Wave Hydro Dynamics
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Module No. # 03

Wave Deformation

Lecture No. # 02

Wave Deformation II

So, now, we will see what is the phenomena of wave diffraction. So, the definition of diffraction is given on the slide.

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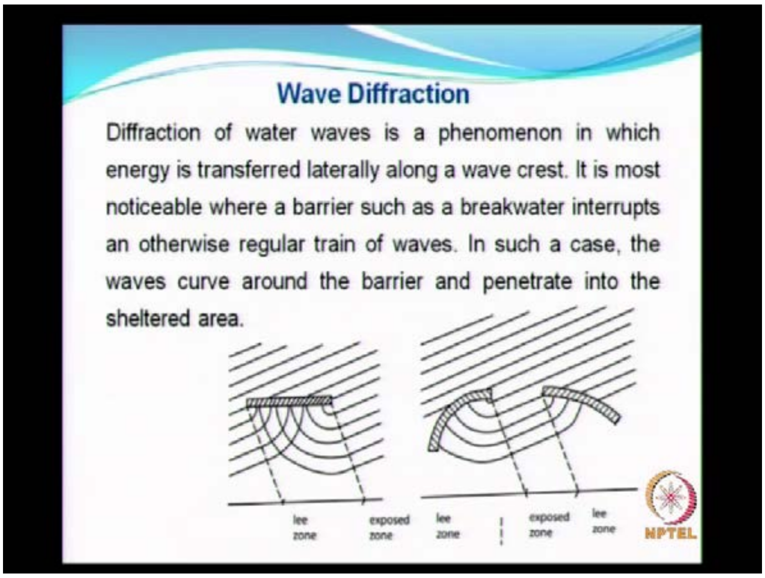

This is a phenomena in which the energy is transferred laterally along the wave crest; that is, we have seen earlier, wave refraction, wherein, when the wave is moving, you have the transfer of energy from deep to shallow waters in the direction of wave propagation. And, in that, we have assumed that, there is no propagation of waves in the lateral direction; but, this may not be true. So, there will be some amount of energy which is getting transmitted in the lateral direction and this becomes more noticeable, in the case when waves beat an obstruction; and, obstruction can be artificial breakwaters, natural reefs, submerged reefs, or emerging reefs, or even trenches and ridges can, will lead to the waves getting diffracted. So, we will try to understand, what exactly is this phenomena, when, by these two examples.

So, herein, we have a rigid barrier, which may be a break water and the waves are propagating from the deep waters. These are the wave crest; I am showing you everything in plan. So, the wave crests are, wave crests, or wave troughs are moving. When I am dealing with this, I am assuming, it is a constant water depth; the barrier is in a constant water depth. Please recollect, when we saw a phenomena of refraction, we observed that the phenomena of refraction is mainly because of the waves propagating over varying water depth. So, we will just keep that aside, and we will just examine the phenomena of diffraction alone. So, for that purpose only, we have considered only a constant water depth here. So, when you have a rigid barrier here, and the wave crests come and meet the structure somewhere here, this is where it meets the structure; when it meets, this area, this area, will be an area with undisturbed wave crests; that is, the wave crest will be moving as it is, it has been moving before being incident on the structure.

But look at this side, shallower area. So, herein because after the waves fill the tip of the structure, there is certain amount of energy being spread in the lateral direction, because of which, the wave fronts will start bending. So, you look at this bending of the waves. So, you see that, the energy gets laterally diffracted. So, this is the phenomena of diffraction. Now, you look at this area; the same thing will happen; same phenomena will happen here. So, naturally, the energy on the lee side of the breakwater, lee side of the breakwater will be much less compared to this area, because these are unobstructed area, wherein, the magnitude will remain same; this area too; only here, the energy will be less, compared to, on either side of the into, I mean, barrier.

So, whenever you have a barrier, because of this phenomena of diffraction, the wave energy tries to penetrate, penetrate into the sheltered area. This is the reason why, we have artificial harbors by constructing breakwaters. So, you want to have calm water for the ship berthing, or other loading and unloading operations in the harbor; you need not much of disturbance within the harbor; and how do we achieve that? You can either have natural harbors, or artificial harbors; artificial harbors, you have, maybe a pair of breakwaters, which will see later. Now, we, it is, we just look at the same diffraction phenomena with a pair of breakwaters. This is a classical example for, when you try to develop an artificial harbor. So, normally, you have a, a gap wherein the ships will, the vessels will flow, move through the gap; and these are the breakwaters, which are likely to offer you the… These are the two breakwaters, which are likely to offer you the required tranquility, tranquility inside the harbor basin. So, when the waves enter here, you see that, here, it will be moving, here, it will be moving uninterrupted, but, whereas here, the energy will be diffracted. So, this area will be calmer zone, compared to this area. So, I hope it is very clear now.

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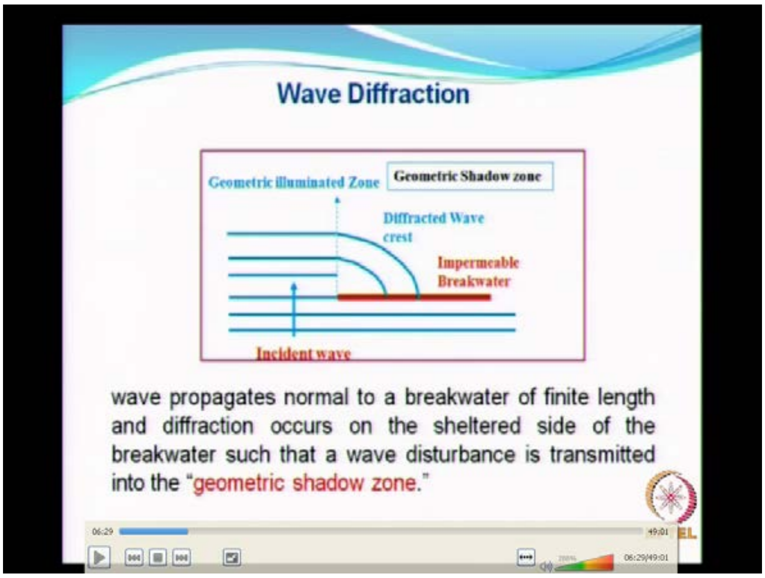

Now, we will move on to, we will again examine the same thing, when you have a rigid barrier, what would really happen. So, I am having a rigid barrier. Now, I am considering the simplest case. I am considering a simplest case; that is, I am having a barrier which is impermeable barrier. Why I call it as a simplest case because, breakwater need not have to be impermeable; it may be permeable breakwater. When you consider permeable breakwater, then, you have to find out how the energy is dissipated due to the presence of breakwater, etcetera. So, all these things are now avoided and we will just examine, how the waves move around, due to the presence of the structure. So, when you have a structure like this, the same way you have the bending of waves as you see here. And, this is the geometric shadow area. What we have seen here, I am just again explaining to you, by considering only one direction, reaching the, I mean, only one tip of the breakwater, trying to explain how the waves bend. I hope this is clear. So, shall I go into the next slide?

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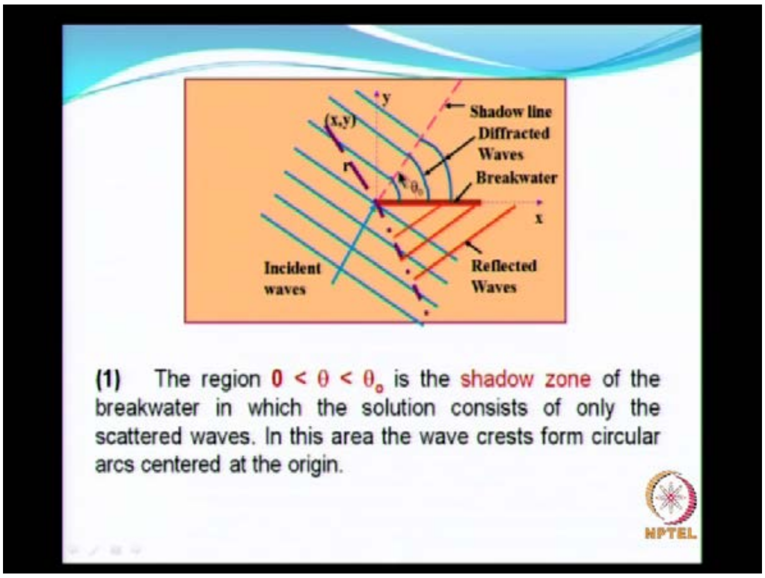

So, we will try to examine a bit more, by considering the same thing. We considered the normal angle of incidence, but the waves can approach from any angle. In this picture, we have, we have a structure here, and we see the waves coming in this direction. So, we will examine that, there will be clearly three distinct zones. What are the three distinct zones? One is the angle, angle that it makes from 0 to theta naught; this area, or this zone is going to be having the bending of wave fronts and these are the diffracted waves. Again, please remember that, we are talking only about a constant water depth. We are talking only about a constant water depth. Now, what is the next zone? So, the first zone is theta, upto, 0 to theta naught, which is the shadow zone, presence of only the diffracted wave fronts.

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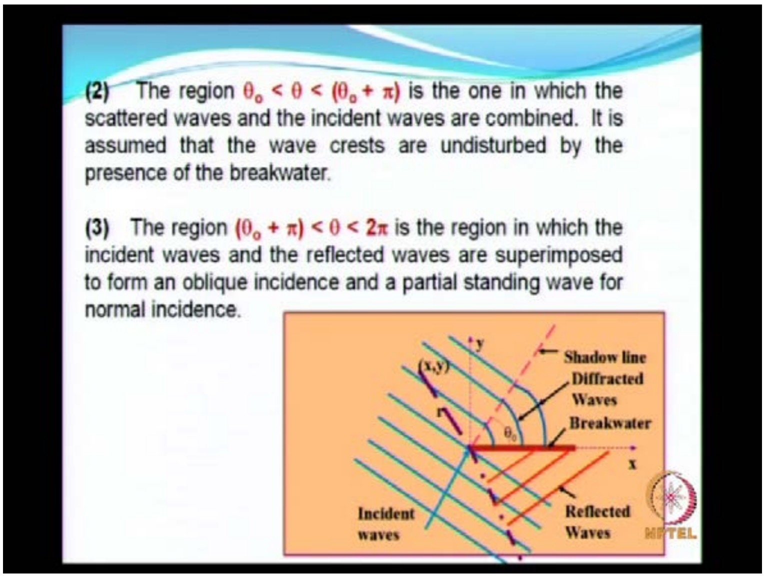

So, next comes theta; this area, where theta equal to theta naught, that is, this, from this to theta naught plus pi. So, I am talking about this area. What is this area? This area is uninterrupted; that is, you will have the wave fronts moving with the same amount of energy and same wavelength, because constant water depth. In the same case, in the same condition, if this structure is going to be in a varying, varying water depth, then, this area, this area, the wave fronts will not be of same magnitude, or, or, the, I mean, the speed, or the wavelength, everything will be changing; the wave characteristics will be changing. So, the last region will be this region, where we will have the phenomena of combined effect of reflection from the structure; and, this will be, this will be superposed on the incident waves. The incident waves will be moving and then, you have the reflected waves. In this case, we have considered an impermeable structure; then, you will have only 100 percent reflected waves. If there is a permeability, again the percentage of reflection will vary.

So, you see that, there is a kind of a complex phenomena that would be taking place, when you have a structure in the coastal area, in which case, the water depth is normally not constant. So, when the…So, different conditions arise, now. So, water depth constant, presence of breakwaters, that will lead to phenomena of diffraction, and plus reflection from the breakwater; breakwaters in a varying water depth, combined diffraction of refraction, combined effect of refraction, diffraction and reflection. So, for simple configurations, it is easy for us to solve the problem. There are some analytical problems also, analytical solutions also; but for the real problems, for practical, for example, we will see later, how to, how all these, this phenomena is considered in the field for practical problem; then, you will see that, we mostly resort to either physical models, or, or numerical models.

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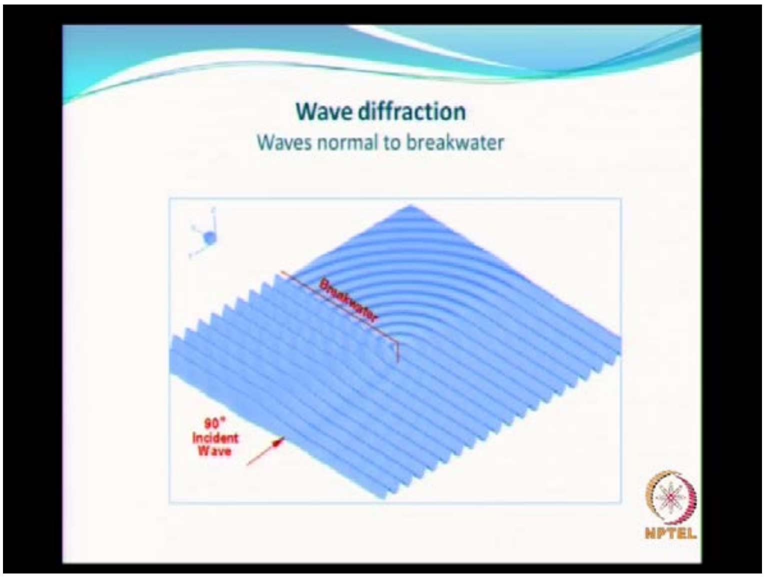

So, this is an animation, wherein you see the breakwater here, the presence of breakwater. The waves are moving, and after it is impinging on the structure, you see that, this moves uninterrupted; this is what I was explaining earlier. And, you look at the diffraction. And naturally here, the wave climate is expected to be very, very less; and, you look at this area, you see that, you have the reflection taking place. So, this animation itself shows us the phenomena of diffraction very clearly.

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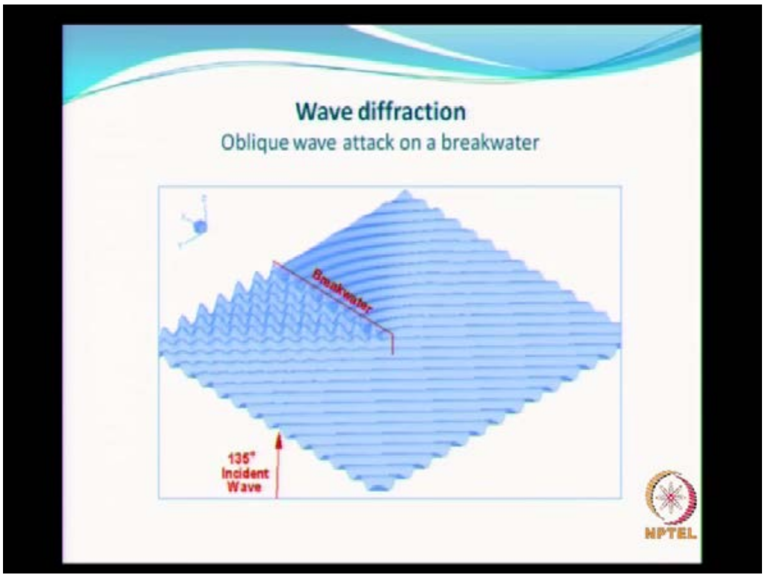

Now, you see that there is an oblique wave of, wave attack. So, you see that, the bending of waves take place here, and you see the reflection is taking place here; and, you can also have similar kind, you will also have similar kind of phenomena, when you have a large structure, or large island, etcetera, and you see this scattering of waves and the lateral diffraction of the waves, wave energy; is that clear?

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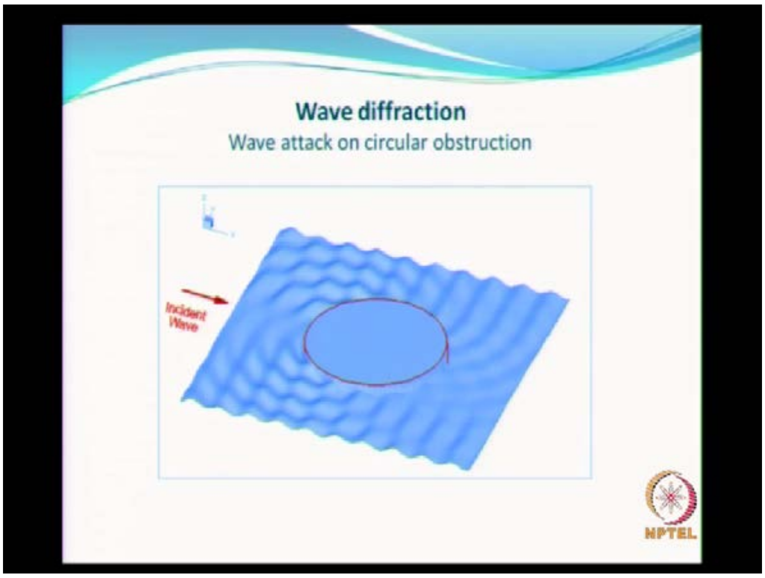

Some of, all these animations have been provided to me by Professor C C (( )), who is one of the well known professors in the field of hydrodynamics, wave hydro dynamics.

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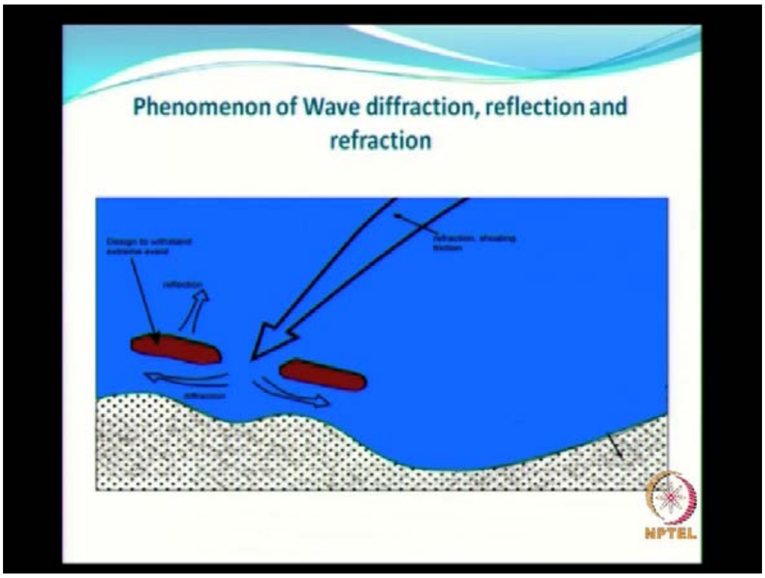

When you look at this picture, whatever we have seen now, that is just illustrated in this picture, where you see here, because, when the waves propagate, because of the varying water depth, you will have the phenomena of refraction, shoaling and as well as the bottom friction, that is offered by the sea bed. And, when it is moving towards, the wave orthogonals can converge, or diverge which we have seen under the wave diffraction; and now, presence of obstructions like natural reefs, outcrops, for example, in India, tip of Indian peninsula you have so many outcrops; all these outcrops can lead to some kind of, will lead to some kind of diffraction; certain extent of diffraction; and, the presence of this, will also lead to some amount of refraction. So, when you want to define, when you want to take up some project, you have to consider all these phenomena before you plan for a major project.

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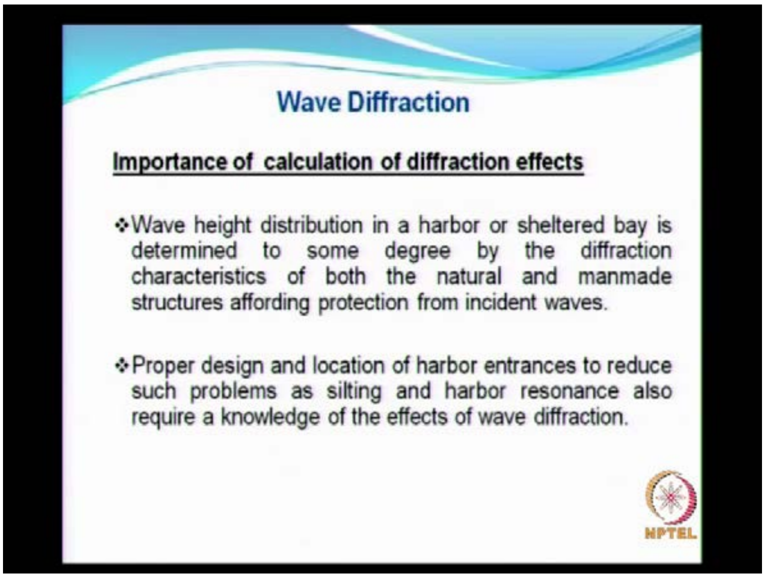

The phenomena of diffraction is extremely important. We have, having seen what is meant by diffraction, we will now see, what is the importance of diffraction. What is the importance? I have, here and there mentioned earlier, the importance, but here, we will just go into the details. Wave height distribution in a harbor, or a sheltered bay, is determined to some degree by the diffraction characteristics of both man and natural, manmade structures, as well as the natural obstruction, affording protection to the incident waves. Natural means what, as I said earlier, outcrops; manmade is breakwaters. So, when you are planning for a major, for a harbor, harbors can be either fishing harbors, a small minor harbors, or major harbors. So, whatever it is, you need to know, how you can align the breakwaters. The several, there are several ways of aligning your breakwater. Please remember that, the main purpose of providing a breakwater, is to absorb; to be more specific, to dissipate incident wave energy, so that, on the lee side of the breakwater you will have calmer area.

So, that is what it says here. Proper design and location of harbor entrances to reduce such problems as silting and harbor resonance, resonance, also require a knowledge of wave diffraction. Particularly, when a very long period wave, like a tsunami enters into a harbor, what will happen? The oscillation inside the harbor will continue for a very long time; and, when you have too much of oscillations inside the harbor, what will happen, the vessels which are anchored, anchored through mooring lines, it will be subjected to motions, and slack moorings can become taut and the moorings can snap and collisions can take place, etcetera. So, when you plan for a harbor, what you normally do is, one is the predominant wave direction; you consider more or less, the long period waves in that area, and you try to align your breakwater, and also fix up the gap between the breakwaters in such a way that, you have minimum disturbance after the construction of breakwaters.

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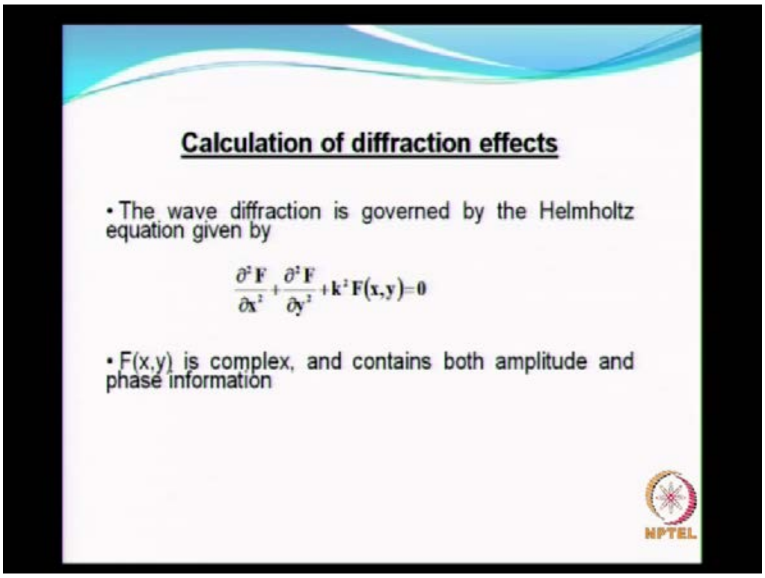

So, diffraction calculation is not so easy, compared to what we have seen earlier, in the case of, compared to refraction. So, wave diffraction is governed by what is called as the Helmholtz equation, where this F of x y, x y is in the horizontal plane, is a complex and contains both amplitude and phase information.

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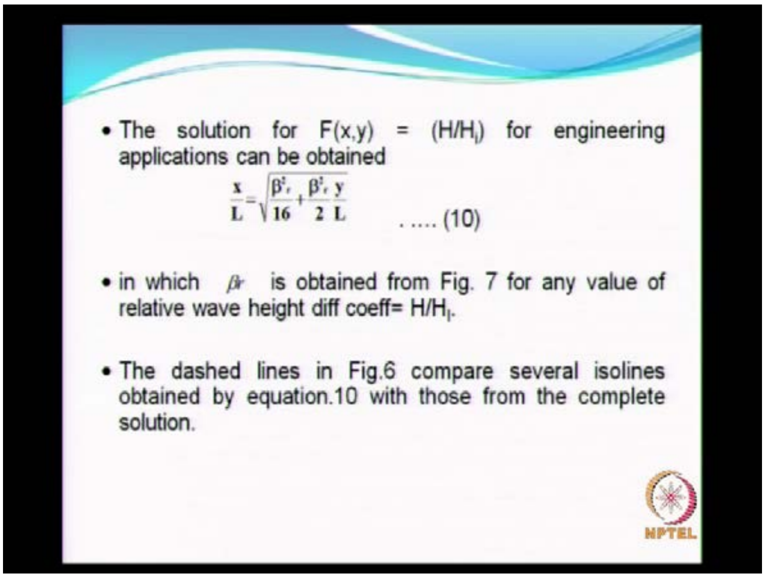

So, the solution to F of x y which is nothing, but directly the relationship between, the ratio between the wave height inside the sheltered area to the incident wave height, can be obtained as given here, x by L, L is nothing, x and y are the spatial coordinates and the beta r is, can be obtained in the next figure, that is next slide, which I, which, you have to see figure 7 in the next slide.

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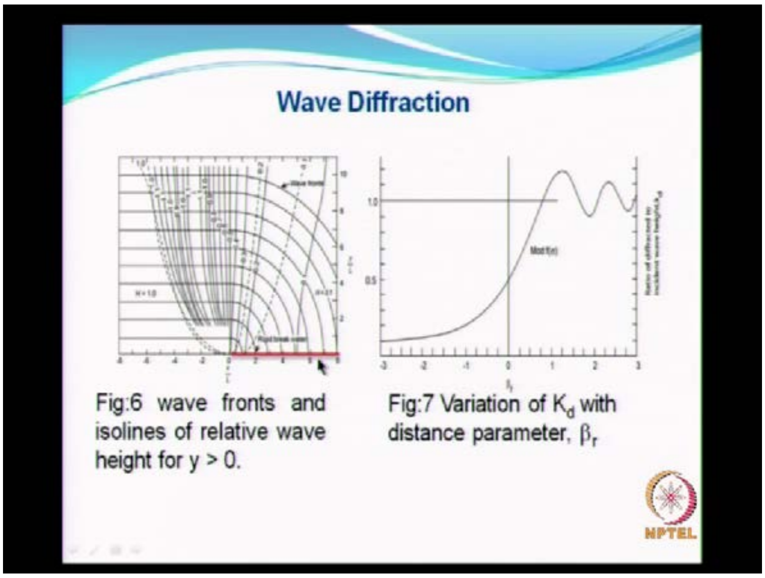

So, you can obtain the value of the diffraction coefficient. You, I will show you the next figure. You have a rigid breakwater here, and this figure shows the wave fronts and the isolines of the relative wave height. So, these are the wave fronts and you see that, this is the, this is your obstruction breakwater; and, you see, how the diffraction takes place; and, these are all the isolines of relative wave height, that is nothing, but their diffraction coefficient. And, earlier slide, we were mentioning about the distance parameter beta r, that can be obtained using this picture, this result. In figure 6, again in the next slide, the dashed lines compare several isolines as obtained from equation 10. So, these are the dashed lines, which I am trying to show.

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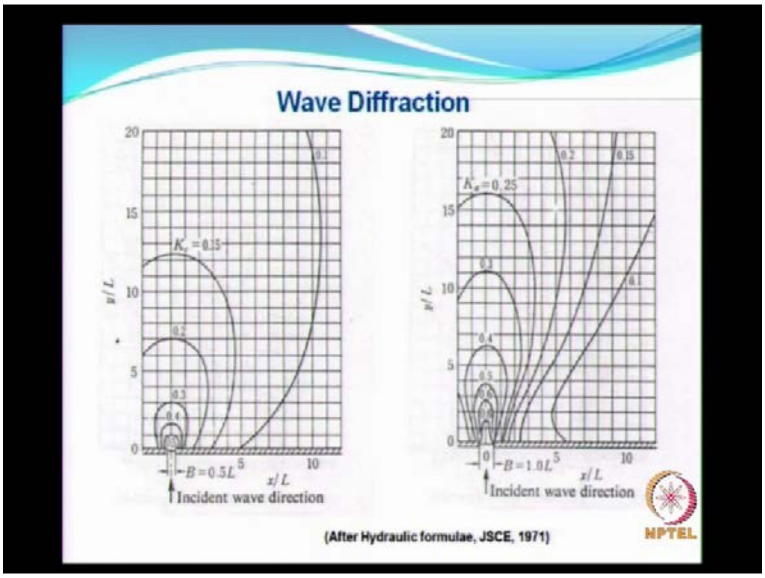

There are published literature available, which can be used to some extent, like nomograms and this is after the hydraulic formulae from JSCE, published in 71, and this also, some of these results are available in a number of text books. Some of these text books are listed after, at the end of the lecture. So, what you see in this picture, on the left hand side, you see the breakwater, the gap between break breakwaters, that is, breakwater, the distance between the two breakwaters, B equal to 0.5 times the wavelength; 0.5 times the wavelength. So, you see the, those curves, those are the isolines of constant K d, or the diffraction coefficient. On the right hand side, you see a similar picture for the breakwater gap equal to the wavelength. So, naturally, if you keep increasing the gap, your disturbance inside the area is going to increase. So, this is where your, see, this is where, you need to carefully design the harbor layout.

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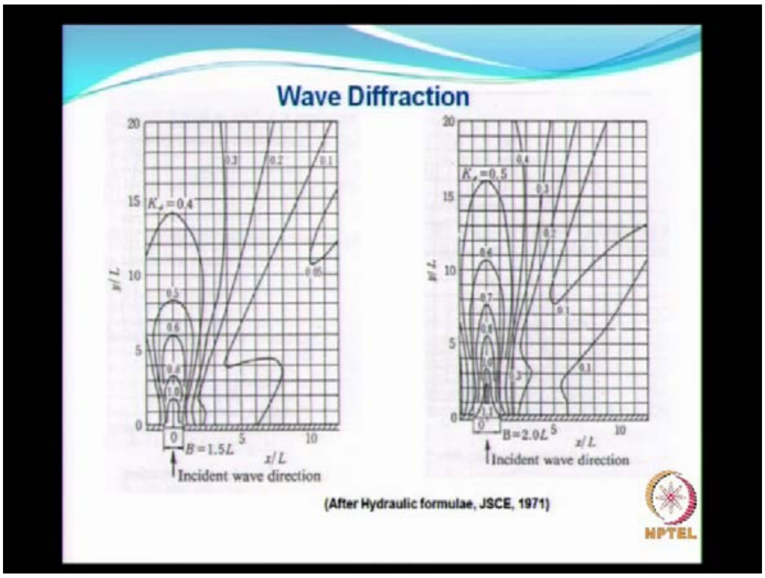

So, this picture on the left hand side shows the breakwater gap width equal to 1.5 times the wavelength. So, the gap between breakwaters is normally decided as a function of wavelength and also, the size of vessels, and also, the type of traffic, that is, whether it is going to be one way traffic, or two way traffic etcetera. All those things are not going to be covered in this lecture, but these are all basic things, information you need, before you finalize the harbor layout. So, on the right hand side, you see the breakwater, twice the wavelength. So, all this disturbance keeps on increasing as they, I mean, as their gap increases.

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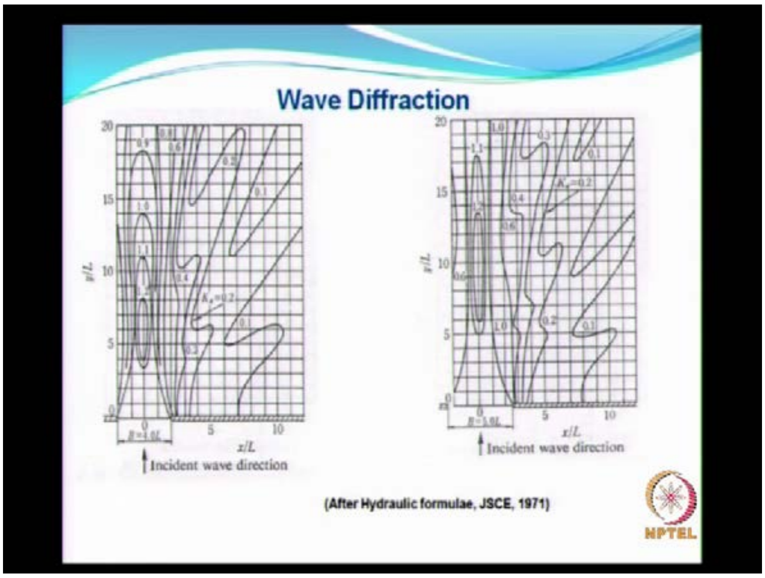

So, you have four times wavelength, and five times the wavelength, how the disturbance looks like. What you should do is, you should carefully look at all these results, once you sit down to understand the lecture; then, you will be in a position to appreciate more. So, this is again for 2.5 and three times the wavelength.

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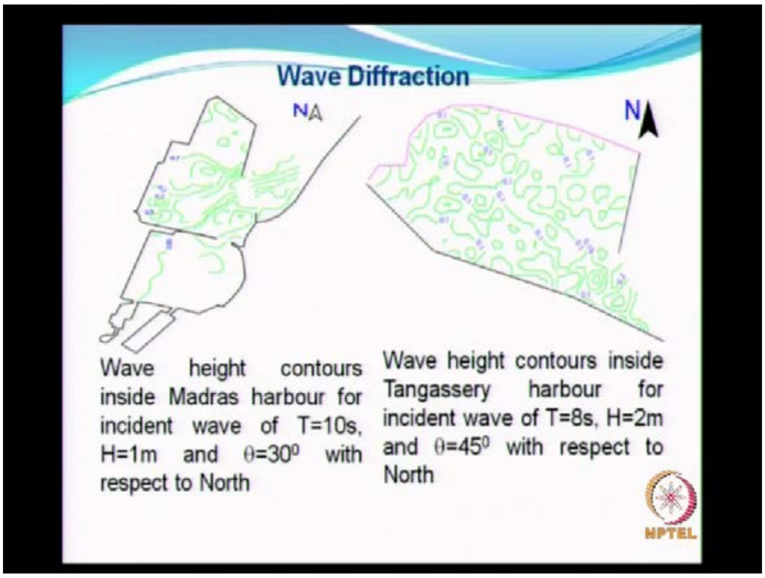

So, in our department, we have developed some basic models upto the advanced models like…See, the basic models do not consider all the phenomena. One phenomena can be, just considering it only as a, only the diffraction is considered. Is it correct or not? Yes or no? That is, in a sense, if you have a breakwater, if you have a harbor, you design the harbor for a given water depth. So, I can always say, it is anyway a constant water depth, so, I consider only diffraction. But major harbors, there can be variations in the water depth; then, you have to consider both the phenomena. So, then, the problem becomes more and more complicated. So, you resort automatically to numerical models. So, this shows, how the wave height contours look like, when a wave, on the left side, you have the Chennai harbor, one of the major harbor; on the right side, you have the layout of Tangassery fishing harbor. So, remember, the breakwater can be impermeable, or permeable; most of our breakwaters are permeable. Which is advantageous? Permeable only is advantageous, because it is amount to, certain amount of, it will account for certain amount of dissipation of incident wave energy. So, we get lot of information from, once you try to have this kind of information, we want to do some alterations within the existing harbor; then, you can always feed into your numerical model and try to understand, what is going to happen, if you are going to change some of the items inside the harbor.

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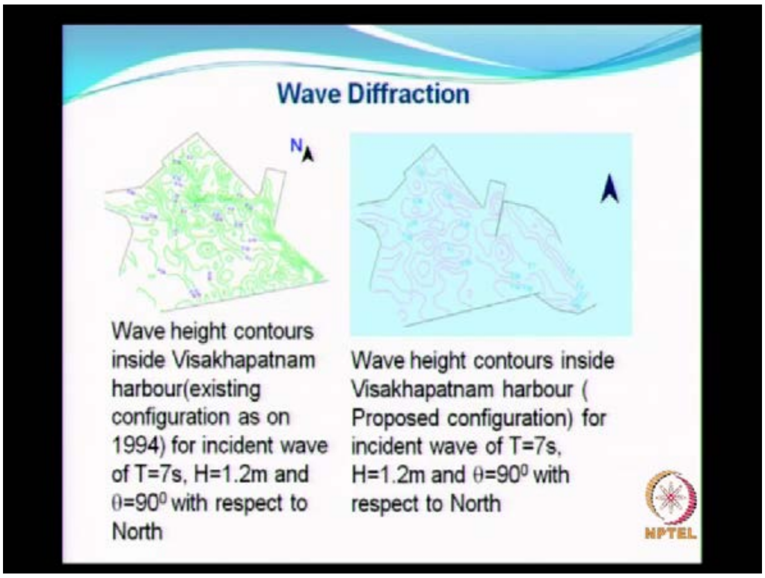

So, this is another, this is the, this is Visakhapatnam port, wherein you have the eastern breakwater here, and what we have tried to do is, we have, on the right side, you see the two projections, of two breakwaters; that was tried out as an exercise to check how the tranquility would improve by having those two arms; can we improve the tranquility further, from the existing ones, with the existing ones. So, of course, this is going to, this yielded good results; then, the point of cost benefit aspect also comes into picture. By having those two arms, yes we have the calmer area, but still, will it be really worth it. So, all these things come as a continuation of the project, before taking the decision. So, all these information will be very helpful, that leads to the decision making.

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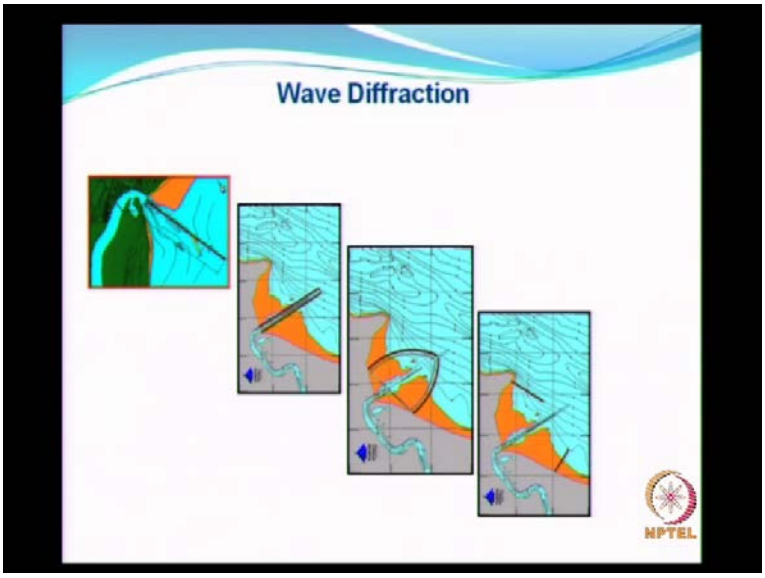

So, this is another example, showing you how this diffraction calculation can be useful, particularly in the case of layout of harbors. For example, here, we have a river mouth; we have a river mouth. So, there is some amount of waves; mostly, the waves are coming in this direction. Sometimes, the waves are coming from this direction too. Sorry, it moves in this direction too. So, can we have only one single breakwater, or can we go in for two breakwater like this, allowing the vessels to move into this; then, you try to find out diffraction through the breakwaters, and try to arrive at the wave energy; or, can we have, because you want to have some more, I mean, area for this, can we have two curved breakwaters like this; or, can we have two breakwaters as shown here. So, you, for a given location, you have different, different kinds of configurations, which you can examine. In earlier days, this used to be done with physical models, only with physical models; mostly, with physical models, but now, you see that, computers have become so cheap, etcetera. All over the world, they now, they resort more towards, they consider numerical models, compared to physical models for, for understanding such effects.

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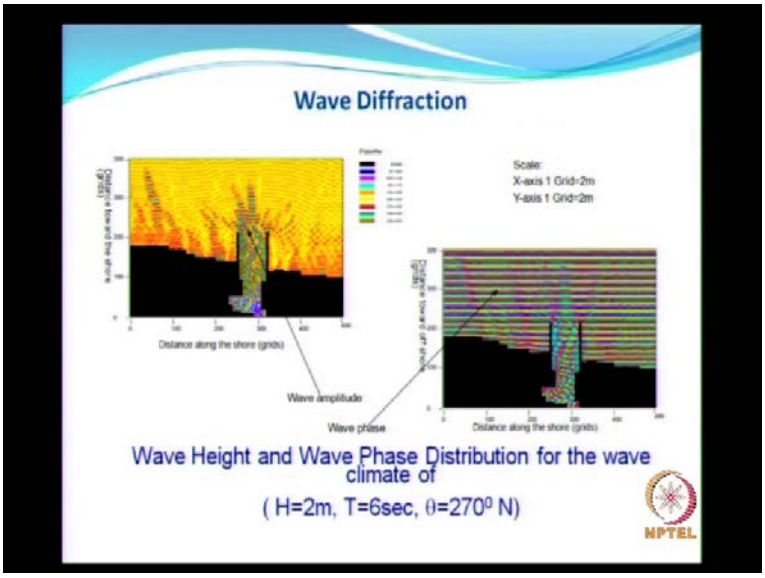

This is what we have done, in our laboratory, in our department, wherein you see the, on the left side, you see the wave height contours, on the left side, on the right side, you see the waves penetrating directly. As you see here, the waves are approaching normal to the shore line, more or less. So, this picture would give us, what is the extent of tranquility, or what is the wave, kind of wave energy, or wave height you would have and will it be within the permissible limit, when a vessel is travelling, etcetera, when a when the vessel is moving.

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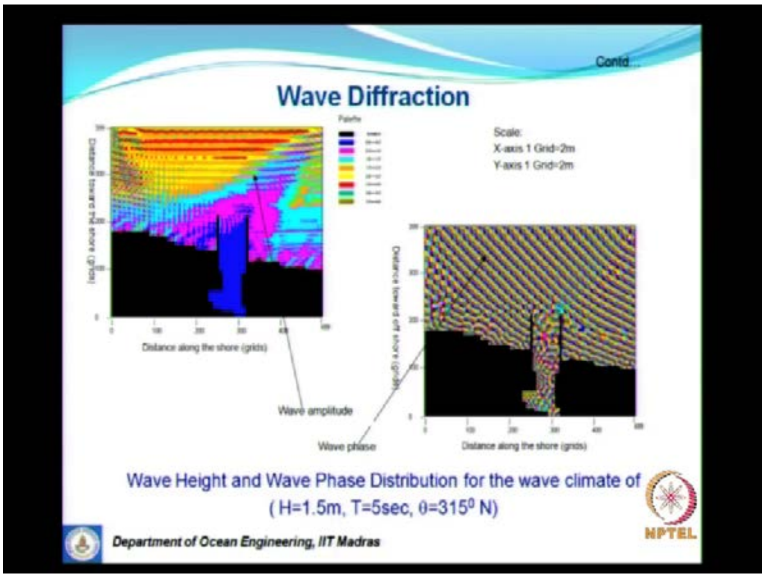

So, here, earlier we saw normal wave angle, angle of incidence. Now, we have the…So, this is called as phase contours, wherein this shows, how the waves try to move; and, you look at this, you see that, the waves are bending and waves are bending and then, once it enters a narrow area, it becomes complicated, because you have reflection from the sides, breakwaters, etcetera and so, you will have a different issue.

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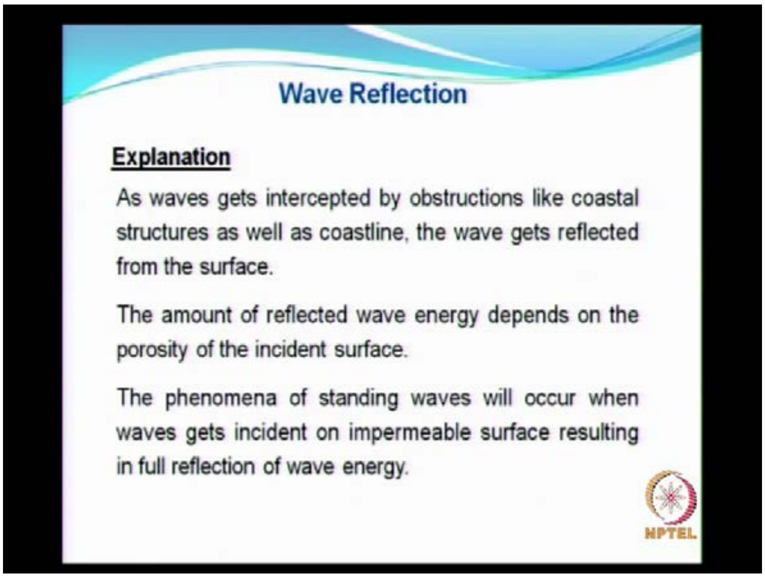

So, I am sure that, you have got a good, good exposure to the diffraction today, wave diffraction. So, we saw what is, what was, what is the phenomena of wave diffraction, what is its importance, and as well as, where do you apply, and how do you apply. The next topic will be on wave reflection. As waves get intercepted by obstructions, like coastal structures, as well as coastal lines, coastlines, the wave gets reflected from the surface. The amount of reflected wave energy depends on the type of structure, beach slope, the incident wave characteristics and in fact, shape of the structure; shape of the structure in the sense, what I am trying to say is, whether it is a sloping wall, or a vertical wall; if it is a vertical wall, impermeable, entire energy is going to be reflected back, which is termed as ((clapoitis)), which we have seen earlier. If it is going to be vertical, you have maximum reflection and if it is going to be inclined, the reflection is going to be reduced. Why reflection is important? Would you like to have reflection or not? Reflection is not that desirable; why, because when the wave is trying to move, propagate, you are putting an obstruction, because of which what happens, in the vicinity of the structure, the wave energy increases. In fact, the wave height can become double the incident wave height. So, when the wave height increases, the forces increase and there is other associated phenomena like (( )) under the structure, undertow, etcetera; all these things create problems. So, there have been enough efforts these days, trying to bring in porous structures, in order to reduce reflection; you understand?

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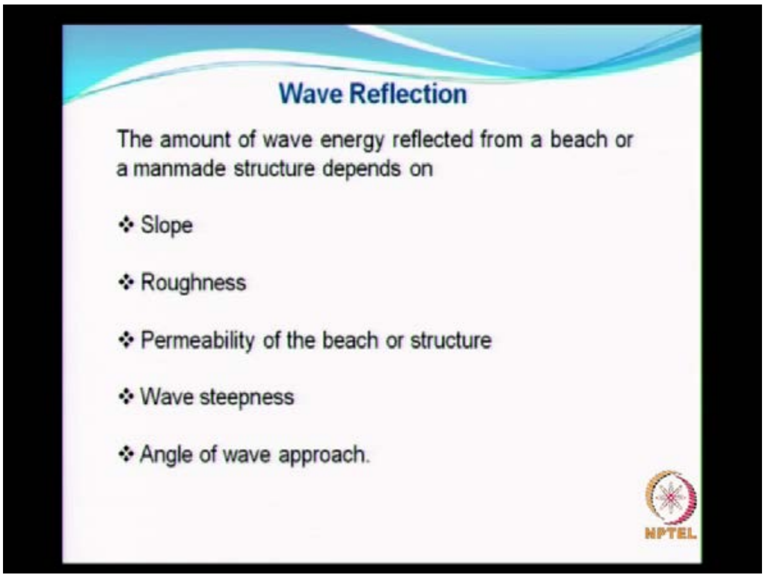

So, this, I have already explained; once again, let us see this. The amount of wave energy reflected from a beach, or a manmade structure, depends on the beach slope, the roughness, permeability of the beach, or the structure, wave steepness, as well as the angle of wave approach.

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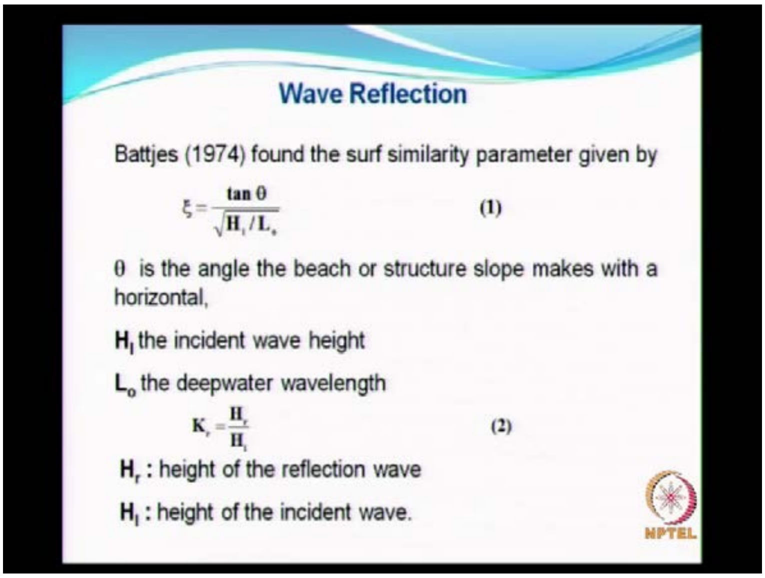

Battjes in 74, he introduced a parameter, which is called as surf similarity parameter, that is given as a ratio of the beach slope to the wave steepness. So, here H i is the incident wave height, L naught is the deep water wave height, and we are looking at K r. K r is nothing, but as we saw in diffraction coefficient, K d, which is equivalent to diffracted coefficient divided by the incident wave height. Here, we have the reflection, reflection coefficient, wherein it is the ratio of reflected wave height to the incident wave height.

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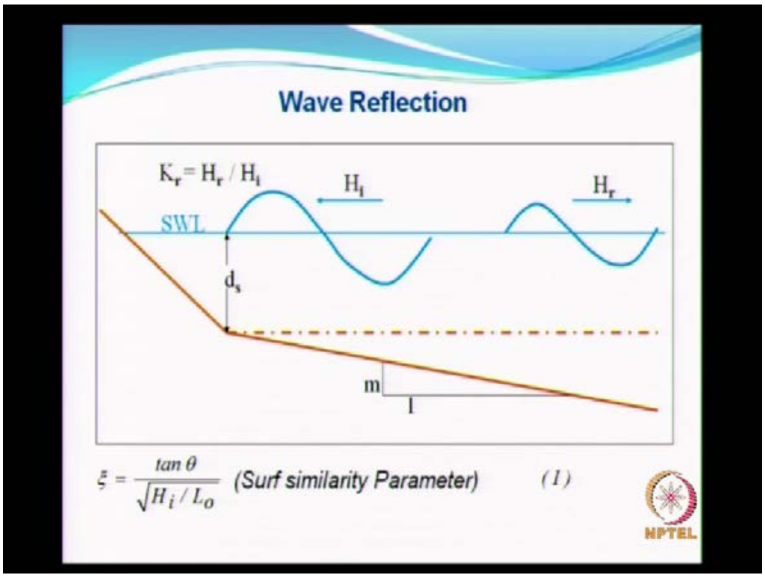

So, this picture gives clearly, the various parameters that are, variables that are associated with the wave, with the wave reflection. K r is H r by H i, and H i is incident wave height, reflected wave height, you look at the slope. So, when the slope is there, H r will be less; and now, this is what is called as the surf similarity parameter, which we have seen earlier. For additional information on wave reflection, you can refer a number of books, or this phenomena of reflection will also be covered in detail, under the subject Coastal Engineering.

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Now, let us move into another important area of breaking of waves. So, when you go to a beach, what, what do you see? When you stand in front of, on the beach, and look into the ocean, what do you see? You see the waves breaking in front of you. Beyond the waves, wave breaking, you see some waves moving without breaking; and then, once a wave breaks, what happens, you will have the gentle uprush of the waves. But we do not really notice, if there is any kind of difference between the wave breaking along, maybe south east coast of India, or along the coast of Goa, we really do not see. For a layman, wave breaking is wave breaking; that is all. But for us, after undergoing this course, you will really understand the difference between, or the classification of breaking of waves; understood? So, let us took, look at the breaking of waves.

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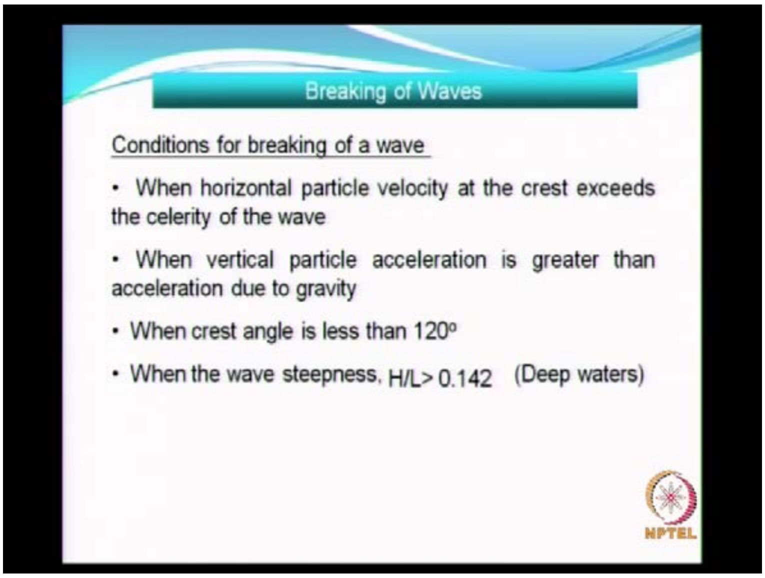

There are some, several conditions, when the horizontal water particle velocity at the crest, exceeds the celerity; that is, the velocity, when we have the crest of the wave, when you have the crest of the wave, the velocity corresponding to the crest of the wave, when that velocity exceeds the celerity, speed of the wave; when the vertical particle acceleration, is greater than acceleration due to gravity; when the crest angle is less than 120 degrees, that is another criteria. It is not that popular, and when the wave steepness is exceeding 0.142, in the case of deep waters, and that 0.142 has to be multiplied by tan h, tan hyperbolic K d, in the case of other than deep waters.

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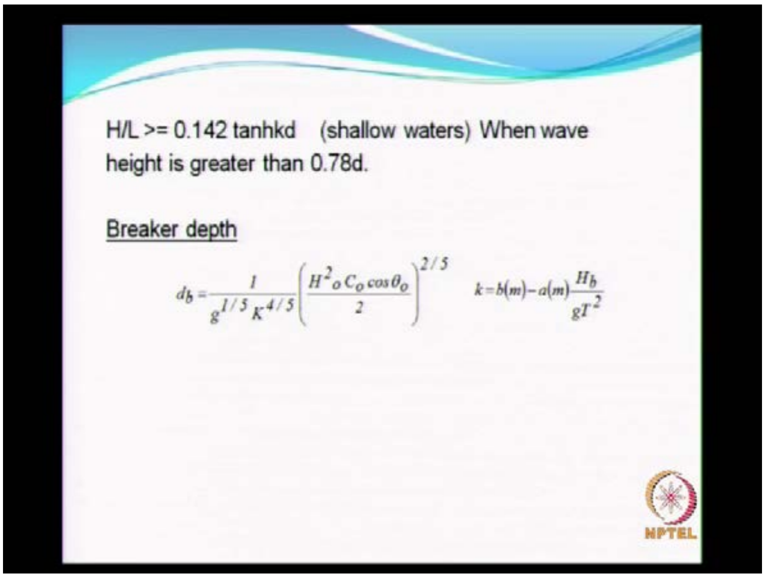

And finally, there is one more criteria which is 0.78 times the water depth; that is, when the wave height is exceeding 0.78 times water depth. There are other criterias. For example, all the other, earlier empirical relation, all our empirical relationship which does not consider the beach slope into account. So, there is another formula, wherein, as you have, as you have here, herein, this K is given by this parameter, and a m and b m are the parameters given here. So, this, the parameters a m and b m are provided here, wherein m is the beach slope.

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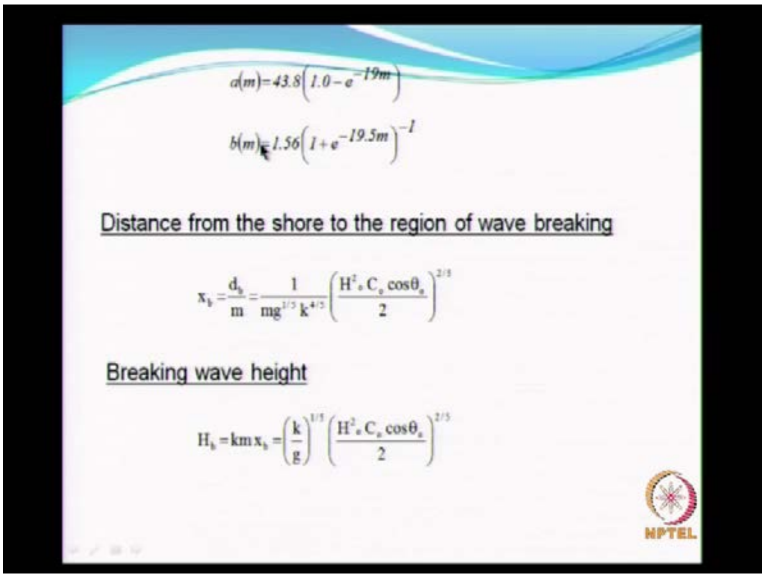

So, you need to go through a kind of an iteration, to arrive at the breaker depth, if you want to consider the beach slope also. And, once you know the slope, you know that, the surf width can be calculated as d b, that is the depth of breaking, to the beach slope. So, using the above formula, you can finally arrive at your breaker wave height, as a function of the deep water, deep water wave height, deep water celerity, deep water direction. So, this formula will consider, considers the beach slope, deep water wave height, deep water celerity, as well as deep water direction. So, I will just run through the formulas again. So, this is the breakwater depth; the breakwater depth is going to be a function of all those deep water wave characteristics, wherein you have k equal to, as a function of breaker wave height and the beach slope, and a m and b m are given, are functions of beach slope. And, with this, we can easily calculate your breaker wave height. Anyway, we will try to work out a problem, so, things will be more clear.

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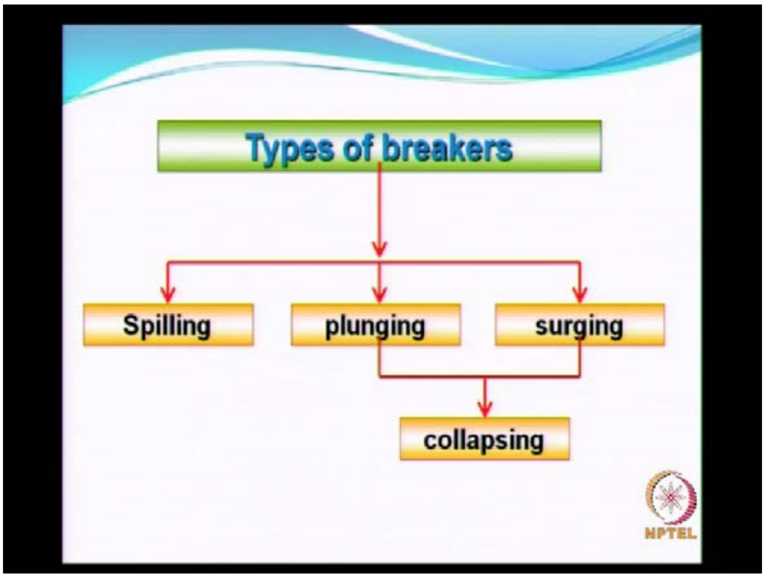

Now, we will move on to types of breakers. When we, when we look into type of breakers, why is it important? Why are we studying about breaking of waves? From structural point of view, when you have a structure, and the waves come and hit the structure, the force exerted is an impact force. So, it is like this. So, it exists only for a short duration, but the magnitude is quite high. And, it is said in literature that, the breaking wave force can vary from something like 8 to 15 times the non-breaking wave force; that is, from structures point of view. But when the waves are breaking near the shallow waters, you see, the beach has been built up; the distribution of sand is quite important, if you want to have good beaches, etcetera. This depends on the type of breaking; not only that, the surfing. Why are certain beaches alone very popular? When you have very flat slopes, then, you say, you see that, the waves breaking may be kind of gentle breaking. You do not want violent kind of breaking; and, not only that, the nature of a beach along the coast, depends on how the sand is getting sorted out by…It is entrapped in the breaker zone. So, these are all some other fields of specialization, but you should know that, this is why you are trying to understand the different types of breaking of waves. So, you have spilling type of breakers, plunging type of breakers, surging type of breakers, and there is a classification in between plunging and surging, which is called as collapsing.

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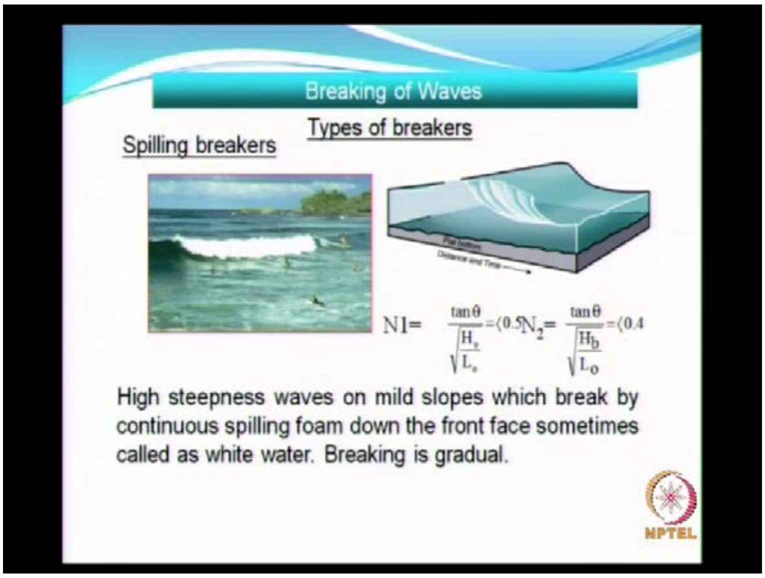

The picture, the background shows a spilling breaker. High steepness waves on mild slopes, which break, by continuous spilling, continuous spilling foam down the front face and this is almost always, sometimes called as white water, and breaking is gradual. For example, Goa beaches, very popular. So, you can walk for a long distance. And, is there any parameter to describe this? Yes, there is a parameter N 1 and N 2 and all these parameters are already known to you; this is less than, N 1 should be approximately less than 0.5, whereas, N 2 should be less than 0.4. Normally, you have deep water wave characteristics. So, N 1 is the one, which is normally used.

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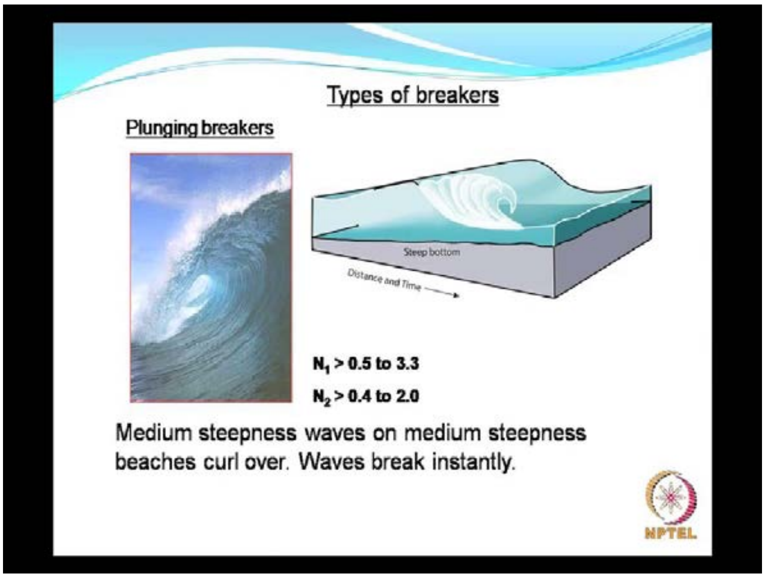

Then comes the plunging type of breakers, and I am sure that, you would have seen a number of advertisements also, wherein you have plunging breakers. It looks very nice. And, when does this occur, when medium steep waves on medium steepness, steep beaches and the waves curl around, and the breaking is instantaneous; wave instantly breaks and it also creates sound, when it breaks.

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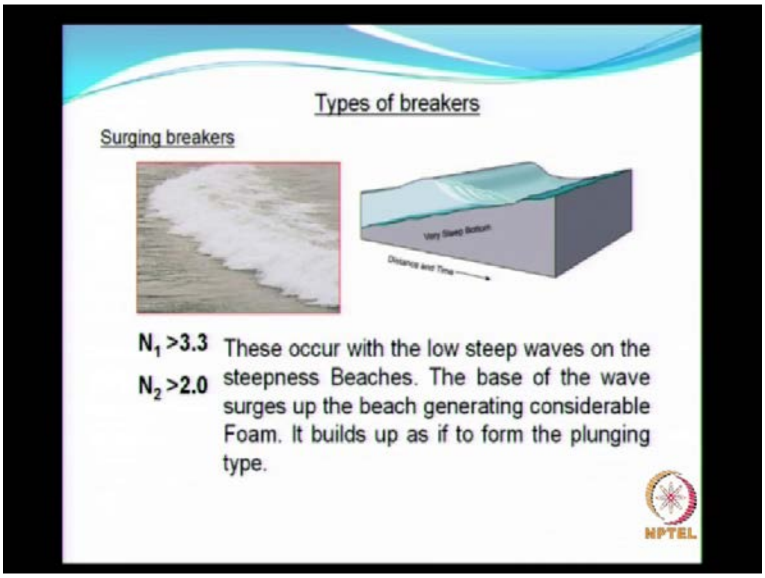

Then, surging type of breakers. This occurs with lower steep waves, on very steep beaches and the base of the wave, the base of the wave tries to surge up the beach, as if it is going to, generating considerable amount of foam, as if it is going to form as a, a plunging type of breaker.