Marine Hydrodynamics
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Lecture - 21
Introduction to Water Waves

Welcome to this series of lecture seven in hydrodynamics, today we will talk about with a brief introduction of water waves. In the subsequently lecture, we will talk in detail about the water waves. Basically, when it comes to true waves, like many other waves we have when it comes to before going to water waves class, let us talk about what I mean by wave and where it occurs? When we look at waves, it is a propagation of energy in a medium and it is like we have a mechanical waves (( )) like waves in a solid. Why we have seen a string of vibration of a membrane or a beam vibration that the waves propagation that is the wave that propagate in a solid.

On the other hand when you look at the energy that is the ellipsometric waves, then in that case it does not require a medium x ray to ellipse. We have light waves, so they are kind of electromagnetic waves and the other hand when you look at waves as I told you by Edison of a beam on the history for a in the sound waves propagation a questions. Then we have these are kind of mechanical waves a similar such waves is the water waves.

The theory of water waves, in fact is a more general one compare to any other wave. In fact it was a total summer field get this statements summer full toll is one of the physician, what he is suggested? He told that in fact the theory of water waves which general model compares to is one of the most senior on model of waves compare to all other waves. So, as I have told in previous class the water wave is one of the most senior type of waves. So, once if you know the theory of water waves are the various filament associates with water waves that are its easy, easily other waves are similar concept of similar methodology can be used for this methodology, can be borrowed to dilute the other ways.

In the last 150 years there is a significant progress in the development of the theory for waves in a major part of the theory of water waves. It based on the assumption of the fluid is in beside in complex able and most in it is 0. However, the complexity comes

from the three surface boundary condition that is here on the three surface. All the condition have highly no liner that makes the problem more complicated. Even if the assumption on the fluid is very simple that means, even if you deal with a potential problem, the pre surface boundary condition which are highly non-linear makes the problem complicated.

As, a result in a few problems of the general model of a water waves can be handle for the solution, they still less, so in the process we again go for idealization of the general theory one is in the process theory has come up to deal with the problem of water waves. In this we will start with the very simple liner theory and understand some of the phenomena of water waves and afterwards will give because will just keep discussion in brief about the linear waves. So, when it comes to the theory of water waves. First of all we need to know the various types of waves as I told you that in case of a waves problem there is a transfer of energy, which takes place and it most very often in a periodic interval the process change in a with a certain periodicity.

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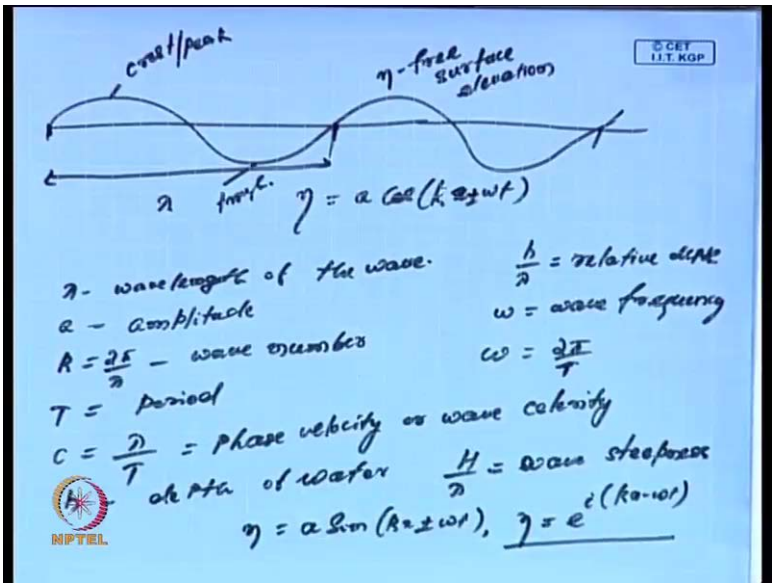

So, if I look at suppose I have a 1 of the simplest wave is such in a shadow wave here. If I just say eta is equal to a cos K X minus omega T is the most general representation of the surface, then I call, suppose I take this region than this is… The total distance I call it has a lambda. Lambda is called the wave length of the wave of the wave and then is the amplitude a is the amplitude.

And then we have K is equal to 2 pi by a lambda h is called wave number and T is the treated as first lesson. Time period and then C is lambda by T is equal to phase velocity or wave celerity. Then we have another factor in the case of a phase the depth of water then we have we have other factors like this point, the maximum highest point is called the crest or peak and this is called this points. We always call this as the (( )), so in once it completes from here to here this is called one complete cycle.

Then it call a complete 1 complete wave again from here to here this is the another cycle, we call this another wave this complete one cycle complete. So, these two this distance will call the lambda the time covered by the wave to propagate from this to this distance is called the period. C becomes as well as the velocity which is lambda velocity and some of the H is the depth of the water than what will happen s by lambda we call this as the elliptic depth.

That call the elliptic depth and we have again we have omega of the frequency called the wave frequency. It is of T sequence call the wave sequence than we have omega is equal to 2 pi by T than we have another factor is called pi lambda is called the waves thickness waves thickness. So, these are the some of the parameters eta is the surface area and this is 1 of the very simple seen under cosine wear than among the other wave forms simplest among the simplest wave form. If I write eta is equal to A it can call it plus minus S sine K X plus minus W not a. Similarly, we can also have in the combined form expellant for me to the I times K X minus T this 1 if you look at the really imaginary parts both of them represent waves real also will gives us the pi and question waves.

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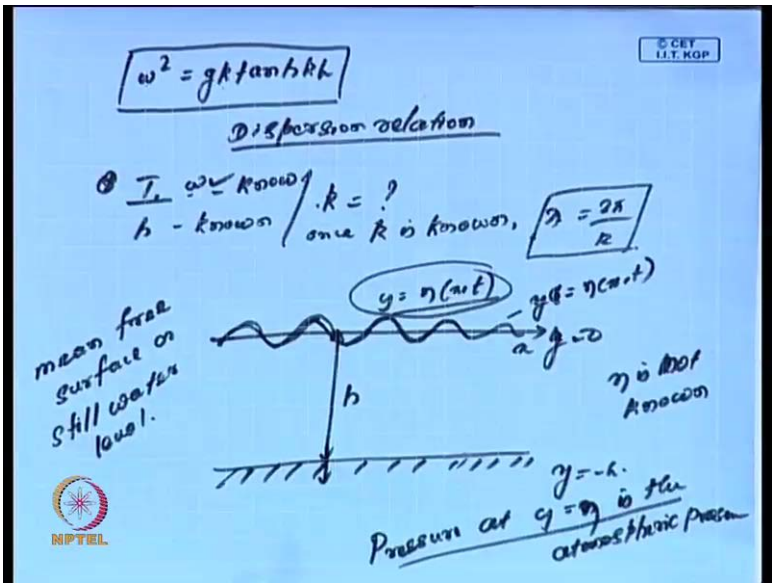

So, this than what is another thing which is important, in which will come when derive letter… But let me put first introduce there is a relation between omega square and K omega and K that is omega square is tan G K tan hyperbolic H. This is a relation that are almost all ways such a relation which exists and that way that relation I call that is dispersion relation. This dispersion relation where it will the which lesson I will use combine relates the frequency of the weight the wave number?

In fact what will happen to this relation, if lots of information about the wave characteristics than often if we know the period of the f T. We know than we know the omega once we know T omega than if you know the water depth age this are the things which we are known. This also this also known one of the major than what will happen can we find K than K is equal to what, so that we can easily find out what is K by solving this equation.

And once we find K, once K is known can always find what is lambda. Lambda is nothing but 2 pi by K. So, this dispersion relation I will come to the detail derivation of this relation little later, but today let me emphasize on this than particularly this is this we are looking at if I had a depth of water is H the water depth is H. If I have anywhere is a propagating on the surface. If I say Y is equal to eta X T, if the surface than we have finish in the sea bad that is generally from water depth that joining from than what we have than what will happen?

This is called the Y is equal to eta Y is equal to eta S. T is at the surface and then this line and this line is the X axis. Suppose, this is negative direction in the downward direction than this I call this H Y H minus H and this is line Y is equal to 0. This X axis is 0 for the line Y is equal to 0 than Y is equal to 0, when Y is equal to 0. This line is called the mean free surface or still water level. There is no way Y is equal to 0 and there is a still water level and when there is a disturbance than we call Y is equal to eta as the surface.

In fact, as I mention on the free surface, this eta is not known eta is not known what is known pressure what surface at Y is equal to eta. Free surface is the atmospheric pressure. So, that means on the three surface the atmospheric pressure is gone which is atmospheric pressure is not gone, but surface so this surface is very dynamic surface and which is not known. So, always we need to obtain quantity surface one of the major problem as well as I told the surface.

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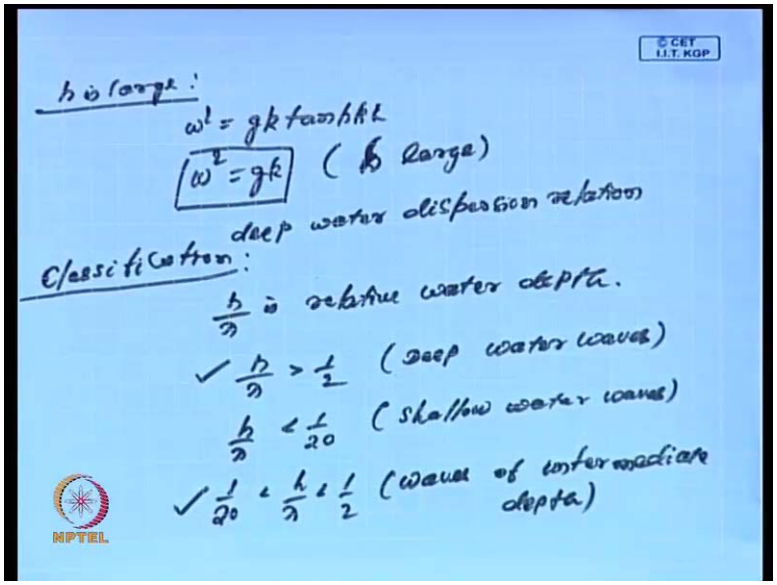

Then another thing, if I look at this dispersion relation. Then I can easily find what will happen H is large when H becomes large H is large then I will have omega square is equal to G K tan hyperbolic K is initially. This becomes G K for K large H large then that becomes omega square is G K. So, that what happens it gives me that this becomes G K deep water deep water deep water, so this omega square is deep water is dispersion relation.

So, now will define what is the classification of the waves, when we look at the classification of waves it comes up to two things as I say the H by number is the is relate in depth, relative water depth. If this is the relative water depth, then what will happen here? Then if a lambda is 0 to 1 and half then we call this deep water on the other hand when H by lambda is less than 1 by 20 it shallow water waves.

And in the other hand 1 by 20 is less than H by lambda is less than 1 by 2 is called waves of a intermediate depth. In fact that is last class, I have told you where we always come across in this case or this case we had the recent Japanese tsunami definition having at 2004 Indian ocean. Tsunami in that case tsunami always model as a salt water. Although, may be deepest in the ocean, but if you look at the waves than compare to the if you look at the dilute water that always you will see that this is a shallow water waves so many such ways existing the ocean.

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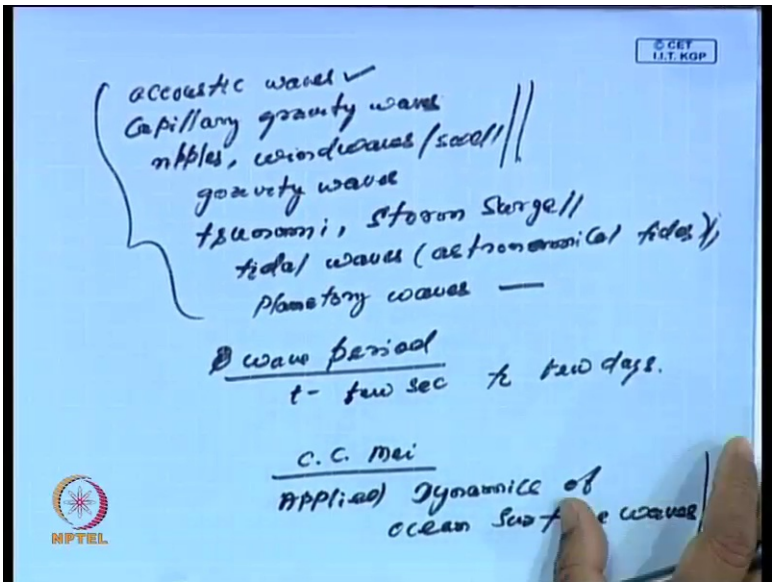

That is like let me just briefly say, what are the various types of waves that all existing the ocean? You know we started acoustic waves, then we have come capillary waves, we have a ripples, we have wind waves, slash rational and then we have a gravity waves. Then we have the tsunami, we have storm surge, then we have tidal waves by we have always astronomical tides, we have planetary waves. So, these are the different types of waves always the question for its only for solving the typical period of this waves. If you

look at the period of this waves, wave period wave period of wave depending on the type of an nature.

It can wary form few seconds, few seconds or a part of a second to few days this. So, like you look at suppose the acoustic waves it is in a very small period is very small of the second and where as capillary they are in seconds. These are all waves which are in seconds and when you look at tsunami storm surge, there in wards tidal waves is in wards again, then in planetary waves (( )). So, if you look at the details one can find from the books of C C Mei of a Dynamic.

Suppose in the surface applied of ocean surface waves. There it has nicely disclaimed the various types of waves the restoring forces acting on it under what it the typical period of this waves and where they occur and how they occur. So, I am not, just briefly say, so when we have seen that we have in general we come out streets of a then will happen to the...

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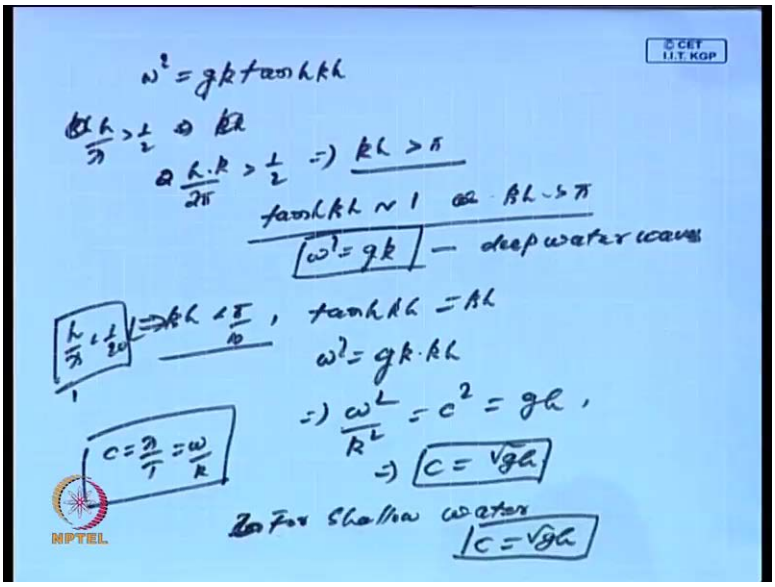

We have a dispersion in a lesson that we have seen the dispersion in a lesson that is have omega square G K tan hyperbolic K H. So, if we say that K H by lambda greater than half which implies, what will happen to this? So, that it will give me than we have a what will happen in case K H will be A square lambda. So, if put it lambda is 2 pi by K. H lambda is 2 pi K is greater than 1 and half, which implies K H is greater than pi. If K H is greater than pi I can see that tan hyperbolic H N tans to 1 K is equal to pi and in that

case will see square is equal to G K. This is basic case of hyperbolic ellipse. In the similar manner, we can see that when K H is less than pi by tan than we have tan hyperbolic K H. It becomes K H, because it is small and than in that situation we have omega square is G K into K H it implies omega square by K square is equal to C square is G H, which implies C is equal to root C H.

So, this is another relation. So, this is equal to C H is the C is nothing but the face velocity and the we have seen that the C is equal to lambda by pi is nothing but omega by K. That is the face velocity, this happens when K is less than pi by tan, that means it is same as H by lambda is less than 1 by 20 weather. This are we say that means in that case, so in case of salt water, so in case of salt water we have seen that the sea in case of salt water for the salt water we have C is equal to root C H and C is the speed of water. C is the way propagate that means the speed of propagation in case shallow water depends on the just the water depth.

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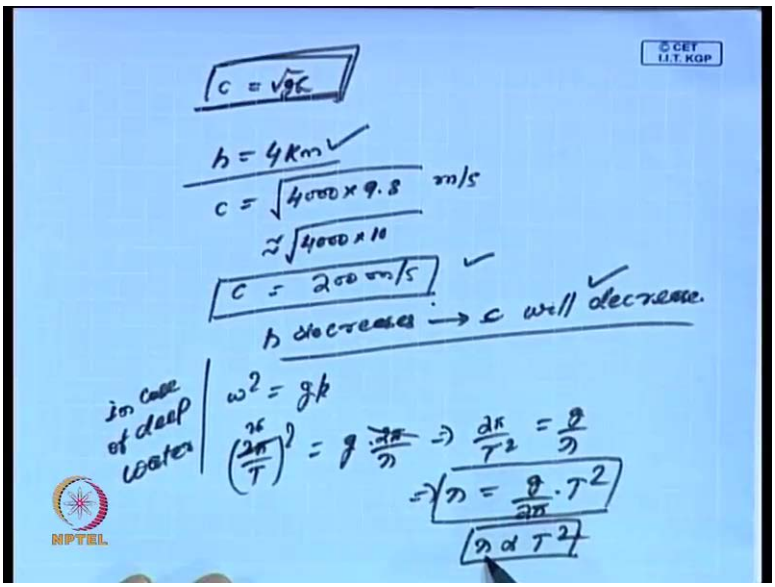

In fact in the tsunami trouble time sat we always, we can always have that the tsunami time starts is best. In this formula use one to know the time taken by the tsunami where it is from the sea always this formula is used to all though this is the formula, which is often used one of simplest formula used. However, there is a proper the depth depth circle are of taken under various points from observation data what the surface taken and various as initially look at tan. Then when the water depth the various location

Than the we always find how much how much time it will take to find out when a tsunami occurs formula, even if you look at the average results to get it just to hide a I have an idea. What will, suppose if I say water depth is 4 kilometer which is the kind of power ocean depth and I just say if it is 4 kilometer than my C is previous pi sine only 4000 thousand into 9.8 root of which I can just roughly say M meter per second you can that say 4000 into if I put it as a tan, just roughly the which can be equal to 2200 meter per second. So, it shows if I am dealing with the (( )) where C is a 0 and the depth of water had a point is 4 kilometer.

This is the observation depth than the speed of the propagation will be 200 meter per second. But what will happen if the same way if we sore line when the water depth decreases. Then I will say that the speed of a C will decreases. So, the speed of a propagation decreases, but the another question comes what will happen. Of course, here I am asking changes in the other phenomena the associate to particularly ruling reflection all these things replace that the is not taking place, in that where we have even associate this kind of force I will come talk later.

But then, so similarly, if I look at a other ellipse that is in case of a deep water in case of a deep water in case of deep water omega square becomes G K and this K omega 2 pi by T square G 2 pi by T 2 pi by lambda. So, it is implies so 2 pi is 2 pi will be over that will be so that will another 2 pi only remains 2 pi by T square 0 lambda, which implies lambda is G by 2 pi T square.

So, that means here It says that in case of deep water lambda where is this as a T square if the period increases, lambda lambda where is as T square C is constant 2 pi is a constant. So, that means wave length will increases which increases in time period, so larger the wave length. So, these two observation which have told this two cases here the depth decreases, you will decreases speed up the small decreases on the other hand that increasing time period T comes wave length of wave fuel increases because lambda various T square.

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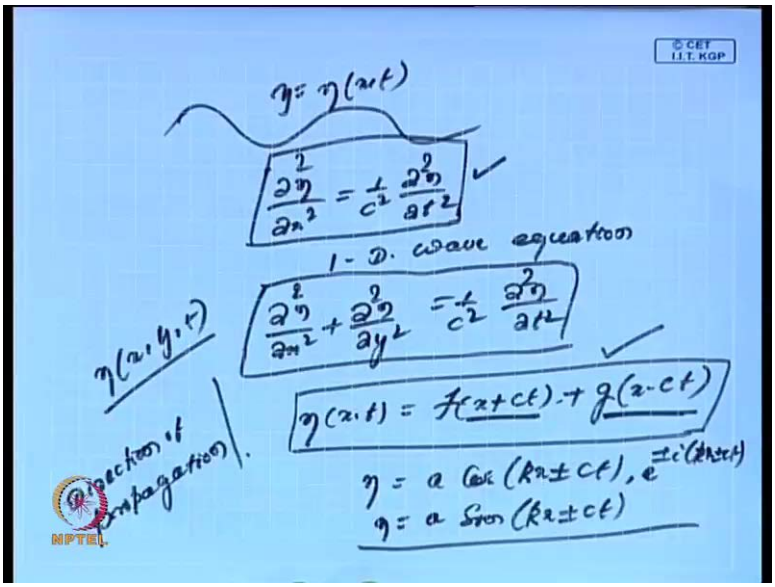

Now, with this understanding now let us have a look at the general nation of the waves when it comes to waves. If I have a surface any surface, if I say eta is a fraction of X T, Y is equal to the surface then what will happen to eta? It has to depend in presence of a if it happen in the eta the free surface and these eta is the square of these eta by dual axis by is equal to 1 by C square duel square eta by duel T square. So, anything which when a movement, I talk about I do not have a surface that surface in the case of 1 minus D 1 in the equation.

Similarly, in case of 2 dimension equation, we have duel square by eta plus duel square by eta by duel square by Y is equal to 1 by C square that is eta by delta square. In this case if I consider my surface is a function of eta function of X Y and T now if you look at the general solution it is time for simplest 1. If I look at the general shallow solution because eta than a solution of this been general of this eta X T F of X plus C T plus X minus E T. This is the general part of this lesson.

Way if here is this is a parts of different equation, so the secondary parts of equation, so it is the solution will be some other functions or like in case of a different at the solution will come into separately constant that the function F and G, but the general factor is A plus G X plus E T X minus E T. So, whenever if you look at eta is equal to A cos X cos minus E T or else cos eta is equal to a sine K X plus minus E T at the general case.

Exponential form like you have E to the cross minus I K X minus eta, then all these forms they are 1 of these particular case of these form. So, they all represent then and these in these form this is the wave, which propagate in the negative direction as well as velocity. This is the wave which propagate the positive direction, as well as velocity C. So, that is what so similarly, so when we think of a waves we have to always think of two things; One is the direction of propagation direction of propagation that is very crucial and another factor when we are looking at waves comes is various phenomena that affected. In fact various phenomena associated with the wave in fact the various phenomenon associated with the waves are the reflection, transmission, scattering, diffraction, refraction, shooling, etcetera.

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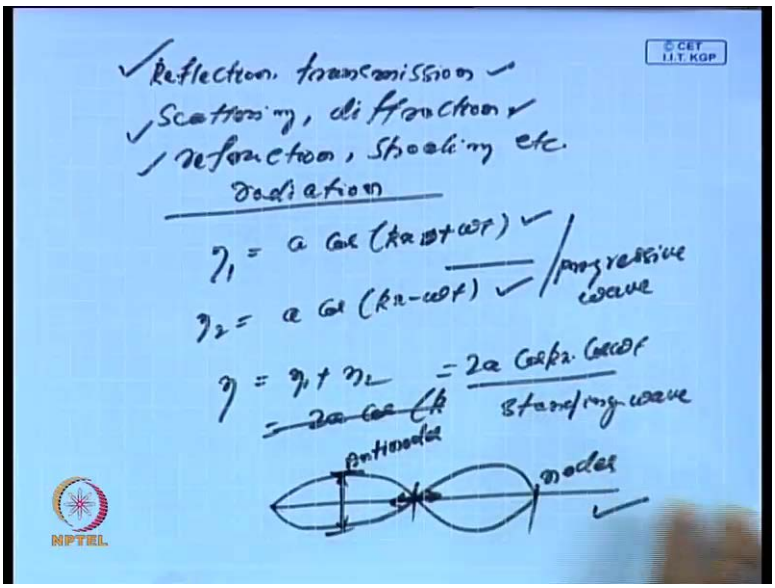

These are the various phenomenon, so in fact it is not only that it is not only then we have radiation, it is not only that only in case of a light we have some of the phenomenon. But any where the moment we have the wave this phenomenon occurs depending on the type of waves type of medium some of the particular phenomenon which dominates this is what we coming.

Here also in water waves also all these waves, all this various physical phenomenon exist. It all depends on the type of problem we are looking into or the nature of obstacle we are looking into depending on depending that we always define, what kind of wave what kind of phenomenon it will be associated with it. Now, because in the next class

also I will come in details, about how the theory of water waves is developed? What I adjust is here since I have taken one I am concentrating these sense very brief class, so I really consider some of the other basic characteristics of the water waves of the waves. In general, suppose I have a wave eta is equal to A cos.

I will come those things in detail about to water waves theory and next class suppose is say eta is equal to a cos K X plus omega T this is a wave which is propagating the negative reduction. Suppose, I have a another eta 1 this is eta 2 another wave eta A cos K X minus omega T, then what we will have the resultant of these 2 waves eta 1 plus eta 2. Then this will give us 2 A cos, this should give us 2 A cos K X cos omega T this is A. So, there are 2 waves the same wave the amplitude of the waves are same were as the wave number frequency.

Everything is same only the move in the opposite direction, then what happen the resultant wave becomes this are all progressive waves were as the resultant wave is just standing wave and the unlike in the case of a progress wave. The standing wave we always see the formation of nodes and anti nodes these are the anti nodes. These are the nodes this is also node. We can see that the extraction of the particle here the horizontal extraction of the particle is highest, whereas at these point the vertical extraction of the particle is highest. So, these will come in detail rather suppose what will happen here I have taken the 2 S same Amplitude, but if I just look at the two waves different temperature.

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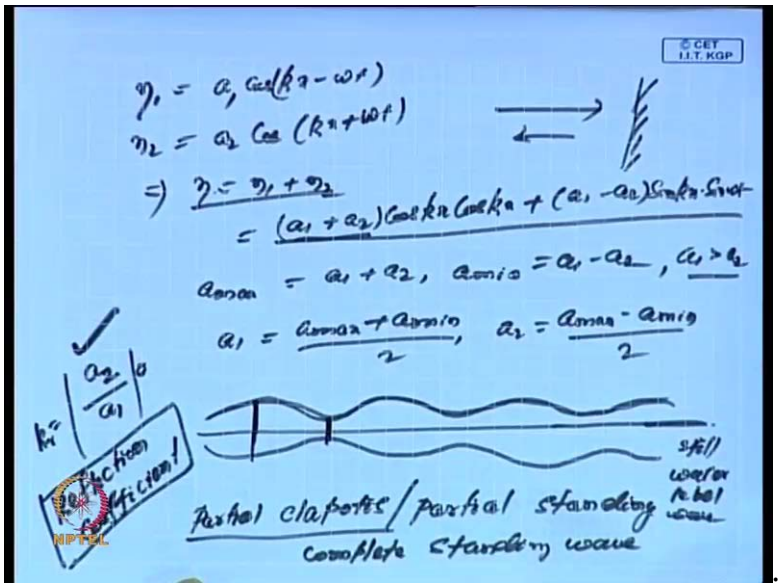

Then what will happen then what will happen to my eta? It changes the combination of eta 1 plus eta 2, it should give the A 1 A 2 1 plus A 2 into cos K X cos omega T plus A 1 minus A 2 sin K X sine omega T. If you look at these, so if you look at the amplitude of these two waves the maximum amplitude a max will be A 1 plus A 2 and the a min will be A 1 minus A 2 provide. We assume that A 1 is greater than A 2 then what will happen then what will happen to A 1 A max plus A min by 2? Whereas A 2 A max minus a min by 2. So, that means if I know and how these wave pattern will look like this is the main shrill, this is the main free surface.

So, this is the type of that will the wave will propagate, so this will be give us here the maximum temperature that this point into a minimum amplitude, where as that this is the still water level this line is the still water level. So, what happen often when you look at the tank, a wave initially you have a wave which was propagating in the positive direction. Then if this was initially these wave was propagating in the opposite direction. It come across a wall and after meeting a wall it get reflected. Vertical wall particularly here is say when it get reflected the resultant wave is this wave, which is a standing wave.

This standing wave then what we see, we always see the surface of the wave that is this becomes my surface of the waves and this wave is what I call this is a capotes partial capotes. That means always partial standing wave and when they became same. Then we

call it complete standing wave. In fact in earlier days the ratio of the amplitude of the incident amplitude of the reflected wave that is A 2 by the amplitude of the incident wave that is A 1, which gives me, we call this as K R that is the nothing but the reflection coefficient this reflection coefficient. Then if we look at, this becomes this used to obtain by using this formulae.

A 1 is A max plus A min and A 2 is A max minus A min, so always this distance used to be measured distance used to be measured because this is the A min minimum amplitude A min. This is the maximum amplitude temperature. So, near a wall to always to know what kind of wave that is from what is the reflection coefficient in terms of a particular wall. This formulae is used was used A 2 by A 1 were A 2 is nothing but a max minus A min by 2 and A 1 is a max plus A min by 2. So, that is a way of obtaining reflection coefficient of a wave another simple things.

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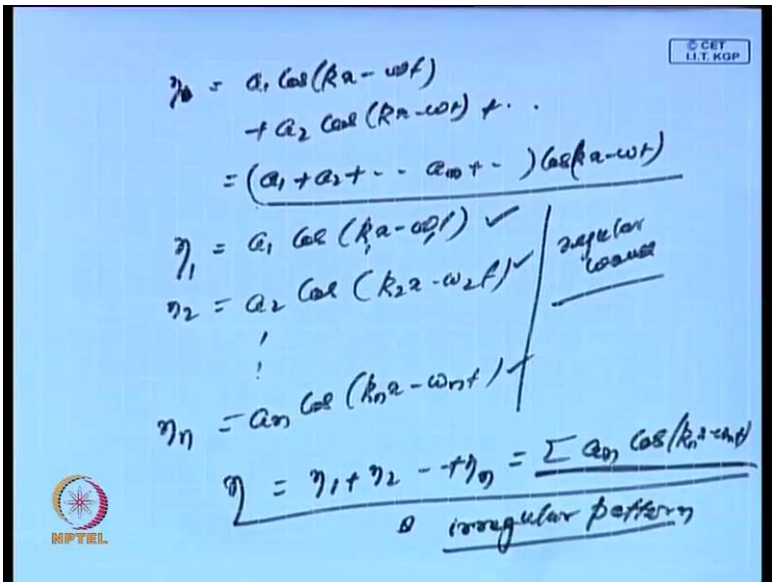

Here see we have just seen that how by changing the amplitude of the waves and direction we are able to. Now, if we look at not only amplitude what will happen if I just say that we have waves of similar nature were propagating in the same direction. Suppose, if I say my eta Is a combination of A 1 cos K X minus mule at the all plus A square cos K X minus W T plus 1. So, only the apertures have send then it will be A 1 plus A 2 plus A N plus.

So, into cos K X minus W T, so it is like as if we exhaust it same mode similar ways there are different episode they propagate in the same variation and only the ampisole than this, but what will happen? what will happen? In version surface we always see those in the surface is combination of waves which are of different nature. So, it can be a 1 cos K X minus W T and 1 of the wave K 1 X 1 T we may have a eta 1. This is eta 2 a 2 cos K 2 X minus W 2 T. Similarly, to go like this to may have eta N is A N cos K N X minus W N T.

Then we look at the total result and eta is equal to eta 1 plus eta 2 plus eta N, then what about the pattern we get? We get sigma A N cos K N X minus W N T. These wave although they have sometimes originated from regular waves all are regular waves, but pattern of this surface what we see when combine all this waves need not be surface, need not look like the regular because combination. These waves will give us severely irregular pattern. But it may happen that all these wave have originated from these all waves. So, let these, but we see when we look at this surface.

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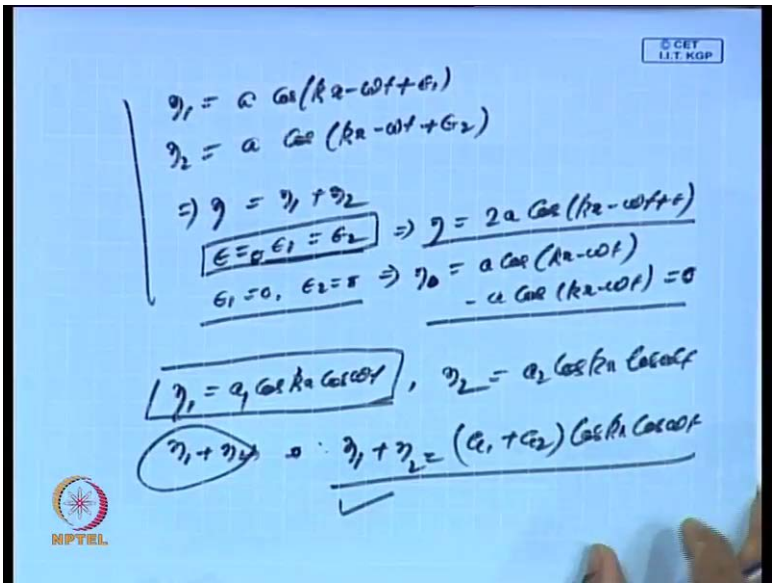

Then suppose, I have I will just tell see these are observations may be very simple, but these observations have a very important while analyzing the various problems related to water waves. Suppose, I say eta 1 is equal to A cos K X minus W T plus epsilon 1 and eta 2 is equal to A cos K X minus W T plus epsilon 2. Then may be Elton wave will be then what will be eta will be eta 1 plus eta 2 and if I just take it this can be… When we

look at 2 things; when epsilon 1 is equal to epsilon 2 if epsilon 1 will be epsilon 2, then eta which the result of the 2 waves this will give me 2 A cos K X minus W T plus epsilon.

Because epsilon is equal to epsilon 1 is equal to epsilon 2, on the other hand that if epsilon 1 is 0 and epsilon 2 is equal to 5 and what will happen? Eta 2, eta the eta will be this will be A cos K X minus W T and epsilon 2 is 5 solution will be minus a cos K X minus W T and that will be 0. So, here the amplitude just to look at the phase chain this is the phase there is a change in the phase, because if both are of the same phase, then the amplitude has become twice that that of the individual ways.

But if they monitivated out of phase that means then there is a (( )). So, in many situations engineers always are interested to know that if they want when captured in the waves they can always clitt away if the 2 waves are same phase. Then that will give me the resultant wave and propagate in the same direction and whereas, Elton wave will be twice (( )) of the Elton wave twice that are individual waves. On the other hand if want to qualify effect of one wave which is propagating one of the mechanism honors to introduce the generated way in different wave whose phase is, whereas a which as a the wave for generate different wave.

That wave should have a phase which is the 1 at a T V difference then the original waves this influent, then in that case we can see that that resultant wave is becoming result. Effect is physically becoming 0, so that is another so there are physical wave is monastrate to introduce. So, these understanding of this things are very crucial because this has very important information to design different types of the structures. So, that we can generate or we can art in with them that are very less. In fact as I have told you that here this in these process, we have this is two various different if suppose on the ways if the waves. Again we have already we have seen that waves propagate in the opposite direction then standing of the form again.

If we look at the standing resultant and what we will do? I standing waves if I look at a standing wave, what will happen to the resultant of the standing wave? Suppose, we have two standing waves, then of the same amplitude or different amplitude. Similarly, we can say that the resultant will be eta one plus eta 2 equal to A 1 plus A 2 into cos K cos omega T. One can look into similar situation like when we have again change of phase in

case of a standing wave. Then also we will see that the similar observation will happen because either we will decrease or it will increase depending upon the… That we are considering waves of the same pairs or a different phase or any other changes, so that will also give us some insight to look into problems where we are looking at generation of waves amplitude higher amplitude waves or lower amplitude waves.

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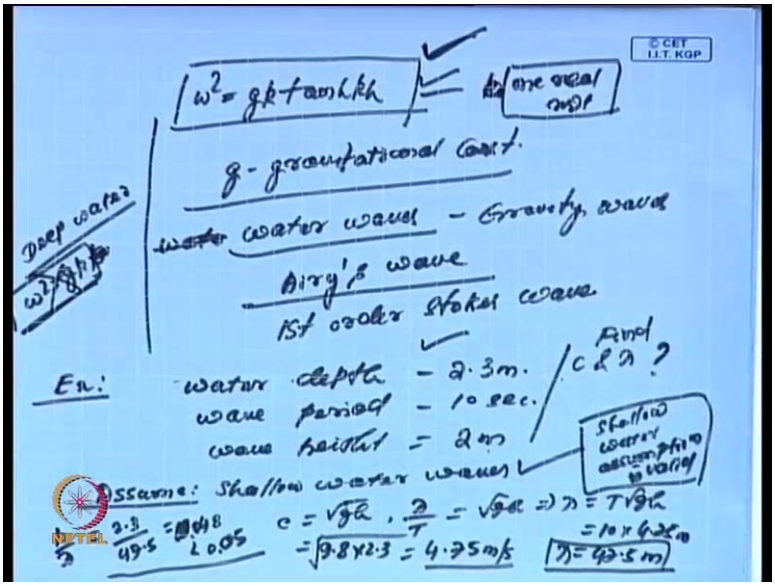

So, with these understanding about the basic, understanding of the waves and as I say that in a water waves basic relation is this personal relation. Otherwise the general nature of the waves remain the same because here, but the process another thing here G is the gravitational constant acceleration due to gravity is a constant acceleration due to gravity. Here this and this is the desperation relation, so often this water waves, so that means because of this all depends on this gravitational J. So, sometimes we call it as space of the gravity waves. In fact the very well known gravity waves as small immature gravity waves is often call the… So this basic understanding about the gravity (( )).

About another example if a, This completing 2 days lecture that will give us a very little in sight the various phenomena happening. Suppose, I have wave which has a exists about an example. Because tomorrow and in next class will talk about how this waves how this all this things are coming of and how it is possible? I am just talking about waves, but how this treasure related for it has to do because in case of, in case of water waves we have we have a fluid motion. Then we have a propagation two things detail

will come in the class. Suppose, I have a wave which the water depth of the waves the water depth of 2 point 2.3 meter.

As the period have a wave period just work out a small engine. This is the wave period is second, then I have a wave height which is that is 2 meter. So, if I am in ask to calculate the velocity and length find the C. Lambda find C and the lambda. So, to do that what I will say, I have the water depth is a very small if he assume because I have a height is a 2 meter whether the water depth is 2.3 meter. So, I must have a wave, which is I am which is depth is similar to the wave height.

So, if I assume is just assume that its swallowed case of a swallowed waves. If I assume the case of a swallowed to is in what will happen? My C will be root is S just I have talked about if C is nothing but lambda by T it is a root G H, which implies lambda is equal to. So, what will be my C C is A G H is A 9.8, 9.8 into H is my H is 2.3. This is this gives me for 0.75, 4.75 meter per second. If I look at lambda by T is G H root is G H which is lambda is equal to T into root G H.

That is T is cube come in into 4.75 that is meter that will be 47.5 meter. So, here we prove, so by lambda becomes 47.1 meter, whereas my speeder propagation in has 4.75 meter occurs. I have assume that this is salver to S if whether let me check whether this assumption is a valid assumption are not. So, if this assumption I have to tell that my S for lambda. What will happen to my S by lambda my S is 2.3 meter and lambda is 47.5 meter and this will become 1 0.84 and which is always less than 0 point, 0.04, 0.048, 0 less than 0.05, 0.05.

Then if it is less than 05 that means 1 by 20, so this assumption I have taken as this assumption at allotted to justify. So, our transformation is a justified is valid. But it is not always necessary that I taken as assumption as is not valid than what in the that case what happen to do than I have to in the other case. I have to go to this equation at Z omega square is equal to as hyperbolic S often what we do we try to valid at this, we always again call it. Suppose, it is a case of deep water and then this is not valid.

If we have to consider the case of a deep water and in that case we will have a omega square is G K tan hyperbolic G K and in that case again I will apply because by water depth is there. In this case I cannot apply. Because water, sorry I have a water depth at the, so I can apply this because it is anywhere no case of finite infinite water depth

because my water depth is 2.3. (( )) by it is 2 meter. So, I cannot apply this result here, on the other hand I if this (( )) hole good I can than I have to directly solve this equation. By a numerical method like Newton aspen method also I can substitute it for T H and G, then on the I will solve it for the numerically to obtain this and I request all of you to show to work out few pro lines numeric to find how the K is obtained by using the nutria option method? Always we will find that it will be 1 positive real root 1 real root of this.

That means for the momentum you have water and you have certain water depth than there is 1 real root. Means one way full exist in the water that is what 1 progress water will exist moment, you have a disturbance that wave will direct. So, with this basic background on water wave system today I will stop. In the next class, we will concentrate relate start from the basic equation of fluid mechanism. Try to you have to come out that there is a wave in a water that details will come. Although, today I have I seen that there is a wave and assuming the dispersion relationship in a particular method in a fluid case that will basic Brazil type, right? But in detail we will come in the next class.

Thank you.