Wave Hydro Dynamics

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Module No. # 02

Wave Motion and Linear Wave Theory

Lecture No. # 06

Standing Wave Theory

We have already seen the characteristics of progressive waves. So, progressive waves are the most important type of waves, which we normally deal with, for example, in order to calculate the forces acting on structures or behaviour of the ocean waves as they propagate from the deep ocean to the coastal area. So, what exactly is a standing wave? Standing wave is a kind of waves, which are formed due to pure reflection; do we have these kinds of waves in the ocean? Yes, we do have these kinds of waves in the ocean.

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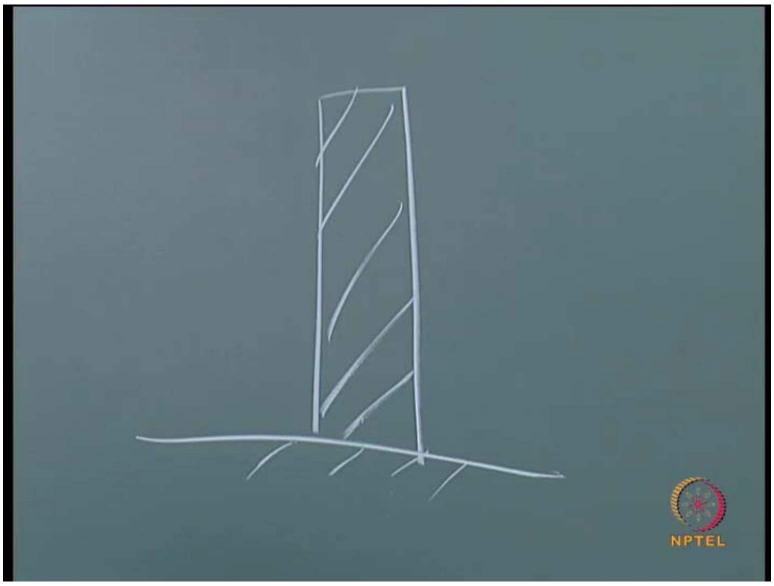

Particularly, think of structures which are which are impermeable and I mean impermeable and vertical.

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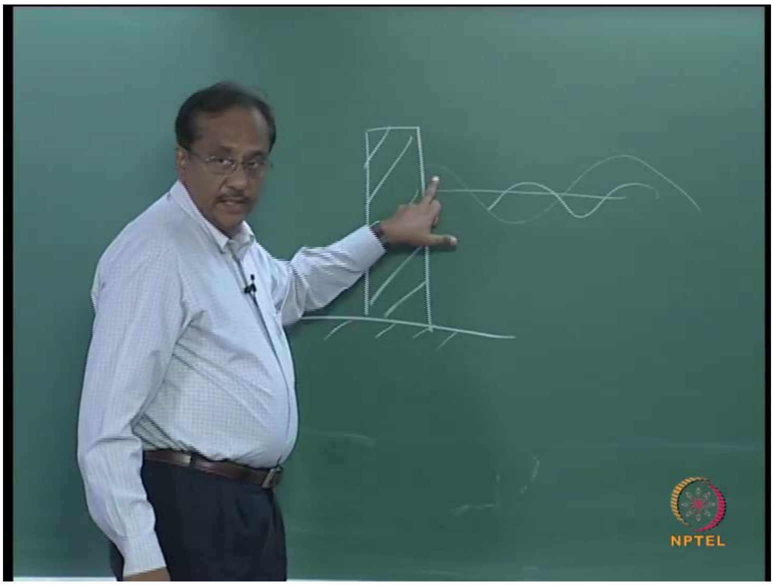

So, in which case, you see that when the waves are propagating, hits the structure and the entire wave gets reflected back. It is to be said that, the forces exerted by reflected waves are much more than non reflected waves, reflection is it good? No, it is not good particularly in the… As you, if you consider reflection, later you will see reflection is not good for the simple reason the forces, the velocities, the pressures, if everything increases in the vicinity of the structure.

The pressures exerted on a vertical wall will be much more compared to if it is a sloping wall or if it is a permeable wall, the force acting on the structure is expected to be much less compared to an impermeable wall. So, from the force or pressure's point of view reflected waves are not good, but there are situations, where you cannot avoid reflected waves.

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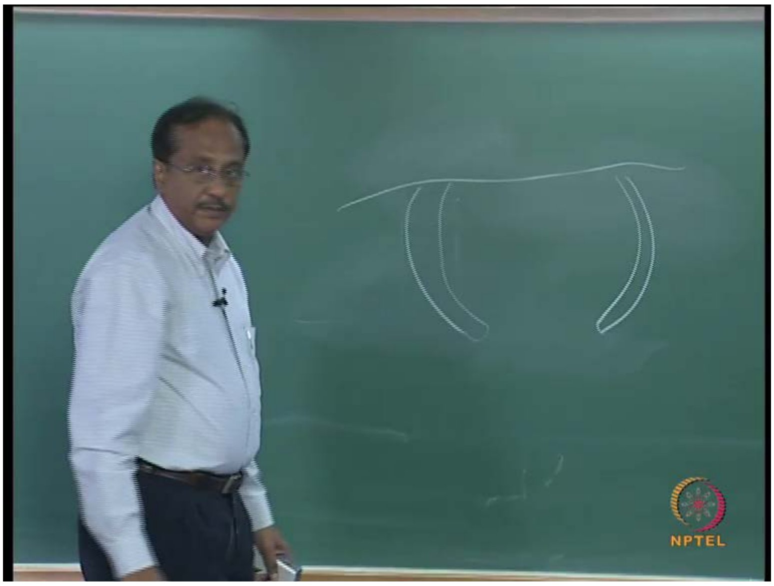

The other aspect is when you consider harbors, etcetera. If you have a reflected wave inside the harbor, the amplification of the wave climate inside the harbor due to reflection increases. So, what happens, if the amplification of the waves inside the harbor takes place, then that is going to be creating lot of confusion, lot of problems. So, actually you have break waters or any kind of structures in order to serve as a sheltered area for vessels.

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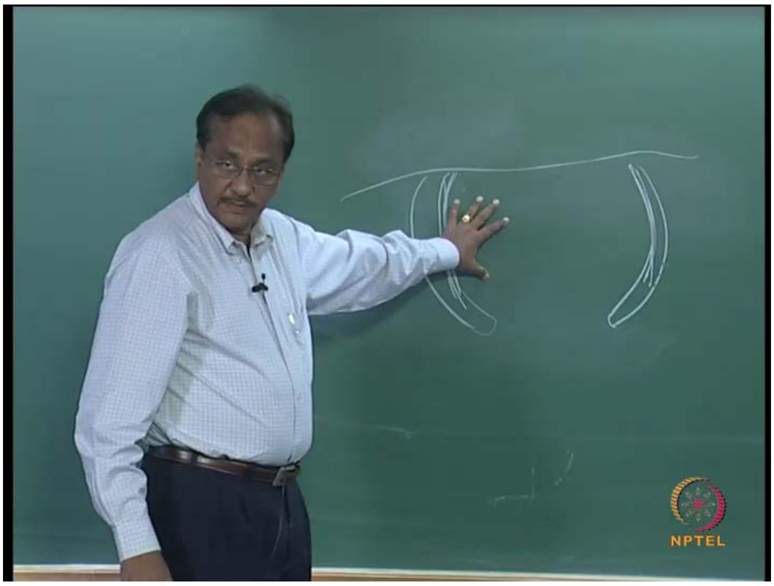

But, if you design structures or the obstructions in such a way they have vertical walls and impermeable walls, then you will have problems, you have to be very careful while designing such structures.

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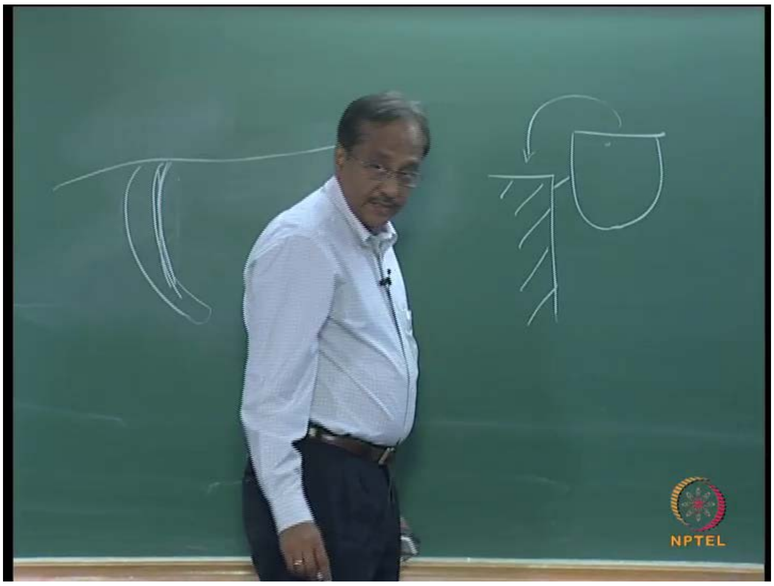

The one typical structure is when you want, you can have you should have something like this inside the harbor for berthing of vessels. You berth the vessel, so you can off load or onload passengers or goods. So, in that way you need to, you will be forced to have vertical structures; whether it is desirable or not from from first point of view, it is not desirable. And also from reflection point of view it is not desirable, but still you will be forced to go in for vertical type of structures, which is going to lead to reflection.

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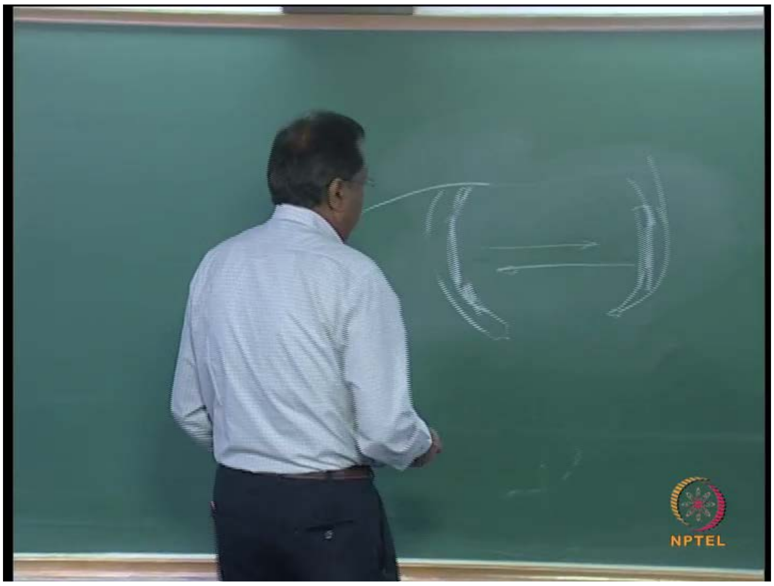

So, whatever waves coming from one end of the structure, if this there is a vertical structure here, that wave will travel and if we have this side another vertical structure, this wave will travel like this. So, for example, in an enclosed basin for typical example is like this, you have a berth here, and also you have a berth here; what can happen, could happen is a wave going and hitting this, because this is a perpendicular, I mean this is a vertical structure (()) going to get reflected. So, this oscillation is going to generate standing waves.

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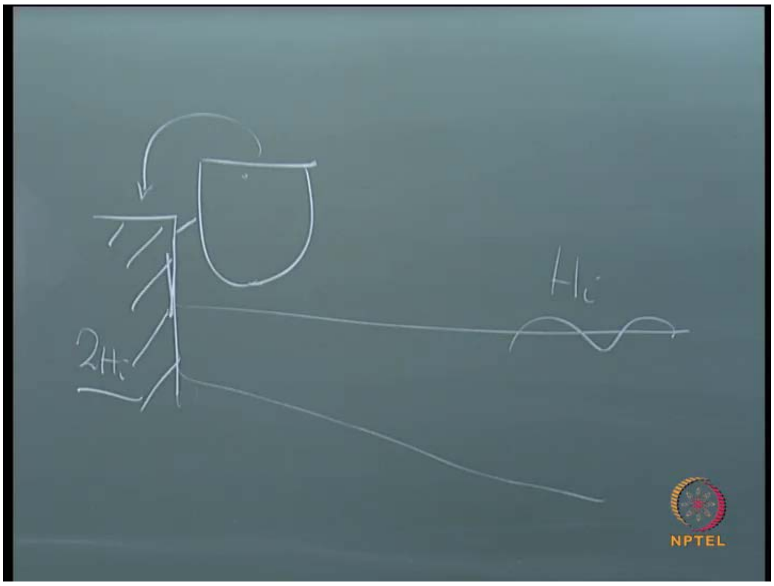

Later you will see that, when you have a vertical structure like this, and when the waves are propagating from the deep water, if this is H i the wave height, the wave height in the on the wall will be 2 H i which we will try to prove. So, from basic propagating waves, we have have already seen progressive waves, we have already seen that the pressures, etcetera will be pressures or the particle velocities are going to be a function of H i and it is going to increase. Now, you see the effect of vertical wall. So, hence it is extremely important to understand the basic physics and hydrodynamics of standing waves.

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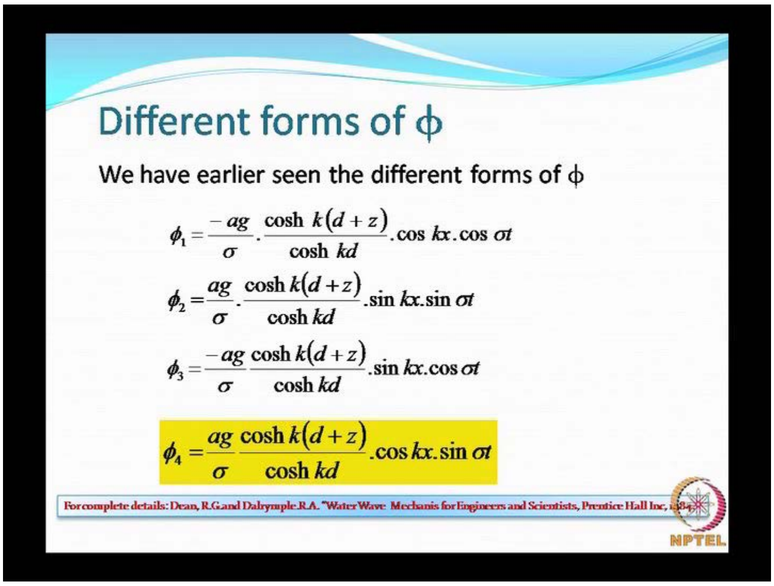

You should recollect that when we when we try to obtain the velocity potential.

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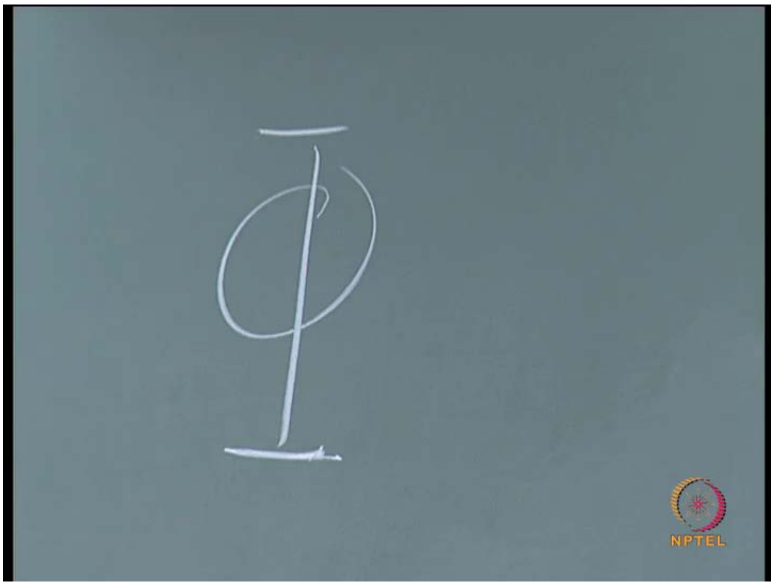

When, we try to obtain the velocity potential phi.

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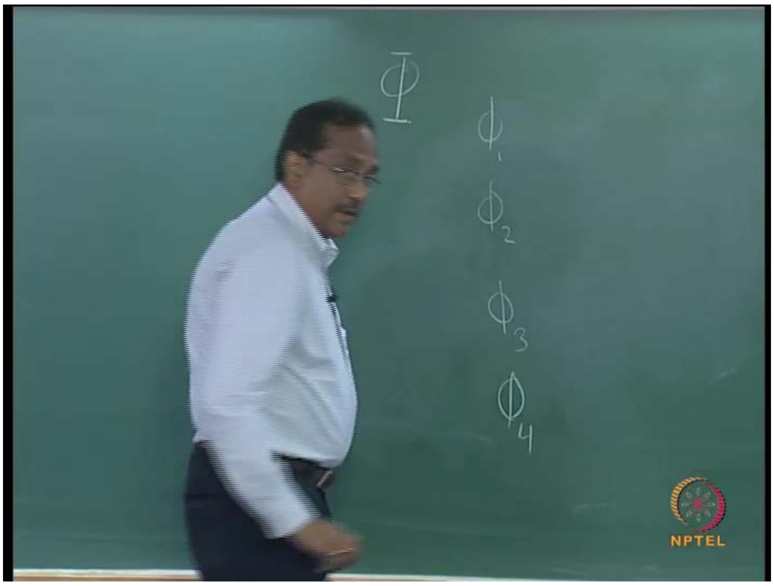

Then we dealt with the progressive waves, we landed up with four forms of equations, phi 1, phi 2, phi 3 and phi 4. You should check the previous lecture or the lecture material what we what you have in hand, for all this five four forms of solutions for the velocity.

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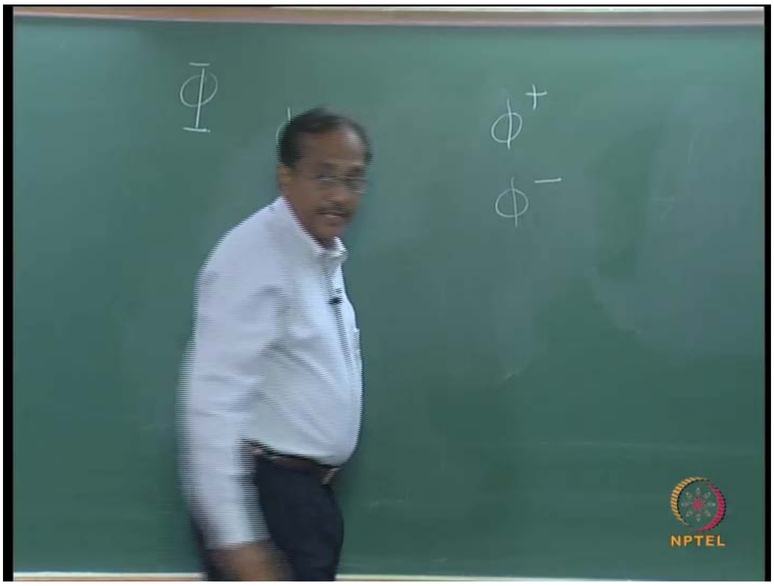

Then what did we do, we took any of the two forms of the velocity potential, we added them or subtracted them in order to get the positive velocity potential or the negative velocity potential ok.

So, we will retain the four forms of the velocity potential, but we will not get into the photo potential initially (()), in order to understand the basics of standing waves. So, I am just taking the form of phi 3 and phi 4, and phi 4 is marked with yellow color that is the one which we are we are going to do, we are going to take up.

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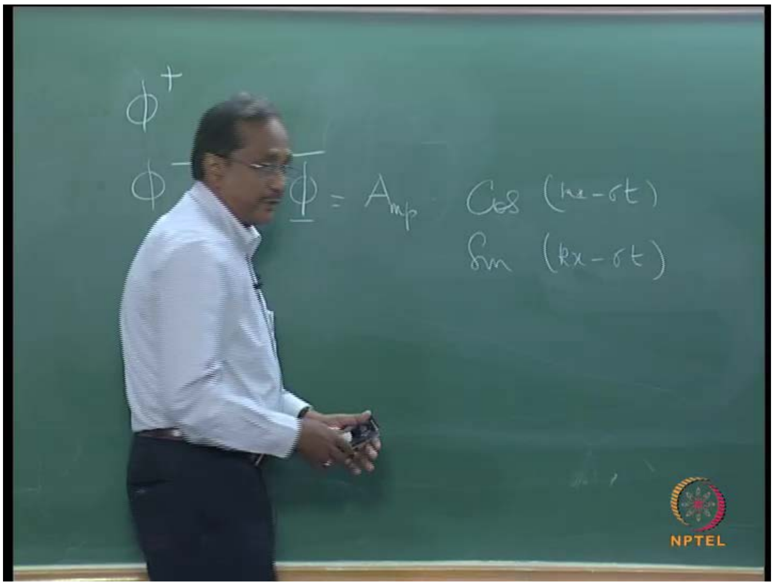

So, in the case of photo velocity potential, remember we had a kind of an amplitude into cos k x minus sigma t or maybe sin of k x minus sigma t and this was called as the phase this was called as a phase. In order to express the expression in this form, we used to take we we took two forms of any two forms of the velocity potential. Now, we are not doing that, instead we are just taking the form of phi 4 and we take that and examine the physics behind it.

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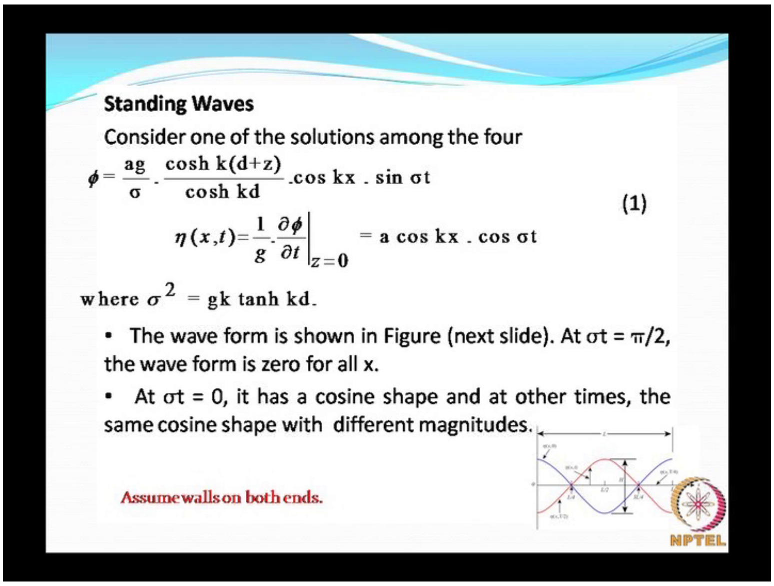

So, consider one of the solutions among the four that is what I have I have taken considered here that is your phi 4.

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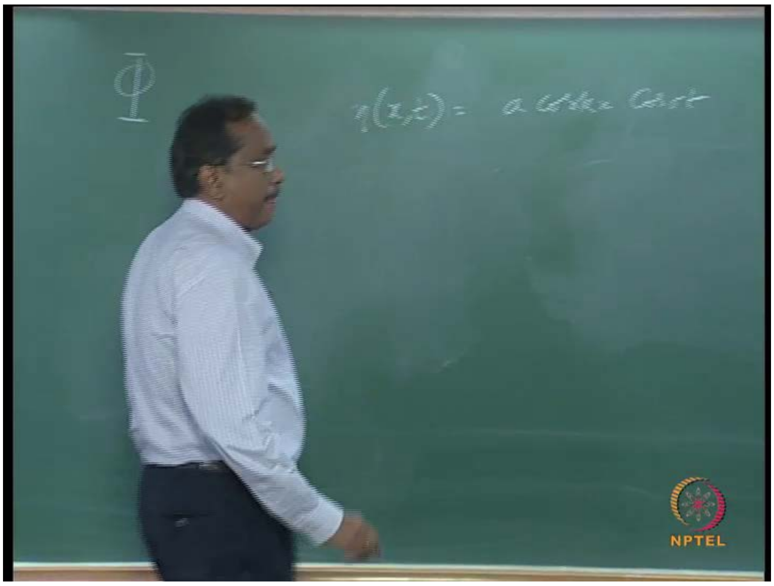

Under this you see that, eta of x comma t using the what condition, the dynamic free surface boundary condition, we get a into cos of k into x into cos of sigma t. Of course, sigma square is g k by g k into tan h k d, the illustration or the variation of the eta will be explained in the next slide with much more details.

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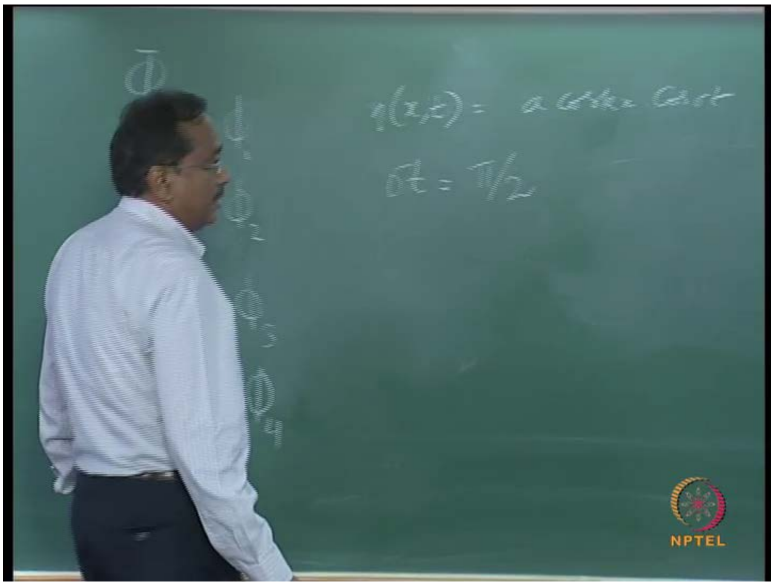

But in this slide, now the right hand side bottom you see that at sigma t, then sigma t equal to how much, when it is equal to pi by 2 what will happen, then pi by 2 that is cos 90 cos 90, it is going to be 0. So, that means the wave formed will be 0 for all values of x, when sigma t is going to be pi by 2. So, this in fact facilitates the position of your zero amplitude is that clear.

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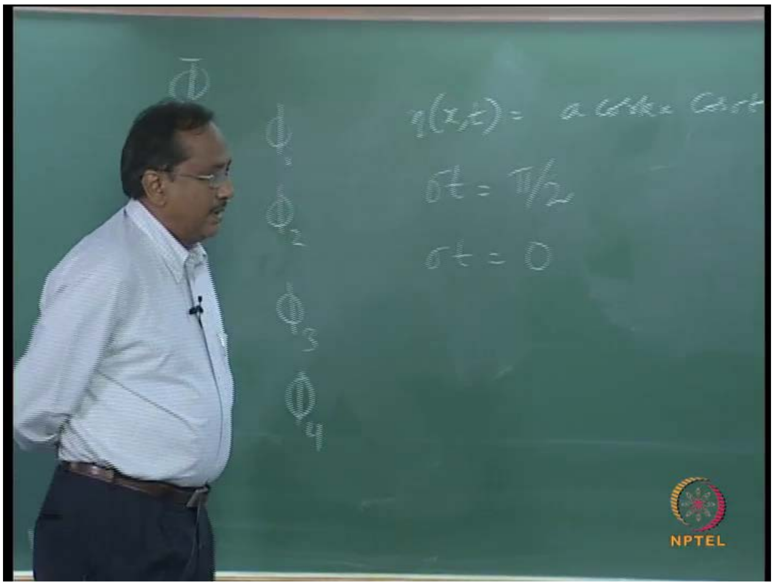

Now, our sigma t equal to 0, what will happen, this will become as a cosine shape factor. Now, this cosine shape, the shape of the cosine function will will be will follow and the amplitudes will be varying, the variations in amplitude will take the shape of a cosine curve.

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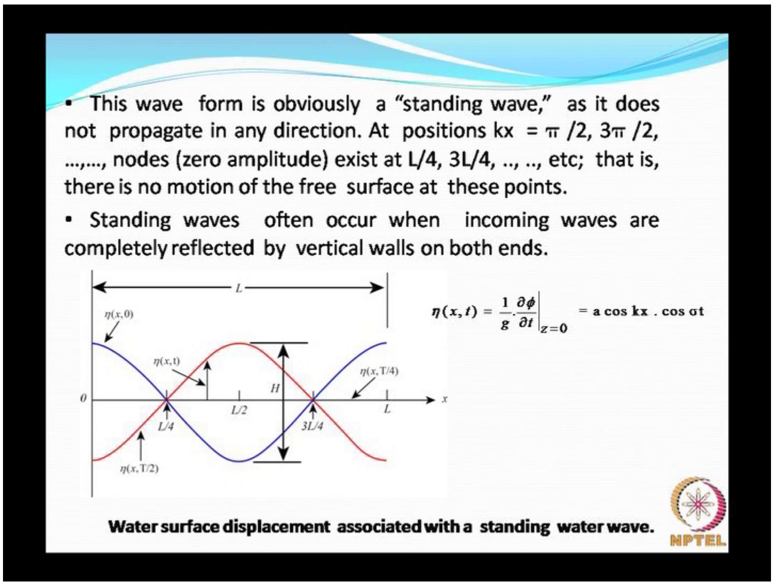

And that is what it is illustrated in the right hand, in the figure in the right hand corner below. Now, this form is obviously a standing wave, because it does not propagate, it is not propagating.

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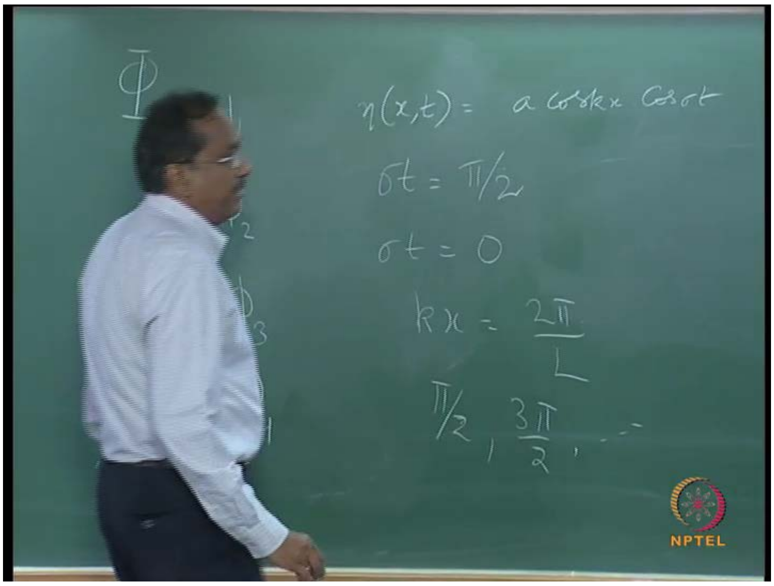

Why, but at any any position, let us talk about the position of the x axis, we are talking about the spatial variation, k x is 2 pi by L. So, if k x equal to pi by 2 pi by 2 or 3 pi by 2, etcetera, what will happen, you will have nodes of zero amplitudes at what locations?

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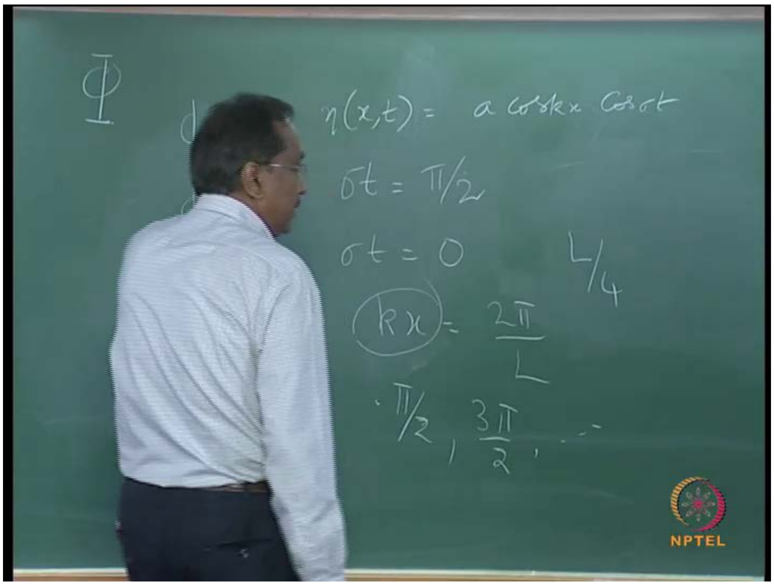

At locations L by 4, because look at this at L by 4, 3 L by 4, etcetera, that is there is no motion of the free surface at these points is that clear.

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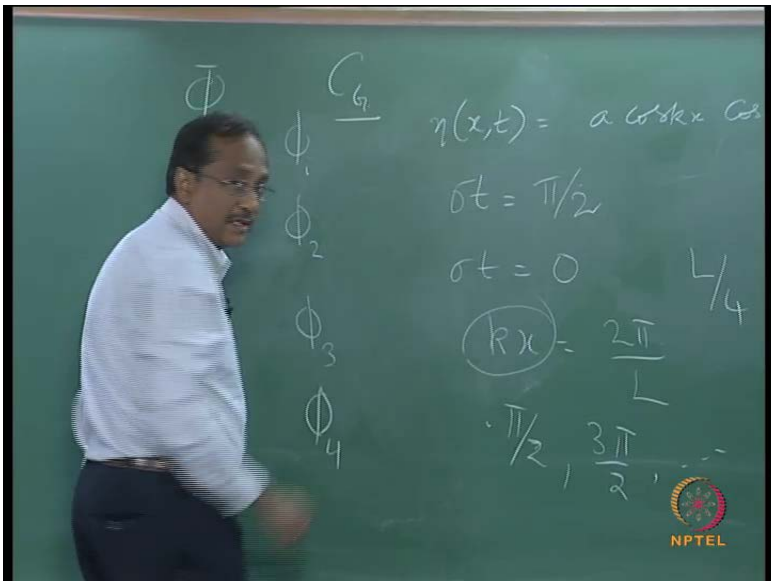

So, this is similar to what we had already seen when we were looking at the variation or the explanation for group (()), recollect we found out the nodes, position of the nodes and try to get the speed of the nodes in order to get the velocity.

Standing waves often occur when incoming waves are completely reflected, if the structure is only vertical wall, and is impermeable, you can expect standing waves. And standing waves standing waves means, if you have a container that is if you have a wall on either ends, then you will see that the waves from one end moves, hits the wall of the other side and the entire energy gets back. So, this is this is not to be in fact strictly generated in the lab, and that is why we have seen the necessity of having an absorber.

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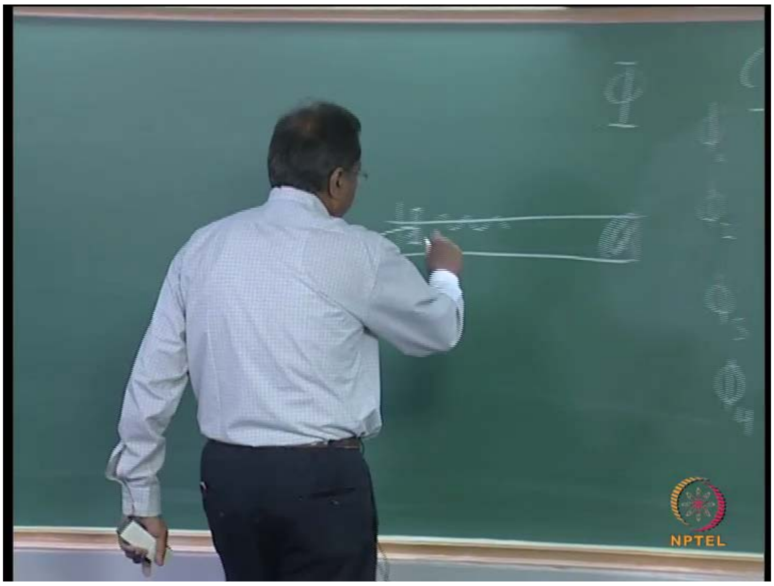

If you look at any wave tank you see that, you will have one wave maker in order to generate the waves in the tank and on the other end, you will see that you have a absorber in order to absorb the waves, so has to have only progressive waves enough for testing of structures. So, this kind of a standing wave is now represented by the expression given on the right hand side, that is eta of x comma t, etcetera, that is a equal to a into cos k x into cos sigma t which is valid for the form of phi 4, how did you get that, by using the dynamics free surface boundary condition is that clear.

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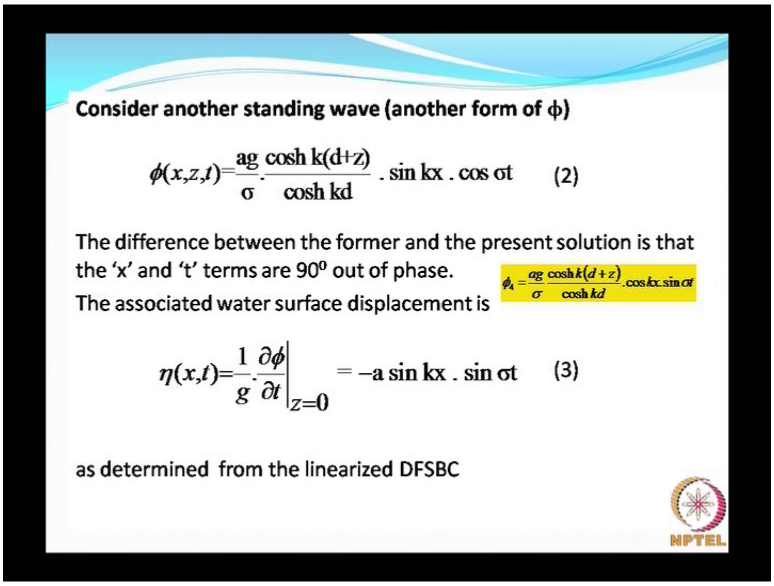

Now, consider another another standing wave, may be we consider phi 3. So, already we considered phi 4, now we are considering phi 3. So, the difference between the former and the present will be the out of phase by 90 degrees, you look at this, you see that you have a a sin sigma t, other one has cos sigma t

So, it is totally out of phase by 90 degrees, now you see that the associated water surface elevation for a phi 3 is going to be minus a into sin k x into sigma is that clear. Of course, this is, they are from dynamics free surface boundary condition.

So, now you see that, what we are dealing is with the Laplace equation and it is a and it is linear.

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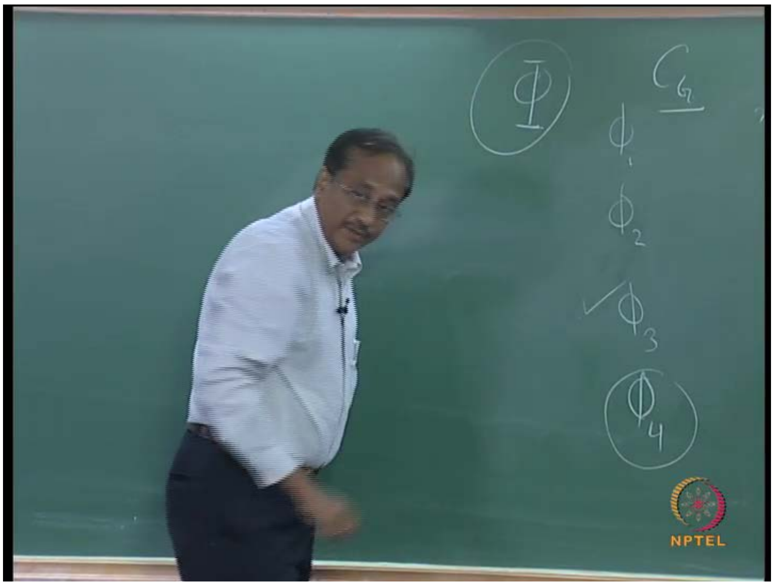

So, this permits us to add or subtract solutions that could be obtained based on this example only, based on this kind of facility only we could, in fact add subtract one of the forms of two forms of, any two forms of the velocity potential in order to obtain the velocity potential for a progressive wave. Now, we subtract the present velocity potential in equation 2 from the velocity potential which has been represented as phi 4.

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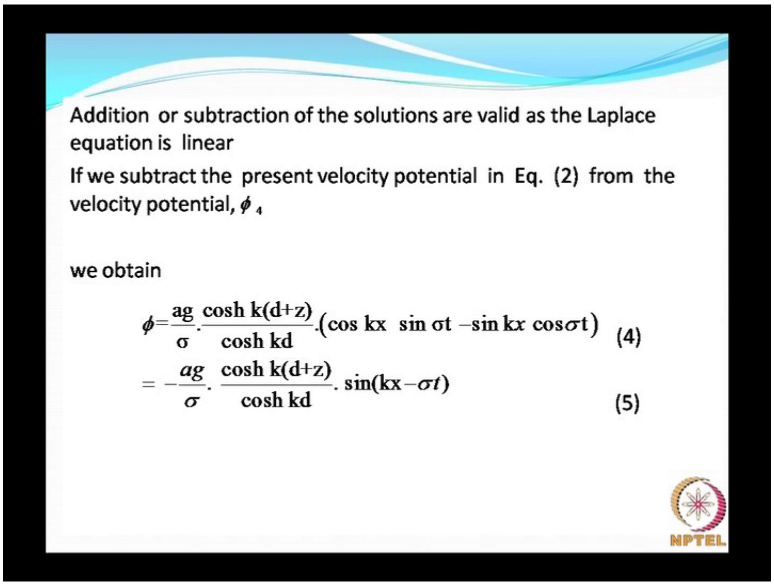

Strictly speaking, we are subtracting phi 3 from phi 4 phi 3 from phi 4. When we do that, the resulting equation will be as shown in equation 5, this is nothing but our classical velocity potential which we have already seen.

I am just repeating whatever I have told under basic physics, basic wave mechanics.

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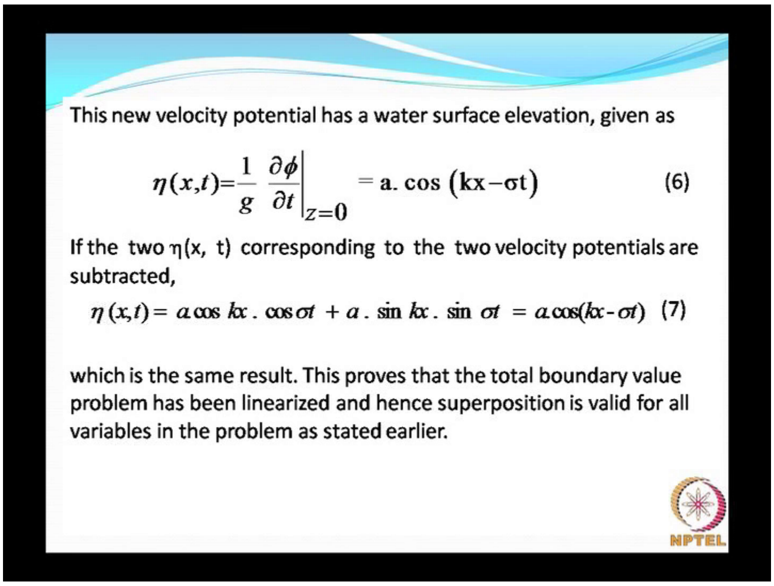

Now, this velocity potential is bound to have the eta variation as shown in here, that is it is going to be for a cosine curve. At this point of time, I would like to reiterate what I have said earlier.

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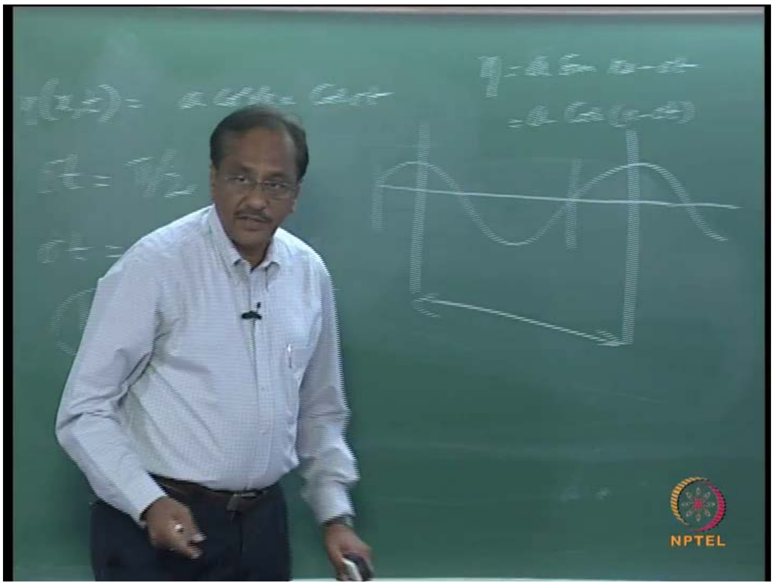

So, you can have a into sin of k x minus sigma t or a into cos of k x minus sigma t. So, certain books use this form of a the expression, certain books use this form of expression, Both are fine, because what it means is when you have a surface wave like this, the first expression (Refer Slide Time: 18:30), consider this portion of the wave in order to examine the characteristics, whereas the second form considers this portion of the wave. As long as you consider one full cycle, the characteristics are taken care whether you are considering a sin curve or a cosine curve.

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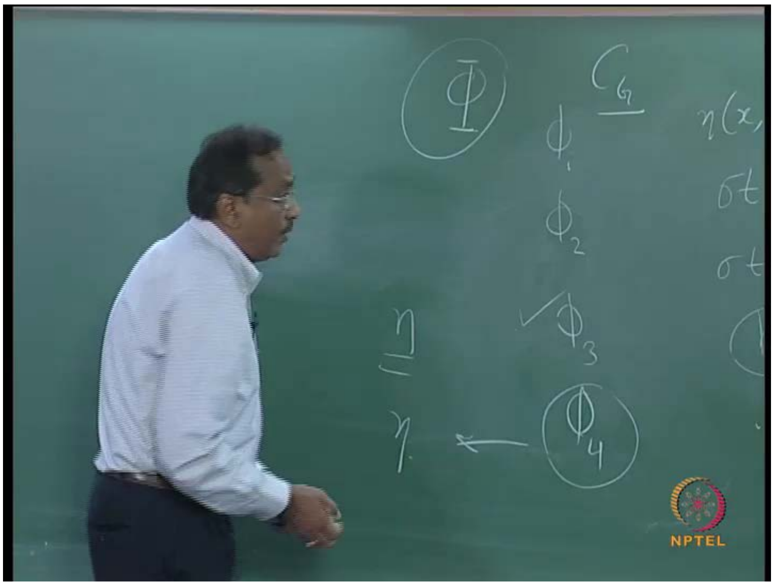

Now, you see that we had a two forms of velocity potential that is, this form of velocity potential, and this form of a velocity potential which will have the corresponding eta, what you see here is, for the total velocity potential that is summing up two velocity potentials that is having a space and a time separately earlier.

But now, we have brought space and time within the phase as you can see, this is a total velocity potential. Now, if you take the eta, you know the expression for phi 3 and phi 4 given in probably the first slide of this lecture, their corresponding eta is also given. So, look at the, where there is for one solution, and then you have here the other one.

So, use if your superpose boat, corresponding to these potentials, then you will see that this eta is nothing but a into cos of k x minus sigma t, which is nothing but which is the same as what we have got here, by adding two separate velocity potentials, you understood? So, what why we have done this is to prove that the superposition is valid is that clear.

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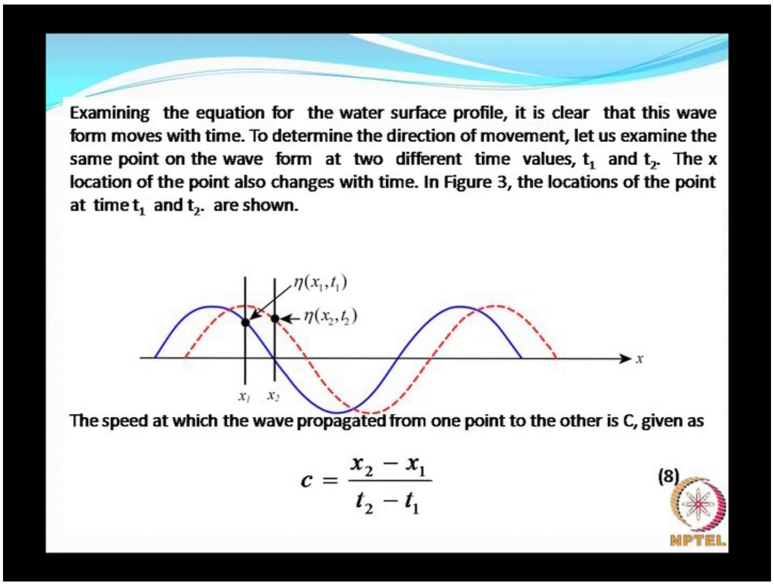

So, now having said about this, now we will move on to examine the water surface profile. Now, I consider, so let us to determine the direction of moment, let us examine some point far away from a two different time values that is, you have the yellow sorry blue and the red, and a position is fixed, the x location of the point also changes in time although we fix up a point. So, this position of this point can be the crest of a wave or a position dou somewhere here in a red color wave, almost the same point as we are talking in the blue color wave.

Both are travelling in the same direction, now the x location of the point also will change with respect to time that is clear. So, in this figure you see that, the locations of point points point at t 1 and t 2 are clearly seen. Now, if you consider them, the speed at which the wave propagated from one point to the other that is naturally what is it, celerity. So, and that has to take place in that interval of time.

So, x 2 the distance, the difference in the distance x 2 minus x 1 divided by t 2 minus t 1 is going to be your speed is that clear.

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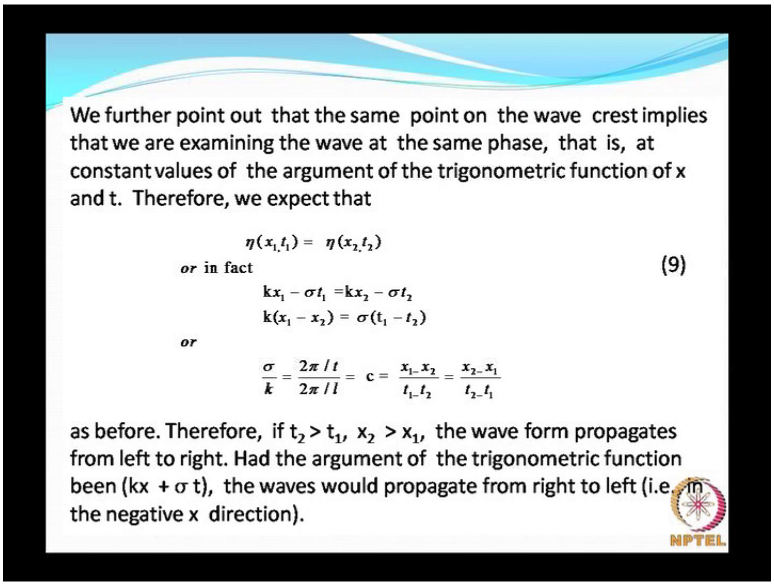

Or we further point out that the same point on the wave crest implies that, we are examining the waves with the same phase.

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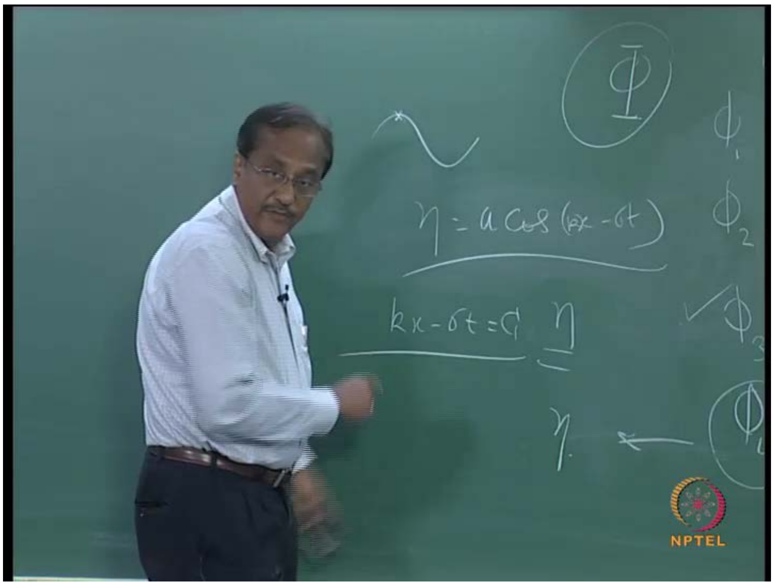

So, when we remember I would like you to recollect again, this is what we did, we identified a point or a wave while moving so that we try to move with the same speed of that of the wave at this point. Then in that case the phase, there is no phase difference, then we said we said that k x minus sigma t is equal to a constant from which we derived C is equal to L by t for a propagation, I mean for a propagating wave, now the same thing holds good here.

Since, we are examining the wave at a same point, that is constant values of argument of the trigonometric functions will be same, equal. So, in this in this case k x k x 1 minus sigma t 1 must be equal to k into 4 I mean therefore with the value of 2, these two has to be same, because we are talking about the same phase. So, then when we go about deriving, then finally you see that the velocity comes out comes down to the difference between the spaces that is x 2 minus x 1 divided by t 2 minus t 1 ok is that clear.

So, if you look back, so this you have here x 2, x 1, x 2 x 2 is marked there, x 1 is also marked there, if you use that picture, if t 2 is greater than t 1, x 2 is greater than x 1, and the wave form propagates from left to right from left to right. Suppose, if the argument of the trigonometric function that is, if you had use a positive sign instead of a negative sign inside that, then the waves will be moving in the right side, this we have already seen under a progressive wave understood.

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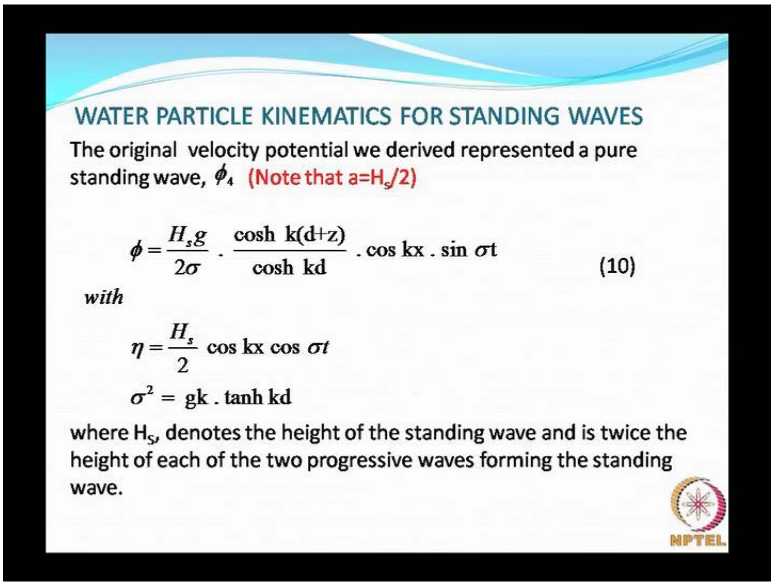

Now, let us look at the water particle kinematics for standing waves (No audio from 26:08 to 26:29). The original velocity potential may be phi 3 of the form of either phi 3 or phi 4, it does not matter, you can take anything which ever you want. So, the original form of a velocity potential that in this case should be phi 4, what we have derived is for a pure standing wave.

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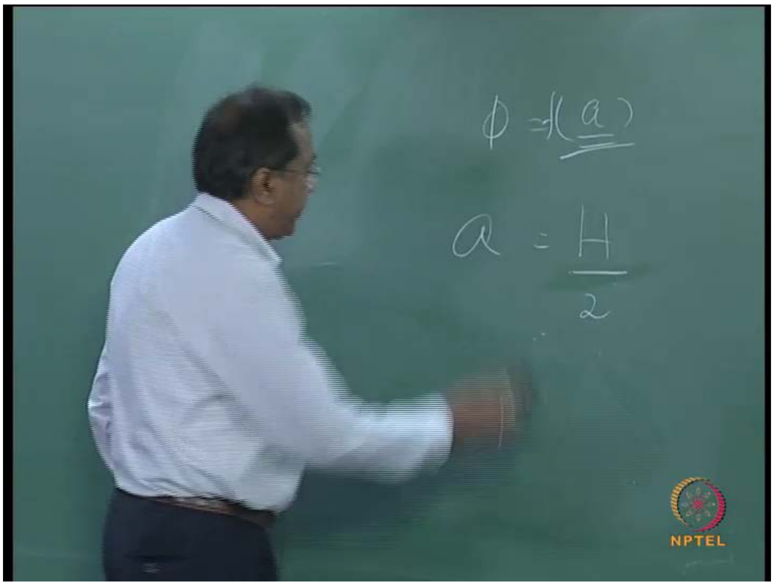

Earlier we retained function as, I mean the velocity potential as in the function of amplitude. Now, since we are going to talk about the standing wave, let us revert, I mean let us start talking in terms of wave height, wave height is nothing but amplitude is equal to wave height divided by 2.

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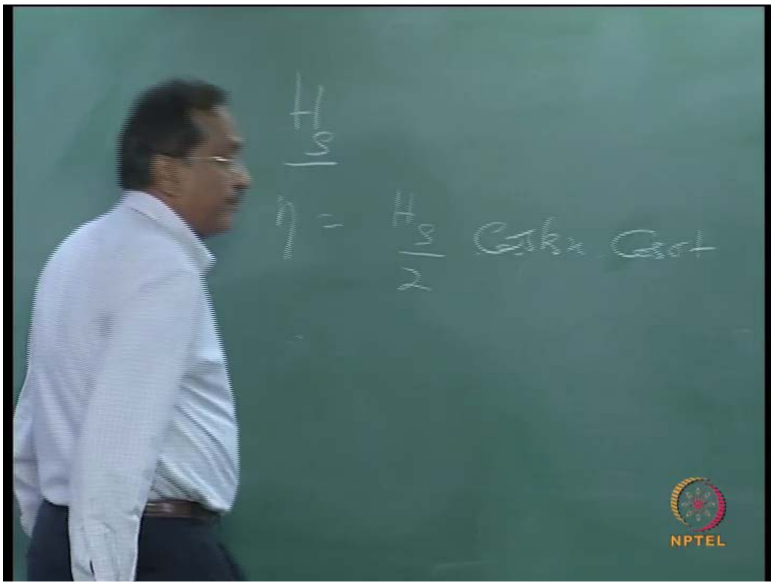

So, the velocity potential now since we have considered the standing wave, I am denoting H as H suffix s, then I have a H suffix s, that means it is a standing wave. For this velocity potential, now my eta is going to be as a function of H by cos of k x into cos sigma t. So, H s is the height of the standing wave and as I said earlier, it should be twice the height of the each of the two propagating waves that should be merged together to form as a standing wave.

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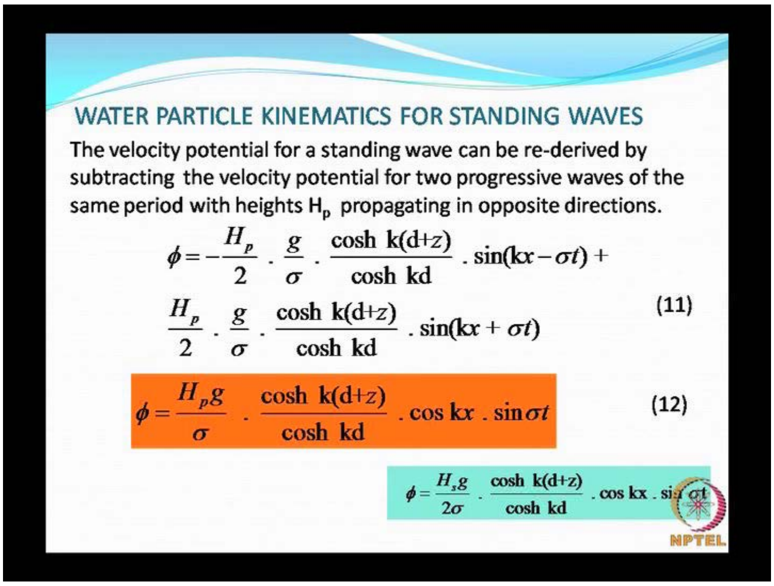

So, particle kinematics in the case for the standing waves, the velocity potential for a standing wave can be re derived re derived by subtracting the velocity potential of two progressive waves, herein we are considering two progressive waves, but when will the standing wave take place, when they are moving in the opposite direction when they are moving in the opposite directions.

So, I consider here one wave, so I am using here as a H p means a single propagating wave, progressive wave. I have a progressive wave here and this is nothing but the form of the expression, what we have obtained by superposing any of the two forms of velocity potential while deriving the expression for progressive waves. So, any two forms can be superposed, but only thing is what we are trying to do here is, we have to take care of this signature and in this the sign, because the wave is going to move in the opposite direction. Only then you can generate a, you can have a standing wave is that clear or can proceed.

Remember that, so this is your standing wave as we have seen earlier, and now this is the progressive wave, single progressive wave which is now of this form that is out of the phase k x and the sigma t is out of bracket. So, dou oh sorry now this is the form of velocity potential for standing wave, the orange color is for progressive waves, now both are same.

So, by examining these two expressions what you see, you see the cycle of 2 appearing you see the factor 2 appearing here, H p equal to H s divided by 2 which indicates clearly that the height of the standing wave is twice the progressive wave height the wave height or twice the wave height of a progressive height of the progressive wave is that clear.

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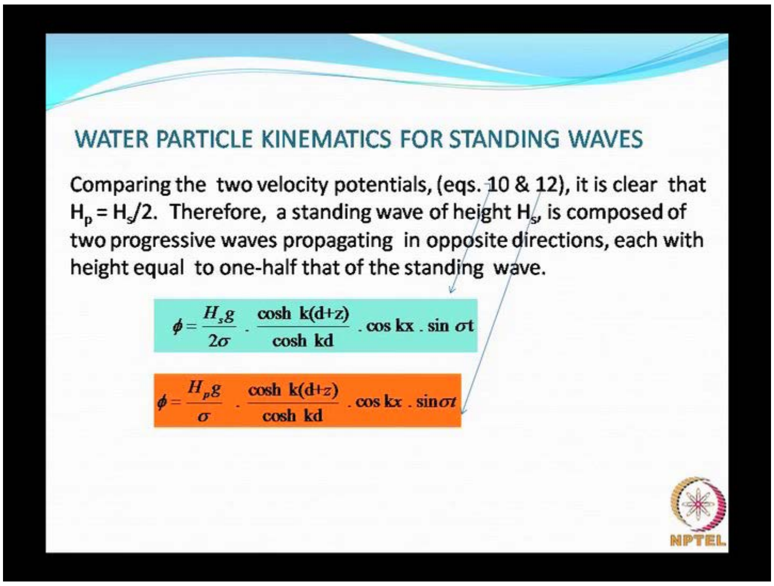

And then is what is explained here, comparing the two velocity potentials, so we get the factor 2 which is again illustrated in this slide, what I have explained in the earlier slide is again repeated here, shall I proceed. Now, as we did now that we have the velocity potential, once you know the velocity potential you know what to do with the velocity potential in order to get the velocity components, orbital velocity components as you have done as you have done earlier.

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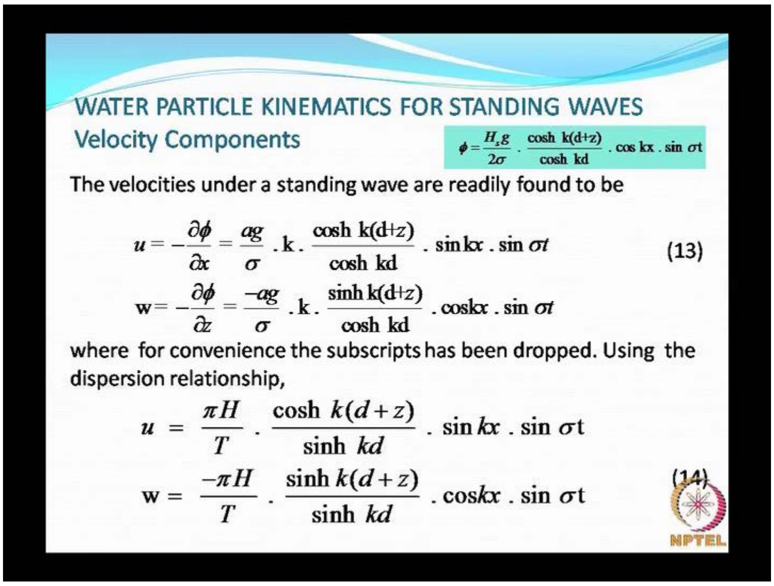

So, the the velocity potential for for this purpose is again introduced here so that you need not have to go back, this is what we have already derived for which use the usual expressions of a u and w for and also using the dispersion relationship, you can get in terms of H and t as we have done for progressive waves earlier.

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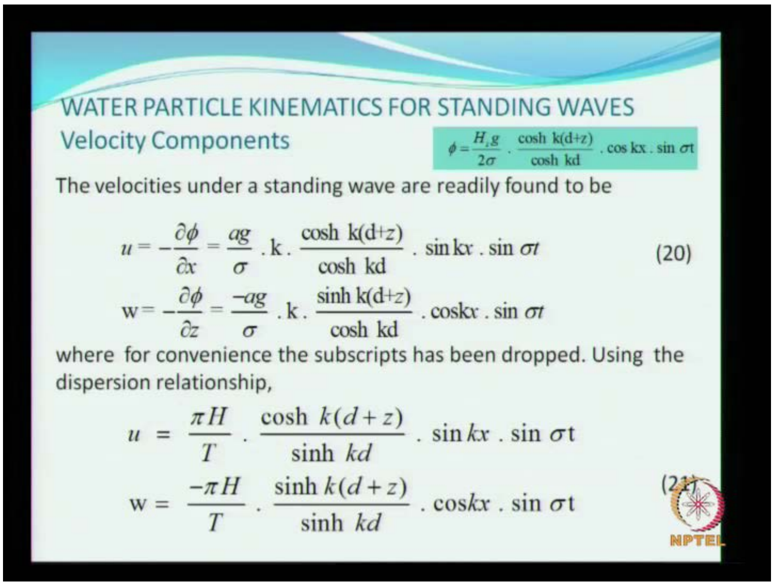

Up to this absolutely no problem, because it is similar to what you have already seen earlier.

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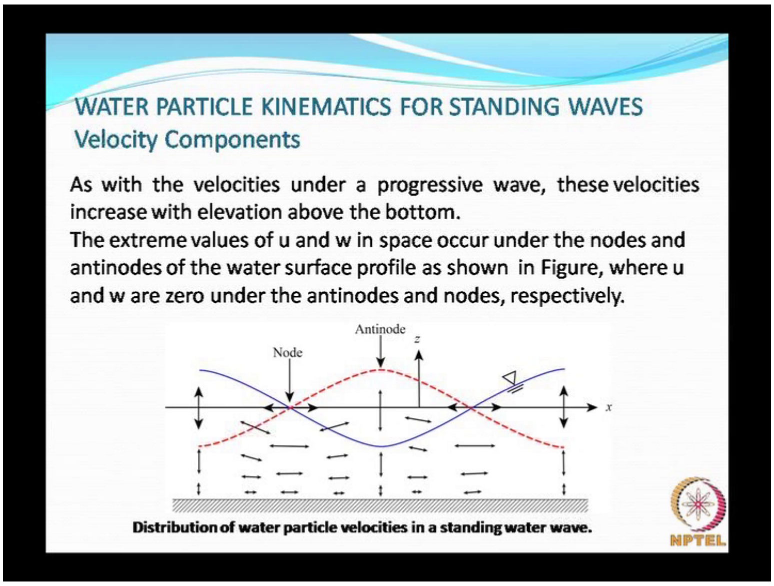

Now, as the velocity under a progressive waves as with the velocities increase with the elevation, the particle velocities are kinematics is going to with respect to the variation along the depth, it is similar what is going to happen when a progressive wave passes.

It is basically a surface waves, so you need, you will have the dominance of the particle velocities, accelerations near the free surface and as you go down towards the seabed, it is going to decrease that implies from the expressions also what we have got so far. Now, the extreme values of u and w that is horizontal and the vertical velocities in space in space under the nodes and antinodes of the water surface will be is shown in the figure given below in this on this slide.

You see that u and w both, for example, if you take this is node, node is nothing but points of zero amplitudes, antinodes are locations of maximum amplitude which we have already seen. So, you see that, here the node the horizontal water particle velocity is going to dominant to be dominant and the vertical velocity is going to be 0 and vice-versa in the anti-node under the anti-node your vertical velocity is going to be the is going to be the maximum and of course, it is going to vary along the depth is that clear. So, now when we are discussing about this, we are considering to be assume that there are two vertical balls on either side, only then you can really have a pure standing wave taking place is that clear.

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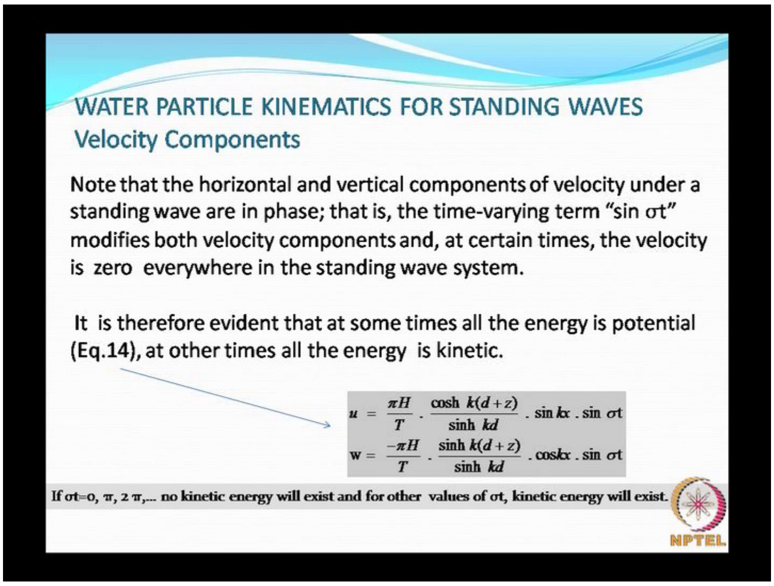

See, note that both the horizontal and vertical vertical components of the velocity are in phase, that is quite surprising, because in the case of in the case of progressive waves, it will be the other way.

So, now you see that, it is going to be or they both are in same phase, both are having sin of sigma t.

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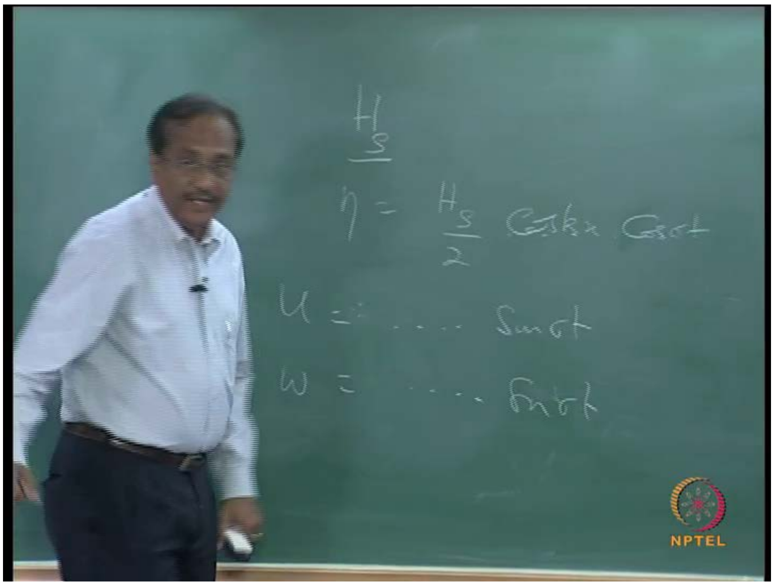

So, u will be sin of sigma t as in the, as we are seeing, whereas this is also sorry also is sin of t, both are in the same phase that is time bearing sigma t modifies both velocity components and at sometimes, because they they dictate the velocity components, but at sometimes the whole thing will become 0 also ok.

So, velocity is 0 everywhere at certain value of the phase sigma t, the whole thing will become 0. So, there would not be any magnitude of the orbital velocity. Now, it is therefore evident that at times all the energy is potential and at some other times, all the energy will be kinetic kinetic, because this depends on the value of sigma t, if you have a value of sigma t, you will have certain values for your u and w. But it is all going to be both are going to be in the same phase is that clear.

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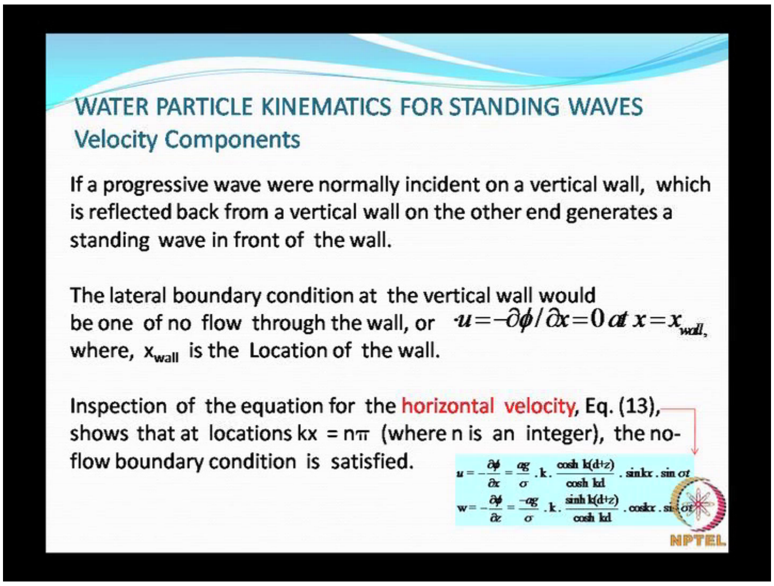

Now, again we continue the particle velocities, particularly when we talk about a vertical wall, when we have a vertical wall, what is the first, what is that kinematic bottom boundary condition, vertical velocity normal to the sea bed is 0, now you are having a vertical wall and you have a wave coming and hitting the wall.

So, naturally the velocity normal to the vertical wall is going to be 0. So, using that at any x x equal to let me say at the at the wall is going to be 0.

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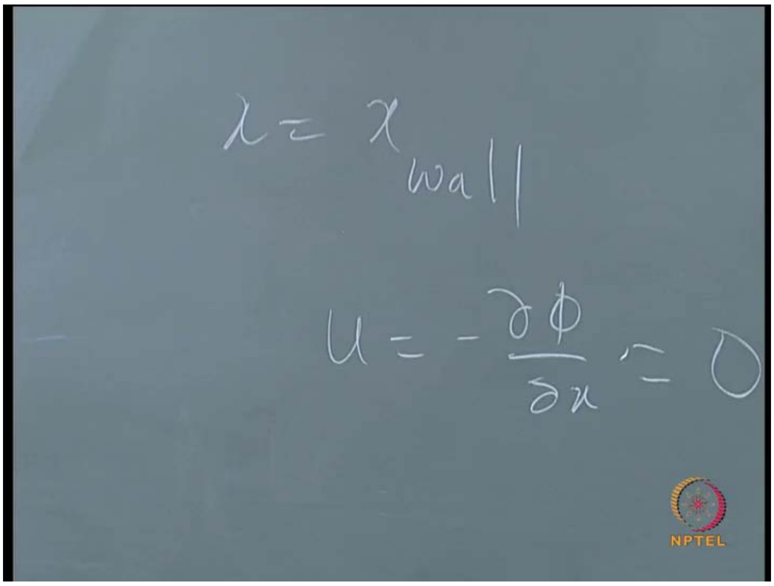

That is equal to u equal to is that clear. Now, if you look at the expression for the horizontal velocity as you can see from equation 2, this is the horizontal velocity and the bottom one is the vertical velocity.

So, if you look for the horizontal water particle, velocity given in the right hand side corner.

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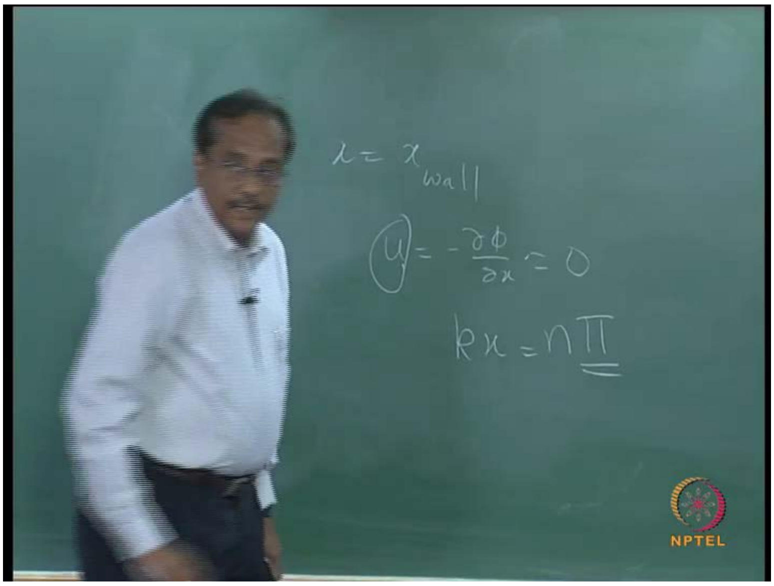

What does that show at locations k x equal to n pi, n is an integer value, when n is an integer value what will happen, there would not be any flow that is no no flow boundary condition will be satisfied is that clear. So, no there would not be any flow into the boundary, that is what it implies.

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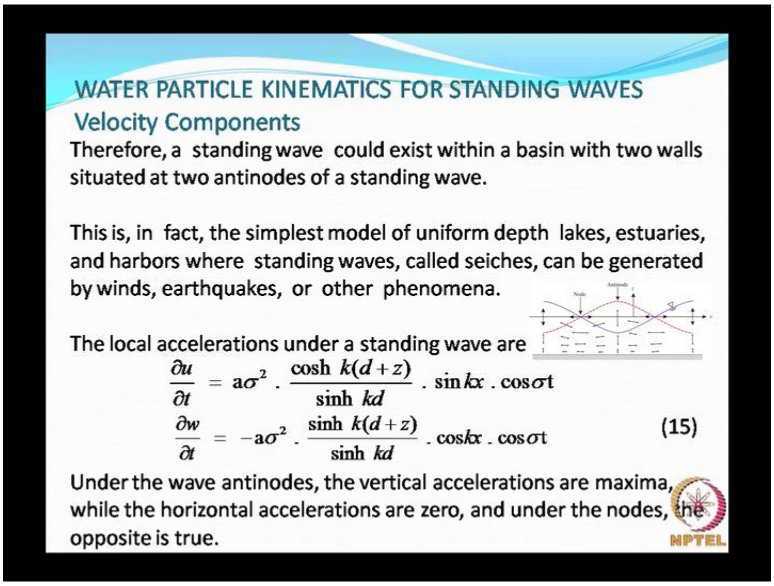

Therefore, a standing wave could exist within a basin, for example we have a wave basin or we have a vertical wall I mean a flume, now you remove the wave absorber, you generate a wave, allow the wave to, allow the wave maker to run for some time, what will happen, the wave will travel, go hit the wall and come back, and what will happen you will initially have some standing wave for certain location, certain stretch.

But then, again the waves which are coming back from the wall and hitting the wave maker again will get re reflected. So, these are all called as re reflected waves.

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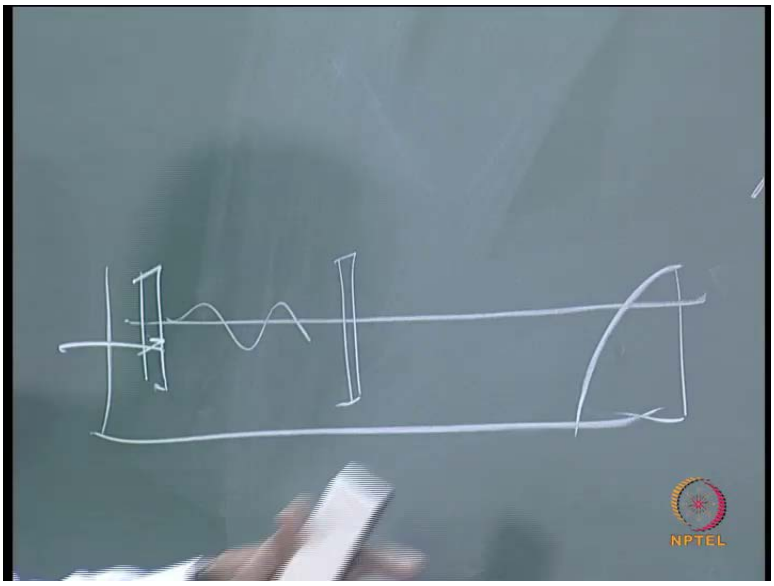

So, for example, if you have a flume facility, strictly speaking what you are supposed to have, you are supposed to have progressive waves, in order to test the structure for example, ability measuring of forces some structure, etcetera, may be measuring forces on a tubular number which is quite common. When you want to do such such such studies, you have to have the wave maker which would be moving up and it will be generating, you remove this, then you are not generating what is going to happen in the field, in the field you are going to have a progressive waves.

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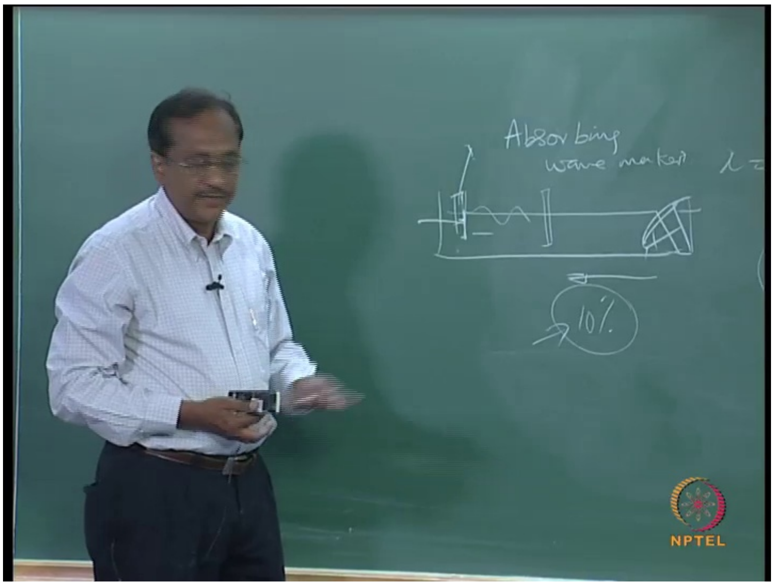

So, even in case you have this wave absorber, this wave absorber cannot absorb 100 percent of the energy of the propagating waves, there will be a certain degree of a reflection taking place, may be 10 percent and this energy, if it reflects back and if it is hitting the structure, hitting this wave maker. So, the next waves, next series of waves is not going to be of the same quality of waves which you want to generate you are, because you are able to generate a wave with a additional 10 percent of reflection.

In order to avoid this re reflection, we also have what is called as absorbing wave makers absorbing wave makers that it what it does is, it digitally it can be altered, the moment of the wave maker can be altered through the signals which we get, this it can be done electronically through a software and the control signal files for driving the, while driving the wave is that clear.

So, coming back that is another part of the story what we are already discussing about the standing waves. Now, this there are some areas where you will have this kind of a a problem, for example uniform depth, lakes, estuaries and harbors where standing waves they are referred to as (()), this could be generated even by winds, waves, etcetera.

Standing waves in lakes or harbor base and etcetera are not good. So, if a tsunami enters a harbor basin, what will happen, it will keep on oscillating, one thing is if it is a a long period wave and enters into a harbor and inside the harbor you have most of them not that much not that absorbing type, then you are running into a trouble. So, what will happen, the disturbance will be continuous, because there is no kind of absorbing.

So, what will happen, you are more in lines, etcetera can be snapped after some time. So, the having seen the velocities, or orbital velocities, you can easily obtain the expressions for the accelerations, under the antinodes the vertical accelerations are maximum and while the horizontal accelerations are 0 and under nodes, the opposite the reverse takes place. So, that is your story about the particle velocities and accelerations under the standing waves.

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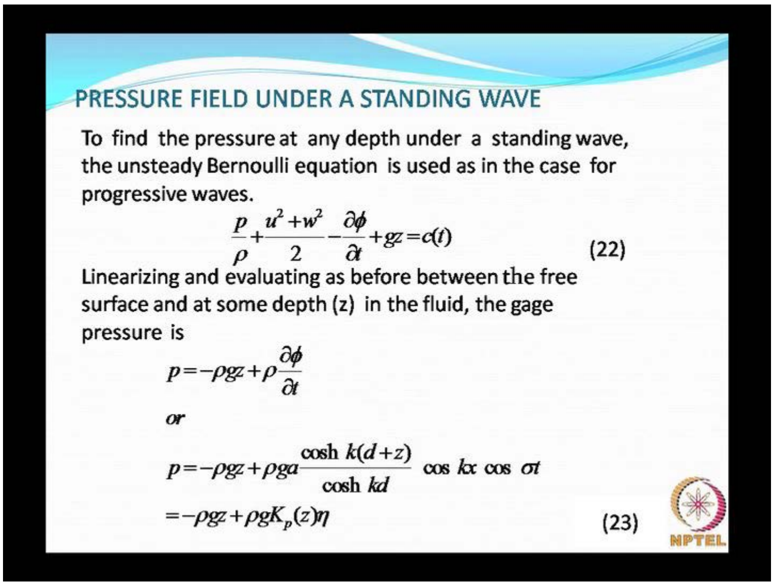

Now, let us move to the pressures under a standing wave, but to find the classical Bernoulli equation is going to be used, same as what we have used for progressive waves and only thing is the velocity potential will be for a standing wave.

So, velocity potential for a standing wave we have already seen, just evaluate them and go through the same procedure as I have already told you for the progressive waves, then you will get finally, a summation of this static head and the dynamic part and there you see that, the pressure response factor is also coming into picture that is cos into k into d plus z divided by cos k d. Please refer to my lecture material on progressive waves under basic wave mechanics.

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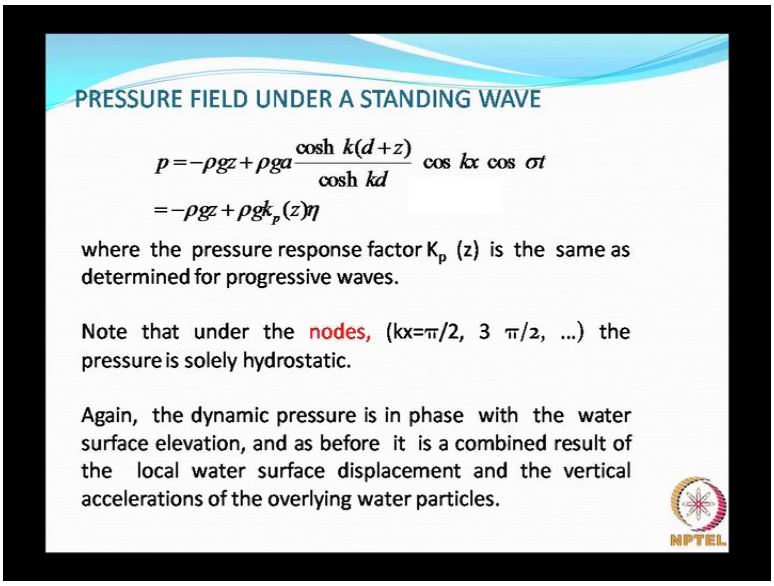

So, this is continuous and there is what you would have and note that, under nodes under nodes that is equal to k x equal to pi by 2 or 3 pi by 2, etcetera, you see that the pressure is going to be solely hydro static is that clear. So, after the lecture, you please have a look at the slides, go through carefully, slowly, I am sure that you are in a position to understand.

And all this part of the lecture are available in the book on, the book on wave mechanics for basic wave mechanics written by Dean and Dalrymple which is a classical text book for people who are interested in knowing about the mechanics of ocean waves. Again, the dynamic pressure is in phase with the water surface elevation, as you can see from the phase elevation and as before, it is a combined result of local water surface displacement and vertical accelerations of the overlying water particles.

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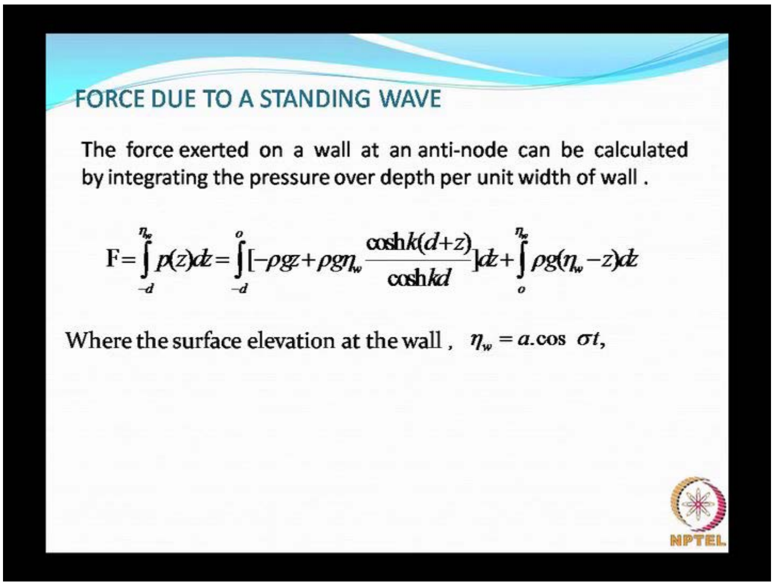

Now, having seen the pressures, you we move on to the force, the force exerted on a vertical wall at an anti-node that is where you have the maximum amplitude which is expected to be twice the wave height, that can be calculated as minus d the integration has to take place from the sea bed up to the wave elevation, that is the first integration which can be split into two halves, you integrate up to the still water and from the still water to the eta.

As we have seen the how to derive the energy, etcetera you know, potential energy, kinetic energy, we used to we have taken that integral, the same way you do this, and here eta w you see that is equal to the wave elevation at the wall at the wall.

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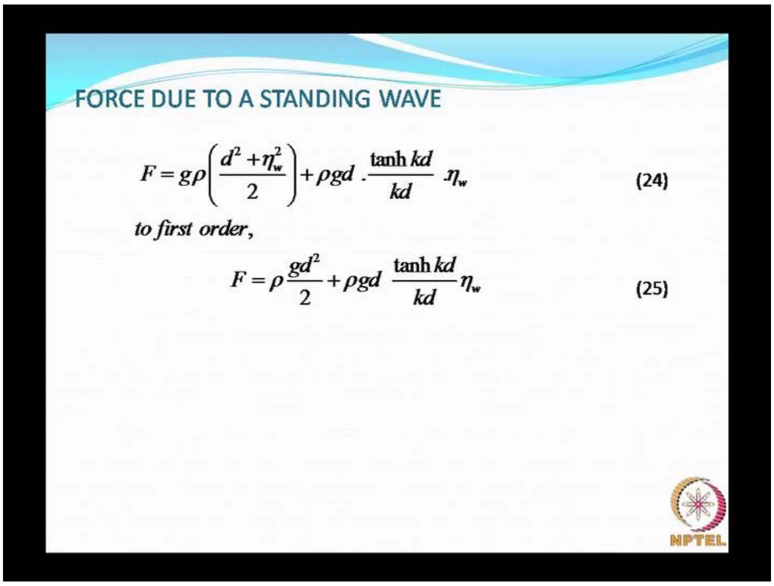

So, once you do this, the first order wave force due to a standing wave can be directly obtained and as you can see here. So, this can usually be used for calculating the wave forces on a vertical wave. However, you can cap with the pressures at the different elevations along the wall and integrate it.

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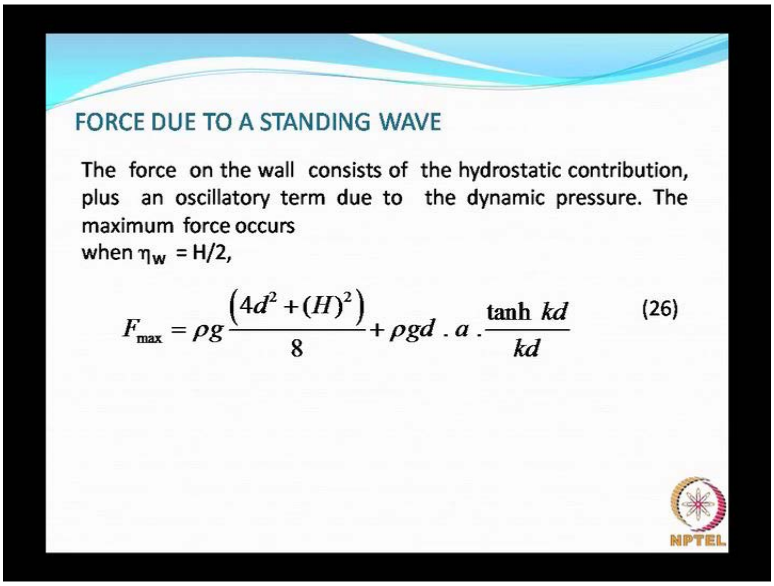

The force are consists of hydrostatic components as well as the dynamic component. So, what I will do is, anyway this completes the basics of the standing waves up, and when we are talking about the wave forces acting on vertical walls that that is coastal structures under the coastal engineering module, then there I will mention more about how to calculate the forces at the exerted on the vertical walls, and there I will also consider both due to non breaking waves as well as the breaking waves. So, that will give a better, much more clear picture apart from whatever we have seen today. Are there any… So with this I am concluding the standing wave, information on the standing waves. And the next aspect is partially standing waves; partially standing waves can be due to some amount of permeability or some slight sloping structures. So, again if you want to have details about this read the go through book of Dean and Dalrymple.