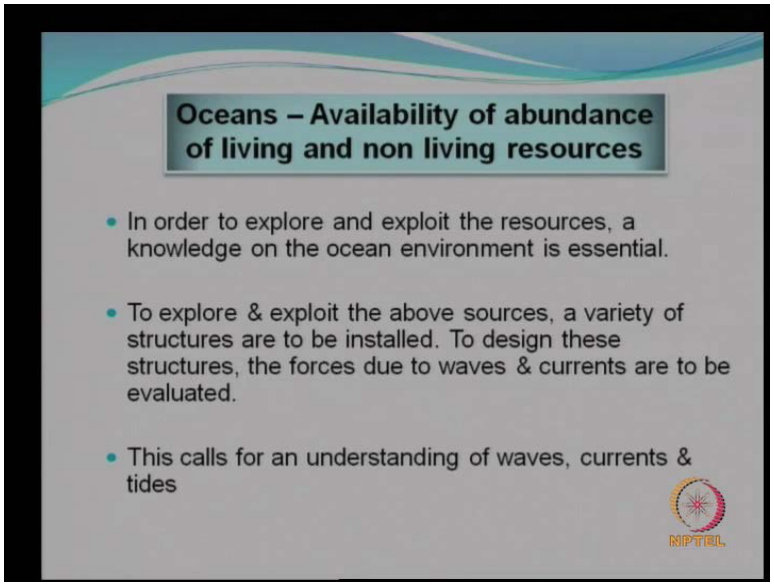

Oceans has enormous amount of living and non living resources. In order to explore and exploit the resources, a knowledge on the ocean environment is certainly essential. In order to explore that is in order to search the resources and also later exploiting them a variety of structures are to be installed. And certainly when you want to design such a structures to withstand the forces due to the environmental loads, it is extremely important that we have a thorough understanding of the physics of waves, currents and tides. That is the purpose of this lecture.

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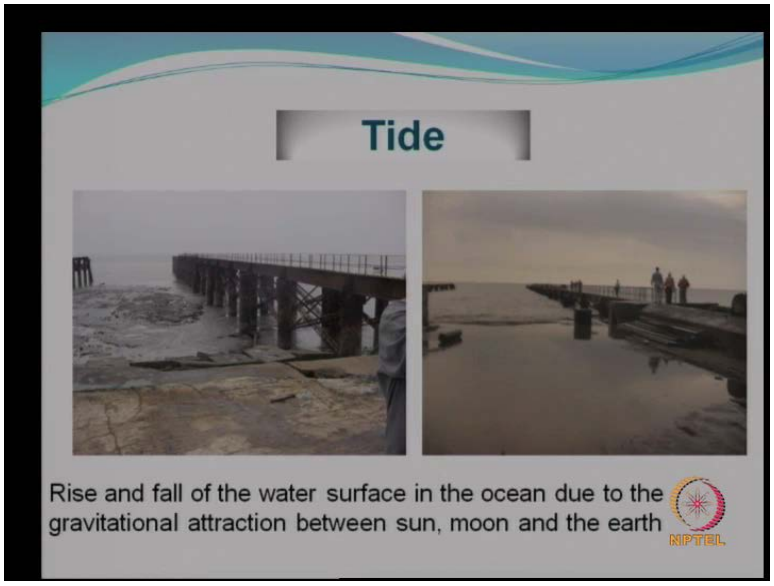

So, let me start with the phenomenon of tide. I am sure many of us have heard the name tide, even in school, but let us have a kind of refreshing. The rise and fall of the water surface in the ocean is called as tide. This is actually vertical movement. First you will have the main sea level, then it goes up to have the high tide and then again it comes back to the main sea level and then goes back to the low tide. So, you have one tidal cycle that is once it starts the water surface, starts from the main sea level goes to high tide, low tide and then again comes back to the main sea level. This is similar to your pendulum oscillating from a mean position it moves on either side in order to complete one cycle.

And this rise and fall of the water surface in the ocean is caused mainly due to the gravitational attraction between the sun moon and the earth so, this slide clearly shows the effect of tides. So, this picture on this picture shows a jetty a shore connected

structure, jetting into the ocean, where in you see that significant portion of the piles supporting the platform is exposed, that is during the low tide. During the high tide or this picture is in between high tide and the low tide you see that. That it is much more than the main sea level, there in you sees that a portion of the piles are submerged on water.

So, this area is referred to as tidal flat, that is this area is alternatively exposed to water that is it is wet and it becomes wet and dry alternatively. So, these are called as tidal flats. The tidal range that is the distance between the high tide and the low tide can vary even up to about 15 meters for instance of Chennai is of the order of 0.5 meters to 0.75 meters of Hooghly may be it is around three meters tidal range. But if you go gulf of Kutch etcetera. It can be anywhere between 5 to 8 meters bay of Fundy that is in Canada it can be as high as 13 meters etcetera.

The tidal range is quite high, you can also use this the tidal range for generation of power. There are number of power stations using this tidal energy in the world. You have this tidal range, why do you need this information? Particularly, at locations where you have the larger variation, you need this information in order to fix the top level of your structure. Be it a ocean bridge or a jetty so many variety of structures being constructed in the ocean or along the coast. So, the tidal level, tidal range is definitely needed for fixing the top level of any structure.

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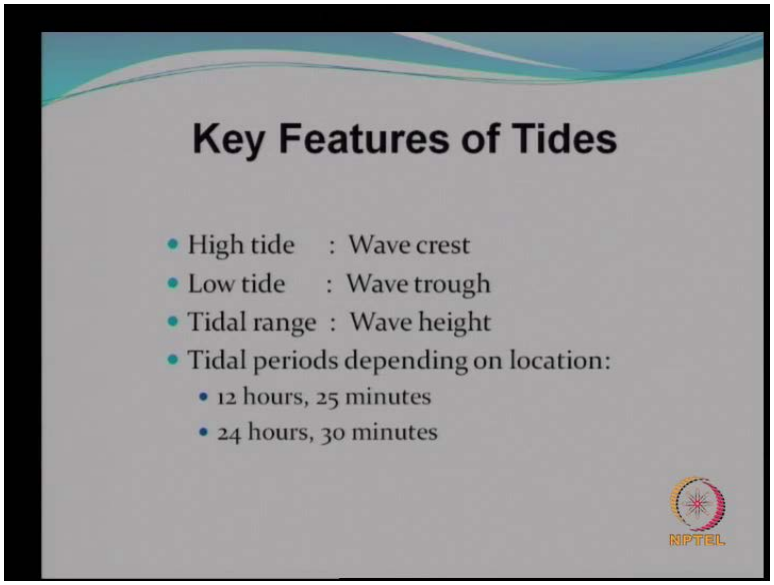

So, key features of the tides are the high tide which I was referring can also be said to be as crest, low tide can be said to be trough and the tidal range can also be equivalent to the wave height. On the right hand side, this is equivalent to a wave which we will see later. Tidal periods depend on location, it can be the tidal period that is stretching for one cycle can be 12 hours 25 minutes or 24 hours 30 minutes, these are the two categories of tides.

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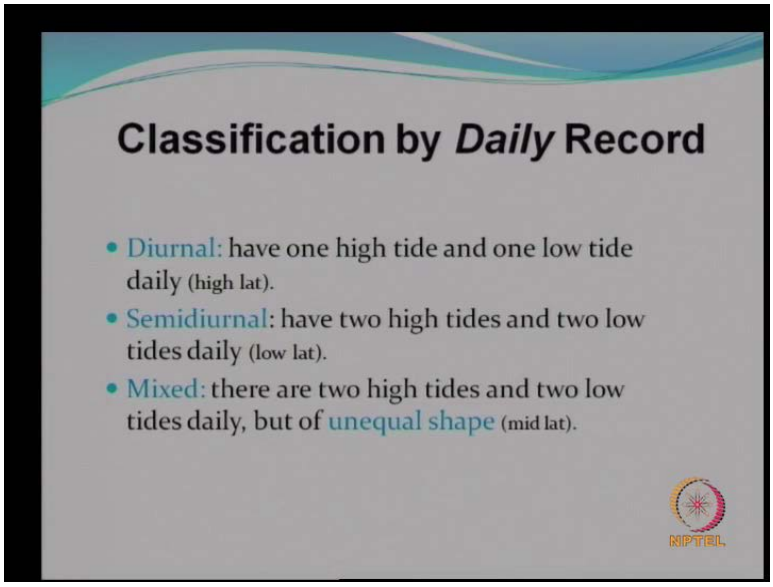

So, they can be classified by daily record. So one is referred to as diurnal that has one high tide and one low tide. Semidiurnal, it has two tides and two high tides and two low tides. Sometimes, so for certain locations it can me mixed, that is there are two high tides and two low tides, but of unequal shapes. So, further details you should look into a number of books on oceanography, which give you much more information about tides.

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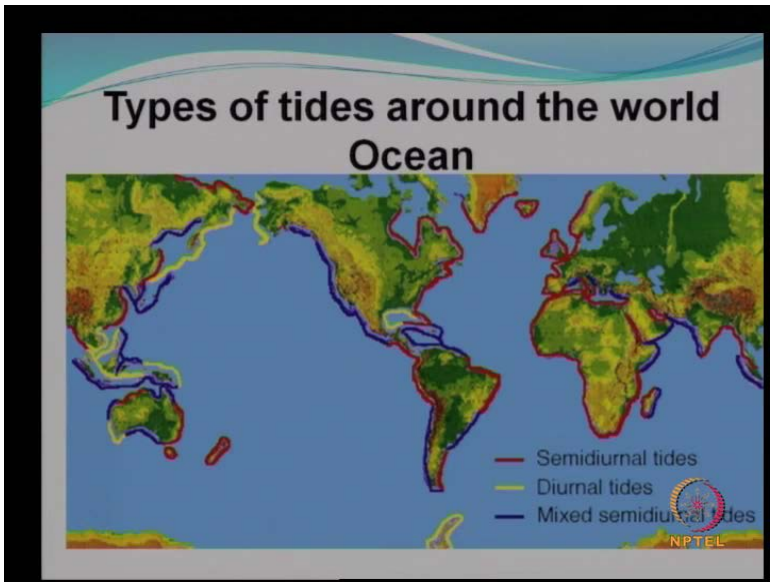

This picture shows the types of tides around the world ocean. So, the red color shows the locations where you have semidiurnal tides and yellow color is diurnal tides and all other locations you have mixed semidiurnal tides. So, along here along the Indian coast we have seen the semidiurnal tides.

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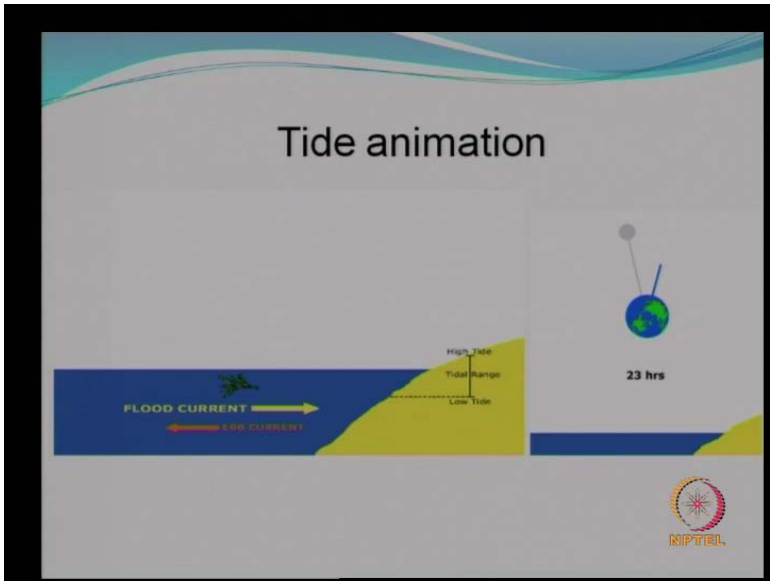

So, as I said earlier, the tidal variation depends on the gravitational attraction between the sun moon and the earth. And within about 24 hours you can either have two tides two high tides or one high tide that is what we have seen so far. So, what happens when this

process goes on in the ocean? You have the water surface in the ocean going up comes to the mean sea level and again goes down. As you can see in this animation and when you have the water level going up, you see that flow of water takes place towards the land. For instance, if a river is connected to the ocean rising tide in the ocean will push the water into the river and then when there is a low tide in the ocean, water from the river will rush into the ocean. This is what is called us tidal flushing is very important for rivers which are connected into the ocean if you have tidal exchange that is flushing then you have that the river is you see that the river is quite clean.

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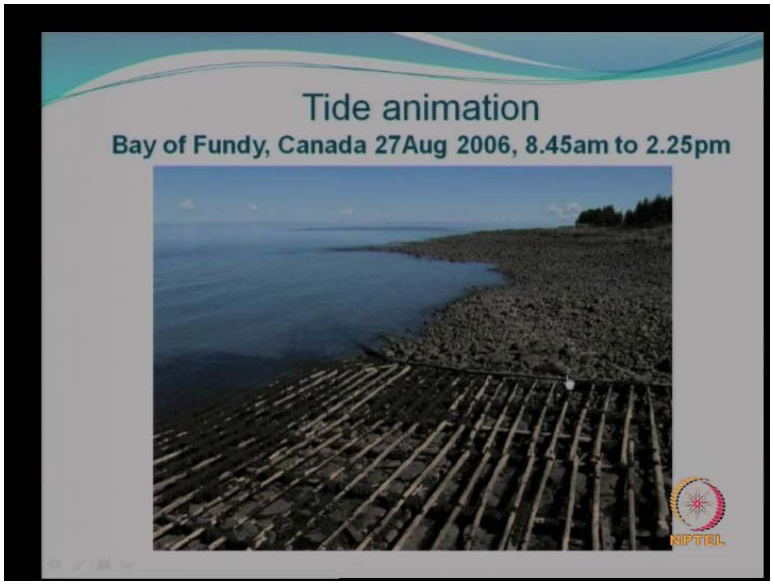

This is a tidal animation so look at this, this is all land and this is in one of the world's largest tide that is in the Bay of Fundy, Canada. And all this area which is exposed will soon be covered by water during the high tide. Now, you understand the tide is just movement of water in the vertical direction, although it is a simple harmonic motion. Is that clear?

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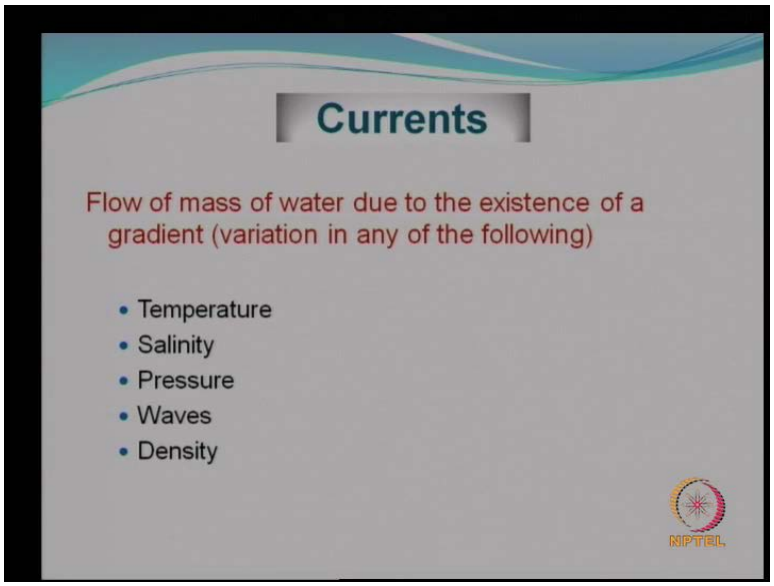

Now, we move to currents. All of us would have experienced the currents, I mean flow of water. The definition is nothing but flow of mass of water, how does the flow take place? A flow takes place whenever there is a gradient and that gradient can be cast in the ocean due to the changes either in temperature or in changes in salinity, change in pressure, waves as well as, density. Under waves, we have a variety of currents that are generated. So, I will not be covering the complete details, but basic information is that current is just flow of water, it will have a direction as well as magnitude.

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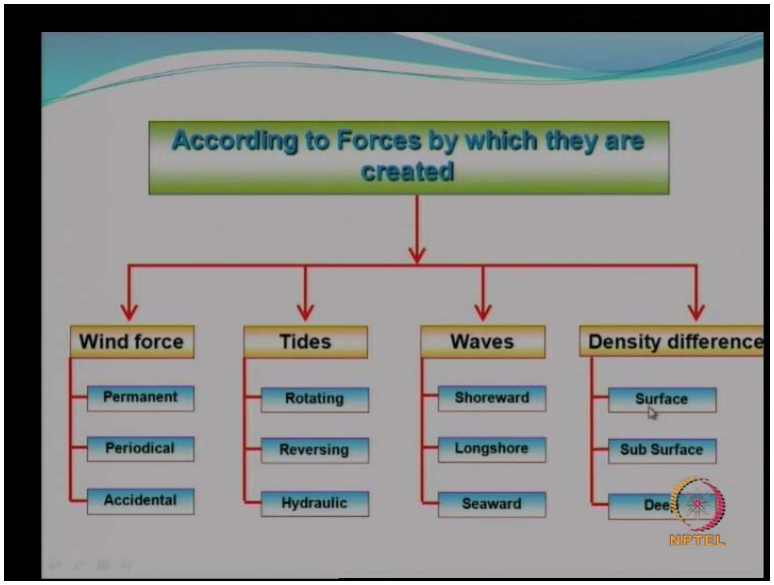

And, these are classified according to the forces by which they are created. I will just mention only the broader classification of the currents. One that is caused due to wind force, which can be further classified as permanent periodical and accidental, I suggest you refer to some books on oceanography again. And due to tides, you can have you will have rotating reversing and hydraulic due to waves, shoreward, long shore as well as seaward. Some of you may be aware of these currents. And due to density difference, you can have sub surface or deep currents. These currents are different from the major ocean currents, I am not going to go into those details, but why do you need the information of currents? The current definitely exert forces on structures and hence need to be considered not only that, the presence of the current in an environment that is dominated by waves. The characteristics of the current of the waves can be altered will be altered in fact, due to the presence of currents. Again it depends on the magnitude and the direction of the currents.

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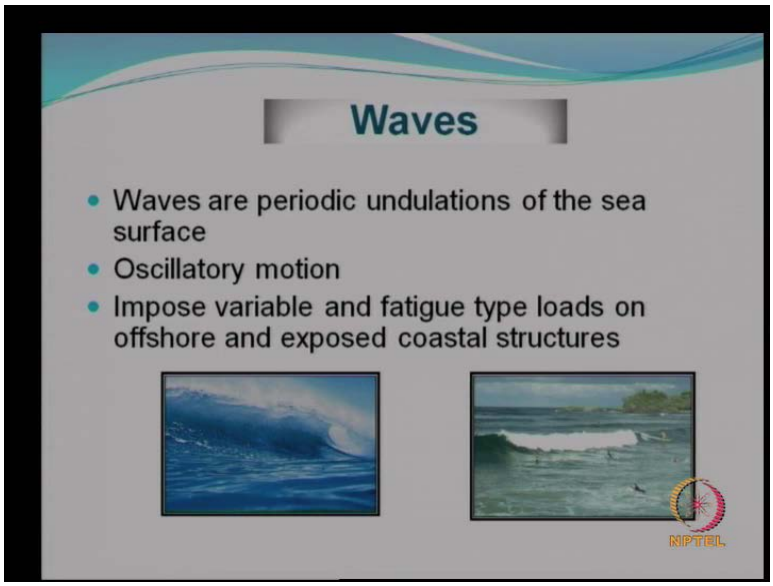

So, you need to know the information on currents. Waves which is of direct relevance to this subject matter is the one which we are going to look into it now. What are waves? Waves are nothing but periodic undulations of the sea surface. How is it cast? It is cast by the action of wind over the water surface, just take a beaker of water, just blow over the water surface. You see that the water surface gets disturbed and if the beak if the I mean if the holder which you are having, it is constrained the disturbance will be quite different. If you are having the same kind of disturbance being made in a larger tank you

can easily see how the waves are generated or how the waves are propagated. Or you just put a stone in a pond, there again you can have waves generated, from the source point. Starting from throwing a stone into the pond, you can have you can go to under water earthquakes, that can generate tsunamis.

What we are talking in this subject is, about ocean waves. Which are cause only by the action of wind over the water surface. It pumps in energy for the growth of the ocean waves and the motion of the surface of the waves is considered to be oscillatory. So, waves are recognized as oscillatory motion, they impose variable and fatigue type of loads on structures for example, you have columns, piles supporting offshore structures or coastal structures. And they are all being subjected to ocean waves as well as currents, superposition of currents and waves all these things come under environmental loads. In order to consider the environmental loads so has to design the structures to withstand their effect. We need to understand the basics of the mechanics of ocean waves. I hope it is all clear now. So, shall we go proceed?

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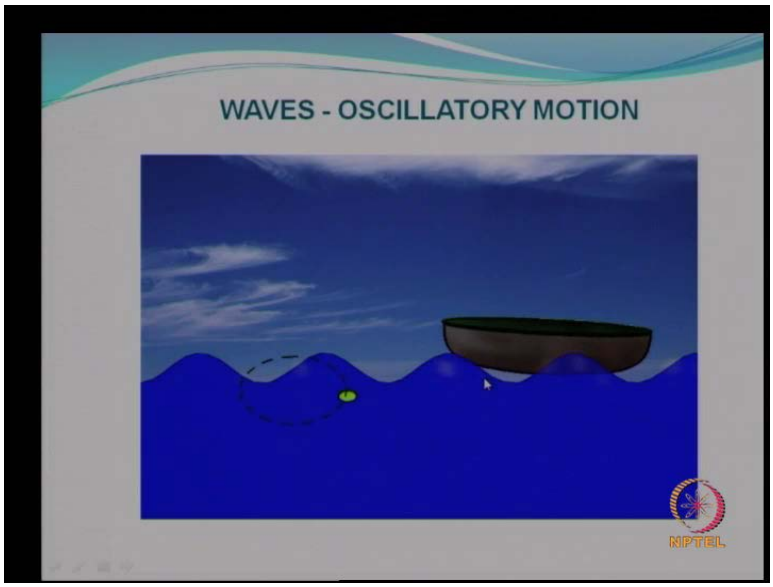

When I said the oscillatory waves so look at this animation, say if somehow if I can sit on the wave, what will happen to me? I will be just at that position, but I will be undergoing an oscillatory motion from the mean position. Again back to the pendulum of a clock say it is position is center it is a mean position. From that mean position, it will be undergoing the oscillatory motion similar to that the boat which you see here, will be

stationary, but it will be undergoing an oscillatory motion. I would like to bring back one aspect here when I mentioned about tide you said I said low tide. Over the low tide you will have the oscillation of the waves and when mean sea level goes over that you have the waves, high tide again you have the waves. Now, you see the difference between waves and tides and currents.

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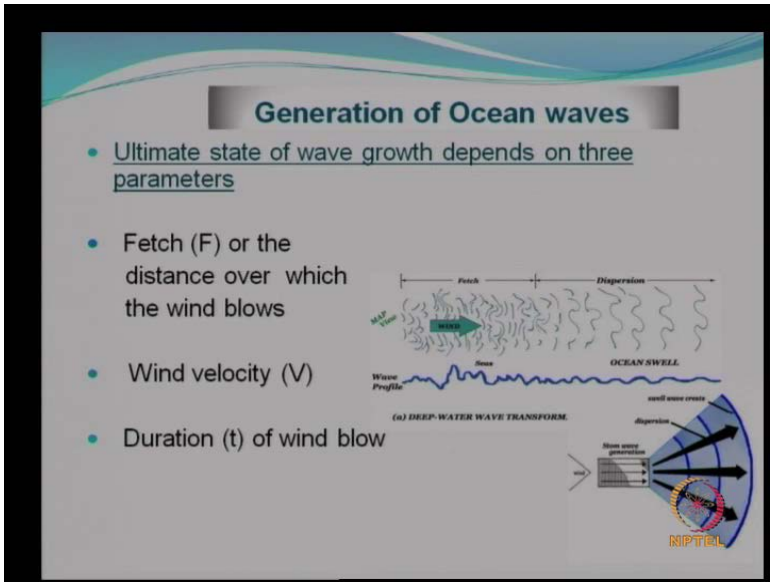

Generation of ocean waves, wind acts over the water surface somewhere in the deep ocean, the forces from the wind is transferred to the water surface. You have the normal stresses as well as the tangential stresses acting on the water surface. Initially, small waves are cast or generated and this is done this is being generated when the wind blows over stretch in the ocean and this stretch is called as the fetch. Initially, you have small waves being generated, but when there are wind continues to blow, more and more energy is being transmitted and the waves increase in it is height. When I say increase in height, it is energy also keeps on increasing.

And the growth of waves also depend on the velocity with which the energy is being transmitted, that means the velocity of the wind, not only that the duration of the wind. So, you have basically three parameters of the wind or characteristics of the wind, which are responsible for the growth of the waves. So, this is clearly indicated in this picture so this is the point where you have the initiation of the wind acting on the water surface. Now, you see small waves are generated. So, within this fetch area, where the energy is

continuously being transmitted which is helping in the growth of waves. The sea state keeps on increasing the state means, the energy content keeps on increasing. While it is increasing it is referred to as partially developed seas.

A stage will come a stage will reach, when energy from the wind no longer helps in the growth of the waves, and such a situation reaches we call it as fully developed sea. But in the generating area, you will have partially developed sea as well as the fully developed sea, but outside the fetch the waves will still propagate and these waves are called as referred to as swell. But please remember that swell is not a wave which is generated only outside the fetch, it can also generate in the deep ocean. So, you can have swell either in deep ocean or in the shallow waters.

But remember fetch outside the swell is outside the fetch region. And this permits us to obtain the characteristics of waves knowing the wind characteristics because the growth of the waves is depending on the wind characteristics. There are several basic formulas like empirical, semi empirical relationships between the wave height and the wave velocity of wind going up to complicated numerical models. So, where in all this acuities are brought and the prediction becomes more and more relevant.

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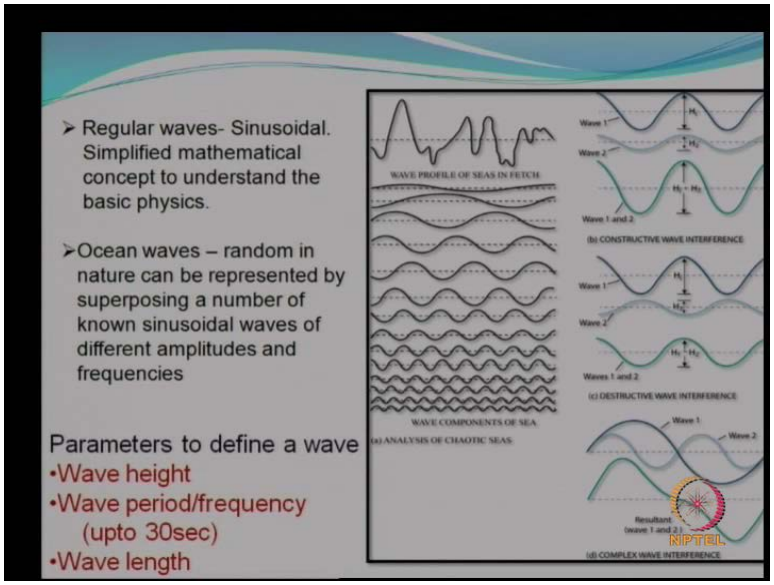

So, before we proceed, how are we going to handle the ocean waves? As I said we are talking about a sinusoidal wave to start with, it is often referred to as regular waves or sinusoidal, which is just nothing but a simplified mathematical concept. Which is formed

or which is available to us to understand the basics of the behavior of waves or the characteristics of waves that is all. If you how do you use this in the open ocean? Because in the open ocean, waves are random in nature so if you go and measure the ocean waves, you will see that the surface would be looking random as you can see in this picture. It is a sample time history of a random wave that is the displacement of the water surface over a mean water line.

So, this is for example, this is the kind of oscillation of the water surface or the wave elevation in the open ocean, which you would have and this is referred to as a random wave. So, when you have a random wave, what will you do with this? You normally try to obtain the wave characteristics, I mean average wave characteristics. When you talk average wave characteristics either it may be mean wave period or mean wave height. There are other wave characteristics which we will not take it up right now or so you finally, land up with one wave height and one wave period in order to describe a random time history. Or this time history can be represented as in the form of a energy distribution which I will, we will consider later.

But right now, you look at how did you get, how you can get such a irregular shape of the random wave? You can get this irregular shape by superposing a number of sinusoidal components or if you have a random wave as shown here, what you are expected to do is to use that time history. And in order to arrive different frequency components or in other words you look at this, this is a one single wave with a different wave height. And a frequency compared to this, this is a longer wave the smaller wave height. So, when you superpose such known number of sinusoidal components with varying wave height and frequency, you can have something close to this irregular shape. Or if you have an irregular random wave, you can break up into number of sinusoidal components. So, either way you need to know about the basics of your Fourier series, all these things have been taught to you try to recollect and you will be in a position to appreciate.

Now, when you are dealing with a wave, as you can see here, this is one single wave. This is how you can represent a sinusoidal wave, the highest point is called as the crest and the lower point is called as the trough. And this is for instance, this is the water level over which it is oscillating the distance between the highest points, that the crest and the trough is called as the wave height. To have a feeling for the magnitude, the normal

wave height which is usually occurring during non monsoon, etcetera. May be ranging between 0.5 to 1.5 meters, may be during a storm it can go up to 4 meters around 5 meters etcetera. In off shore, it can be much higher so, you know how a feeling for the wave height.

Then comes a wave period, what is a wave period? Before going into the wave period I will tell you about the wavelength. The distance between any two successive wave crest, that is from here to here is called as the wavelength. And the time taken for the wave to travel one wavelength is called as the wave period. So, in this picture you see how you can when you superpose two components, this is the kind of resultant wave you can get. If you have two other components which are completely out of phase, then you may have something like this, and you have one more these two kinds of waves. When you superpose, you may have something like this, now you extend the same kind of analogy. When you superpose a number of sinusoidal components, then you will get this kind of a surface.

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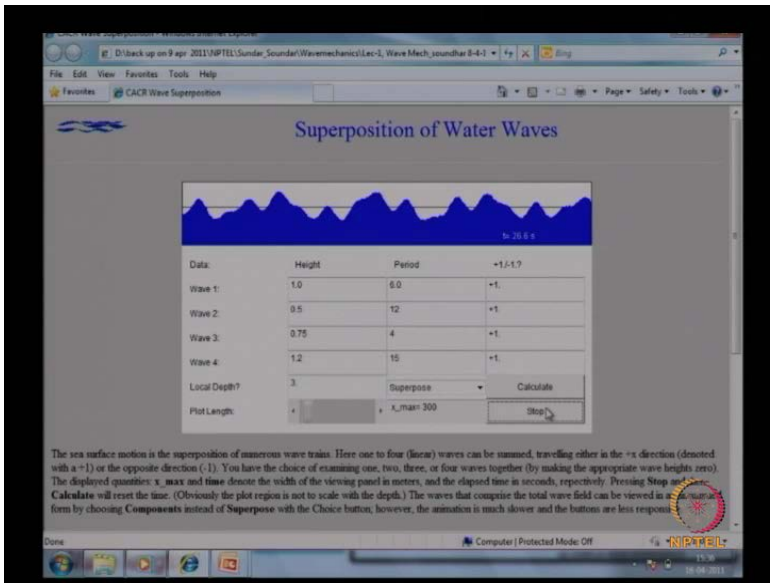

So, now let us look into the animation to understand the superposition of waves. So, to begin with I have considered a wave with a height of one meter period, six seconds propagating in a water depth of three meters so, this is how the waves will propagate. Now, let us move into superposition of two waves. So, I am considering now a 0.5 meters and a 1 meter wave and here this is 12 seconds. Let us see how the resultant

surface looks like, this is how the wave elevation would the waves would propagate, that is two waves superpose on one another.

Now, let us superpose four waves by considering 0.75 and let me say this is 4 and then this is 1.2. And maybe I take a long wave and see what is happening now. We see that we have superposed four different waves of different amplitude and different period propagating in a water depth of three meters and this is how the wave would be propagating. So, this is what is called as superposition. So, if you superpose a number of sinusoidal components may be hundred or two hundred, then you will have what is called as a random wave.

Coming back to the wave period waves, the disturbance in the ocean can be called as waves. As long as the period of the wave is up to about thirty seconds beyond that, we normally do not call it. Although, we refer to as a wave, we do not consider them as a gravity wave. We it is also refer to as gravity wave. So, in the case of a wave, the wavelength can be of order of few hundred meters which we will see later. So, what is important is the magnitude of the period which is up to thirty seconds that is called as waves. And the frequency is nothing but reciprocal of wave period and it is referred to as hertz 1 by second is nothing but hertz I hope things are clear now.

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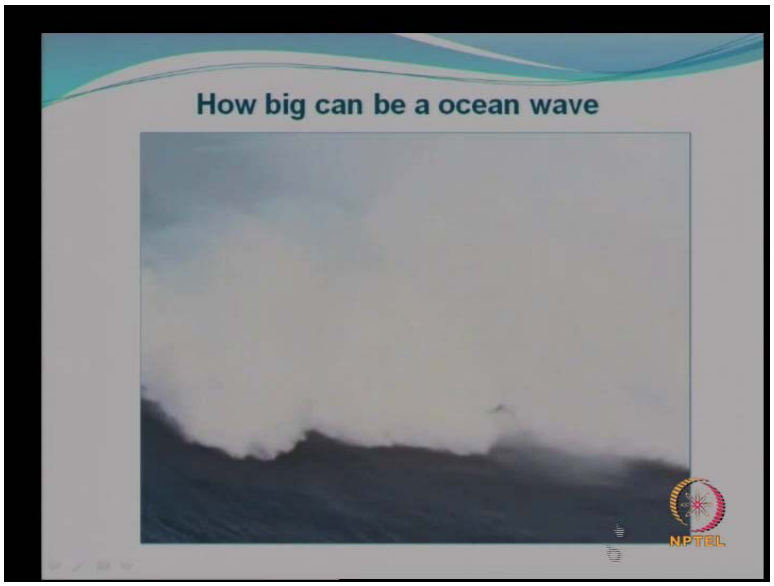

Look at this movie how big can a wave be a ocean wave. When you go to the beach, you normally look at waves of a few meters high, may be one meter. Or so by from visual

observation, you mostly see the waves which are breaking beyond breaking the waves can be about of the order of about one meter or one and half meters. But look at this animation so, the waves can be really very very big and the wave climate can be very severe. Particularly, during a cyclone now the waves are breaking here so, we look into the wave breaking etcetera. The phenomenon of all these kinds of waves I mean the these kind of characteristics later.

So, now this gives you a feeling for the magnitude of waves. Just watch a short movie that run for about four minutes which will give you a feeling of the nature of environment. You are now trying to understand that is about the waves hitting structure or propagating particularly during a storm. This is yet another movie that shows you the behavior of waves during a storm, this is also for about four minutes and after this you get a clear idea about the environment.

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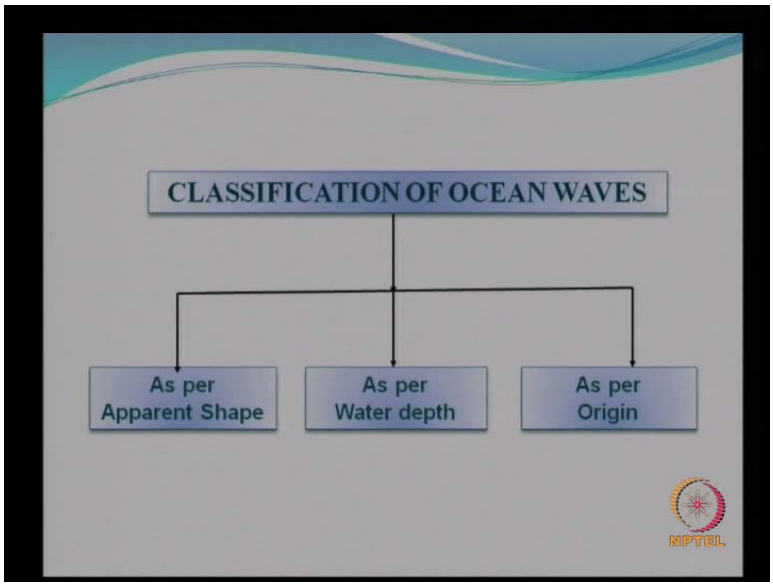

Now, let us move into classification of ocean waves, it can broadly be classified as per the apparent shape, as per water depth and as per origin.

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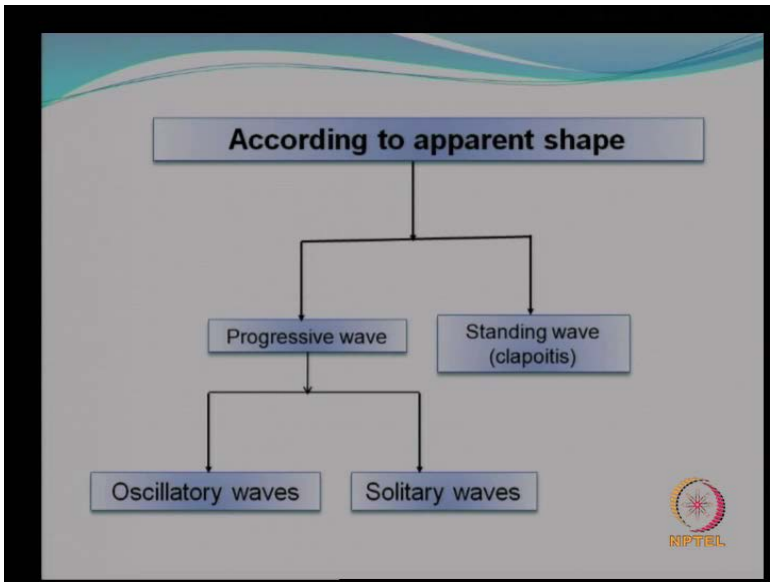

So, let us look one by one by apparent shape, what does it mean? You can have a progressive wave or a standing wave when you go to the beach, what happens you look into the ocean? You see that the waves come from somewhere from the deep waters and then what do you see? You see the waves breaking in front of you and after the waves break it touches your feet probably. If you are around the beach, energy is lost because once waves break, energy is lost then you have just a gentle up rush over the beach. But then again the next wave comes so, it is in progress so, you have what is called as progressive waves. If you want to simulate the ocean conditions in a laboratory, which is normally the case, what you do is you generate progressive waves that is at one end of the your facility, the energy should be absorbed.

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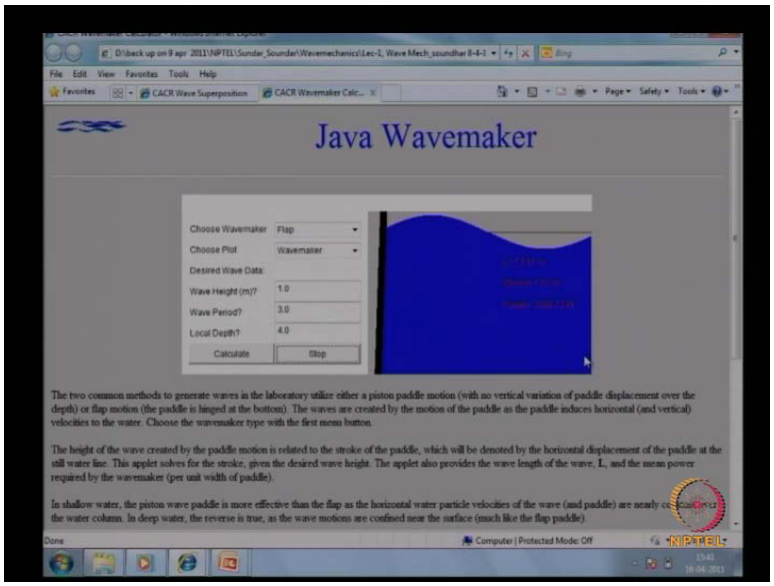

So, most of the problems related to behavior of waves and it is actions on structures are tested in laboratory. One kind of the testing facility which is referred to as flume wave, flume is housed with a wave maker and the wave maker can be in the form of a piston or it can work as a flap type. On the other side you will have observers to generate only progressive waves as stated earlier. So, now let us look at this animation with the help of a piston type wave maker and we are considering a local water depth that is in the flume, in the lab. So, local water depth is around four meters, it is four meters and we would like to generate a wave of height one meter and period so, you will now see how this wave maker is going to move. So, the movement of this wave maker can easily be controlled by a computer, giving proper signals and tuning the wave maker and then you will see that the waves are generated in the tank.

So similarly, you also have what is called as a hinge so, piston type mostly it is generally used for generating shallow water waves. And if you want to have a deep water waves, then we can have a flap type wave maker. So, where in it will be hinged at one end and then you see the oscillation of the wave maker here. So, there are a variety of there are waves, this kind of testing facilities in a number of laboratories worldwide. And now these days even numerical wave flumes have come into existence and there are number of numerical codes to simulate the type of wave, you are interested in understanding it is effect on structures. Now, all of you understand what is meant by progressive waves.

Now, when the waves are progressing towards the coast for various reasons, you have a structures somewhere in between and you try to abruptly stop the waves. The entire energy which is hitting the wall or the structure will get reflected back so, hundred percent of the energy is reflected back, then you call the phenomenon as cloperties. When can you have hundred percent of energy being reflected back when the wall is impermeable and vertical. If there is a sloping wall and if it is impermeable, you cannot have a cloperties because certain amount of energy will be lost. Please remember that cloperties of few reflections can take place only when the wall is vertical and impermeable.

The characteristics of a standing wave and progressive waves are completely different. Let us concentrate on progressive waves; progressive waves can be classified as oscillatory, broadly classified as oscillatory waves and solitary waves. You have other this also I am classifying this because oscillatory waves or sinusoidal, it has a trough and it has a crest. But you have a still water over which you have the crest and you have the trough whereas, the solitary waves you do not have the trough at all, you have only the crests at regular intervals. So, in order to understand that if you have a structure, if you have the solitary waves, the effect will be like this. But when you have a an oscillatory motion or oscillatory waves, the effect will be something like this.

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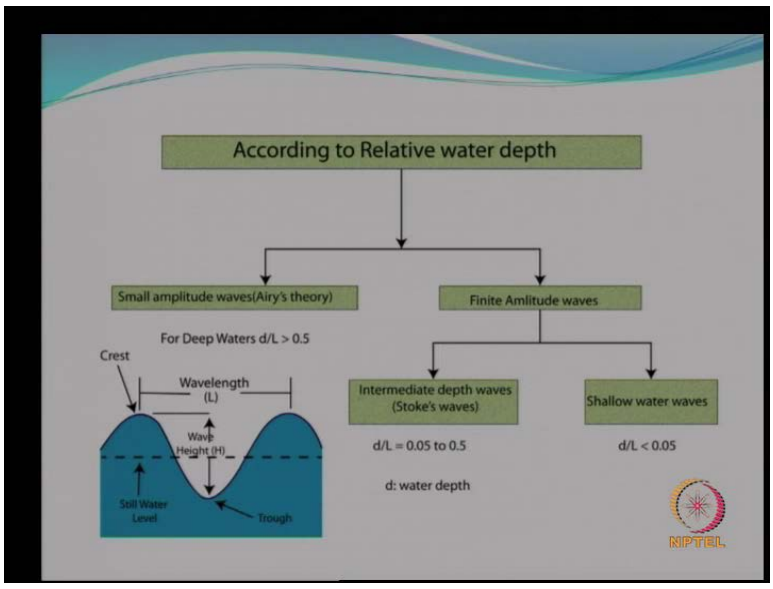

Now, as per relative water depth, here I have brought in theories. When you want to understand the behavior of waves, naturally you have to go in for some mathematics, some theoretical background. So for waves mostly in deep waters, where in the behavior of the waves can be described can be assumed as sinusoidal waves, then we use the theory which is called as the Airy's theories. The assumption here is that the wave height is small, compared to the wavelengths. Mostly applicable for deep waters, but several cases for several instances they use the linear theory or the small amplitude Airy's theory even for shallow waters.

The other kind of theory is called as the finite amplitude wave theories. So, these are applicable to intermediate water depths, that is we call the type of waves in intermediate water depths. As stokes wave when do we say that waves are in deep water or it is a deep water condition, when the water depth divided by the wavelength, which is referred to as relative water depth is greater than 0.5. So, intermediate water depth here it is between 0.05 and 0.5 and the shallow water waves. We have a variety of wave theories to describe the mechanics of waves in shallow waters. And here in the d by L will be the relative water depth will be less than 0.05. So, when you talking in terms of hydrodynamic point of view and when you are discussing about deep water, shallow water or a I mean intermediate water or whatever it is you talk in terms of d by L relative water depth.

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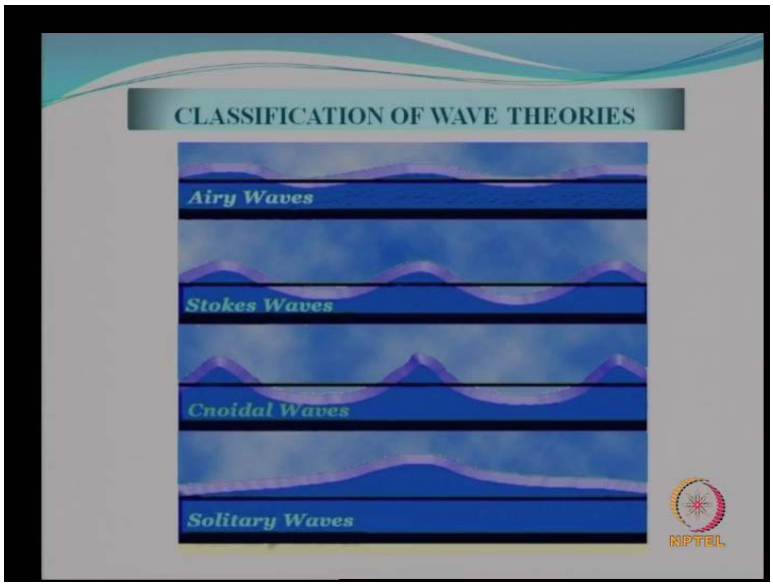

So, these are the kind of wave theories that are available, one is the Airy's theory which are nothing but the sinusoidal waves then the stoke waves where in you have the steeper crest and the flattening of the trough. Then we have further kinds of waves which are shallow water waves where in you have the steepening of the ocean waves. Because the waves when they are propagating over a shallower depth, the steep, the crest becomes sharper and the trough becomes flatter. And this I have already explained that this is a solitary wave which will not have a trough. So, I am sure that we have covered the basics of waves only up to the classification of wave theories.

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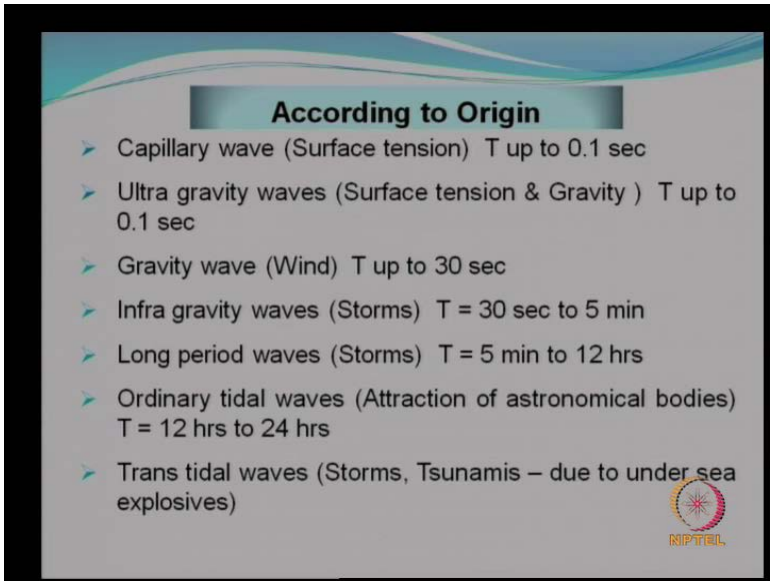

We also have the based on origin, which is given here capillary waves, this is because of the surface tension. And the wave period is given as 0.1 second ultra gravity waves are of which is due to the surface tension. And gravity where in T is approximately up to 0.1 the kind of waves which we are interested are the gravity waves and it is caused by the action of wind and you can have up to 30 seconds, that is what we have already seen. And infra gravity waves which are caused due to the action of storms and where in your wave period can be as high as up to about 5 minutes. And similarly, you have long period waves almost similar to storms during the storms and here in it can be much longer and can go up to 12 hours.

If the attraction between the astronomical bodies are much high, then you can have much larger wave period ranging between 12 hours to 24 hours and these are referred to as

ordinary tidal waves. You also have a trans tidal waves, what are these trans tidal waves? These can travel several kilometers, uninterrupted in the ocean and these are types of waves which are caused due to extreme storms, tsunamis and also due to it may be also due to under sea explosions.

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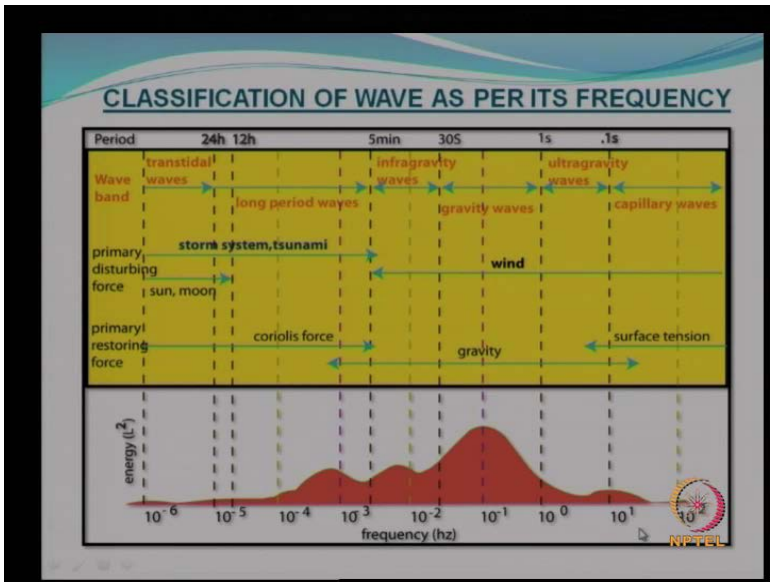

And these are the classifications based on frequency. This is the area which we are interested, that is for the gravity waves. So, whatever I have explained earlier is now characterized with this picture. Where in on the x axis, you have the frequency and then the classification is as given here, this is on the top you have in terms of period.

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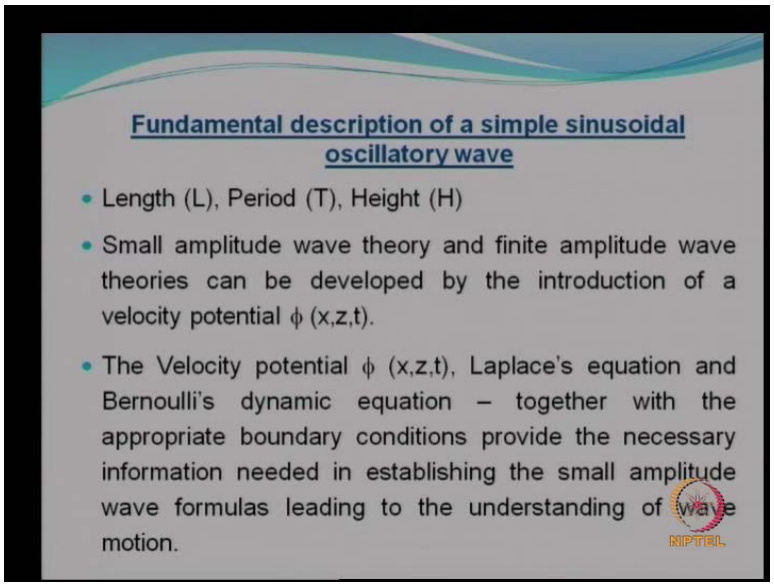

So, today we have done. We have seen the introduction to waves, currents and tides. So mind you waves are the motions which are can be said to be like this. And waves the motions can be said to be like this and currents said to be like this. So, very easily you can distinguish between these three which are very often used in ocean engineering or coastal engineering or anything to do with marine environment. So, we will stop here and probably we will get started with more on the mathematical aspect in order to understand the mechanics of ocean waves. Any questions? If you have, you can ask me and if you still have some questions which could be asked later also, you are welcomed. No problem.