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**Module - 1**
**Wave Deformation**
**Lecture - 1**
**Wave deformation – I**

After having seen some of the aspects about the behavior of ocean waves, particularly with it is about its characteristics, and also having seen some of the worked out examples, we now move on to understand how this ocean waves behave as they propagate from deep to shallow waters. So, they undergo a number of kinds of a few types of a deformation which we will look into. Before that here is a slide which shows the zonation based on the behavior of ocean waves.

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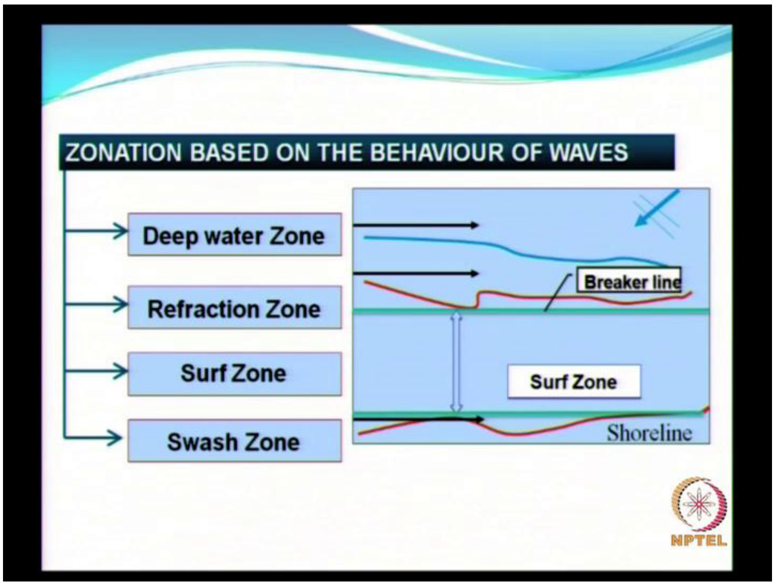


The first zone is the deep water zone wherein the wave crests are parallel to each other. Some of the books or some researchers, they call it as wave fronts; so that is in plan in elevation you represent waves like this.

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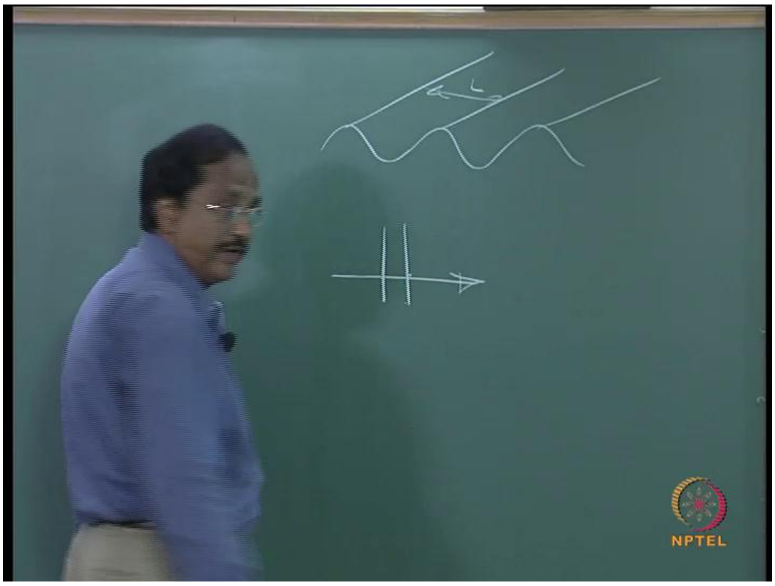

When you see from plan, it will look like this and then this is the wave length. Normally, when you want to represent waves, you represent like this. So, this shows that it is a direction of propagation and these are the wave fronts or the wave crest. So, in deep waters, the wave crests are parallel to each other. Why it is parallel to each other because it is not a function. The speed which is the waves are moving in deep water is not a function of water depth; so you have a very well defined deep water, I mean direction, very well defined direction when the waves are moving in deep water. So, then comes the refraction zone.

What is the phenomenon of refraction? So, we had in basic physics, you know, refraction. In physics lab, we have an experiment to conduct the refractive index, to measure the refractive index. The other way of simple explanation is have a bucket of water; then insert a stick and look at the stick from top. You will see as if the stick is bent. This is because from the air, air is one medium and the water is another medium; so you have that bending of the stick; it appears as if the stick is bent. So, the most important phenomenon takes place in the refraction zone. The waves start feeling the bottom as they propagate. The speed becomes a function of water dense and this phenomena is extremely important and also controls the stability of the shore line.

So, here, the refraction zone the waves start bending; the simple definition is waves start bending and this phenomena is called refraction; that is the simple explanation, but we will see in the details. We will see the details later. Once waves undergo refraction, although I have written it as a breaker line it is actually a zone where you see the waves are breaking. As I said earlier, the waves start feeling the bottom, attenuation is being offered and then the waves start steepening somewhere close to the breaker zone and the waves break. So, when you stand on the shore, you see the waves breaking. So, that is called as a breaker zone and forms the deep water zone that is d by l greater than 0.5; that is called as a deep water zone. So, this zone, this zone is approximately d by l equal to 0.5 that line or the region. so this is the region where the waves are breaking and this zone you see is the refraction zone.

Then, from the refraction zone, from the breaker zone, from the breaker zone up to the shore line we call it as surf zone and this surf zone varies with a wave climate. Every, I mean even daily it may vary and the surf width that is width of this zone varies with season or with months and it is not a constant width. And this zone is also very important because it is the area where all the sand you see on the beach is being transported. It is not covered in this subject. So, the surf zone is from the shore line up to the breaker zone. I think that is clear.

Now, in addition to surf zone there is another zone which is called as swash zone. What is swash zone? I have an explanation written explanation later, in the next slide probably, but I will explain the physical meaning. So, when you go to the beach, some of them they do not like to wet their feet. They stand at a distance. So, most of the time the water will be coming may be few feet or few meters away from him. Occasionally, all of a sudden, you see that the water line, water will run up to higher plane; that is, it will run beyond you and then you start running because you do not want to wet your feet. So, the distance between the point or the region up to which normally the waves run and the distance, the point up to which the maximum run up takes place is called as the swash zone.

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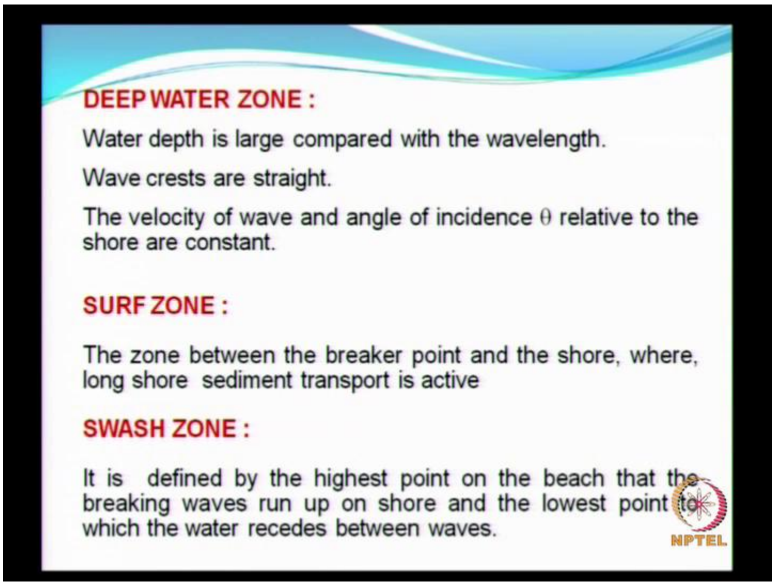


So, these are the important zonation of the waves and this is what is shown in this slide. As I have already explained all these things surf zone, swash zone, of course breaker zone is defined by just one line that is the zone of wave breaking.

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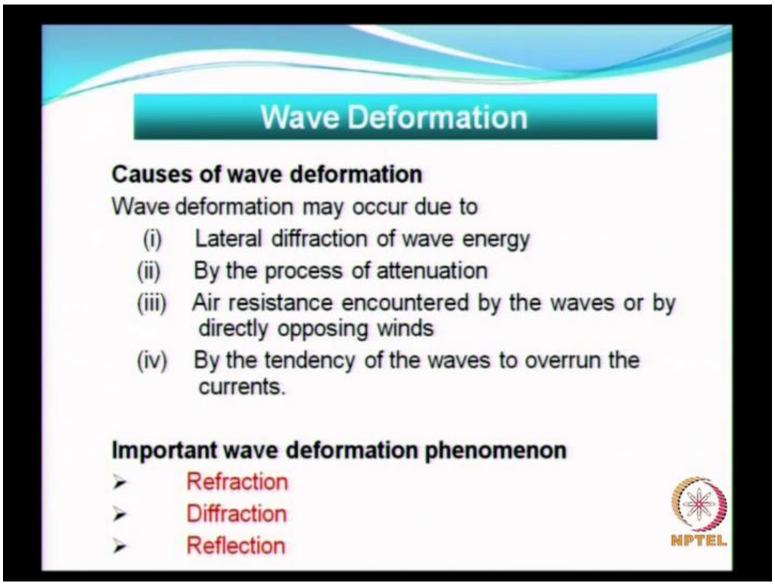


What is meant by wave deformation? Any kind of deformation of the wave surface, we call it as wave deformation. What are the main causes for the wave to deform? Although there are several causes, the most important causes for the wave deformation to take place are the lateral diffraction of wave energy. What is meant by lateral diffraction of wave energy?

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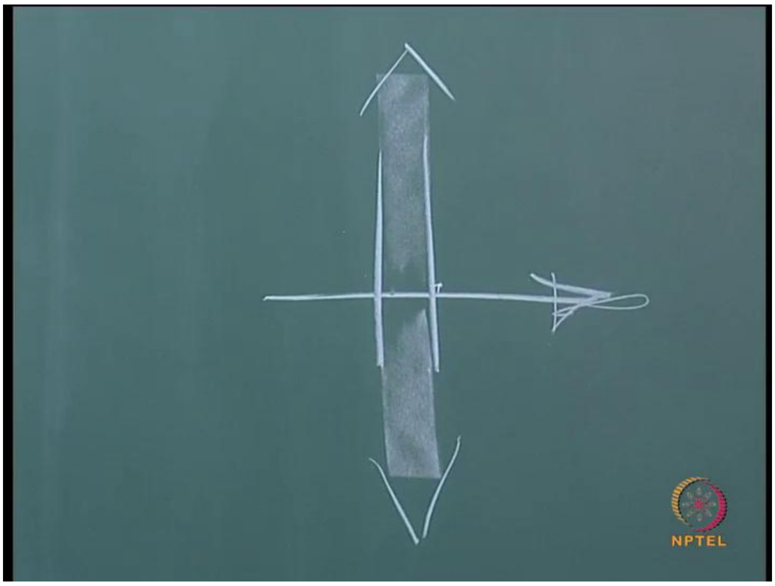

So, you expect if the waves are moving in this direction, as per the definition of average power, what is the definition of average wave power? You have seen in the first earlier classes. This is the rate at which the energy is transmitted in the direction of wave propagation; that is wave power. But for some reasons, there is certain amount of energy which is transmitted in the lateral direction. Then we call it as lateral diffraction of wave motion. We will see about this later.

By process of attenuation, this attenuation can be due to anything; the presence of a outcrops, submerged out corps or reefs.

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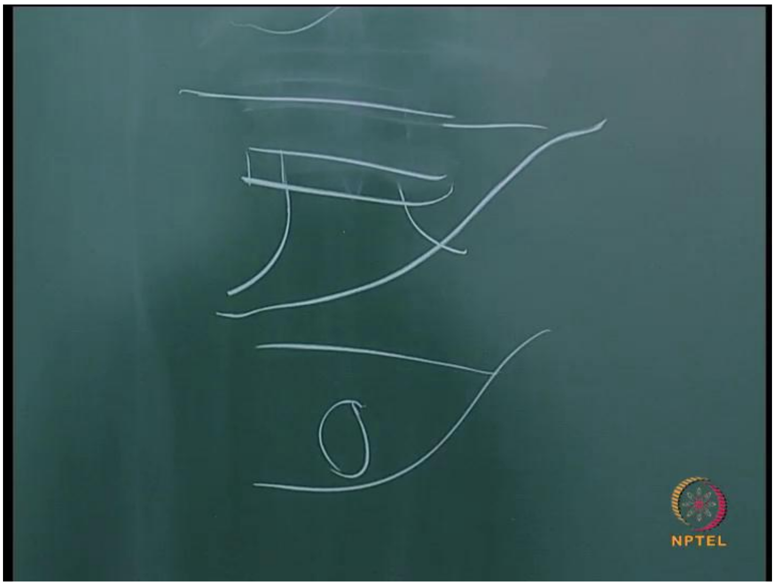

You have the waves moving. So, you have some kind of outcrop or reef or a ridge for that matter. So, that is going to offer some kind of an effect; mostly it is attenuation; attenuation is reduction. The energy will get reduced. This is what, this is natural attenuation that is naturally there are outcrops, reefs, etcetera that gives some kind of reduction in the wave height, or there can be a artificial means. How? For example, you may have some kind of a structure which is floating. This will also deform the waves. This structure can be at the surface or it can be also at the bottom or maybe even a pipe line. So, these are all artificial kinds of attenuators which can alter the waves, the shape of the waves, air resistance encountered by waves or by directly opposing winds. So, if you have the wind blowing against the waves, then there can be some amount of air resistance.

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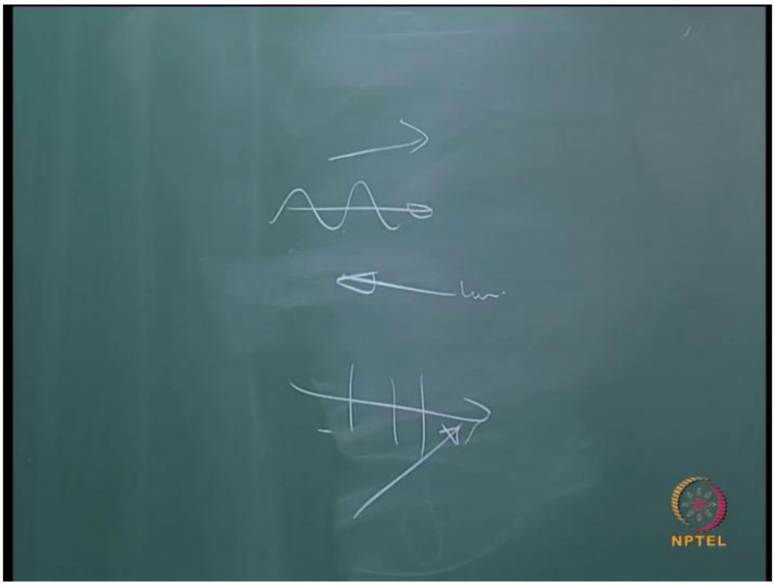

Then, by the tendency of the waves to run over the currents; so you can have a situation in the ocean where the waves can be in this direction moving with a following current. So, the current will be here and then the waves are also moving in this direction; that is this is called as the following currents or you can have a current in the opposite direction. So, this is current and these are waves or you can have waves, but the current is in it may not be following, but it may be at an angle; all these kinds of situations are possible. Each one of the scenario will have its own effect on the change of the shape of the wave and this change of the wave shape is called as the deformation.

The important wave deformation are refraction, diffraction and reflection; refraction diffraction, reflection; of course, shore line is always there. So, we will just see, one by one, what are these phenomena and how these can be accounted for in the calculations. But basically, you should know why you need all this information - why do you need the, why do you account for the refraction of waves or diffraction of waves. Only then you can represent correctly the behavior of waves in the ocean.

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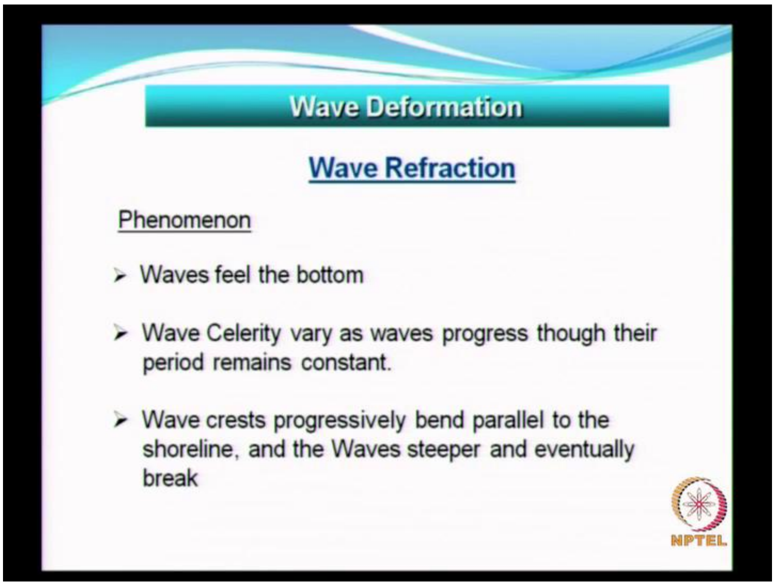


So, let us look at wave refraction. Waves feel the bottom; that is what I said. Waves feel the sea bed, presence of the sea bed. The speed of the wave varies as waves propagate through their period, remaining although their period is going to remain constant. Wave crests progressively bend parallel to the shore line and the waves steepen and eventually break.

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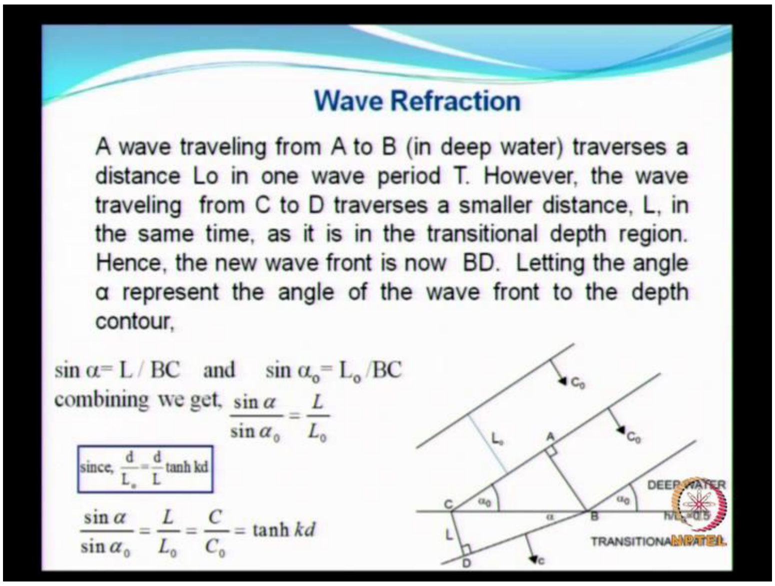


This is the phenomenon which I am trying to explain.

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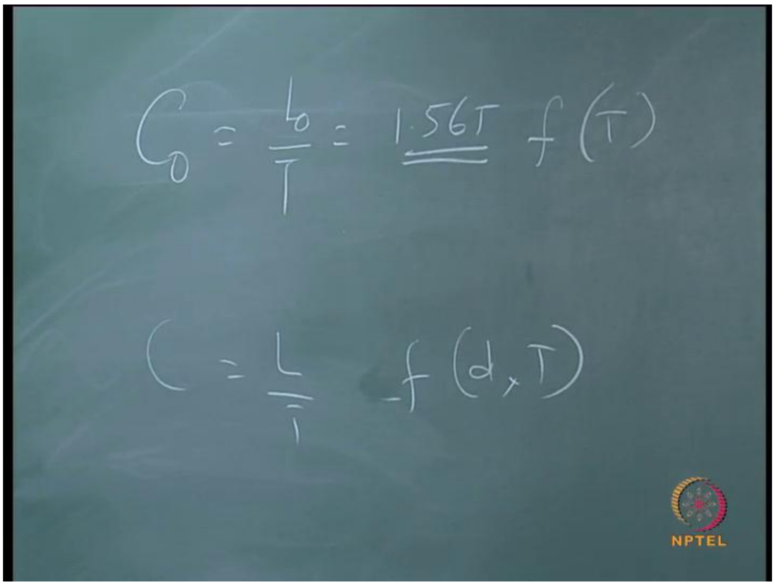


So, try to recollect deep water celerity is l naught by t which is just 1.56 into only a function of tau. It is not a function of water depth which we have already seen. The same thing only wherein shallow water, it will be l by t and it will be function of water depth and t.

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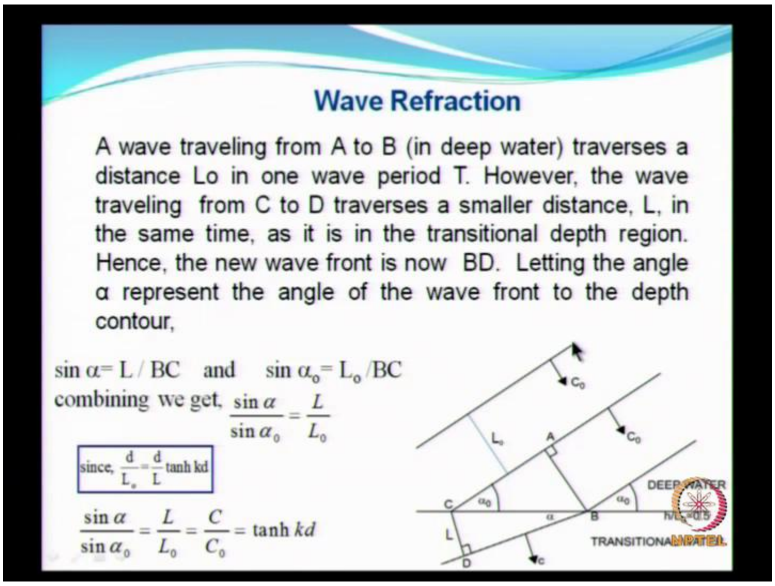


So, as a wave travels, we now consider a wave crest which is entirely in deep water and we also consider a wave crest which is a part of the wave in deeper water and part is in transitional waters or intermediate waters. When you take two wave crests in deeper water, so these are the two wave crests, this one and this one; the distance is separated by l naught l suffix naught because it is the important condition. When this wave is a crossing the line which is indicated as d by l naught equal to 0.5, then you see that the wave is going to bend as shown here. This would mean that the wave length is going to decrease compared to the deep water wave length. So, if this also had been deep water, then you would expect that this line would be straight. So, let me say that this is the water depth and then the angle that is made by the wave crest with water depth contour is alpha naught which becomes alpha with with this, when the wave front is in transitional waters.

Now, look at this picture. This is what conveys the phenomena of wave diffraction. Now, sin alpha that is this angle is given by l divided by b c and alpha naught is again what is that? That is this distance which is going to be l naught divided by b c. So, I can equate this and get an expression for the sin of angle of the waves which make with the shallow water depth contour and the sin of deep water wave angle equal to the ratio of the wave length in shallow waters to the deep water wave length.

Now, we have already seen from the dispersion relationship that d by l naught equal to d by l into tan h k d because of which now you can get an expression which relates the angle celerity and which will be equal to tan h k d; tan hyperbolic. I hope this is clear. So, what exactly is happening? This is bending of the wave crest. I will come back to this again (Refer Slide Time: 21:22)

Now, herein, in this picture, what is this? This is nothing but the wave direction. You see that this is the wave direction. You extend this this has to be perpendicular to the wave front. So, this will be the wave direction and it is also referred to as wave ray or wave orthogonal. So, different books, they use different terminologies, but everything pertaining to the wave direction. So, now, if I want to draw the wave direction at this location, this will be like this. So, this this line, like like this. So, this will be perpendicular to the wave crest (Refer Slide Time: 21:56).

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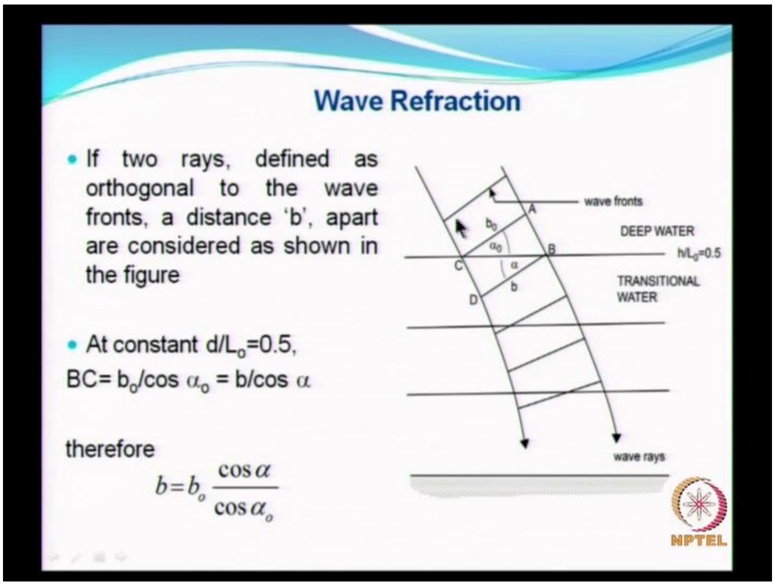


This is what is represented here. I am taking only one step. I mean I am taking two wave directions; I mean single wave direction, but two different points.

So, I am taking a wave curst here and then trying to locate one point here, one point here, and I am trying to traverse how this wave will go. When I try to do that and that is what I get as the wave ray or the direction of the wave (Refer Slide Time: 22:35).

So, I can extend this for a complete region running for hundred kilometers and this distance what I am trying to say is we can assume this distance, where the distance between the orthogonals in deep waters, may be if you want you can assume a 2 meters or 3 meters or 50 meters or 100 meters and try to see how it is going to keep changing as the waves are going to bend. So, here we are trying to see that we are having some water depth contours and these waves are trying to bend.

So, in the deep water we are assuming the distance between this equal to b naught and the same distance in the transitional water, if you assume it to be small b then I can get a relationship at constant h by l naught b c equal to in terms of a l naught I mean alpha naught and b naught and in terms of b l cos alpha. You understand? So, this without suffix 0 pertains to transitional waters; the parameters of the wave in transitional waters.

So, earlier we have an expression in terms of we have the expressions for l wave length as a function of wave length or celerity of function of deep water wave characteristics of like there are deep water celerity and deep water angle, and here we are having a relationship between the distance between the orthogonals in the deep waters to that of the distance between the orthogonals in the transitional waters.

Does it convey something? Yes. It conveys a lot.

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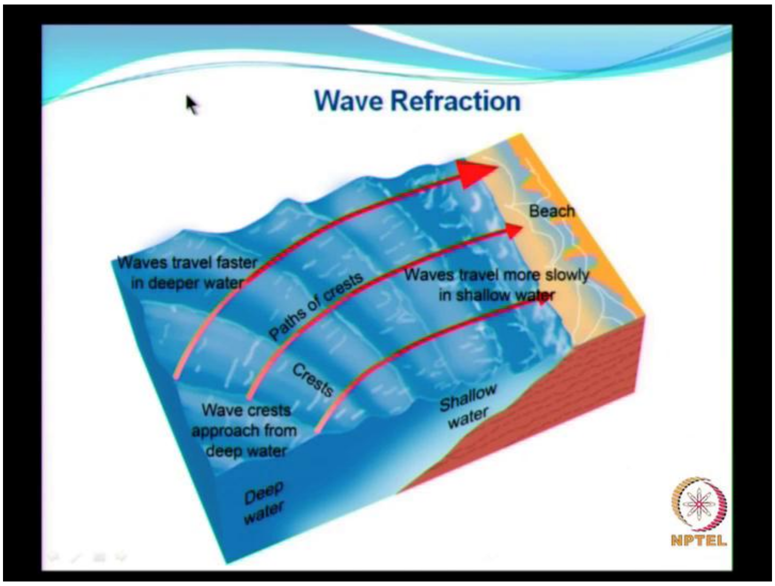


This is one of the basic phenomena which is extremely important and let us try to understand this. What it a defines is the portion if you take a wave crest, as long as it is deep waters there is absolutely no problem, but when it is moving in to the transitional waters, you take a single wave crest; the portion of the wave crest, the portion of the wave crest in deeper waters; I am talking about a single wave crest; the portion of the wave crest in deeper waters will move faster, will move faster compared to the portion of the wave, portion of the same wave in transitional water. For the simple reason, the speed of the wave is going to be higher when it is in deeper waters. So, you will see that the bending takes place. What is it trying to do? When the waves are trying to move, it tries to move faster and try to align parallel to the depth contours.

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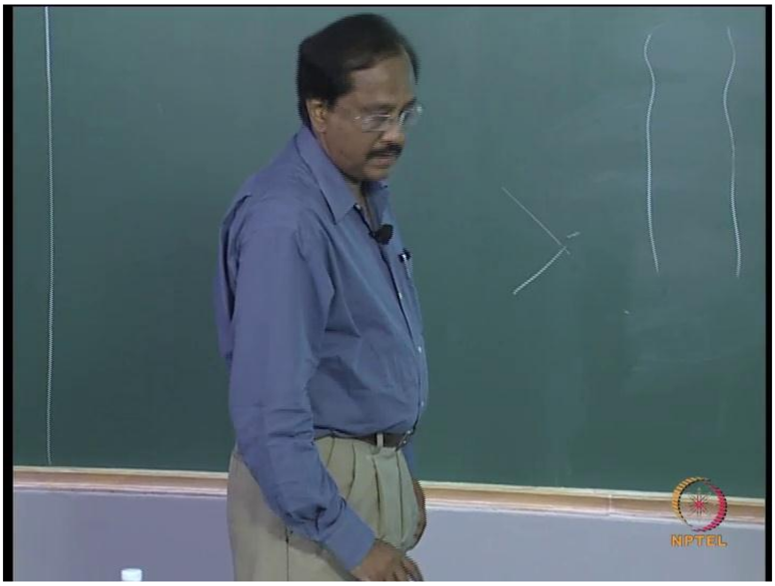

For example if this is the… And then you have the waves moving in deep waters, so look at my hand; so when the wave is moving then it will move and then it will try to move like this. So, you look look at this portion of the hand. What it is trying to do is it is trying to align itself parallel to the bottom depth contours. These are all the sea bed contours. Remember that the sea bed contour is more or less parallel to the shore line when you are talking in terms of, when it is close to the shore. And this is one of the reasons when you go and stand near the beach, you see that the waves are almost more or less coming parallel to the I mean approaching normal to you that is the wave crests are parallel to the bottom depth contours.

There are certain locations where the waves may be coming at an angle, but that that small angle also even if the angle is very small, it does make some amount of difference in terms of the stability of the shore line. So, this is what I have covered here and this picture clearly shows you how the bending of waves takes place, the path of the wave crest, etcetera; the path of the wave crest is perpendicular to your wave crest or wave fronts. So, this kind of a picture when you have, when you draw it for a given stretch of course that gives you how the wave energy is getting distributed. So, you want to plan for some kind of a structure or a development of a harbor etcetera along the course. You need know how the wave is going to behave even before you are going to construct something there; for a given deep water wave height, deep water direction, how this transformation takes place? And in between, we assumed that the energy is being propagated only in the direction of the wave propagation and the energy is concerned in between any two orthogonals.

What does that mean? There is no lateral spread of energy, wave energy. So, this phenomena of propagation of energy only in the direction of wave propagation being concerned is called as your wave diffraction and now we do not we do not do not… we assume there is no transfer of lateral wave energy. So, this is very important.

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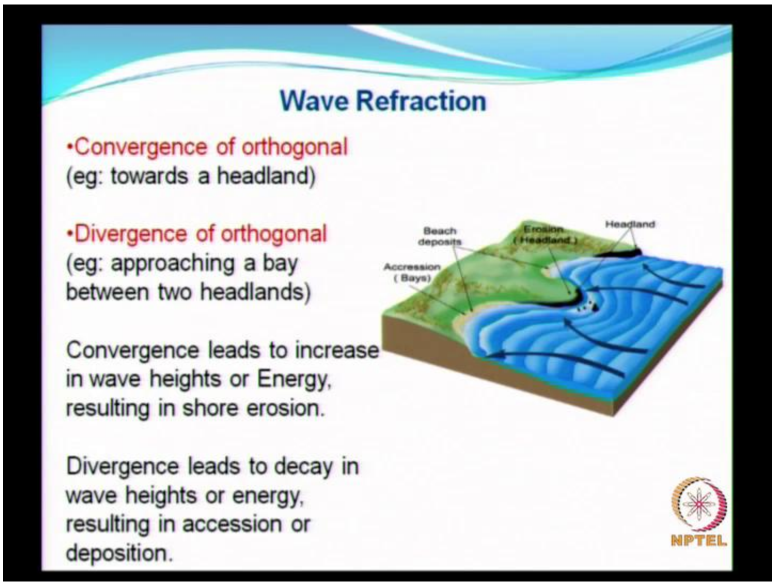


Then, what kind of information you can get? As I said earlier if you try to draw such kind of a plot which are supposed to do in the planning process any kind of a project, be it a coastal engineering project or a port project, and this and also in order to understand the stability of a shore line, you might have to do this for may be 100 kilometers or 50 kilometers or just for 3 kilometers. So, in that case, you have to one has to use his own judgment and experience in selecting the distance between the orthogonal which you assume initially; that is b naught. If you want to have more accuracy, you have to use smaller value for that b naught. Is that clear?

Once you get that, so you can prepare a refraction diagram. What does a refraction diagram gives you? The refraction diagram gives you the wave symmetry of the area. It also gives you the wave rays. What is this wave ray? For example, this distance conveys us something. Depending on the water depth contours, the orthogonal can converge or can diverge; depend this depends on the sea bed topography and your wave characteristics. So, when once you try to get a refraction diagram, you can easily understand what a refraction diagram can convey. For instance, if you draw a refraction diagram, a simple explanation is here. Whenever you have the convergence of the orthogonal that means the energy is getting converged; I mean converged; the energy is going to get concentrated.

So, within these two orthogonals, the energy of the converging point is going to be higher and when the energy is going to be higher, it will automatically lift the sand material around that location; or on the contrary, if the orthogonals are diverging, you see that the energy it is getting diverged; so there is a question of the deposition taking place. So, here that is what is explained here. These are all the bottom depth contours and assume that this drawing is already available to us. So, this is only an illustration to understand the physics. So, you see that you have a bay here and when you have a bay like formation, that is a location that is the stretch of the coast where you can anticipate so divergence of orthogonals leading to deposition of material. And herein you see that convergence taking place; energy gets concentrated; removal of material takes place. So, such kind of a diagram, refraction diagram needs to be constructed before you take up any work.

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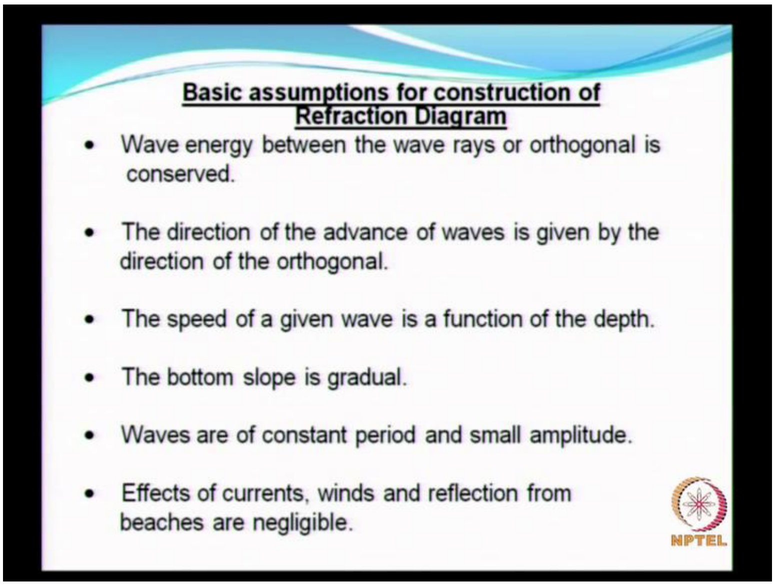


So, earlier, this refraction diagram it used to be very difficult to draw when you did not you when you did not have these fast computers. We used to have what is called as a template method, but now it is all forgotten and there are so many kinds of user friendly software available in the public domain to draw the refraction diagram.

So, you should visit some of the sites for the programs available in the public domain and they have some kind of demos. Now, some of these programs are also user friendly; so you can try to give your own data and try to see how all this physics really take place. So, while you construct the basic I mean construct the refraction diagram, there are some basic assumptions which I have already told some of this things: the first one is already mentioned; the second one is the direction of advance is of the wave is given by the direction of orthogonal; that is because that is the wave ray.

The speed of a given wave is a function of water depth. We assume that the bottom depth contours the bottom depth bottom slope is gradual. Why gradual? If you have a very huge obstruction, then there is other phenomenon which is called as diffraction coming to picture. Waves are of constant by a period and small amplitude, and herein when we are trying to construct a basic refraction diagram, we neglect the effect of currents winds and reflection form beaches.

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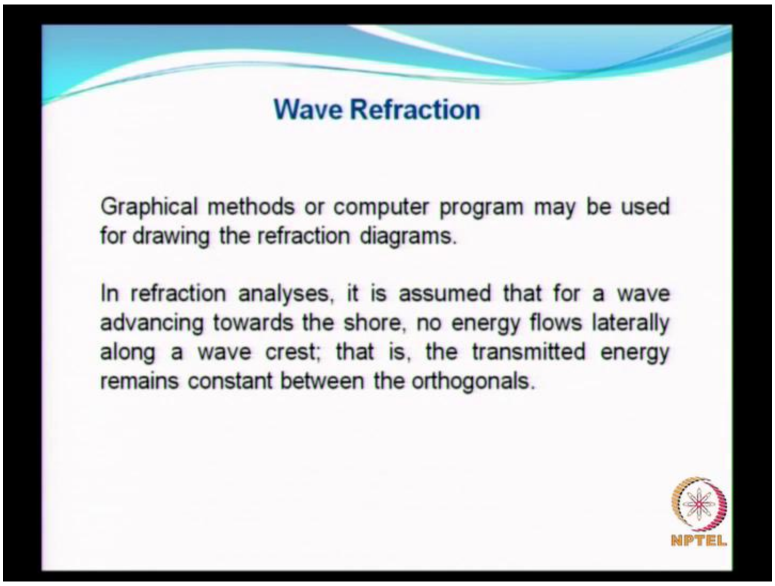


As I said the earlier, graphical methods or computer programs may be used for drawing the refraction diagrams and all other the points also have been discussed. No energy flows laterally along the wave crest; that is, the transmitted energy remains constant between the orthogonals. All these points are extremely important.

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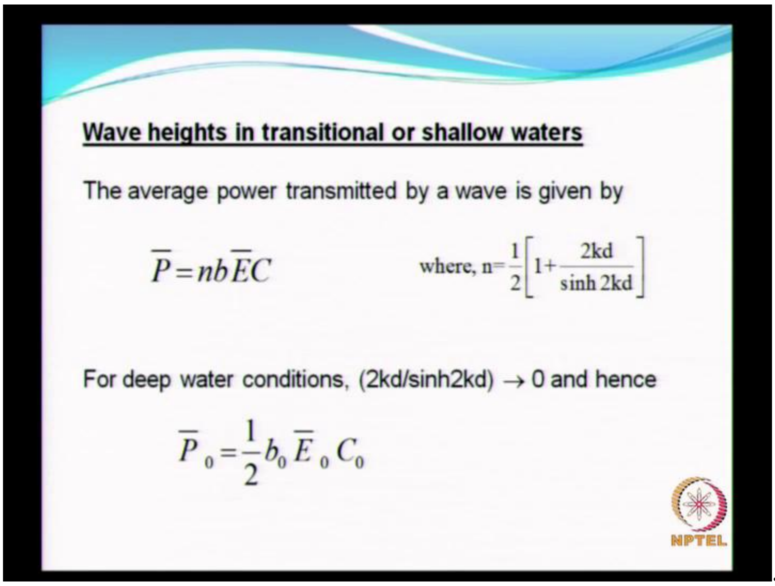


How do we relate? Remember, I hope you can recollect the shoaling coefficient. What did we do in the case of shoaling coefficient? We equated the power in the deep waters to the power in the shallow waters on the assumption that it is parallel water depth contours; so you do not have the refraction taking place; only shoaling is occurring. Now, the same thing is being extended; this is nothing but already we have seen under power; n into that is what is power; power is energy into group celerity.

I am retaining that group celerity here n into c is still the same group celerity into energy but I have introduced b because I am assuming that the power is I am considering an area in between only two orthogonals in order to obtain an expression, when I do that, the power between any two orthogonals in a transmission waters will be n into b. So, only b will come into picture. So, you know about this that in deep waters what happens to sin h k d and because you know n is given by this, and in deep waters the power p naught will become half into b naught into e naught into c naught, deep water energy, deep water celerity and the distance between the orthogonals in deep waters. Now, we know that the energy according to the energy conservation, power conservation, the power in deep water and the power in the shallow waters are to be equated.

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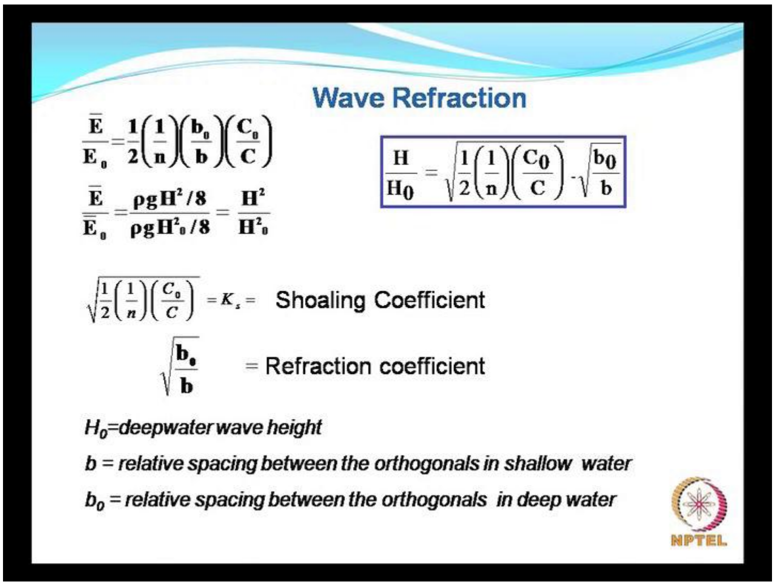


So, when we equate that what happens? So, this is what happens. When we equate, we can get a relationship between wave height in a transitional water, as you can see here, wave height in a given water depth to wave height in deep water as a function of c naught and c. What is this? This is nothing but the shoaling coefficient. What is extra coefficient we are having now? We have included that b and b naught; that is all we have done. In fact, we have re-derived the equation by introducing b and b naught and now you have the refraction, wave refraction coefficient as like this. Can refraction coefficient be greater than 1 or less than 1 or equal to 1? What happens if b naught by you if the shoaling if the refraction coefficient is equal to 1? Pardon, you will not have refraction, but what nature of sea bed it would be?

It would be like a ram, like ram. So, it will be something like only the water depth contours will be parallel to each other. What happens if the refraction coefficient greater than 1?

So, what will happen if the refraction coefficient is greater than 1? Look at the refraction coefficient. Refraction coefficient is b naught. If refraction coefficient is greater than 1, b naught is higher than the… That is the distance between the orthogonals and deep water is higher; so that means the orthogonals are converging and hence the wave height will be higher. So, you should not be surprised whether or you should not be thinking whether the shoaling the refraction coefficient can be greater than 1 or less than 1; it can be anything.

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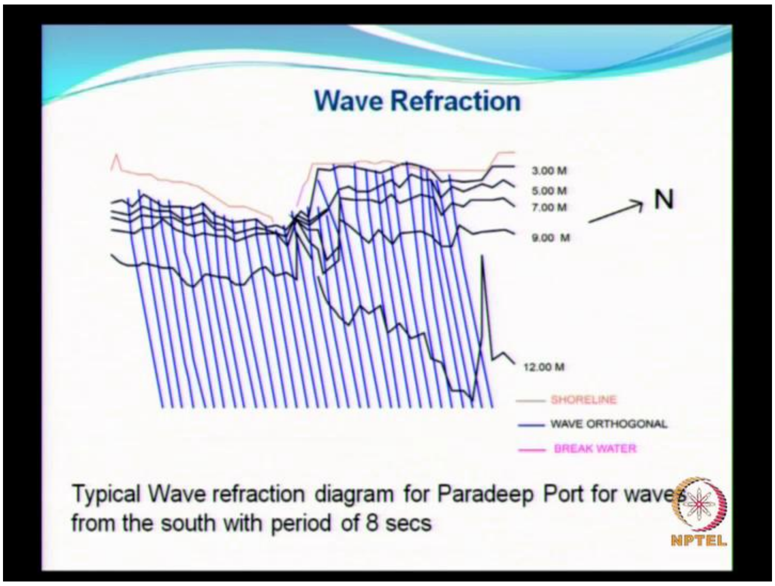


So, this is a typical refraction diagram and this refraction diagram has been drawn ages back; that is as early as early 80s, wherein these are all plotted by using a plotter, wherein see I can show the break waters here. This was done for the Paradip port and these are all the bathymetry. The 12 meters contour is quite of is irregular. And for a given wave period, what we do is how do we construct the refraction diagram? You can construct the refraction diagram for a given month; for a month for a mean wave direction or a particular season. For example, non-monsoon season or northeast monsoon season or southwest monsoon season, you can take a an average wave direction and then draw the wave diffraction, wave refraction diagram or you can also take the most frequently occurring wave direction for which you can draw the wave refraction diagram.

So, when it is a very important project, you need to study or obtain the wave refraction details for different wave directions, for the waves approaching from different direction for that particular coast for the deep water. So, you normally have the deep water, deep water wave characteristic; allow the deep water waves to propagate over a given bathymetry and then you get the details and from which depending on that, there are ways and means to calculate; not only with this, you can arrive at the zones of it. If it is converging, you can try to find out whether there are zones of erosion. When it is convergence, you have erosion.

So, you can find out the zones of erosion and deposition along the coast and you can also find out there are some basic calculations that need to be done through which you can also calculate how much of sand is removed, how much of sand is being deposited. Is that clear?

So, with this, I will today's lecture, I will, we will close and then from tomorrow, we will form the next class. We will just look into the other types of a wave deformation starting from wave diffraction and also wave reflection and then the combined effects.