Numerical Ship and Offshore Hydrodynamics
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Lecture - 02
Introduction to Seakeeping

Welcome to the Numerical Ship and Offshore Hydrodynamics. Today, we are going to introduce about some basics of the Seakeeping, Okay.

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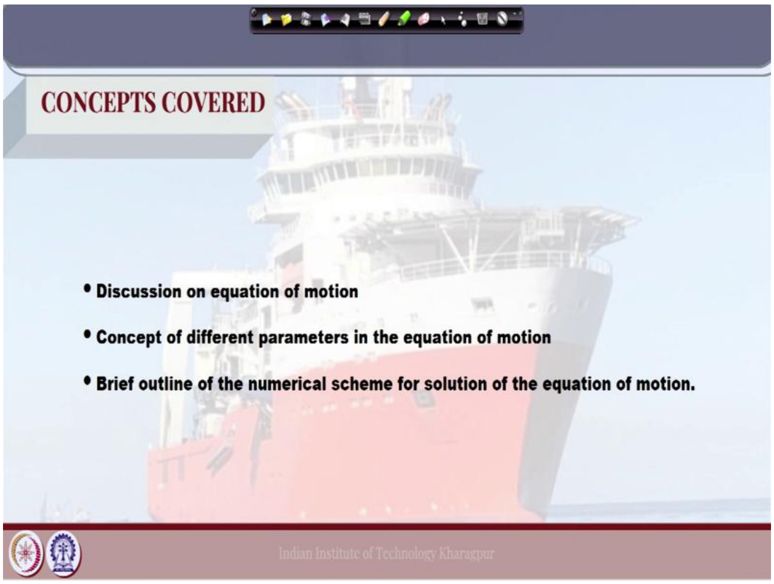

So, today this concept will be covered. So, we have to discuss on the equation of motion, ok and then concept of the different forces or different parameters in the equation of motions and then brief outline of the numerical scheme for the solution of the equation of motion, ok.

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So, this is the keywords that we are going to press to get this lecture, ok.

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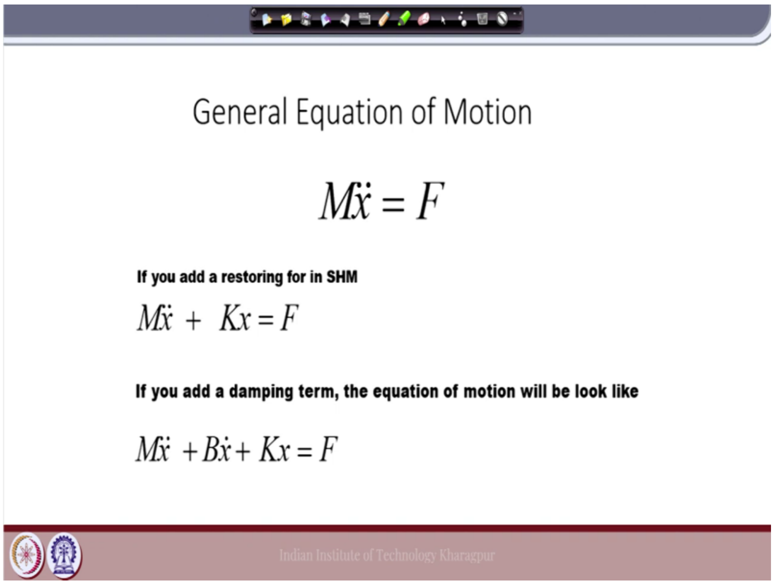

Now, let us start. Now, we know that this is the equation of motion we know the second law, Newton's second law of motion which is $M\ddot{x} = F$ and that is also we are apply here, but in a different form, right. And, now if you add the in a in equation of motion $M\ddot{x} = F$, if you add in the force, if you add the restoring component also then it becomes $M\ddot{x} + Kx = F$. So, it is called the simple harmonic motion.

And, now if you add the damping term in this equation which is there here you can see that $B\dot{x}$ a damping term I added. So, therefore, this equation of motion becomes $M\ddot{x}+B\dot{x}+Kx=F$, right. So, what is the equation of motion for in the domain of ship hydrodynamics? Let us see.

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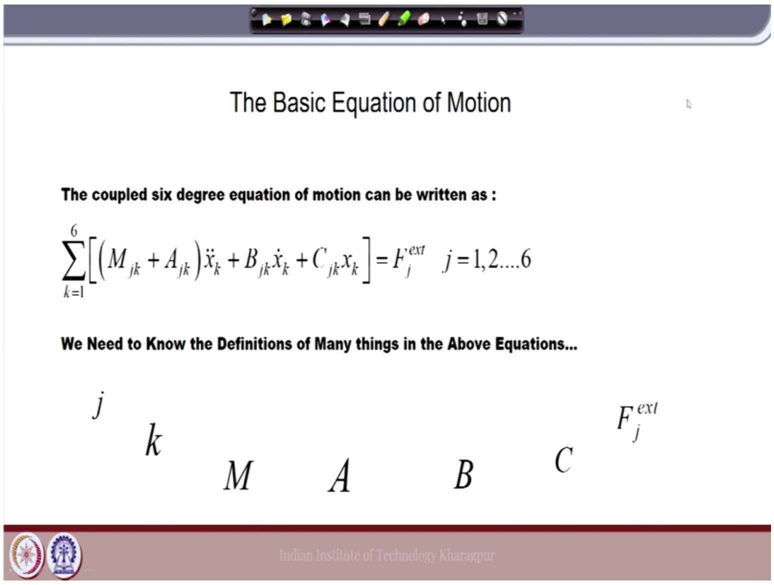

Now, this is the equation of motion that actually you are going to deal with. Now, here if you look at there is lot of lot of unknown parameters are here, right. So, as a part short it may be little bit complicated for you like so many unknown things that we do not really have any idea about many parameters. So, let us see one by one all these parameters.

Now, the first thing that is unknown to what is the meaning of the j, right, then may be the, what is the meaning of the K, right. Then of course, the M; so, M we can guess which is what is M. Then, but again what is A, because in your standard equation of motion you do not have the concept of A, but here you have something A what is the A?

Then you have B, then you have C and in the right hand side you have $F_{j_{ext}}$. So, now, let us try to understand one by one today at least like what is the meaning of all these parameters ok.

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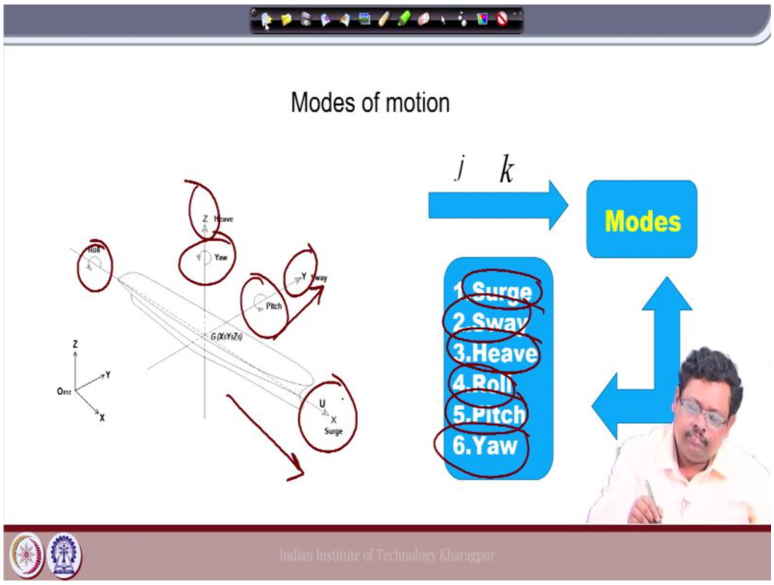

So, let us start with the j and k. Now, j and k is called the, the modes of the motion. Now, let us see that let us take my hand like if I ask that you know what is the degrees of freedom of this particular joint? So, you can see one because I can just move this way. However, you know we have this hand you can do this way and also may be this way. So, it has more degrees of freedom of course, and of course, our head so many things.

So, if you give me like; give me some object in my body I can see what is the degrees of freedom of that object. Now, same applies for a ship. Now, if you look at the car if I ask you what is the degrees of freedom for a car? So, you can see that car can move steadily take a right turn take a left turn, but it cannot you know go like this way right or it cannot jump, right.

However, if you look at the ship and if I ask you that what is the degrees of freedom of a ship, then you can see that we have the 6 degrees of freedom. Now, something called surge, something called sway, something called heave, something called roll, something called pitch, something called yaw. Now, what are these things? Let us try to check out.

Now, in this picture you can see that we have define in a, is a horizontal axis X and then you have the transverse axis Y and you have vertical axis Z, right. Now, a ship can move steadily in forward and this is my mode 1 which is called the surge, ok. Now, the ship also can slowly go in the direction of Y also.

You can see that ship is moving forward, but at the same time is slowly moving it is moving forward, but again it is slowly moving. In that case it is the 2nd mode which is called the sway and also when the ship is moving, ship actually can, you know oscillate vertically also right it moves, but then it moves like this way.

So, you can do all three things together. It can go slowly here with oscillation and then slowly drifting in the Y direction. Is moving forward, it oscillates and also slowly drifting. So, this third mode we can call is a heave, ok and then we have, it can also have a, some moment, angular motion also. Now, what is roll? Now, again if I think of the ship it is moving let me take, let me take this mobile as a ship.

Now, if we go forward at the same time it can do this also, right. So, that means, it goes here and also it can oscillate in this direction, in this plane and then if it is called the roll. So, you can see the roll is the moment about the X-axis. Now, similarly you know this look at this pen it go up and go down this also the ship is we can see that right the ship is moving this way also. So, in that case it is called the pitch ok.

Now, if you see that it is basically the movement about this axis, right and also which is [Laughter] very important now if it is comes near the port what happen? The ship turns also this way, right. So, here you have and then the ship is coming here and then it can turn in this X-Y plane, right. So, I have got the Z-axis and this we call is yaw ok.

So, therefore, the ship has 6 degrees of freedom of motion. It can go fast is called surge; it can go in the transverse direction, you can call sway; is definitely have heave; it has moment about the X-axis which is called the roll; moment about the Y-axis we called the pitch and also moment of the Z-axis we called as a yaw ok.

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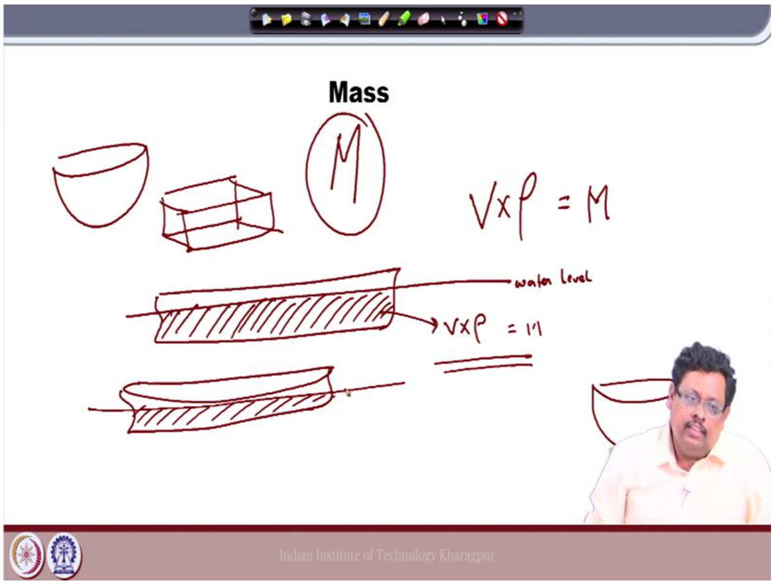

Now, the next term which basically we call the mass and actually you know it is *M*. Now, this mass how we calculate mass? Everybody knows how to calculate mass. Basically, if you know the volume *V* and if you multiply by the ρ, you can get the mass. Now, in case of a ship how we can calculate the mass and just see it is also easy, right. So, let us draw a simple like a rectangular or not rectangular kind of ship.

And, then this is my water level, and then, now this is called the weighted surface which is full of water, right and everybody know what is the Archimedes principle. So, we have to find out the volume of this weighted surface and then we need to multiply by the rho and then you can get the mass, right. So, getting mass is not basically a very difficult task.

But, however, how to get the underwater volume numerically that is the crucial part. Like you have you really do not have a problem like if I, if I consider, let us say something called a south hemisphere, right. So, if you have a hemisphere you have no problem you know that exactly analytically what is the volume of this hemisphere.

Now, if I take a rectangular barge or you can say box, right. You know you really do not have any problem you know that what exactly the volume of this. So, for the regular geometry you know every time you know that what is how to get the volume.

But, the problem is when you get the typically ship shape body when you get a typically ship shape body kind of this and then what is the underwater volume that time is really is not a very elementary task and you lot of numerical calculations to do that. Definitely, we are going to discuss in coming days how to calculate this mass and all because this is important to find out the solutions, ok.

Now, but, but now that let us, let us find out the other parameters.

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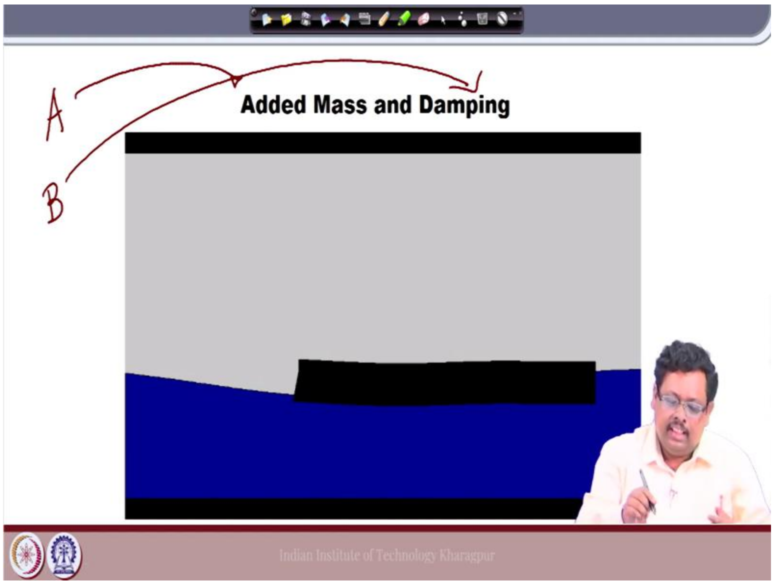

Now, like *A* we have this *A* in this solution and also we have this called *B*. Now, this *A* is stands for the added mass and then *B* is stands for the damping. Now, what is actually this added mass and damping that we need to know and that is very important concept for this particular you know course.

Now, how to calculate the added mass, how to calculate the damping, this is how actually this all about this course how numerically obtained this. But, before that you must have an idea that what is called added mass and what is the; what is called the force because of this and what is the force because of this term *B* or damping.

To realize this let us try to see this video once. Now, if you look at this video carefully you can see that there is a phase lag between the waves as well as the- the motion of the body. Now, look at this typical thing. Here you can see the waves actually coming down. However, at this time this you know the ship is moving up. Now, you can see very clearly here, right. Let us see. Now, you see here, the - the wave is going up. However, the ship is moving down you see. Now, you can so, you see the this is something called phase and this is very important for us and this actually play crucial role to obtain what is about the added mass and what is about the damping.

Now, let us say that it is always happened here in for all joint also we normally see that we have a pen over here and then if I oscillate the pen now you can see that I as I move my hand the pen and my hand has perfect coordination. But, if I move faster, then you can see that when actually I go down this hand that pen is moving up and if I move up the pen is moving down.

So, that means, that when I apply the force to the pen immediately you know the pen is not reacting. So, it always happens right, in normal life also if you some sometimes, right. If you get some shock, you get some time to react, right. So, that is something called the phase lag, right.

So, which is which is happening over here. You can see again let us see the see the video again it is very interesting to understand this concept. Now, when that body is get hit by the waves and then when the body is reacting there is a gap and this gap is called basically the phase lag, ok.

Now, let us understand that what is the phase lag once again like I have another video. Let us see what is the phase lag? Let us see this video.

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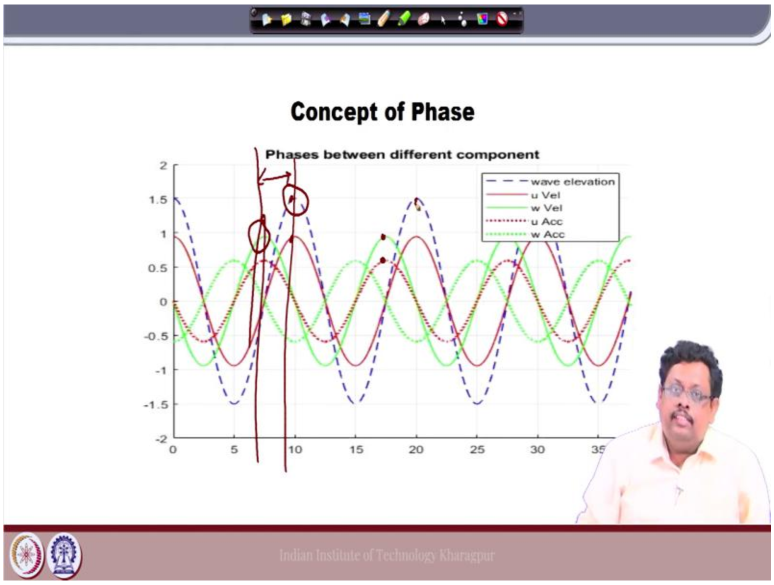

Now, you can see that there is a different component like we are really going to discuss later on what is *u*, *v*, *w* etcetera etcetera, but now let us we get sufficient to understand the concept of the phase lag. Now, you can see that all are harmonic function, but all the functions have some kind of phase lag.

All are not oscillating all in same time; that means, that what I am trying to say is that if you look at this you know the blue and the green. So, the blue is get at this point it becomes maximum. Now, you can see the green is maximum at this point. So, therefore, we can see that you know there is a phase lag.

Now, you can see the red and now red and blue both are in the same phase right because both get the maximum at the same time right and you can see like the dotted line and the green line both are almost the same phase, right. However, the dotted line and the green line the blue line has a phase difference and then the green line and the blue line also has a phase difference. So, this is the meaning of the phase difference.

Now, let us try to find out that how this phase difference actually you know help me to find out this added mass and damping ok.

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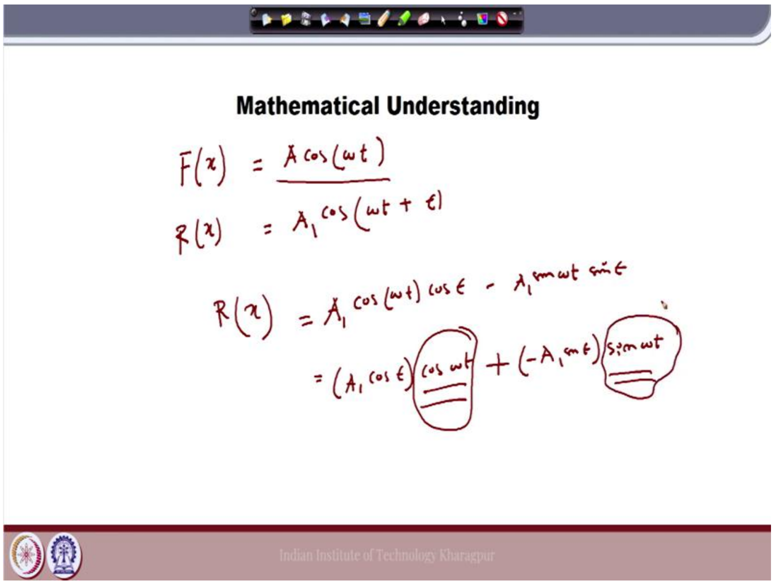

So, let us see that what is the mathematical concept behind this or what is the mathematical understanding behind this. Now, let us see that waves you know I assume that everything is a harmonic function. So, I can let us write a harmonic function.

So, let us take this is the forces is which is applied you know to the ship which is let us say at some amplitude A and then it is with some frequency ω. So, this may be the thing and then because of this the reaction force. So, we can call this $R(x)$. So, it has some another amplitude A_1 and then the response also in the same ω, $\cos\omega t$, but now it has some kind of a phase epsilon, right.

So, now you see like I am so, what I am just the same thing that I just say right now like if you look at this green dot in the previous slide and then the red one now there is a phase lag. So, if you consider one is basically the force and then another one is a response. So, definitely you can see that there is a gap and this is a steady gap of epsilon let us say now this reaction force $R(x)$.

Now, if I just simply break this. So, you can say the $A_1\cos(\omega t)\cos\varepsilon - A_1\sin(\omega t)\sin\varepsilon$ and then you have $A_1\cos(\omega t)\cos\varepsilon$ and you can just simply write A. So, it is $-A_1\sin(\omega t)\sin\varepsilon$, ok.

Now, you see we have come to a very interesting thing. we started with a harmonic motion $\cos\omega t$ now we can see that it actually have, you know two different component, right. One is with goes with the $\cos\omega t$ and then another goes with the $\sin\omega t$, right.

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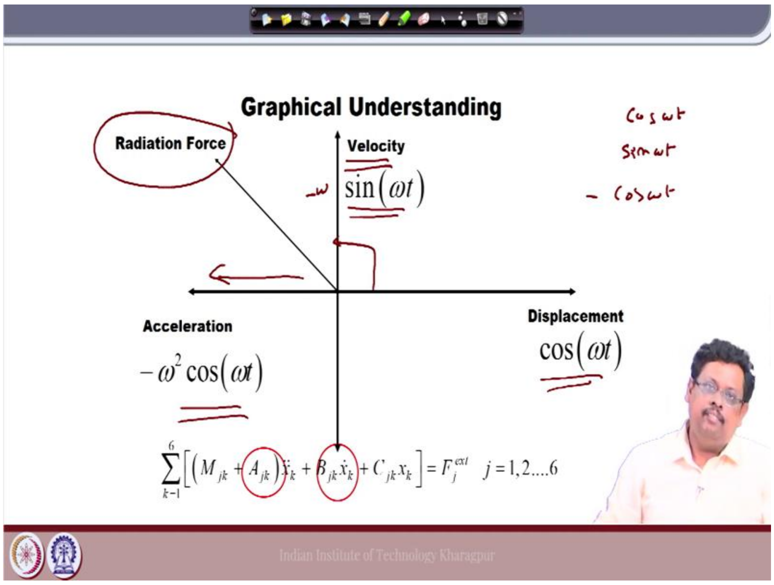

Then what is the meaning of this? Let us see try to understand graphically what is the meaning of this. Now, you see like now I understand now here we have to understand that all the forces are basically harmonic in nature. So, it is either $\sin\omega t$ or $\cos\omega t$.

Now, if you write here like if you now I see that if the displacement if you say it is $\cos\omega t$ and if you differentiate with respect to you know t. So, ok I just write this it should be know it is minus omega should be here like if I make it more correct. But, however, I am only interested about the *sin* and *cos* term. So, then the velocity is definitely with you know, $\sin\omega t$.

And, again if you differentiate further which is the component of the acceleration and it in again is a $-\cos\omega t$. Now, what is happening? So, it everything has a 90° phase lag, right. So, it means that if you write a harmonic function to that when this one is actually the maximum this *cos* term goes to 0, when *cos* goes to maximum *sin* goes to 0, right.

So, it called it is called a 90° phase lag, right. So, and again you can see that *cos* this displacement and the acceleration also has a you know 180° phase lag. So, when it got the peak is the minimum, when it is got the maximum it gives the minimum.

So, 90° phase lag means when the displacement is maximum then velocity should go to 0, when the velocity go to maximum displacement should be 0, when displacement is maximum the acceleration should be minimum, when the acceleration maximum the displacement is minimum.

However, the radiation force, what is the meaning of the radiation force? It says that body is oscillating and then as I said that in my previous slide about this radiation force is that when if you remember that we discussed that when the ship start oscillating it create waves right and this waves are called the radiated wave, right.

Now, my argument is that when the ship starts oscillating and when it creates the waves it has a phase lag ok. Now, when something starts oscillating definitely you have a pressure field around the body and because you have a pressure field around the body and then you have some forces, and this wave got created because of this force and that is why the name of this force is called the radiation force, ok.

This radian radiation force comes when the body start oscillating, right. If you remember my previous slide in the previous lecture we initially we start the body start oscillating and because of that some wave got created and that wave is called the radiated wave, ok.

Now, we understand this radiation force is because it has some phase lag. So, it definitely it has some component which actually you know in the direction of the velocity and then it has some another component definitely which is the direction of the acceleration, ok.

Now, now the, the force which is direction of the you know acceleration we let us see, yeah. Now, the force the direction of the acceleration we called which is called the added mass and we define this as *A*. And, the component which is basically going with the velocity we call this component is damping and it denoted as the *B*.

Now, you understand, right? We oscillate the body it is harmonic, it is $\sin\omega t$ or $\cos\omega t$ anything and then the response takes some time like I start the body start oscillating and then there is some phase lag of epsilon and then we have the radiation force. So, therefore, the signal of the radiation force should be again $\cos\omega t$, but with a phase epsilon (ε).

And, because of this phase lag we can have physically I can see that one component is actually along the velocity and another component is along the acceleration. The component along the acceleration we call added mass and the component along the velocity we called the damping. Now, why the name of the added mass you know is very well it is with the acceleration, right. So, it is basically kind of inertial forces, right.

So, therefore, we call mass multiplied by acceleration we can call inertial force. So, that is it is something is added with the mass we call it is an added mass and something called the radiation damping; it is nothing to do with the structural damping. It is the damping because comes from the radiation force you can call it is a radiation damping, right, ok.

So, somehow at least we understand some concept about the added mass and damping the physically why this added mass is coming right? that is why that is why I will tell you that when in a very low frequency region assume that you are actually in beach and then wave is coming and then you can see that you are just you know your body is just moving with the waves, right.

So, it you remember at that particular time there is no phase lag that when the wave gets the peak you go up, right when waves amplitude minimum you go down. So, your movement and the movement by the waves is there is no phase lag, right. So, that time probably do not experience this such radiation forces.

However, if that is not happening like when actually the waves going up and you are going down and if you have some kind of phase lag then you are going to you know experience all this sort of radiation force, right. So, that is why you do not feel in beach that what is the radiation force, but in middle of the ocean the ship experience is very much and it is huge. Anyway, so, this is something concept of the radiation force we understand A and B also.

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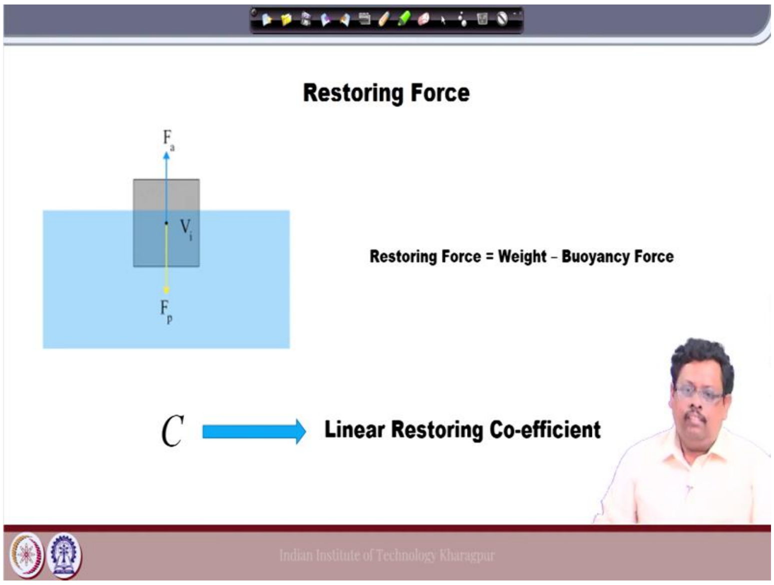

Now, let us try to understand about the another component which is the *C* or the restoring forces, right. If you remember that equation of motion we have some term *C* also, right.

So, today in this lecture we are just try to understand the different part of this equation of motion and later stage actually we are going to find out the numerical technique to obtain such forces. Anyway, So, let us coming back to this *C* term which is called the restoring force which is basically the difference between the wave and the buoyancy force, ok.

Now, this is the classical thing it difference between the weight and the buoyancy. Now, we are doing the linearity as you know that we are actually dealing with the linearity. So, therefore, we must introduce some linear coefficient. So, we introduce a linear restoring coefficient we call it *C*, ok.

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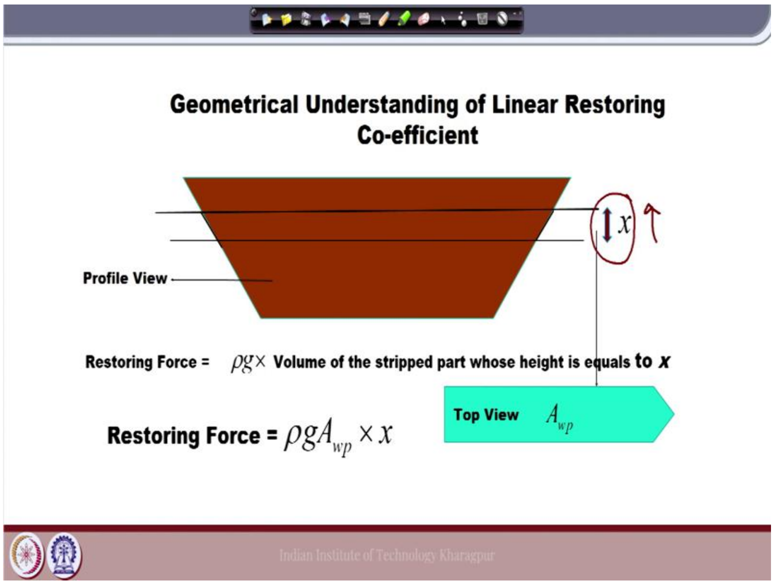

So, now what is *C*? Now, if this is you're the-the -the profile view and let us say that at some point of time when the ship is moving up little bit, okay? Ship is moving from here to here little bit and if this displacement is let us say x, ok, so, then, then the restoring component is nothing, but that ρg into this displacement and this is called the linear restoring component, ok.

Now, if you look at the top and what is the volume of the stripped part that let us try to find out. If you look at the top view from the ship so, you can see this is basically the top view and this component actually we can call this a water plane area. So, therefore, what is the volume? The volume is basically this water plane area multiplied by this distance. So, therefore, my restoring force component is $\rho g A_{wp} \times x$, ok, fine.

So, we are going to discuss more on this later stage that how we calculate the restoring forces and all definitely, but today we just have an idea about what is this forces, right. Here it is nothing but the displacement of the vessel multiplied by the water plane area which is basically the if you look at the top view you can find out and if you multiply by the ρg, this is the typical hydrostatic force or restoring force.

Now, concept of exciting force today we are not going to discuss this is a complex phenomena and when actually we study later about the exciting force let us coming back to this slide. Now, here in this section at least we can discuss everything now. We can discuss about the j, we discuss about the k, we discuss about the M, we discussed about the A, B, C, but three things we did not discuss.

One thing that we did, we did not discuss about this you know that exciting force this one we did not discuss and also we did not discuss this jk term what is doing here, right. So, this part also we did not discuss. So, in our coming lectures we are going to discuss everything, but today we are going to stop here.

Thank you.