**Seakeeping and Manoeuvring**
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**Module No. # 01**
**Lecture No. # 02**
**Regular Water Waves - II**

Today, we are going to basically continue what we have done yesterday, that is Regular Water Waves part. First, let me begin writing some of the expression that we have developed yesterday.

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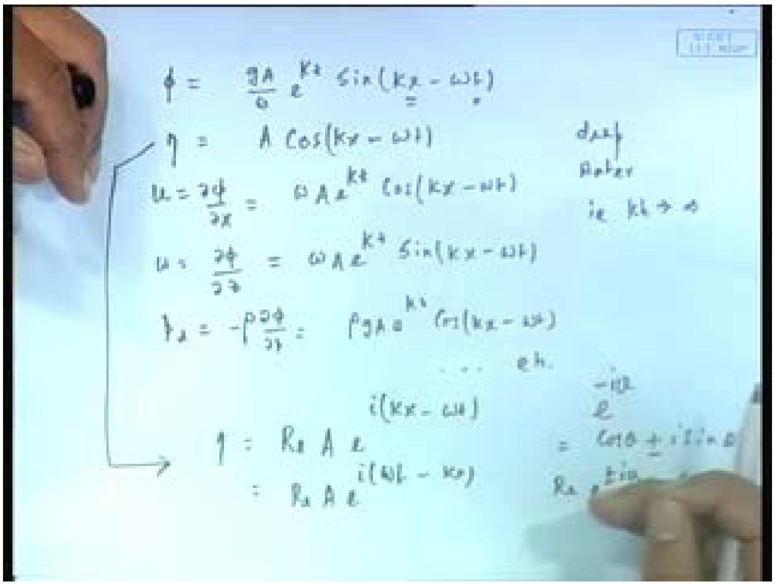

What we had was, in deep water (No audio from 00:35 to 01:50) etcetera, so this is what we had in deep water (No audio from 02:02 to 02:13), what we have done was yesterday these expression. And I as I mentioned to you, if you look at these expressions, all parameters are essentially sinusoidal both with respect to special parameter x and with respect to time parameter t.

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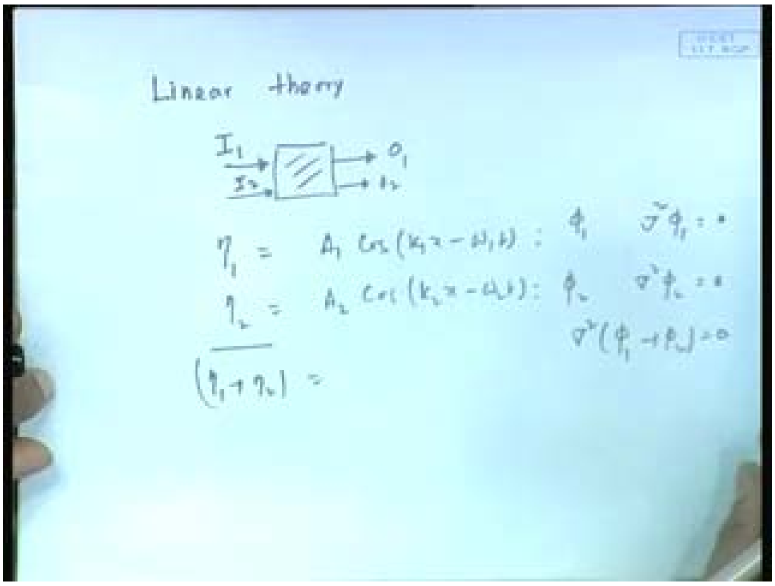


So, we will continue today on building upon these. First of all may be, I will introduce you the concept of group velocity and energy in waves, keeping it to aside. See, one thing that we realize that, this theory is based on the linear theory. Now, linear theory implies the the linearity implies that, if I have for example, a system like a black box, if I have an input I and output O.

Let us say, input is I 1 output is O 1 and an input is I 2 output O 2, if the system is linear then, I 1 plus I 2 would give me output of I O 1 plus O 2. Or conversely, k I would give you k O in other words, O and I are linearly invited. What it means? If the box is linear, then I can have solution number 1 and 2 and 3 and I can add them all up and they still remain the solution of the system.

Now, if I look at this linear water wave theory; I have a wave height eta 1 let us say A 1 cos k 1 x minus omega 1 t. And if I have another wave, A 2 eta 2 as A 2 cos k 2 x minus omega 2 t, what it means is that, I can add this two up and eta 1 plus eta 2 becomes the sum of these two. But, the important point is that, eta 1 plus eta 2 will also be a wave possible wave with satisfy the same boundary value problem; which means that, linear waves can be super imposed one other and what I will get is also a possible linear wave. So, there wave (( )) impossible that is the most important point and you will find out that, it has really a very high consequence as we go along the subject.

So, therefore, the reason we can do that, a very simple example. Let us say, this one it was the solution of phi 1, what was phi 1; it was satisfying the equation del phi equal to 0. This was the solution of phi 2 and I have the equation phi 2 is 0. But now, this equation is linear, because we know that, del square phi 1 plus phi 2 is also 0 simply.

So, therefore, like that we will find out that, phi 1 plus phi 2 would also represent a feasible fluid motion and since phi 1 solution is eta 1. Of course, after the boundary condition phi 2 is zeta 2, we end up getting the eta 1 plus eta 2 becomes feasible solution.

Now, this is very important because, what we will do now is that, we will consider two waves and add them together and see that, if the waves differ by a very small amount of frequency then, we end up getting a group wave. Now, before doing that I will like to bring back to this eta expression (Refer Slide Time: 05:39). And I will tell you that, it is quite often, when I have the sinusoidal function easier to write as, real part of A e power of i k x minus omega t as eta, why because. Or I can also write this as, real part of A e power i omega t minus k x; both are same because, you see we understand that, e power of i theta is equal to cos theta plus i sin theta and if you make it minus, it becomes minus.

So, real part of both; that means, (( )) of e plus minus i theta is nothing but, cos theta. So, this is an expression that is sometimes used that because, it becomes easier to do operation algebraic operation very easily. So, we are going to use this expression, because it will be easier.

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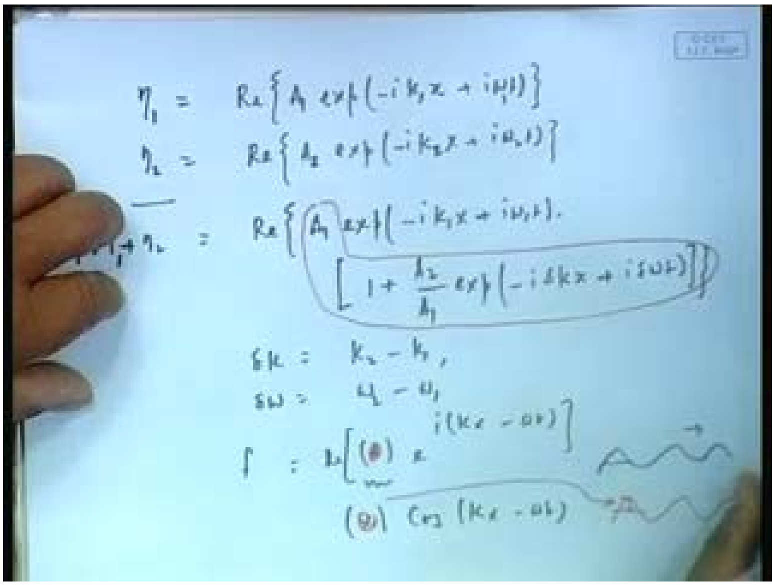

So, now, we consider two waves; One is eta 1, which has which is written as real part of A 1 it will we can write it exponential as e 1 minus i k 1 x plus i omega t. Now, I am going to add another wave; eta 2, which is real part of (No audio from 07:10 to 07:25). Now, if you add this two up, we end up getting R we do some manipulation A 1 (No audio from 07:39 to 08:02).

I will tell you, what is this, this is a simple algebra. If you did that, simply you know what I have done is here you write k 2 as k 1 plus delta k, omega 2 as omega 1 plus delta omega; you simply add, you get. Now, the most interesting part of this here is that, see any function which is any function which is something into e power of i k x minus omega t real part of this can be anything is actually a waveform.

It is a waveform travelling in plus direction with amplitude given by this quantity, that is by definition and by this is what it is. Now, you what is this part, let us look at this slowly this means actually this expression means this into cos k x 1 minus omega t, this expression let me take a different pen.

See, this expression implies something here this star into cos k x minus omega t. Now, (( )) where to plot this, what is that? It this is the sinusoidal form, this is nothing but a sin form of amplitude given by this star, this star is this here (Refer Slide Time: 09:33). So, that means any expression with something into e power of i k x minus omega t is the waveform with that something as amplitude.

Now, look at these expression, here I have got some something into e power of i k x omega t into this full thing, if you take the A 1 here. So, that means here I have got a waveform, whose basically amplitude is this (Refer Slide Time: 09:56). So, I basically I have a wave, which having amplitude of this excuse me.

Now, if you look at this part carefully you will see that, this itself is a waveform, because itself has got e power of minus i d k x plus i t omega t; basically it itself a waveform of length d k and period d omega and speed d omega by d k. So, this means that, the amplitude itself is a oscillatory curve and itself is moving.

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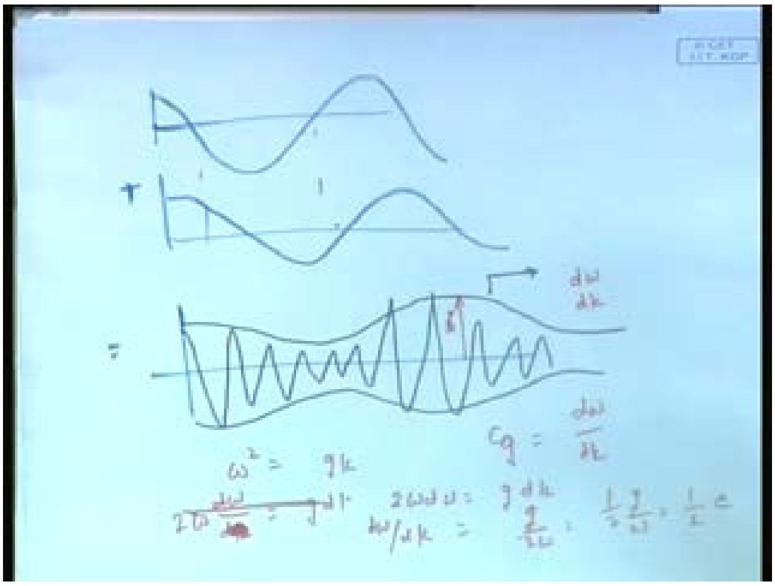

In other words, if I were to add that two together; that means, if I were to add this wave and add the other one, which is slightly different see, maybe here etcetera. If I had to add this what I end up getting is, actually a wave which would look something like, which has an envelope; the envelope, which is my A this envelope which is my A star, itself is moving with a wave velocity.

So, the envelope itself moves with the speed. So, the lots of the student's lot of people have difficulty understanding, how the two waves which is slightly differing; can actually cause gives rise to an envelope. Because you think that, this is very nice sin curve, this is another sin curve, when I add the two sin curve; which is only differing by a very small amount in length. How it can actually cause a modulation? So, the reason is like this you know.

Now suppose, you take this certain length let us see you know is easier to see in terms of length say 10 units. So, every 10 th unit; 10, 20, 30, 40, 50 have a crest. Now, you take another one 11 units, what will happen? 11, 22, 33, etcetera in an in 55, this one has 55 a (( )) that will have 55 a crest you understand, what I am saying. See, this is you see this this way, it is very interesting to illustrate.

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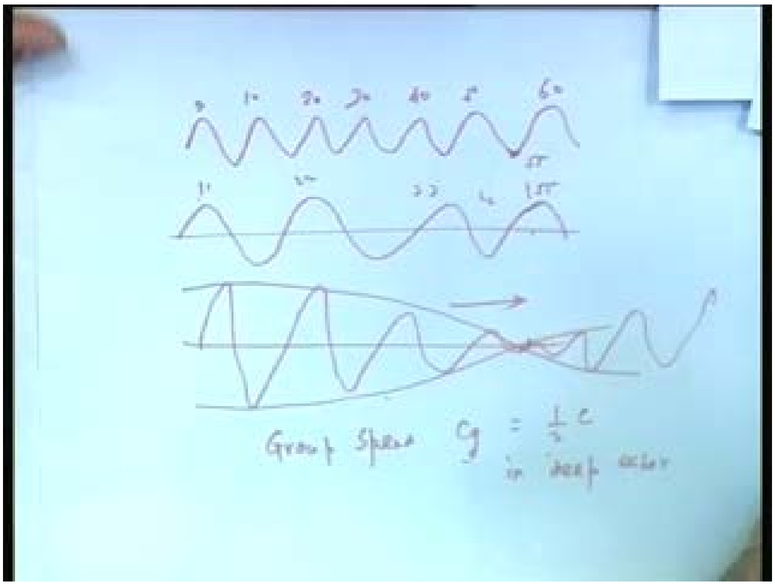

See, if I were to this one two three four five. So, this 10 say 0, 10, 20, 30, 40, 50, 60, this is 55. But, the other one we will have this crest; 11, 22, 33, 44 at 55; it will have the top and here this is bottom (Refer Slide Time: 12:45). So, what happen if you add this two up, here the resulting wave will show actually 0, somewhere here it will go up, this is exactly, why? This modulation will look like etcetera.

You see although its differing slightly, but it will have now remember this evolving, so this entire thing, this front part would also appear like moving forward, this this whole thing will moving look like moving forward. So, this is what is called group wave.

And this particular you know this envelope and the speed of the envelope is known as group speed (Refer Slide Time: 13:20). So, we can also work this group speed out very nicely, because we see that, this particular one in a wave of frequency d omega and speed d k. Therefore, the speed of that envelope is going to be d omega by d k, that is by definition.

Now, as soon as d omega d k are not perfectly 0, you have a group speed. Now, if you make a wave continuously; it is successive of waves, you always have slight frequency difference as a results, you always end up getting a group. Now, how do I get this, now you see in deep water omega square equal to g k. So, d omega by d k equal to or I will say 2 2 omega d omega d k equal to g d k no sorry sorry.

Let me write it again 2 omega d omega equal to g d k. So, therefore, d omega by d k equals to g by 2 omega half of g y omega, it is half of C; because g by omega was c, we have seen earlier. So, you see what happen therefore, what we end up getting is a group speed, if I have to call this group speed.

The speed of that, it becomes half the phase (( )) in deep water excuse me. In the other extreme we can show that, when k h tends to 0 that is very shallow we can actually show that, C g tends to C, but that limit is of no interest to us as I said, for this course sea keeping we are mostly concern with deep water cases, we are not concern with shallow water cases.

So, now this is very important because, what happens is that now, the energy of a wave always moves with that speed. Let me now come to now before going to the energy propagation, let us now established energy relation itself. So, groups will be understand.

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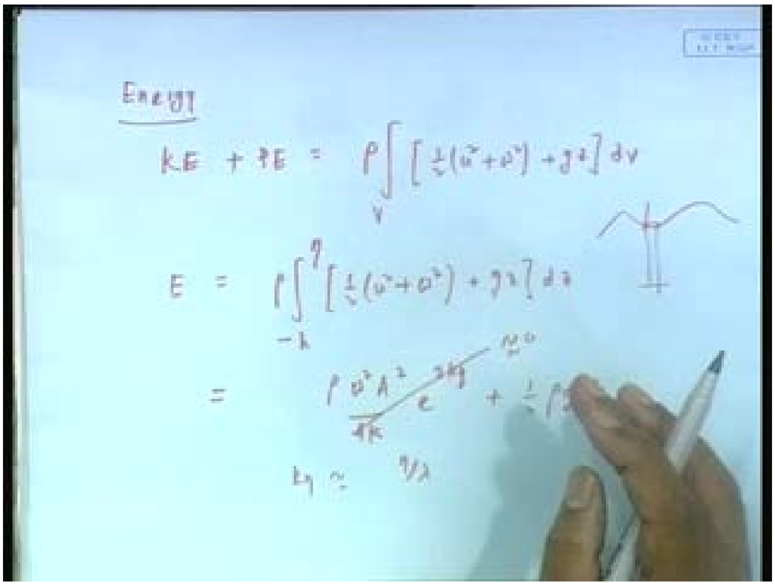


Now, let us look at the energy; obviously, the energy expression if you do kinetic energy and potential energy will look to be integration over volume of see, it is velocity square and position. So, it is (No audio from 16:07 to 16:17).

Now, so this is total energy. Actually, if I were to do this, if we take a vertical column of water that is I take a vertical column of certain area and look at the energy of the waves what would happen is that, this expression will turn out to be minus h by eta. In fact, we need not do all these things. Now, if you (( )) this out, we are not going to the detail working, but if you work it out, it will turn out to be this expression will turn out to be omega (No audio from 17:09 to 17:22).

Now, this is how it happens, if you do the manipulation (( )) see this part k eta, what happen remember we have said, k eta is small; it is small amplitude wave theory, eta is height, k is lambda inverse of lambda; k eta is proportional to eta by lambda. So, is now e power of some small quantity that to twice e square you know, if I call k eta to be an epsilon is e power of 2 epsilon. So, now this part becomes very small (Refer Slide Time: 17:51).

So, linear theory is consistent to neglect that, because this is actually second order term; because k eta is of order epsilon, 2 k eta is order of 2 epsilon. So, we end up getting this relation (Refer Slide Time: 18:04). Now, this one if I were to put you all the expression were eta you know like eta etcetera, we end of getting E.

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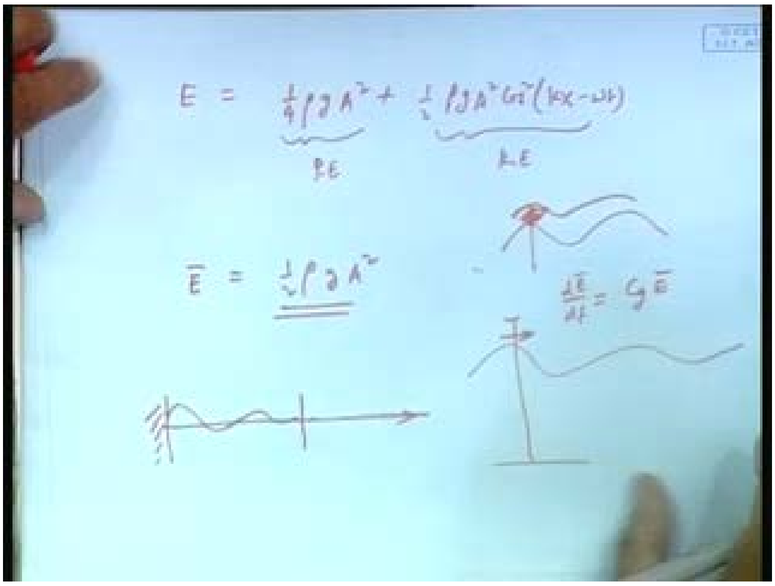

Again, I am just writing with the derivation as one-forth rho g A square plus one-forth rho g A square cos square k x minus omega t. In fact, this is my potential energy, this is my kinetic energy (Refer Slide Time: 18:29). And now what happen; obviously, kinetic energy is you know showing this sinusoidal dependence term, because particles are not constant; they are continuously undergoing changes.

Now, what has happened, if I were to integrate energy over one period you know like, if I take a bar here, (( )) kind of measure the energy from 0 to time, t; total energy in that and divide by t then, what I will get is, what is called average energy over an average surface area, one unit surface area average energy.

If you do that, the we end up getting E bar to be equal to half rho g A square. Actually, what you end up getting is that, this becomes half rho g A square one-forth rho g A square, this is one-forth rho g A square. So, the total is half rho g A square. So, this is my average energy remember, this average energy.  Instant energy is different, because of this time dependency.

So, average energy over one period; 0 to t over a unit area on the surface is this. In fact, if you see the unit you will find the unit of that is energy per unit area, the unit of that. Now having said that, it turns out that if I were to this also fix and attention of to a vertical fixed observation line, let us say.

Some constant line you will find out that, energy plus travels to that line, that is d E by d t turns out to be C g into E bar. Again this, we are stating without proving that there are number of way to established that. What it means is most interesting, the energy travels forward with group speed not with phase speed.

So, phase speed has nothing much to do with the energy the physical quantity; phase speed is to do only with the form, this is something that we must understand. Whereas, groups speed to do the physical quantities like energy. Particles for example, do not move at all, they are like a circle, but energy thus move forward; obviously, it makes sense because, if I have calm water here and if I were to turn on some wave making device you will find out that, water is basically moving forward and energy will be propagating at group speed.

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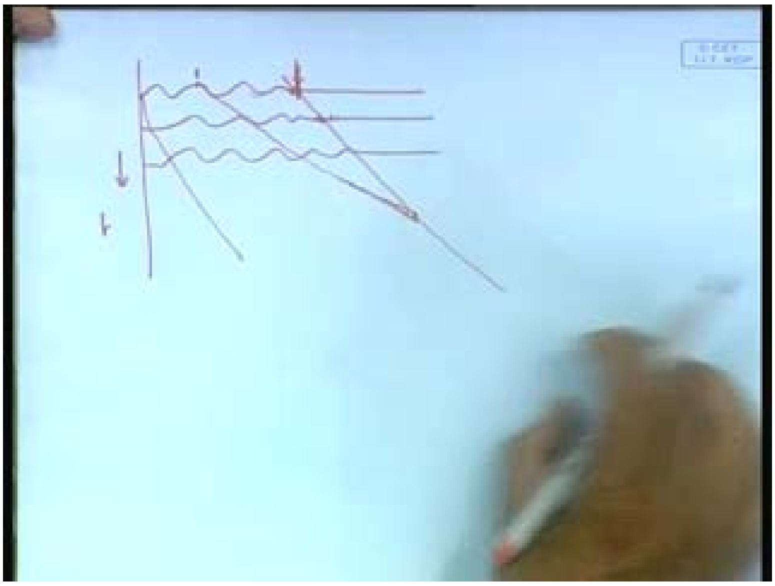

So, this part is very interestingly seen in this way you know like supposing, I tune a wave maker at some point of this time you will find out that, if some time the wave is like that; next instants the wave is like that, so this form would have move at this speed, this is actually say, t with time. So, you know like this is a sometime locational front, next instant etcetera.

But, if I were to concentrate on any of the phase the form you will find that, this actually move at twice a speed then, the confusion come in peoples mind is that, what happens to this? Actually what would happen is that, as it catches up here, the amplitude becomes 0 and there is no phase speed basically. In fact, you simply disappear like these lines do not exit any further.

How it happens, why? Now, there is a physical explanation here, how do I explain this is the speed of energy, no it is very simple. You see, initially this is calm water, if I take a line, so at this point I have no energy at all its calm water, but just next point; I have energy because, wave wave is existing here.

Now, so naturally next instant this front has moved here. Obviously, the energy has moved up to this point, because just here, there is no energy. So, this front; obviously, carries energy. So, this is exactly why the wave front is moving with energy. And same thing was happen to back, if you switch it (( )); this back line will also go like that.

So, this is actually, so classical I keep telling that it is in fact, on the cover page of that (( )) book you know that the flap this very nice actual picture taken from an experimental wave you see and photographs. So, this is extremely important that we have this. Now, this is we will find out afterwards, because we may have a question, why are we studying this energy etcetera, where where do they relate to my ship motion; we will find out that, yes there are very very good application of this eventually, when we talk to ship motion.

For example, even earlier we have seen in wave resistance for example, the energy propagation is extremely important because, if the energy was propagating at the same speed as the ship then, you end up getting a very large distance, energy getting trap. Just like in sonic boom case of aircraft.

Similar thing would occur in ship motion also in spectrum we when we go to that. So, energy relation becomes very important. Now having said, the energy now part, now I want to go to the one more aspect which becomes very important, when we study wave effects on floating bodies structure, shapes etcetera, that is connected to the concept of let me take this of phase.

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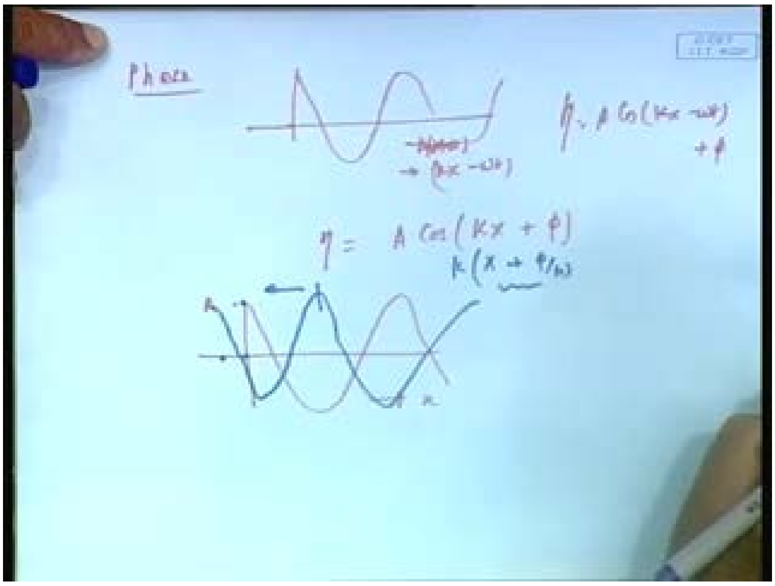


You see here, when I write an equation eta equal to A cos k x minus omega t well I can write this k x minus omega t here, rather and the graphs looks like this (Refer Slide Time: 24:35). But now, if I were to add an angle here phi, what it means is that? It means that, I actually shift you see what happen rather maybe another one, I will do better way of doing is eta equal to let me just write this way, A cos k x just A cos k x let me call initially and (( )) phi. What would happen you know that is see here earlier, when I my phi was 0 at x 0 my eta was A, that is when phi is 0; this x here, this A here. But, when my phi is having some value then, what would happen is that? When x is k x is equal to minus of that value that is it is somewhere else, this would shift. What it means is? In fact, I am actually relocating the x axis because, I can always write this as x I can take k out and I can say x plus phi by x etcetera etcetera.

Basically I am changing x to x plus phi by k, which means I am changing this origin; which means that, my my graph would probably look like in this case, when x is equal to minus phi by k then, it is 0 because, this must be 0, so somewhere here. So, it is get shifted either way this way depends on which sides you take you know.

In fact, I can say that, sin curve and a cos curve is nothing but, phase shifted curve by 90 degree. So, this shifting of phase is very important, why because? What it means is that, phase tells me the location of its peak with respect to the x coordinate, which could be of course, in this case physical x or time t, depending on what you are looking at or k x minus omega t.

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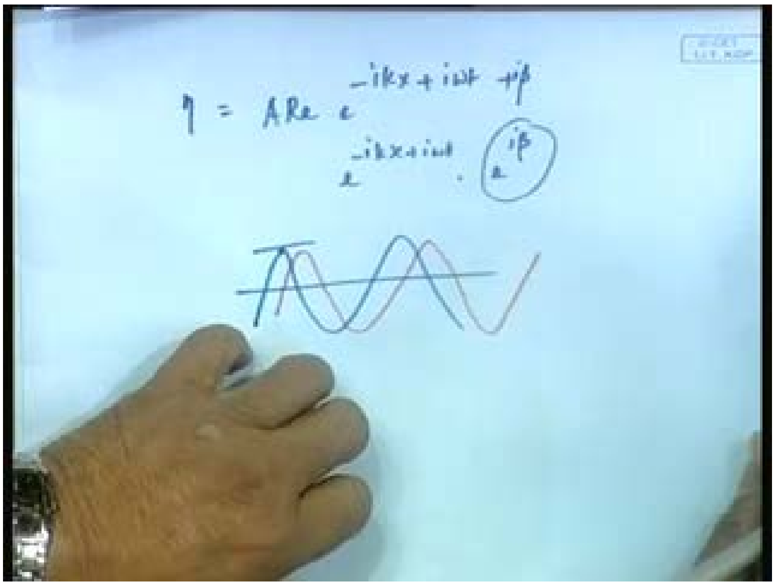

So, when I am writing this expression of eta earlier, what we wrote that, we say eta equal to real part of A e power of minus i k x plus i omega t whichever way you can write it is ok. Now, if I were to add a beta here which is nothing but, say e power of into e of i beta.

Actually this there will be i here that because entire thing is under I (Refer Slide Time: 26:56).

This is my phase or this tells me with respect to x is equal to 0, where the t is equal to 0, where the peak occurs. Now, this is very important because, what happen in water wave mechanics; (( )) the floating body response subsequently things do not occur at the same time, the peak value all.

Say, if something happens highest now, something maybe lagging behind it. See, I want to give you this example maybe you look at this my hand supposing I twist my hand I said that, before probably, you will see that, if I were to see my hand; this tip point it goes this way, but this point may not exactly follow that; that means, if this is having a peak here, if you observe you will find out that my this one is actually reaching.

See, I go here as I come back, it is going up you know, if you do this way as at the instantly of begin to come at the back; it is still trying to go up. So, that means that this tips oscillation is not phase centralize with my top oscillation. So, that would occur something like see, it is occurring here that will occur slight later that, will actually go like that.

So, this blue one would be this point and red one will be this point, oscillation; this is phase, this is what exactly what we are talking of phase you know. And this is extremely important for us from all points of view because, later on we will find out that things now occur simultaneously. When a body is for example, move the wave is moving up, the body may not move up, all though it is still sinusoidal.

So, phase is extremely important we need to realize that. Now, what does it means, now let me look back at this first expression of that is why I wrote this first page, all these expression here (Refer Slide Time: 29:58). I will come back to this in a minute. See here, what happen you know you see, eta is a cos curve, but w is a sin curve. Now, if I were to plot eta and w now, what would eta look like?

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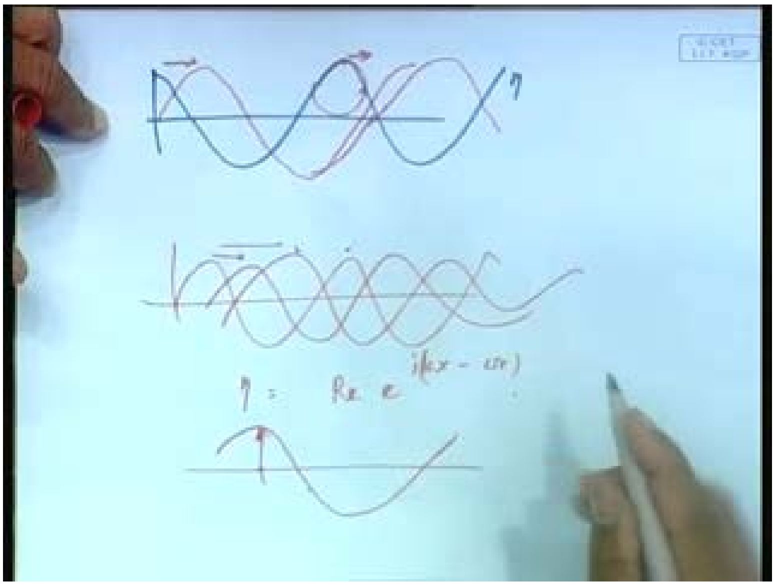

Eta will look like let me take another one see, eta will look like this the cos curve, that is eta, but my w is a sin curve. So, the w will look like is there is a positive sin curve. So, it is going to look like this sorry like that.

So, basically you can say that, this is a phase gap and that is very easily explain, because a cos curve is nothing but well sin is nothing but, cos minus 90 degree plus 90 degree yes plus 90 degree. So, what happens is that, essentially sin and cos differ by its phase of 90 degree. And I can always say therefore, that the phase between eta and omega w sorry is 90 degree.

Now, similarly you will find out there are all kind of phase, which means the top most point I have actually not the highest vertical velocity, which also makes sense, because the particles are moving this way at this point; my velocity is most this side and downward velocity is 0. Whereas, at this point; somewhere here, my downward is maximum (( )), so that is what is a phase and that is extremely important (Refer Slide Time: 30:31).

Now, the one problem that comes is, how do I measure phase? It is like I have a graph number of graph; see this one, see another one, another one here. Essentially, the phase tells me gap between various graphs; time gap, but I have to put them in number in some sense, so what (( )) measure phase with respect to (( )).

So, what normally people do is that, you write eta to be real part of e i k x minus omega t or whichever we have write. And measure everything with respect to this (( )) phase which means mostly phases are measured with respect to eta; taking eta to be a cos cups with respect to its x equal to 0, t is equal to 0 means; if, I were to take an origin here and I consider eta to be like that that is occurring maximum here with respect to this signal I am measuring the phases.

You can you can always debate why this way I can also measure another way, no problem, because phase after all information content is what is the gap between the two; that is the information content as long as you can get it.

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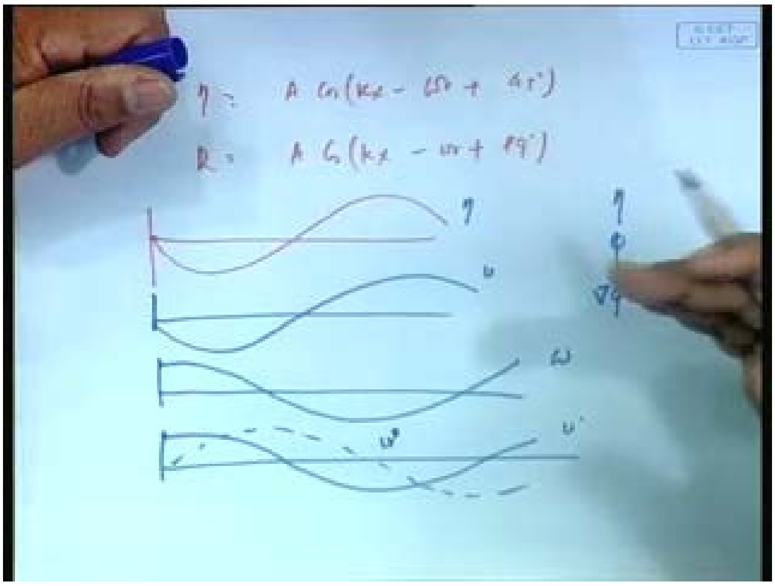

Now, you know that supposing I say, that like I I I let me give another example. I say that, eta equal to A cos k x minus omega t plus 45 degree and then, some other signal say R is A cos k x minus omega t plus A 89 degree. What would happen is that, you can always say with respect to some difference eta is having a phase 45, R is having a phase 89, but I can also make this 45 as 0 and make this actually as 44 degree right that makes more sense generally in our study, because we will find out in sea keeping study.

What we are trying to do is that, measuring everything with respect to eta, because eta is my primary input. Remember what we are trying on to do, what we want to do is? I have a wave, my ultimate aim is what does the wave do to my ship, how dose my ship move, how does my body move. So, eta or the wave is my primary input.

So, I want to basically measure everything with respect to eta, but it is not mandatory, it is upto you as long as, you do not make a mistake what my point is essentially this. So, given another example that, the phase versions are very very very well established with respect to for example, various signals.

See, if if wave profile eta goes like this, it turns out u will having the same phase, this is my eta, this is my u then, my w goes like that then, my no w goes no no z component acceleration x component of acceleration will go like this, that is u dot and this will go like that w dot (Refer Slide Time: 33:26).

So, you know what I am trying to say that, these are all the the as far as the acceleration velocity are concerned, the relation is very well established. This, of course, everybody knows very well that in a sinusoidal signal; the displacement that is eta or phi, the velocity that is (( )) phi or you can say, phi dot if I want to tell. And the next integration all differ by 90 degree 90 degree, that is why displacement and velocity 90 degree, velocity acceleration 90 degree. Displacement acceleration opposite that everybody knows it in any signal.

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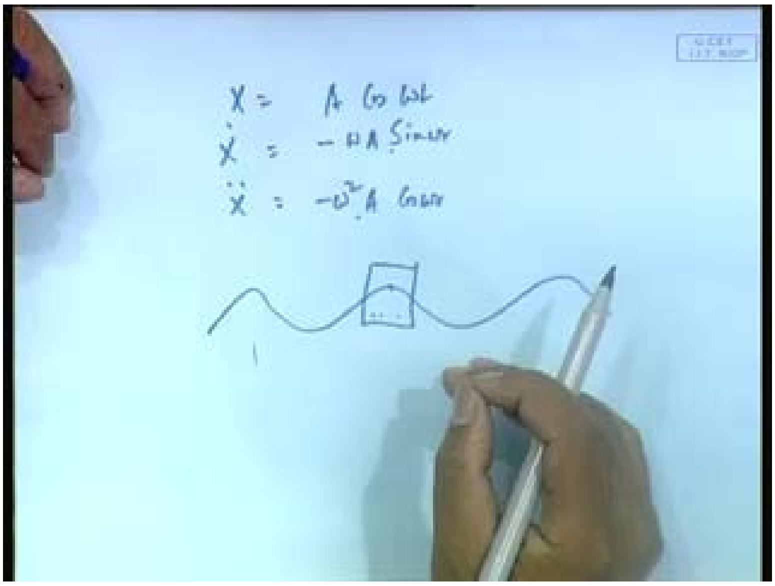

There is also very easy to see, because if you write anything as you know like X equal to A cos something say, omega t then, X dot is going to be you know minus omega A sin omega t, X double dot is going to be minus omega square A. So, we can see this and this opposite 180 degree, this and this is 90 degree etcetera (Refer Slide Time: 34:54).

So, this is very well established, but what we will but what what will happen to our subject subsequently is that, I have this wave here. Now, I know everything of that, but I have going to have a body here, this body's motion are response or force or pressure whatever, I have to figure it out; it will also be sinusoidal, which I will come later on, but it will not occur exactly in the same phase. It will occur some time later, some time before phase is very important.

And also it has the very practical meaning because, for example, take pressure if all the pressures were going to occur at the same phase then, I would have a very large load; when there was a you know like crest coming and just the opposite, when trough coming; it does not happen that way. So, this is very important that we understand about the phase relation.

Having said that now, Let us try to work out the some simple problems, I know rest of the time let me try to, so we will now spend the you know last few minutes of this class on trying to do some kind of problem with also involve maybe phase.

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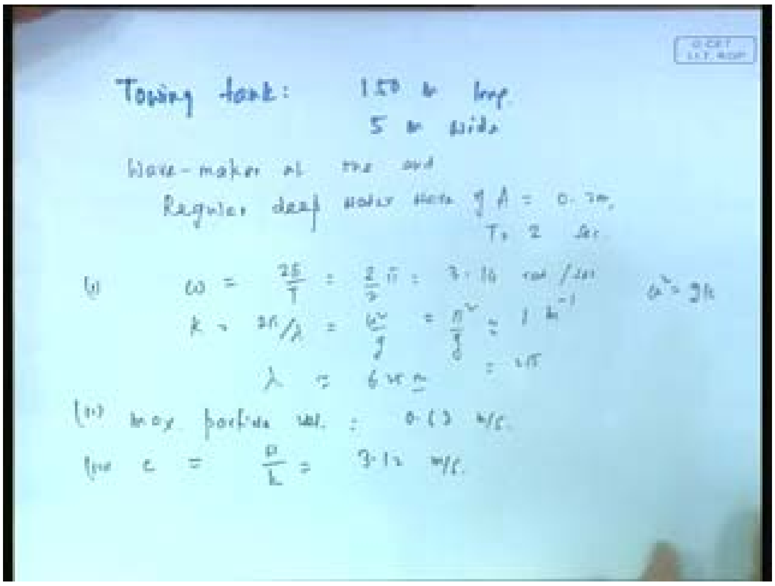



Now, suppose there is tank the problem says; there is a towing tank 150 long, 5 meter wide, there is a wave maker in one end and this is what we, this pen is not so sharp, there is another one. Let us say, the problem says that let us make we are making a regular (No audio from 37:01 to 37:16) and T equal to well.

The very simple problem find out omega which of course, you know absolutely (( )) we do by this 2 pi by T. So, this is turn out to be 2 by 2 into pi equal to 3.14 radian per second. This is very elementary you just to know about how to get omega, k etcetera. We will come to the phase problem in a second k of course, is 2 pi by lambda.

Now, how do I do this 2 pi by lambda now you tell me. So, you have to use the dispersion relation first, so dispersion relation tells me how to get actually this thing, but we can also without that we can do see omega square is equal to g k. So, k is simply omega square g, this this also can be omega square by g. We can straight forward use that, which is that which is the same thing you just using the same thing differently.

So, this will turn out to be something like omega square is in this case, pi square by a approximately come to be about 1 1 meter power 1 and lambda therefore, come to be approximately 6.25 meter, 2 pi; basically 2 pi length. Now it says that, find out maximum towing particles velocity in the tank; let us say tell me this, now you see here we will have to go back to our expression for what we have done before of u and (( )).

Now, you see here, what is the maximum u max this is this because, you know it is remember that, maximum value of e k z is only 1 because, z cannot be positive; z is 0 to negative (Refer Slide Time: 39:20). So, this amplitude is maximum value, similar this is maximum value. So, you (( )) but then, remember that that total maximum is not going to be simply some, because the maximum there is another point. u square plus omega square you cannot do by this two addition because, when this happens this is 0 remember, when this happens; this is 0.

So, the maximum would occur actually this only, the modulus do not use u square plus omega square with this value and this is square as you did. So, we end up getting this maximum particle velocity to be something like, if you work it out about 0.60 meter. Now, what is celerity c is going to be omega by k. How much it comes to be? It comes to 3.12 meter per second. And now the question is the the interesting question when a phase is there, that this question says like this, no no no it is phase speed not group speed.

We are we are talking of phase speed. See, phase speed means this form speed, group speed is the front front speed, which I will come the next problem is on the group speed, but here this this particular question is now on the phase, what is the phase? (Refer Slide Time: 41:04) (No audio from 40:05 to 41:33)

This you see now, so observer is standing here, the question is what the phase of the wave 2.5 meter here is. So, you see now, this is how do you, how do you work it out. Now you see, this is observer standing here and what the question is what would be the phase, if I were to go to 2.5 meter towards the wave maker say, this is my wave maker.

So, now see with respect to this of I were to call this to be x, what is my eta? See, suppose this is my x I start from here then, it becomes eta equal to A cos k x minus omega t. But, now the question is that, I need to call this measure with respect to this or rather I have to find out this with respect to x equal to here. So, now, this is 2.5 meters, so what is happening that, I have to measure this with respect to a parameter when x has been made see by this x plus 2.5 meter. Because see, if I were to measure something any point here is x, but if I measure from here; it is x plus 2.5.

So, I that the expression for that with respect to this point is going to be, A cos k x plus 2.5 minus omega t, so this if you work it out, it becomes k x minus omega t plus k into 2.5. Now, k into 2.5 is therefore, the phase. What is k (( )) 2.5? 2.5 into 2 pi by lambda what we found out earlier is.

k is 1 sir

k is 1 absolutely. So, it is 2.5 radiant straight forward. So, it is like this you end up getting therefore, that 2.5 radiant, which will be about 144 degree. This is the idea for the phase. Now, we will see one more case is where the question was asked regarding this group speed, that we will we will work out (Refer Slide Time: 43:57).

Now, here it says, another again a wave maker problem; it is making wave of frequency omega, period well actually in fact, omega period; period is given as 2 second and amplitude A is given as 0.25 meter, tank length; length of the tank is (Refer Slide Time: 44:32).

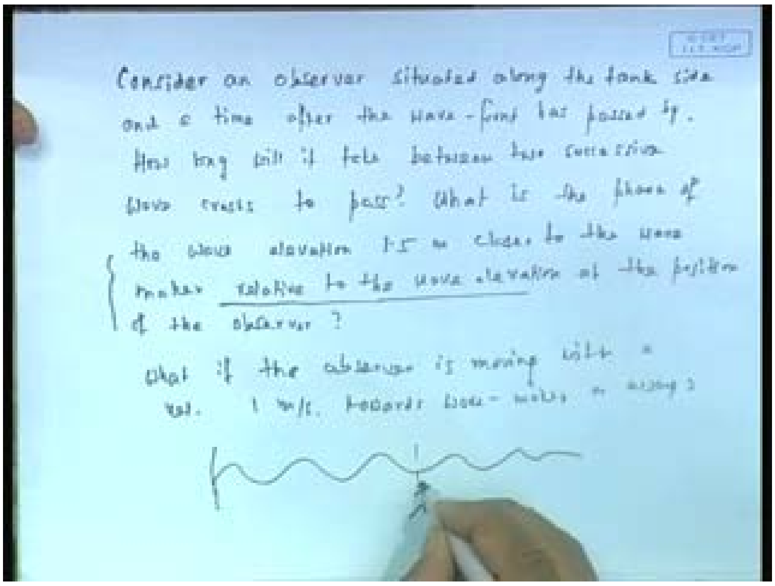
Now here, the first question approximately, how long will it take a wave front to propagate from the wave maker to the (( )) tank. First question is, how much time will it take front to reach the other end of the tank. Now, the question here what the question was asked, this time taken for wave front this is going to be L by C g, because the front will travel.

So, what is C g here, we can first find out. Now, in this particular problem assume deep water, so my T is given. Now, how much is C first of all, you have to find out your C? C is we can always (( )) C is omega by k.

And let us see, how we can write in terms of you know like T. See, omega square being g k (( )) omega by k equal to g by omega equal g by to 2 pi lambda. So, C is this thing, g into lambda by 2 pi. Now, of course, lambda we have to again work out let say no actually no sorry sorry g by omega we can write simply g by not lambda T, this is T making a mistake (Refer Slide Time: 46:12). So, this is like this, g T by 2 pi how much this comes? T is 2 second. So, it is g by 2 pi into 2. So, g by pi, there is approximately let us say, 3 3.2 3.2 meter per second.

So, therefore, C g is 1.6 meter per second. So, therefore, time taken is going to be 100 by 1.6 second, approximately is equal to 100 by 1.6 would be about how much? 62.5 second. So, these are the group speed. Now, I will I am going to do one part, which I will now leave it for you to work out, because you know it is with respect to this thing, phase again.

(Refer Slide Time: 47:20)




Now, see here I I will I will write it down, consider an observer situated along the tank side, time (No audio from 47:51 to 48:07). This next part of course (No audio from 48:10 to 48:35) this of course is very simple this part, because the answer is that, it will be the phase speed you know like after you have the wave front has passed you are standing and you are trying to now see the the crest passing.

Now you see, what would happen is that, the crest would pass much faster. So, you will actually see it (( )), but it important point is next one, what is the (No audio from 48:57 to 49:23) this also we have done last time (No audio from 49:26 to 49:52). See here, this is what we have done before, what is the phase of the wave elevation 1.5 meter closer to the wave maker relative to the wave elevation of the position of the observer. Important point is this, see this phase is being measured relative to the wave elevation, you have to measure phase always with related to something, you just cannot say phase is so and so, it make no sense.

The word phase necessarily connected to a measurement. But, now there is a second question is that, what is this this phase this this part, what if the observer is travelling moving with a velocity 1 meter per second either towards the wave maker or the other way around the wave maker.

I will I will explain this picture in a minute, this I will leave it to you for thought. What happen here now, this is a tank here, wave maker is here and waves are going passed it, now you are standing here let us say, standing here. Initially of course, you are saying that with respect to that what is the phase? Simple problem we have done last time, but now the question is more interesting. Now, I want to define the wave with respect to moving frame of reference.

See earlier, what happen if I want to find it out all I have to do is, to measure this as my reference frame. If I have my cos k x minus omega t, I simply define x with respect to that, but now my x is very (( )) because what is happening is that, I am actually walking towards this or walking towards (Refer Slide Time: 51:47).

Now, remember this supposing I was with the crest see the (( )) and I was travelling with the phase speed, what will be the phase gap? 0, because I will always see a crest in front of me, it was going slower; my crest (( )) passed by, if I other way around means something. So, what would happen? There will be a phase gap, but the phase gap is not going to be constant because, constant what would happen in this case; phase gap would keep on evolving with time; that means, my phi that is k x minus omega t plus phi would become a function of time t.

So, therefore, what happens is that, in this problem you end up finding out a evolving phase because, there is not going to be constant and that is what may be you could work out for the next class and you would kind of see it is. So, I am going to more or less yeah end it here, today on the wave part.

This gives us a kind of a basic understanding of linear water wave that we are going to use continuously, when we study sea keeping. I will close it by saying that, water waves you know are sometime little bit difficult to understand because, by wave we do not we always mean the form, where the particle never follow the form; particle have a different motion. So, the dynamics involve is not as severe as it might think, but they also be more.

What I am trying to say is that, what you think intuitively may not always work. It just does not work because, the very fact that two waves can interact is an interesting example, I can look at calm water and I can tell you theoretically it is equal to two waves of exactly opposite phase. It is like saying, 4 is equal to you know 2 plus 2 minus 4 or equal to plus 4 minus 4 equal to or 0 rather other way round, 0 is equal to 2 minus 2 or minus 2 plus 2 or whatever So, you know the waves are like that.

So, this there is some kind of conceptual understanding required what we talked of only one wave, when we add the (( )) will start because, when we add we will find out that, I can always say that calm water as I say some of n numbers of waves. And now we will find out in a wave maker I will just end it by saying, supposing I will say that and I say that, I suppose you have a wave maker and you want to make a wave by pushing this way and we find out that, if I actually have two waves of out of phase; I have no wave at all.

Now, the question is, how do I make it to move, (( )) make a you know like wave maker move, so there is a calm water. The interesting part is that, if supposing person one wants to make a wave of phase a, so he wants to push it and if person b wants to make a wave of phase minus say at that instant, he has to pull it. So, both will pull and push and the plate will remain steady and therefore, it is like force is plus 1 minus 1 is zero, water also remains 0.

So, you know it get explain by that. So, you cannot make, you cannot move a plate to make a 0 wave, because the movement is going to be 0, is like doing nothing. So, this is what, but then we will always tell that, yes to calm water is 1 minus 1 with that, I am going to end it. And we will go tomorrow next class onwards to the you knows the actual we will begin to put the ship in waves in regular waves, thank you.