Marine Hydrodynamic
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Lecture - 24
Capillary Gravity Waves

Welcome you to this lecture on marine hydrodynamics. In the last lecture we are talking about what particular kinematics of the water particulars, and we have seen that the water particulars have follow on elliptic path and in case of infinite depth, they path become circular in nature. Again we have seen that that how the reasonless occur in case of a close turn open basin and we have seen that the in case of views in the net tank or in a base bay or the bay or basin it the primary modes of oscillation which plays significant roles.

Today will earlier had also I had mentioned that out of several there are several types of waves that exist in a ocean, and one such a wave is a comparable two waves and that is due to it is a basically the effect of surface tension un gravitates. So, and that is why you call it, because corporally rise corporality comes from the corporality, un gravity two waves. So, basically is a effect of surface tension un gravity waves. So, let we will see how this equation comes into picture or the how the boundary condition on the surface is gent at the motion is affected in the presence of surface tension.

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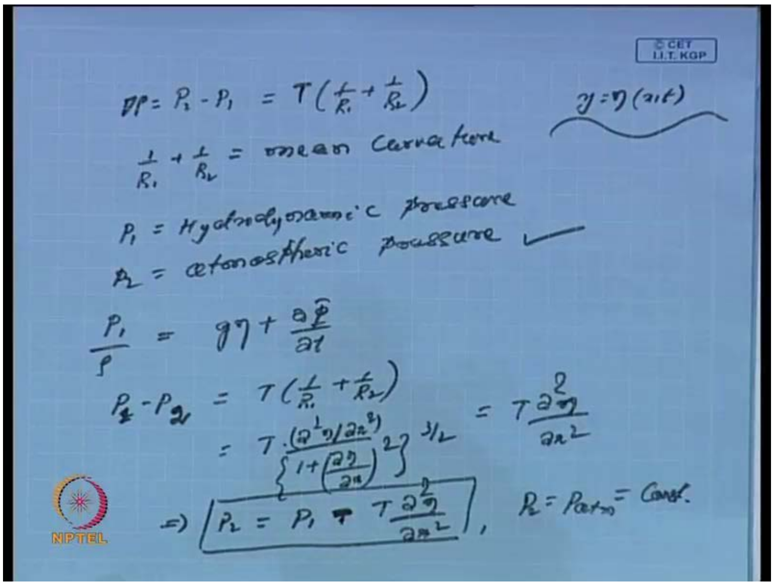

We all know that the pressure P 2 minus P 1 is equal T into 1 by R 1 plus 1 by R 2 where if basically if y is equal to eta is of the surface and this is the free surface and so, 1 by R 1 by R 1 plus 1 by R 2 basically is the mean curve feature the curve ways is equal to eta. Then we have seen P 2 minus P 1 is the difference of pressure or we call it as a gradient pressure, there is a difference of pressure on both sides in the presence of so, that barriers Anthamine curve nature. We have seen that grant P is equal to T into 1 by R R 1 plus 1 by R 2. Now, what happen in case of T surface, in case of the surface my P 1 is the hydrodynamic pressure, hydrodynamic pressure and my P 2 is the pressure atmospheric pressure.

In fact, we have seen when P 1 is equal to P 2 use to say that hydrodynamic pressure is the case of the atmospheric pressure. On the other hand if there is a they are not same and what you say in case of corporally rise is grand P where is as 1 by R 1 plus 1 by R 2 and this is called what is the surface tension force then it is a, T what you call the coefficient of surface tension or the surface tension itself. So, then what happen here P 1 is the hydrodynamic pressure. So, P 1 in the P 1 by rho is equal to g eta plus del phi by del t.

Again, but what will happen to P 2? When P 2 then P 1 from this equation P P 2 minus P 1 that is P 2 minus P 1 is equal to is equal to t times 1 by R 1 plus 1 by R 2 and 1 by R 1 plus 1 by R 2 is nothing, but t times del s peroxide eta by 1 plus del eta by del x is the definition of curvature 3 by 2. That gives me because if I ask him the surface eta is a small then on the pre surface this should be T del square eta and del x square sorry, del square eta by del x square because I assume eta is small. So, del eta by del x will be I can smaller, it is square will be very small. So, this term only give by me 1 and then this becomes so, P 2 minus P 1, so if it implies my P 2 P 1 plus…

So, P 2 is a P 1. So, my P 2 minus P 1 is there is a P 1 is the hydrodynamic pressure and P 2 is. So, this should be there is a, this is P 1 minus P 2. So, this is P 1 minus P 2. So, my P 2 P 2 is the atmosphere pressure. So, P 2 will be P 1 minus minus T into del square eta by del x square. So, this is my pressure and this pressure is nothing but but my P 2 is the atmospheric pressure. So, this will be 0. So, if we P 2 is 0 P 2 is constant P atmosphere and that I assume as a constant. So, on the surface we have a P is equal to P atmosphere. So, in the process what happens?

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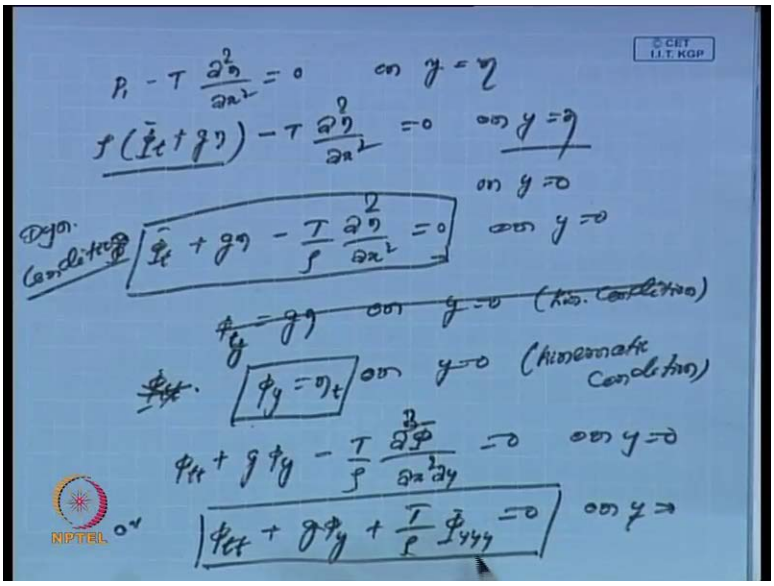

So, I will have; that means, my P 1 minus T del square eta by del x square is equal to 0 and on y is equal to I can call this eta again. What happen if I substitute for P 1 is the hydrodynamic pressure P 1 is rho by rho into phi phi T plus g eta and that is minus T. Del square eta by del x square 0 on y is equal to eta and that taken for the because I am considering the early in the rise part to a theory. So, this y is equal to eta you can also be retracted as an y is equal to 0 because hydrated term will not conclude and in the again, in the in this derivation of a P 1.

I have only taken the linear part now linear parts have neglected because I assume that eta is small as you have done it previously. So, then in that process, what will happened, it will give me rho or phi t plus in g eta minus T by rho del square eta by del x square 0. This becomes on y is equal to 0, this is the laniaries it becomes the laniaries dynamic condition on the surface in the presence of surface tension and we all know that the kinematic condition. This becomes the kinematics condition, it is remains the same phi t is equal to g eta on y is equal to 0. It is becomes my kinematic condition and this is the kinematic condition this is my dynamic condition dynamic condition in the presence of surface tension. If we you g phi combine these two that gives me phi t t phi t t plus g eta t, if we phi t plus g eta phi t, it will give me eta t is a phi by phi by this is not this it is gives me phi by is eta t.

This is on y is equal to 0 this is my kinematic condition that comes from divided t why when is eta is 0 1 by is equal to eta. So, this is what. So, so if we I combine this eliminate eta from the dynamic condition, this is the kinematic condition that will give me phi t t plus g eta t will give me phi by minus t by rho here. Can I have eta t r that will give me phi by. So, that will del del e cube phi by del x square del y is equal to 0 on y is equal to 0, which can also be the use in Laplace equation that I can also call phi t t plus g phi by plus t by rho phi triple y.

This is a capital Y is 0 on y is equal to 0. In fact, this is the laniaries pre surface condition in the presence of surface tension and this condition is very important because if we have seen that if it t is equal 0; that means, if there is no surface tension then what will happen this term will be contribute 0. So, here phi t t plus g phi by 0 and that becomes the pre surface laniaries, pre surface boundary condition in case of a gravity rise or in case of corporally gravity rise this extra term is coming. Here we see that there is a hydrated term in the derivative itself that is contributing coming in to picture. Now, if I just a take this pre surface boundary condition.

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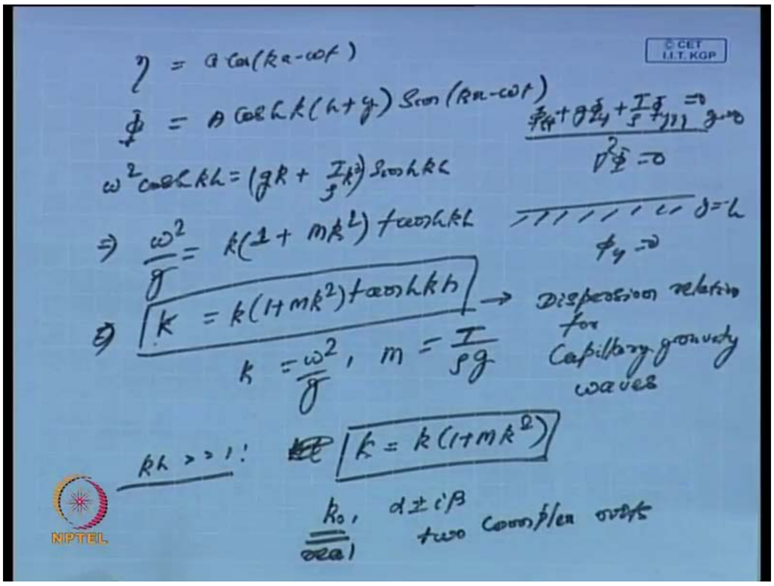

Suppose, I say that I have a wave eta is equal to a cos k x minus omega T and I will have seen we have seen that in that case if there will be a phi which will of this path and if you substitute for this phi for phi satisfy the Laplace equation. This will satisfy the Laplace equation, if we it is it also satisfy the bottom boundary condition on a bottom boundary you have phi by 0 this is y is equal to minus h and here y is equal to 0 on the y is equal to 0. You have the condition is phi t t plus g phi y plus t by rho phi triple y is equal to 0 and you have here del square phi is 0 in the few domain this is the main pre surface. This is the bottom surface, earlier the rise space.

And in that case what will happen here, we have we can easily see that that if phi has to satisfy these equation, you will see that of this will give us phi t it will give us omega square, this will a be cos hyperbolic k h and that will be minus will be layer. So, if I have bring this g phi by g k plus T by rho k cube have to sine hyperbolic k h is same as omega square by g is equal to k plus k into 1 plus m k square tan hyperbolic k h is can be written as and here. So, if I call this capital K it is equal to small k into 1 plus m k square tan hyperbolic k h and here capital K is omega square by g and my m is T by rho g. So, under these routes, under this if you use the symbol than k, this and this equation this is the dispersion relation for capillary gravity waves.

So, here these exist because as I have seen that when there be it is a only exist when there is a change in the two sides presides. P 1 minus P 2 or we have seen from the definition that that where is on the mean curvature; that means, in these case of surface tension the two surfaces there is a difference in the pressure on both sides. In the process we got a corporally rise because the surface the rise means the pressure on the have is higher on the atmospheric pressure is higher than the pressure hydrodynamic pressure. In this case and in because of that the there is a rise in the rise in the fluid and that rise.

So, that is why there is a corporally rise and we have seen that in that case in we have that dispersion relation is this we can if we analyze this, what will happen when k h is become in what you greater than 1? In that case it will give us capital K equal to small k into 1 plus m square and this gives us a cubic equation in small k. If we assume that we know capital K and we know m, then it is a cubic in small k and it will have two roots. It can be seen that it k 0 and this is it should be alpha plus minus I beta it can be easily check that if k there is a it has mean real root this is real and they are two complex roots.

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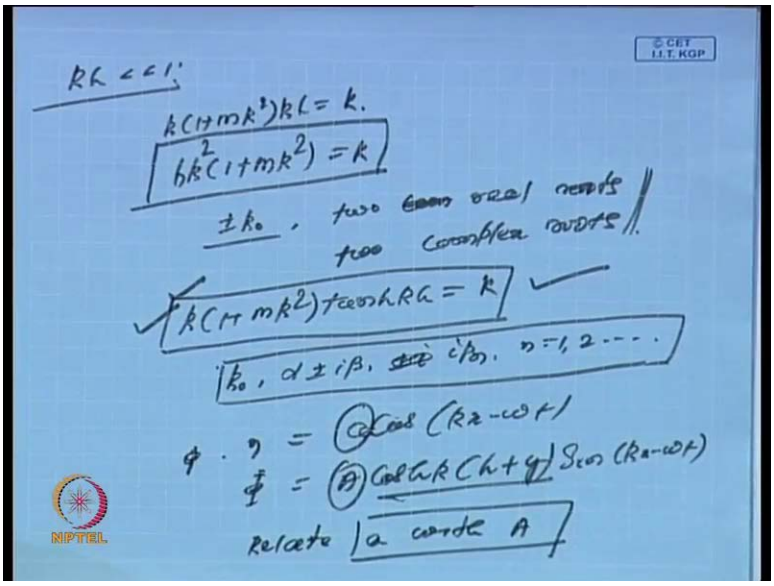

Further if I look at this equation further again that if a k h is amongst less than 1; that means, in case of shallow water will have k into m plus k square into k h is equal to capital K. So, that gives us that k into k square h into 1 plus m k square is equal to k. That will be 4 roots out of that it can be easily seen that plus minus k naught are the two roots real root and it will have further again two complex roots 2 real roots and two complex roots. So, in this case it has four root and on the on the other hand in case of the general case k into 1 plus m k square into tan hyperbolic k h is equal to k.

If you look at this one and these dispatch on the lesson has one real root k 0 alpha plus minus I beta are the two roots 1 plus minus I are I p n are the infinitely when I imagine a roots. So, this give the these are the all the roots of the dispersion relation associated with this equation. So, I will come after some more over after some time that how these roots are what is the behavior of these roots and how they depend what is the maximum minimum how this behavior, how the root root behavior will analyze a little letter. Be the next lecture what would I already other spend a little time to before going to the root behavior and we talk a little about something about the group velocity and the phase velocity of their avid usage.

Then capture (( )) and after that I will come to this. So, let us and then again another thing. Once we know eta we can always phi, phi because we know if we apply applying the kinematic condition because we have already know for the eta is equal to a cos k x minus omega T. We have the corresponding of phi is equal to a cos hyperbolic k into h plus y into sine k x minus omega t and the using the kinematic condition or one the kinematic condition, we can easily get a relation between small a and capital A.

An exercise relate A, with A this is a very simple as I have done what I am not going here. What I leave this is an exercise as a simple exercise, which can be derived easily. Now, we this understanding let us will come to in detail about the behavior of these waves, particularly how the corporally rise affect the (( )) motion that I will come a little letter. Before that let me talk about the (( )) energy basically the group velocity or wave envelope.

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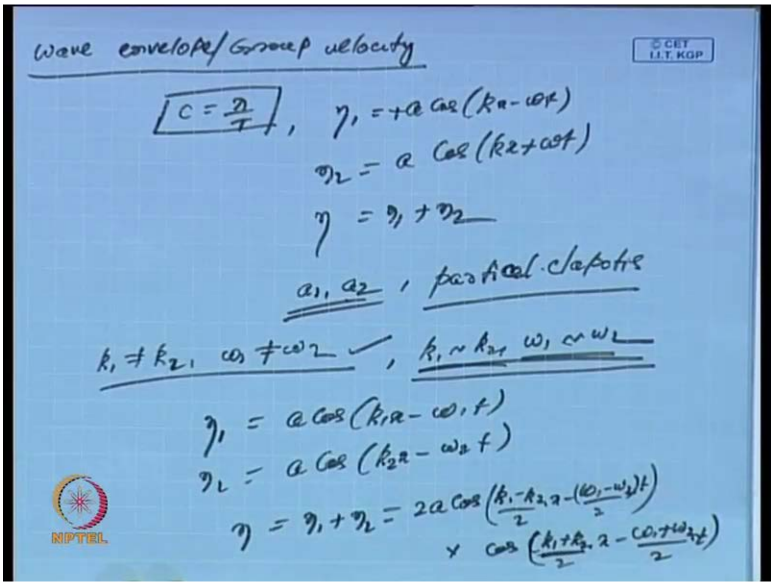

We have seen that C is equal to lambda by T and that gives us the rate out of which the wave travels one of 95, we have frequency omega or the time period T. It travels and these we have also seen that to be half two waves and another wave eta 2 is cos k x plus omega T. We have seen that is written to f is eta is equal to eta 1 plus eta 2 that gives us a standing wave and that standing wave. It has amplitude twice that of the individual pre basic waves this is plus and so what we have seen that here amplitude of this wave this is generates a standing wave from the amplitude digit, twice that of the individual that of the individual waves.

Here both the waves are the same amplitude, only problem is that there apposite in direction. The two wave propagate and they are opposite in direction. Again I have seen that when there is a change in amplitude when we have two waves of different amplitude a 1 and a 2 then we have seen that it forms partial standing wave for partial clapotis, but here the waves are propagate the in the opposite direction. But amplitude only variation in amplitude and here in there is a amplitude variation and also variation and direction. My question is, second question comes what will happened if k 1 is not equal to k 2 and omega 1 is not equal to omega 2?

What happen in a reality, when there are (( )) waves we have always see in that that waves of similar nature propagate, but always it may get same wave which propagate. So, when k 1; that means, I am looking for which one k 1 is behaves like k 2, omega 1 is behaves like omega 2, but the amplitudes of the waves are same, whereas they are similar in nature as per as the wavelength of the waves and the period of the wave circles are… In such situation, now suppose I have two such waves eta 1 is equal to a cos k 1 x minus omega 1 t and eta 2 is a cos k 2 x minus omega 2 T.

What I say they are similar in nature, but the not exactly the same. In this situation what will happened to than eta is equal to eta 1 plus eta 2 and that gives me 2 a, it will give a cos k 1 minus k 2 by 2 into x minus into we have cos k 1 plus k 2 by 2 into x minus omega 1 plus. So, this is the resultant wave, now what will happened, if I look at this resultant wave? There are two things I will observed there are two infected looks like a standing waves and these standing waves are as a.

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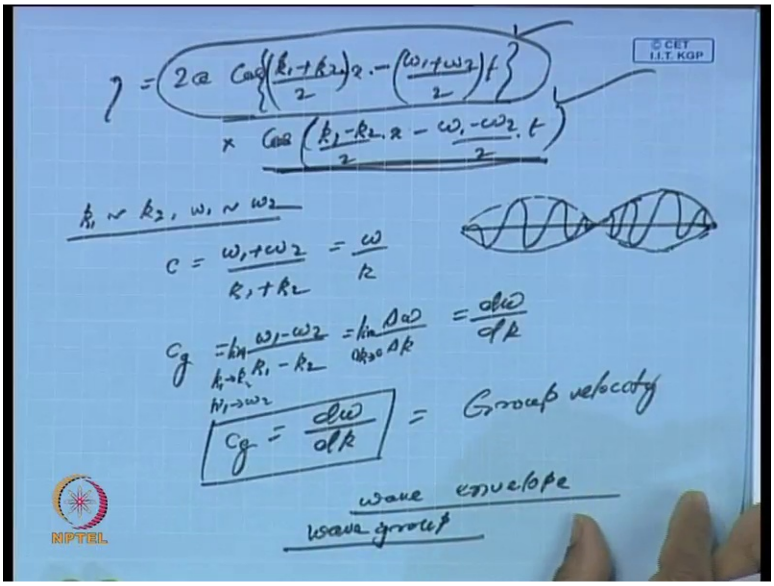

So, my resultant wave is basically 2 a cos k 1 plus k 2 by 2 into x minus omega 1 plus omega 2 by 2 into t multiplies is in by k as k 1 minus k 2 by 2 into x minus. So, now what will happened, because this is there are two things here. This is a again a wave this is again a wave. So, is a product of two waves. So, what will happen when k 1 approaches k 2 and omega 1 approaches omega 2? If this two are same then this part the first part becomes the same as the one of these in the initial waves, original waves, but what will happen to the second part of the waves?

So, this way this becomes if you look at this one, in that case this becomes twice that of the individual waves, but what will happened to this part and that will be more obvious because they are not going to be this part is not going to happen the same way. So, what will happened in this case? If I look at the lets analyze it from the point of view of the phase velocity the first phase the phase velocity c will be because omega 1 plus omega 2 by k 1 plus k 2. If I say k omega is standing to omega 2, then this will be give my omega by k that comes from the first part, but what will happen in the, if I look at the second part as my wave and this part I taken as the envelop amplitude of the wave.

The second part my c g I will call this as a c g and that it gives me omega 1 minus omega 2 by k 1 minus k 2 and this is when k 1 tends to k 2 and omega 1 tends to omega 2. So, this is a, if I just say limit k 1 tends to k 2 and omega tends to omega 2, that will give you del omega by del k. I call it limit del k tends to 0 and that will expand d omega by d k and this I call it as c g. So, my c g is nothing but to d omega by d k and what is d omega by d k d omega omega is a frequency of the waves.

So, d omega by d k tells me in the rate at which the waves of similar nature the propagate; that means that gives in the date at which the wave energy propagate. In fact, it can be easily seen that this will give as this I call this as the group velocity. So, if I look at this, how they will look like the wave will actually look like this a. This is my actually the wave will propagate like this is the way the wave will propagate and this is the one value. So, the combine wave will propagate in this pattern and this will follow this. So, to one observed or it look like as if an it is a wave envelope.

Often will this is call as wave envelope and this is the rate at which the… So, the total wave it looks like the wave envelop, it is a group wave group. In fact, in the ocean when you see the wave will see that always it looks like it always the wave envelope or wave group which propagates which is not the individual waves what we see and this is the wave and then in that case this is the velocity this is a that is d omega by d k.

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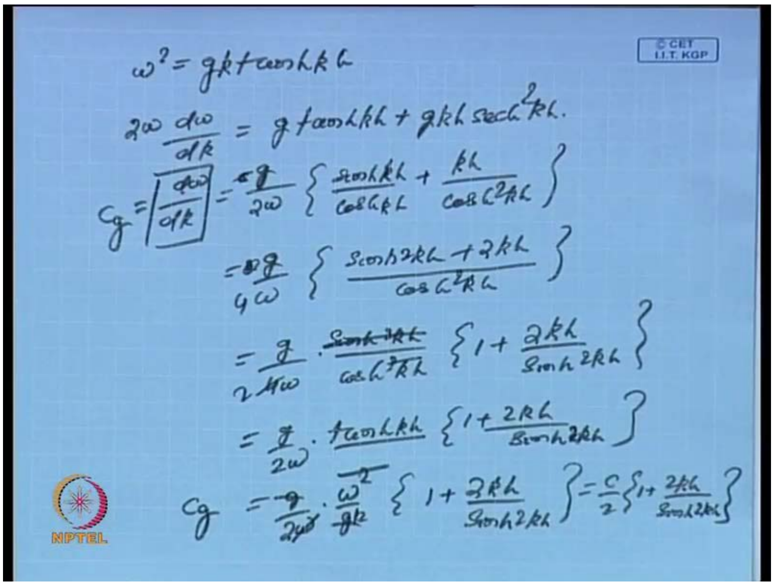

So, now, if you look at this let us look at this d omega vertical, what happen? We all know that omega square is g k tan hyperbolic h. Then what will happen to d omega by d k? So, d omega by d k will be 2 omega 2 omega sand, then this will give me d omega by d k that will give me g tan hyperbolic k h plus g k h sec hyperbolic h square k h, that gives me 1 by 2 omega it should give me g. So, if I take this will give me I will call it by 2, I will call it sine hyperbolic cos hyperbolic, call it is sine hyperbolic 2 k h 2 time 4 or 2 is gone to 2 plus k h divided by cos hyperbolic h square k h. If I take this, I will write it g by 4 omega square this I call it sine hyperbolic 2 k h by cos hyperbolic square k h.

I can call it to 1 plus 2 k h by sine hyperbolic 2 k h and this I can always write sien hyperbolic 2 k h will give me this will go this is sine 1 cos will goes this will give me 2 g by 2 omega. And this will give me sine tan hyperbolic h and tan hyperbolic h 1 plus 2 k h by sine hyperbolic 2 k h and tan hyperbolic 2 k h omega square by g by 2 omega and omega square by g g k. Then that becomes 1 plus 2 k h by. So, I have omega this omega get cancel with this omega, g g get cancel that will give me c by 2 into 1 plus 2 k h. So, this is what this is my c g that is nothing but d omega by d k. So, what I am getting my c g is a c by 2.

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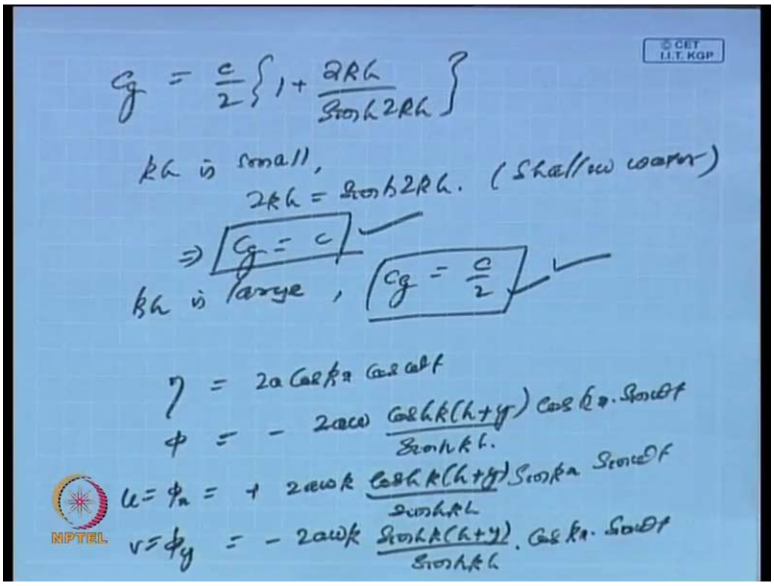

So, the group velocity c g is nothing but c by 2 is the fasciblous into 1 plus 2 k h by sine hyperbolic 2 k h. This is the most general definition and this is the rate of which is the wave energy propagates. Then we can see that easily that when k h is small when k h is small we have 2 k h sine hyperbolic 2 k h and that case c g is c and that will have 1 k h is large. Then we have c g always c by 2. So, in case of a deep water I can always say that the phase velocity the wave energy propagates at a rate which is half of the rate at which the individual monochromatic waves propagates.

On the other hand in case of this is a in case of shallow water, in case of shallow water we can see that the energy propagation is same of the individual wave propagation. The speed of propagation of the individual wave is same as the data to which the wave energy propagates. Now, this is a, this is another interesting result which we can use at a later stage and see what happen? Now, another thing here will see that in case of standing waves I will come to the capillary to this later.

Let me go on little more about the standing waves I have see in that case of a standing wave. I have seen that in case of a standing wave eta is equal to 2 a cos k x cos omega T and if it is 2 a cos k x, then the corresponding phi will be, we have seen that this minus 2 a omega cos hyperbolic k into h plus y 2 a cos by a cos hyperbolic by sine hyperbolic k h into cos k x into sine omega T. From here let us look at what happen to phi x phi x is minus 2 this should be a plus 2 a omega k. Similarly, what will happen to phi y and phi x is nothing but u phi y is nothing v and phi y will be minus 2 a omega. Again k this will give me sine hyperbolic k into h plus y by sine omega t.

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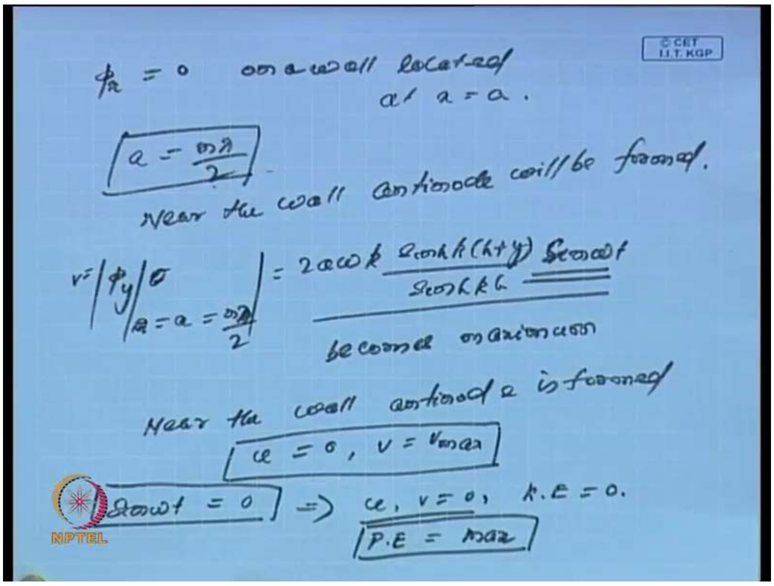

We have seen that on a wall if it is phi x is a wall 0 on a wall located at x is equal to a then we have seen that that a will be n lambda by 2 and we have seen that because this standing waves and near the wall. We have also seen that near the wall anti node will be formed, but in that case what will happen to phi y because phi x ix 0 on a. That the wall what will happen to phi y? At the same point phi y will be because phi x is becoming the 0, but phi y what will happen to phi y at x is equal to a is equal to n lambda by 2.

This we can say that phi y will be at on the maximum that is 2 a omega k because it will be cos n lambda by 2 k into n lambda by 2 and that will be plus minus 1. So, if I look at the maximum velocity, that will be v I take the maximum of this that will give me 2 a omega k sine hyperbolic k into h plus y becomes into this part will plus minus 1. So, this is a have taken the positive sign. So, this should be into sine omega T this is what. So, that what will tells, so that the vertical velocity that point b becomes the maximum, this becomes maximum.

So, although antinodes form although in standing wave near the wall, anti node is formed. So, and here horizontal u velocity value u is 0, but at the same time v becomes maximum v is v max. So, that is what happen here another point I want to look into in the both the cases u and v, if you look at the sign part time dependent part both are sine omega T terms because this is not affected now what will happen if sine omega T is 0. If sine omega T is 0, which implies both u and v are 0 and once u and v are 0 will see later that u and v from the energy definition kinetic energy definition.

That will show at that will a lead to kinetic energy as 0 because u v 0 and once the kinetic energy will be 0 because the energy will be constant. So, in that case what will happen? The potential energy will be maximum and when sine omega is becoming 0, u v becoming 0 and kinetic energy becoming 0 or the other hand what will happen? So, potential on the other hand, but what will happen if I just say that instead of sine omega t is 0.

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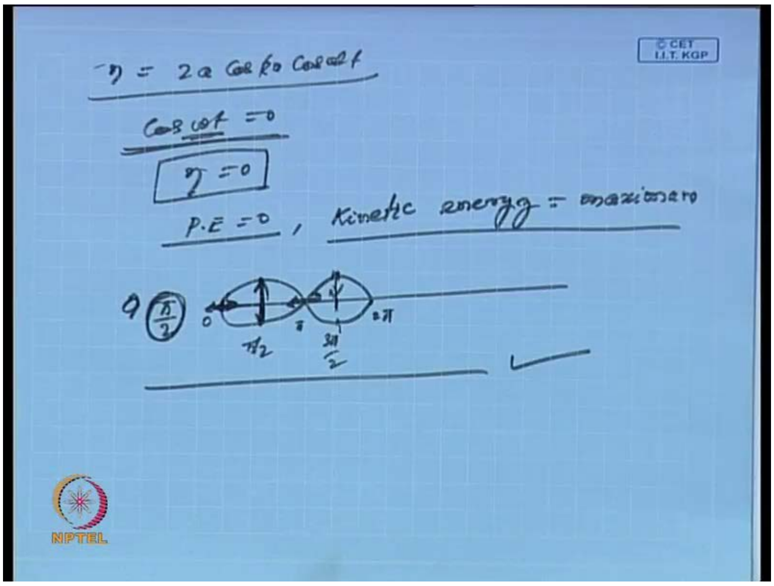

If I just say that my eta because eta has a term 2 a cos k x cos omega T, so in this case suppose what will happen if cos omega T is 0? If cos omega T is 0, then once cos omega T is 0; that means, eta is 0, once eta is 0, then what will happen? The potential energy will be 0 because it can be will see the will come to the definition of kinetic and potential energy, but once the surface is not moving at all. So, the potential energy will be 0 and once the potential energy is 0, because the total energy if the kinetic combination of the kinetic and potential energy. So, once the potential energy is 0 kinetic energy will return the maximum.

So, here this also not only the both the behavior, if not only the space component is contributing special derivatives special component is contributing the time component is also contributing to the wave motion particularly the transfer. So, what is happening when the particularly this sine to cos? If eta changes sine to cos at a interval of pi by 2, there is phase change. If the once energy change of phase of phase of phi by 2, then the… So, that what happens if you look at the standing wave pattern, so this is total is 2 pi 0 2 pi. So, vary basic in trouble of pi by 2 if this is 0 this is pi by 2 this is pi.

This is 3 pi by 2. So, we see that at a every interval pi by 2 eta is changing from if eta starts from here. Then at a interval of pi by 2 comes it will reach here and here. If this is the total energy, the eta is 0 here this point and; that means, potential energy is 0 here the kinetic energy is total energy is always in this way. Then on the other hand when it becomes here the wave energy propagates maximum energy excitation in this way again it reaches here. The x energy excitation becomes in this way and again when it reaches here whole energy excitation is in the vertical way.

So, this is the way how the energy… So, it is the always that the energy transfer from kinetic to potential and potential to kinetic takes place alternately and this from. So, there is a periodic changes from of transfer of energy from kinetic to potential and potential to kinetic and it takes place in a alternate manner. It is a also in a periodic manner. So, this is what now with this I will go to the basic definition. Now, let us see you what happen about the energy associated with the wave if I look at the energy associated with the wave impact. I will just define what exactly the hoe the energy transfer is taking place, if I look at the… Let me define potential energy and kinetic energy how I define the potential energy.

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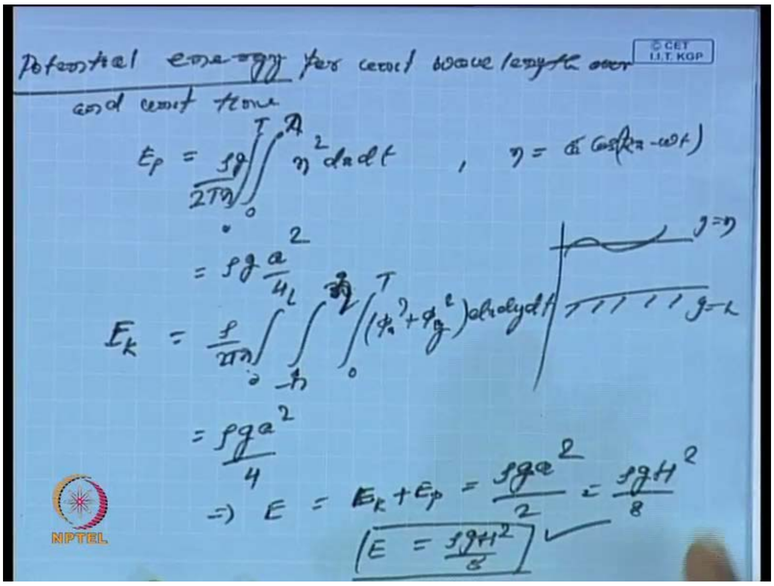

So, the potential energy for is the energy whether the potential is for I will talk it as a energy density for a unit wavelength and over wave unit wavelength and unit hour and that will give me that 0 to l and that is, this is rho g at 2 T l 2 T lambda 0 to lambda, then it is eta square. That is d x d T here is a double integral 0 to T. This if you calculate it try eta is equal to because k x minus omega T. If you one calculate total energy it will give me rho g a square by 4. In a similar manner, what will happen to the kinetic energy?

It will be because as the basic definition kinetic energy will be rho by 2 half it is like a half m b square into 0 to l 0 to m into the surface is minus raise to eta because if it is a surface is where from 0 is equal to minus s, this is y is equal to eta. So, minus s to eta, then we have over the total interval is 0 to T and that is phi x square plus phi y square d x d y d T. What will be by T by lambda and if you calculate this, also get I am not going to rho g a square by 4 that will give me the total energy E as E k energy density rather I call it E k plus E p that is a rho g a square by 2, a is a square by 2. So, I can call it rho g into H square by 8. So, that is the definition of energy E is rho g h square by 8.

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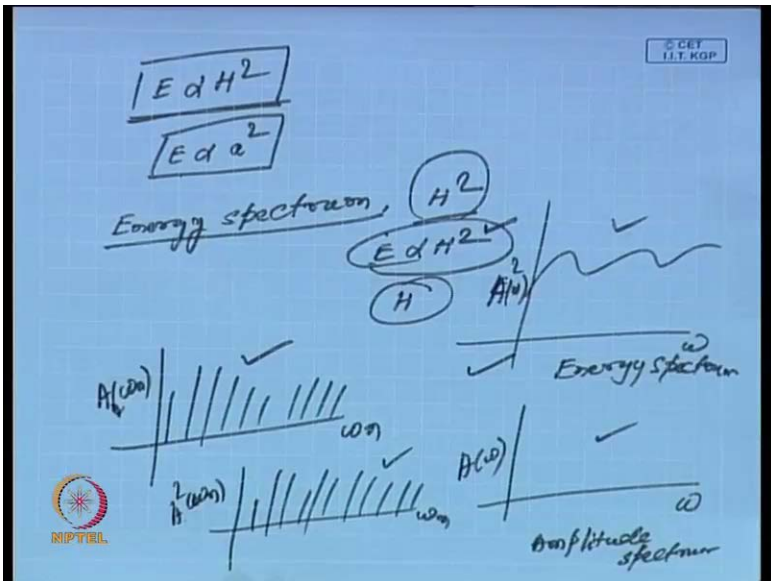

So, this definition is rho g H square by 8 that says that as if the wave energy go E H square here. I am not going to the inter derivation of energy, but this once we know eta we can easily find what is phi? What is phi x phi y and first digit for in the definition of a energy and will get it get this simple? We have seen that, so in fact, in this situation E varies as H square or we can call it E varies as amplitude square a square by 2. So, and this these relations are vary. In fact, it is because of this in the data collection ocean data, data of data collection particularly o y data collection.

Data collection of amplitude by satellite when eta is the energy spectrum is collected energy spectrum, you and get the spectrum; that means, because once we know the energy spectrum are that case; that means, we get the energy and we get the a square H square. That means, we know that E varies at H square that. So, once we get the energy from energy that we know a square and once I know H square and once I know H square, then we can easily get H. So, in many situation satellite data collection or other form of data collection many time we get the energy associated with the waves energy spectrum, what we say particularly.

How the wave data will collect it? That is this omega that is E square y or a square omega or incase of amplitude spectrum. We always get it omega and we call it a omega these are all continues spectrum, but in case of a discrete spectrum, what we do even given data, where is data is discrete data? So, this is may be a n a omega n, this is omega n and this is or will get it a square omega n, that is omega n. So, we get it various types of data and these are discrete spectrum these are discrete spectrum these are all continuous spectrum. This is amplitude spectrum, we call these sometimes amplitude spectrum or this is called a energy spectrum.

So, this is very important in case of ocean data collection and that and of course, I am not going to the statistical distribution and the probability distribution data here. At the so, but here one has to make a note in that when a amplitude spectrum is collected it is basically the wave amplitudes are known, but in case of energy spectrum data is data distribution. In terms of energy spectra, then we say as if the amplitude square is known. So, this is what is a and that comes because always we know that, it is the energy is always varies as amplitude square at the square. So, that is the another point to be noted.

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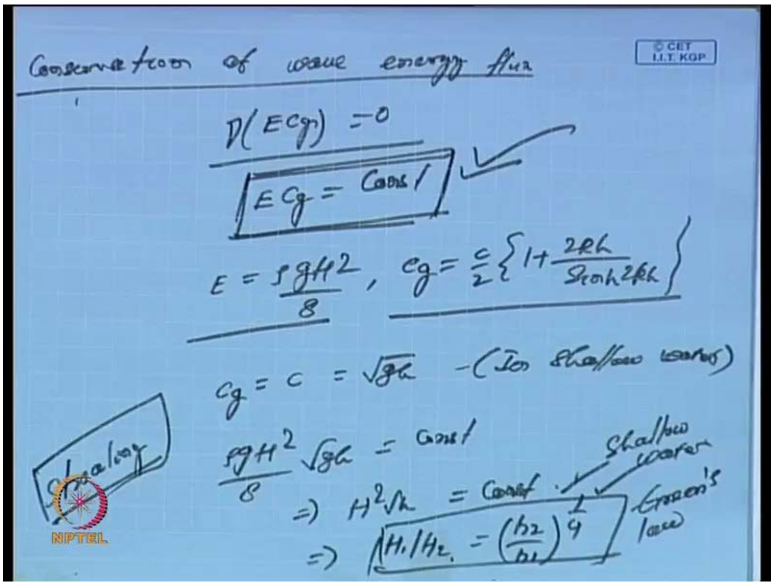

Now, with these understanding, so I will just break another point, what is energy plots? In fact, conservation of energy it says that total energy the conservation of energy says the grade of E c g is constant is E c g is 0; that means, the total energy that is through any cross section will think the total energy passing through any space. There is no much, there is they will not be integer always I put it in a integral forms oil it will give me E c g is constant; that means, if you look at a any cross section the wave energy propagates through any cross section the energy that propagates any cross section. So, that means… So, what is E? That means…

So, E is rho g H square by 2 H square by 8, whereas c g we have already c g is the group velocity and that is nothing but c by 2 1 plus 2 k H by sine hyperbolic 2 k h. That is this gives us the group velocity, this is the wave energy associated within single wave per as that, this is the energy flows conservation of the energy blocks. In fact, every when the wave propagate over a surface are in the ocean wave propagate every time follows this energy flask because this equation is constant. I will just say in brief what happen suppose c g is is equal to c. That means, in case of shallow water.

So, that is root g h. So, in shallow water in case of shallow water and then what will happen E is rho g H square by 2 8 into if I say in case of shallow water root g H. So, that gives me a constant. So, which gives me H square root, H is equal to constant in case of shallow water; that means, my if I have initial by H 1 by H 2, this will give me H 2 by H 1 to the power 1 by 4. This is what happen in case of shallow water. So, wave propagate from deep water to shallow water deep, water region to shallow water region. So, there is a change in a wave amplitude because as we say when the wave propagates from deep water to shallow water region the amplitude changes.

Some amplitude goes on increasing in that follows this and this is often called this as a known as the Greens law. So, there is change in amplitude, particularly the wave height, the depth ones. There is a change in the water depth, then if there is no refraction these process of change in the water depth the associated with the change in is referred to as (( )) . In case of shallow water is follows this and there is no refraction or diffraction, only the water directly it propagate to the from deep water to shallow water. Suppose there is a change in water, then they will follow this rule and that comes from the energy wave energy conservation of the wave energy blocks this is particularly this means in this case of a shallow water, but in general this is this.

So, that is another observation. This is very important one as to it is very easy to although it is very easy to show at the what it is a gives, that is a clear idea about that how the changes takes place, when there is a change in the wave height and how the water depth is related? So, with these today will be conclude the lecture today and tomorrow will go into other details. So, about the wave characteristics, this particularly a simpler few cases more. Few more cases will consider about the how the conservation of energy is used in a various other cases, particularly in case of deep water or in case of water of inter mediate depth thorough an example and that will come in the next lecture in detail.

Thank you all.