Numerical Ship and Offshore Hydrodynamics
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Lecture - 59
Including Non Linear Forces in BEM Code (Contd.)

Hello, welcome to Numerical Ship and Offshore Hydrodynamics, today is the lecture 59.

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Today we continue the discussion that we have done in last class that how we can incorporate the green water load, after that actually we are going to discuss something on the slamming load. Now the green water load we apply for a rigid structure ok. However, this slamming and green water load again we apply for both flexible structure in the next, ok.

And then we are going to discuss that something on the three-step boundary element FEM CFD based method. Now this in this full course that we do not touch CFD because it is a several aspects and it is out of the scope of this course; however, I would like to introduce some part of it. So, that you can have an exposure that frankly speaking if you really want to have a deep study on this you have to have some CFD based approach ok.

I mean the Navier-Stokes based approach to do that anyway or maybe some particle-based approach called smooth particle hydrodynamics. So, those things are required. But; however, suppose he the why I put it here the simple reason is that if you have that particular solver the NS solver or the (Refer Time: 01:48) based solver how beautifully you can use it here that again we are going to discuss. So, this is the idea of having some discussion on that part also ok.

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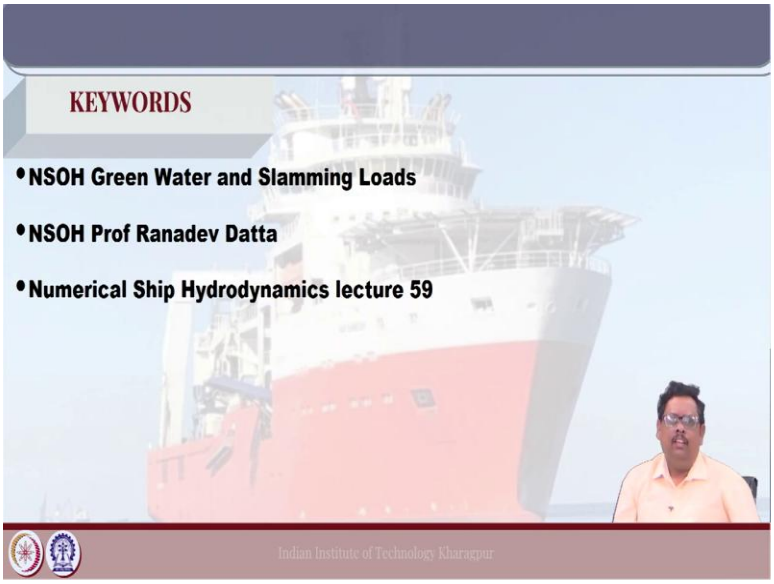

So, and this is the key word that you have to use to get this lecture.

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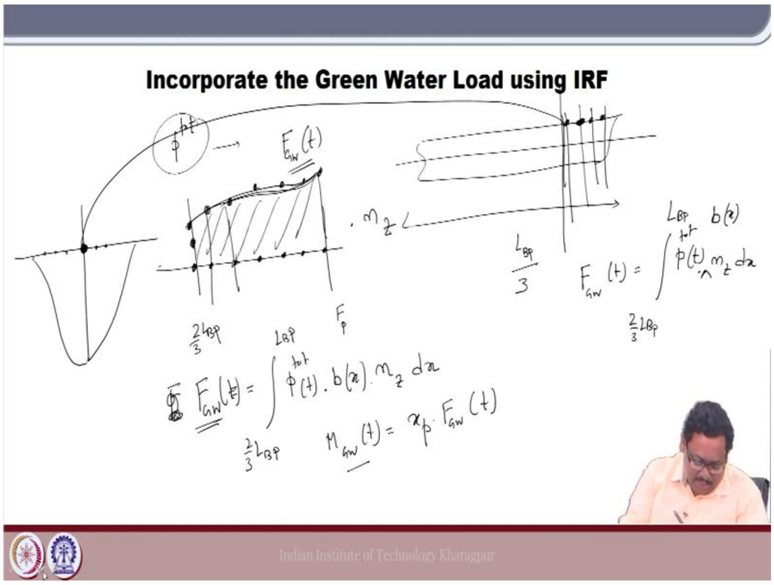

Now let us start that how we can incorporate the green water load using the IRF based method. Now in the previous class we actually find out that how we can get the p total or we can call the P^{tot}, it is the pressure; however, we need a green water load or we call this as you know green water. So, just $F_{GW}(t)$. So, we need actually the green water load not the pressure.

Now here you can see like if I have let me draw again this picture. We say that we are having the pressure at this particular point. Now as I said there are various way actually, I can convert this pressure to the load or the force. Now here you have this pressure and then what you can do is that you can do some cross sections along this along the length.

Now, normally if the length between perpendicular or L_{BP} is the length between perpendicular. So, we can actually try to figure out what is the green water load till $\frac{L_{BP}}{3}$. So, that may be the good estimation of this. Now, what we can do is till $\frac{L_{BP}}{3}$ I can take lot of stations and then each station actually I can get the green water pressure.

Now so, therefore, what you can get. So, now, this is my stations from you know the forward perpendicular this is my forward perpendicular and this is actually if I calculate from here this may be the $\frac{2}{3}L_{BP}$ let us called ok. So, from this point; so, from this point actually you are trying to calculate the green water pressure all the points.

So, maybe you can have this is the load I mean it should be less this is the load, this is the load, maybe this is the load, this is the load, this is the load you know let us say this is the load. So, I can get a curve like this or we can call it is the pressure curve. Now if we integrate the entire thing and if you multiple multiply by n_z then definitely you can get the green water load. So, so this is one way of getting it. So, green water $F_{GW}(t)$ it is nothing but $F_{GW}(t) = \int_{\frac{2}{3}L_{BP}}^{L_{BP}} P^{tot}(t)b(x)n_z dx$. So, that should be the force. Now once you have the force if you multiply with the now the moment. So, $M_{GW}(t) = x_p.F_{GW}(t)$. So, this is the two equations that actually I can get the green water load.

Now this is this approach is fair enough one can take it, but suppose if your idea to just give some approximation using some approximation here also. So, sometimes you know what normally you know as a homework what you can take is as follows like what you could do is.

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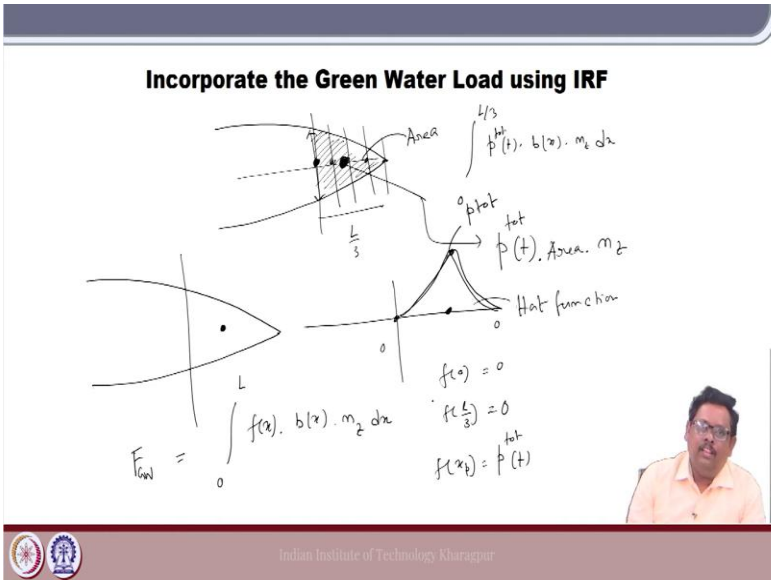

Now, if I see the ship from the top. So, let us say this is the ship and suppose you are getting at this particular point you are getting the pressure. So, what we you could do is as follows you have to understand that sometimes maybe you the best idea is to you get everywhere you get as I said you get the pressure at each point.

So, then what you are doing? So, you need this pressure and now this length is nothing but $\frac{L}{3}$. So, you integrate this. In fact, this and this both are same and then again you can find out the pressure. So, that is what I said the $\int_0^{L/3} P^{tot}(t)b(x)n_z dx$. So, this is one thing.

Now, the other part what you could do as follows; you take a middle point somewhere here a single point ok, and then you can get the area. Now, this is let us say this is the area of this particular thing and this is any arbitrary point ok. So, what you can do it as a homework you take this point and you calculate $P^{tot}(t).Area.n_z$.

So, this is another way you could do that. Now third way that, that third alternative way you can again do the same thing as follows. I am drawing again the same thing here. So, I pick this point now I am drawing the profile view like this. So, now, this is the $\frac{L}{3}$ I am picking the middle point of the $\frac{L}{3}$ and I can approximate a function, which actually behave like a polynomial or kind of a impulse function kind of thing because. So, so we can approximate a function.

So, you can call this a hat function now it is not actually hat it is not linear. So, it is you know it is up to you we can fit a cubic polynomial or even you can try with Gaussian also that is what the idea of the smooth particle hydrodynamics itself. So, from that also we can get this idea like you can fit a polynomial curve.

So, here that value is 0, here this value is 0 and here that value is equals to P^{tot} and then you fit a cubic cut and then when you calculate the green water load. So, at that point you can use that $F_{GW} = \int_0^L f(x).b(x).n_z dx$ that is also possible.

Now, why this $f(x)$ is $f(x)$ now here we can say that $f(0) = 0$, now $f\left(\frac{L}{3}\right) = 0$ and then $f(x_p) = P^{tot}$. That is the nature of the curve and then you can approximate some kind of this function $f(x)$ and again you can do this green water loading. So, that is how we can approximate the green water load. So, this is; so, this is one now how you can incorporate into the IRF based solutions.

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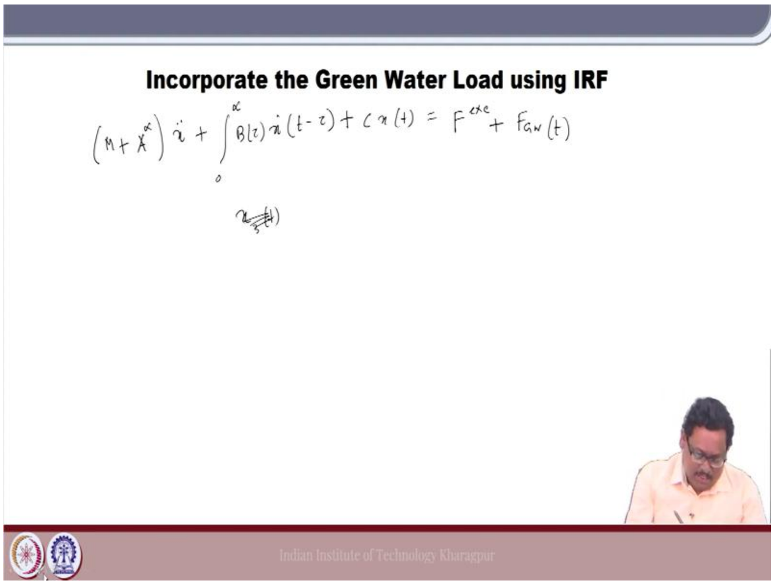

Now, if I if you know that what is the IRF based solution, I am just writing a single degree of freedom because you can extend this very well. So, it is $(M + A^{\infty})\ddot{x} + \int_{0}^{\infty} B(\tau)\dot{x}(t-\tau) + Cx(t) = F^{exc} + F_{GW}(t)$ ok.

So, now this is how actually one can incorporate the green water loading into the IRF based solution ok. Now, you know that how to write the algorithm very well right. So, here you will get the value for the heave. So, from here you could get the value for let us say $x_3(t)$ now if you use now here you.

So, here $x_5(t) = 0$. So, you cannot get the full benefit of it of course, in order to get that you have to incorporate the coupled equation also right. So, I am just writing it if you suppose if I want to solve heave and pitch coupling then how we could do that ok. Let me write it and then we can move to the next topic ok.

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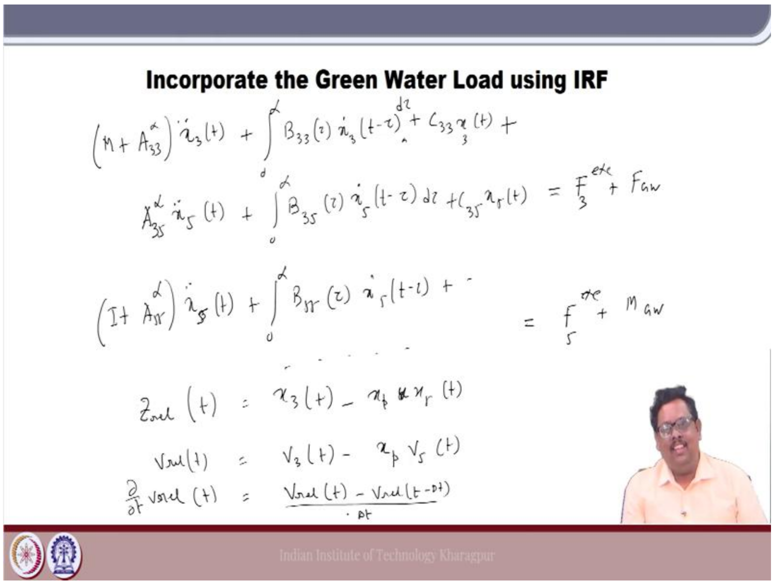

I am just quickly writing it. So, it should be $(M + A_{33}^{\infty})\ddot{x}_3(t) + \int_0^{\infty} B_{33}(\tau)\dot{x}_3(t-\tau)d\tau + C_{33}x_3(t) + A_{35}^{\infty}\ddot{x}_5(t) + \int_0^{\infty} B_{35}(\tau)\dot{x}_5(t-\tau)d\tau + C_{35}x_5(t) = F_3^{exc} + F_{GW}(t)$ And then similarly we have to write for the $(I + A_{55}^{\infty})\ddot{x}_5(t) + \int_0^{\infty} B_{55}(\tau)\dot{x}_5(t-\tau)d\tau + ... = F_5^{exc} + M_{GW}$. Now this is how actually you can use this green water and then we can find the value right.

And one thing actually I forgot numerically how we can get the now I know how we get the Z_{rel} and $Z_{rel}(t) = x_3(t) - x_p x_5(t)$ right. So, then actually $V_{rel}(t)$ also similar way we can get it is $V_{rel}(t) = V_3(t) - x_p x_5(t)$ right.

Now you have problem with the derivative of the $V_{rel}(t)$ because you have to find out $\frac{\partial}{\partial t}V_{rel}(t)$ that also you need to find right how get the derivative of the $V_{rel}(t)$ then you know that is actually you can use the forward difference scheme. So, you can take $\frac{\partial}{\partial t}V_{rel}(t) = \frac{V_{rel}(t) - V_{rel}(t-\Delta t)}{\Delta t}$ ok.

So, now I think you are ready to incorporate this green water into the solution of your IRF based system. So, try to do that I think by this time we have already the code for the IRF based solution. So, now, we just incorporate this term into the IRF based solution.

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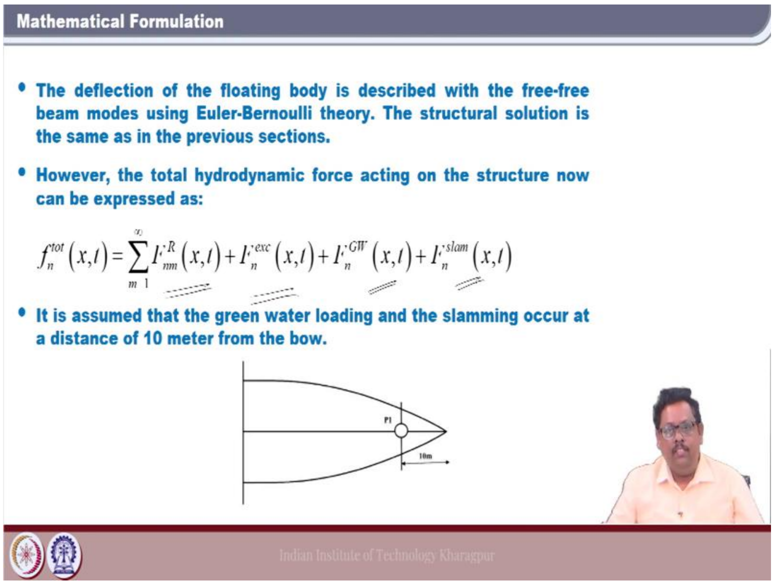

Now let me now just move into the next part that the slamming. Now, here what I am going to do is that I am just giving you the key aspect of it and then I will I just see suppose you have this hydrodynamic code the semi analytic code. How can incorporate the green water and the slamming now this is the whole setup?

Now here the F total again you know this combination of this exciting force plus radiation force and then you need to add again in the right-hand side these two terms right. Now how we can write it using the semi analytic method or the mod of super.

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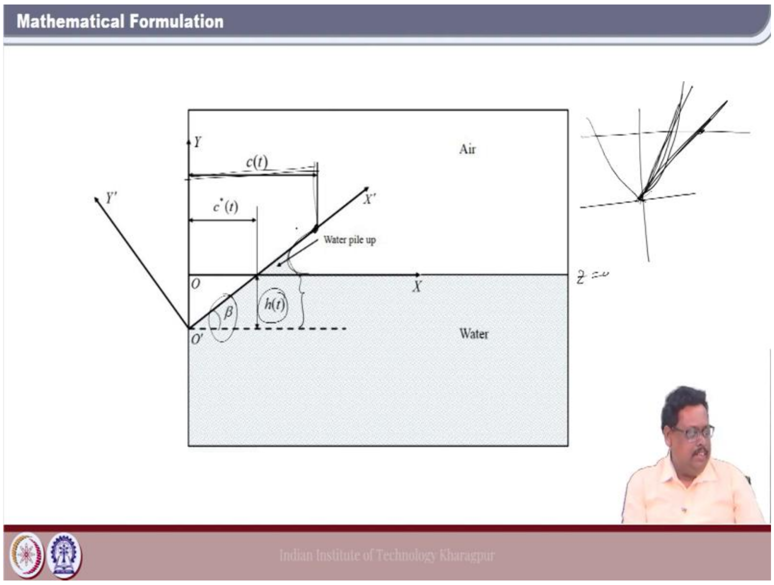

Before that actually it is the Wagner theory it is very well-known theory, you can refer this classical Wagner and also at the end I put the reference from that book also you can get that the final expression of the slamming load.

Now, but just to give you a brief that suppose this is the this is the half breadth of the. So, it is a you know like if this is the ship not the ship now here is the body plane now this one is this line. Now this actually penetrate into the water and because of that some water is piled up right now this part is basically the free surface.

Now, this is the distance from this half you can say that the middle plane ok. So, that YZ plane passing through Y equal to 0. So, XZ plane passing through Y equal to 0. So, this is this one is that line actually the body plane and this is the line the symmetric line. So, now, I just taking the half part of it right. So, so this distance is the c.

And now if I take this angle as beta because is a slope, we can take the slope also because mostly the ship is not like this. So, may be the if this is the line of the ship. So, we can take the slope also and this is the angle beta and now this point is actually it is $Z = 0$. So, so h t is the how it penetrates into the water from there to the $Z = 0$ is $h(t)$ and now this is the setup.

Now, if we if you find out that what is the value of $h(t)$ and what is the value of the β and then it this is the point actually till this point actually ship. So, this is the free surface. So, you know this point.

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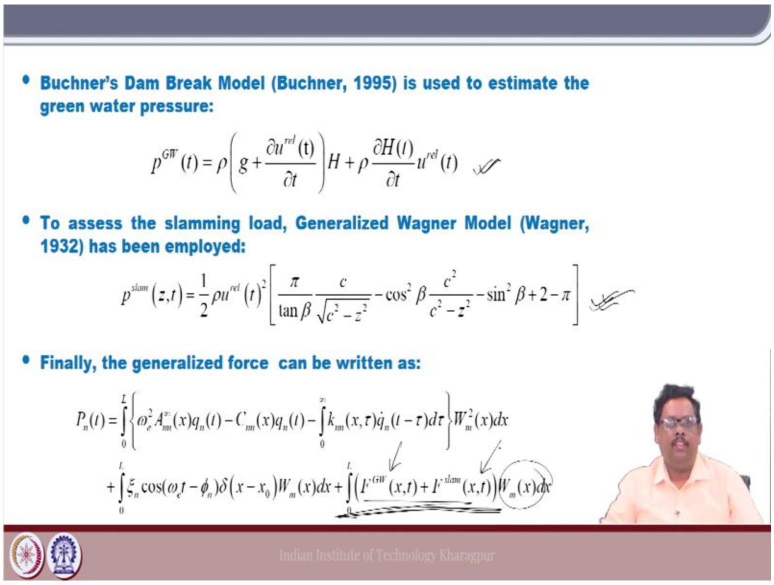

So, you know this distance also, once you know this data then you can directly use the that slamming pressure with respect to this formula. Now here you can see here that beta you know, you know the relative velocity of course. We discussed a lot about the relative velocity you know what is the *C* that is the distance between the *Y= 0* to the free surface that that *Y* distance ok.

So, then you know what is the slamming pressure and this is how actually incorporate the green water pressure. So, these two I mean this we discussed a lot this we are simply using this the Wagner formula. Now idea is how I can incorporate so, in the solution. Now, if you look at this solution here, I am integrating actually it is from because it is we have to do that from *0* to *L*.

Now here the idea is how I can incorporate the green water load and then and the slamming load into this particular solution right. Now here this is the little bit tricky part I would say it is not complex of course, but how I write this the green water and how I can write the slamming.

Now, the idea is when you calculate the green water and the slamming you can take a rigid body mode and then you can get the pressure assuming that it is a rigid body mode and then you can multiply with the mode shape to get the slamming load as well as the green water load. So, this is the idea.

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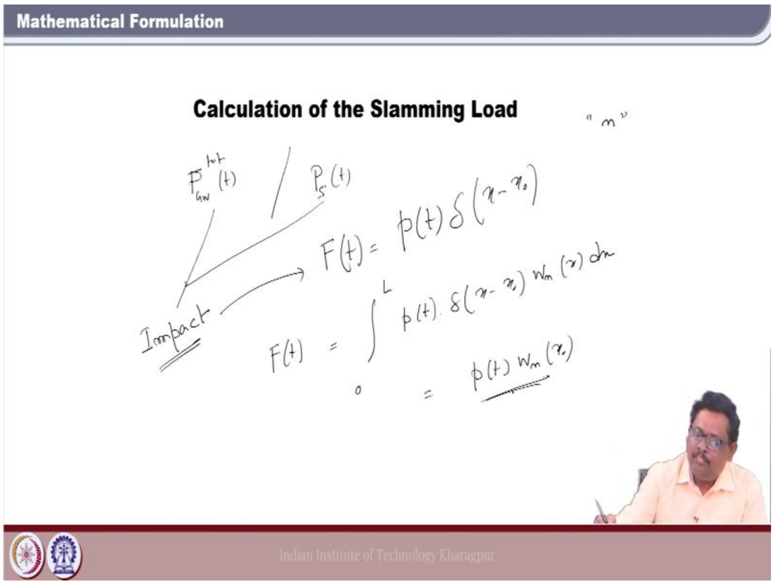

So, now, the again the that. In fact, it is not the slamming even the green water load also which is the same. So, you assume a rigid body. So, we assume a rigid body and then you calculate what is the P_{GW}^{tot} and we can calculate using the Wagner method what is the now slam.

So, I just write $P_s(t)$ that slamming pressure at the point at any time t. Now, there is a many ways to replicate this. The popular idea as I said that you can assume this as the impact load which is normal if you look at this journal paper everywhere it is we can call the both are kind of impact.

So, then impact let us the best way to define this that that load that *F(t)* and whatever the green water or it is slamming does not matter you can just write that $F(t) = P(t)\delta(x - x_0)$.

You can do that; this is one way of doing it right. In fact, this is the best way of doing it assuming that it is a this is an impact load impacting on that particular thing and then when you integrate it along with the length. So, then you will get that now then. In fact, suppose I am talking for the mode shape the mode n some arbitrary mode. So, therefore, when you do that then my total force $F(t) = \int_0^L P(t)\delta(x - x_0)\omega_n(x)dx$ which is tells you nothing but $P(t)\omega_n(x_0)$.

So, so, this is way you can get in now what the idea is you have this ship let me just draw the ship and let me explain let me erase some part of it because I want to have these things. So, just erasing this part I am showing you. Now idea what the idea is as follows what I am thinking that this is along the length, ok.

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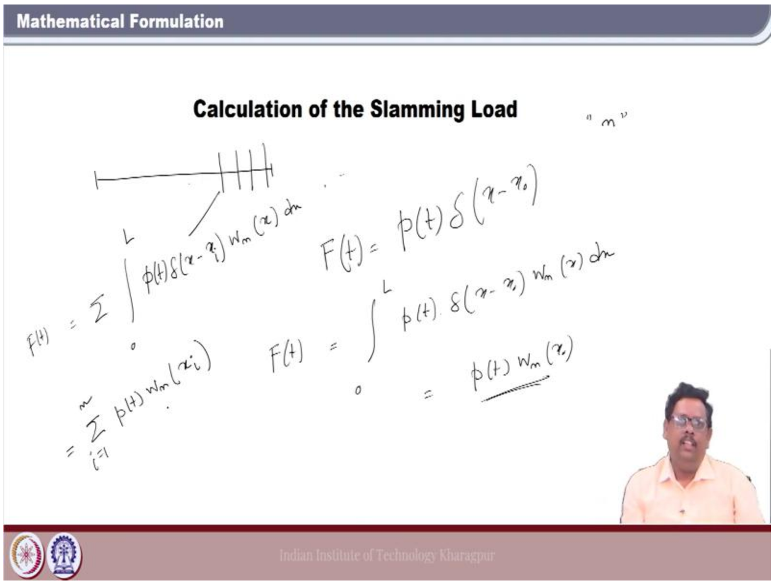

And then you are having some sections and each section you are calculating the total force $F(t) = \sum \int_0^L P(t)\delta(x - x_i)\omega_n(x)d$.

So, what is happening actually the total force you are getting let us say you can make let us say n sections let us say. So, it is become $F(t) = \sum_{i=1}^{n} P(t)\omega_n(x_i)$. So, that is how actually you can approximate the slamming load.

So, this is many ways you can do that right you take the pressure at each point and you multiply with a δ function and then actually you can integrate along the length.

So, this is how you can incorporate the slamming load. You see that is what actually he has done I mean in this expression also the same thing has been done we multiply this with this the mod shape right, ok. So, now this is how we can incorporate in the flexible code also the slamming and the green water.

Now as I told you that in the last part of this very quickly, we are going to show you that a three-step method ok. And if you have this panel method code or if you have the boundary element code and then if you can develop this CFD based method then actually very rigorous way you can calculate the effect of the slamming and the green water into the hydro elastic code.

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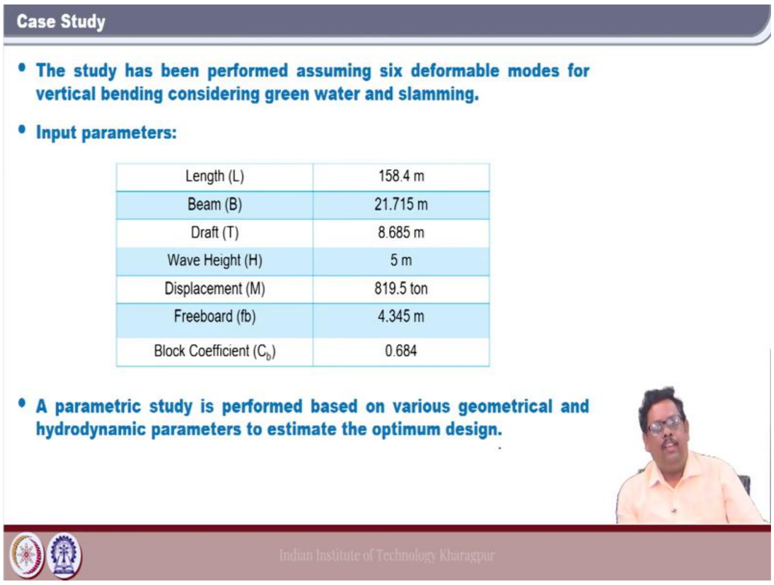

Now you see ok.

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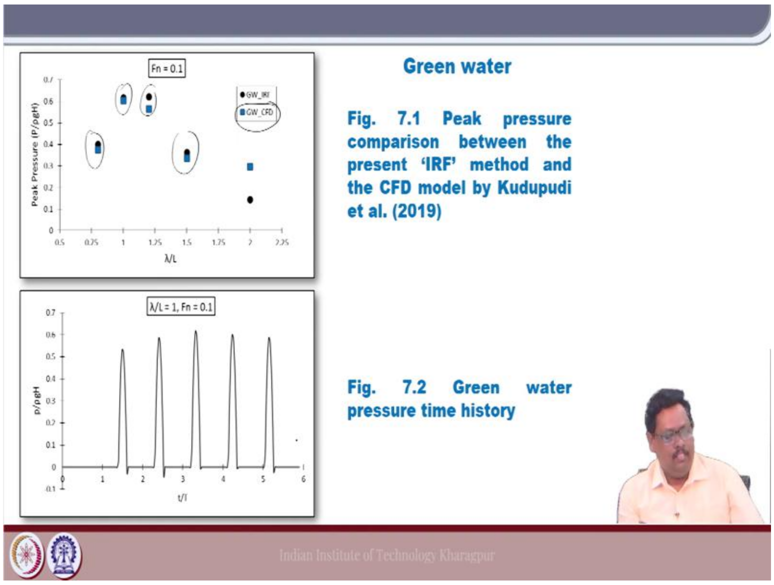

Before that I just show you this the results you can see here using this semi analytic method that you know this compared with the proper the CFD result as I told you that this method may not be very well capture the detailed phenomena, but if you talking about the magnitude of the force, it actually really captures very well the magnitude of the force right and the sometime history for the green water load.

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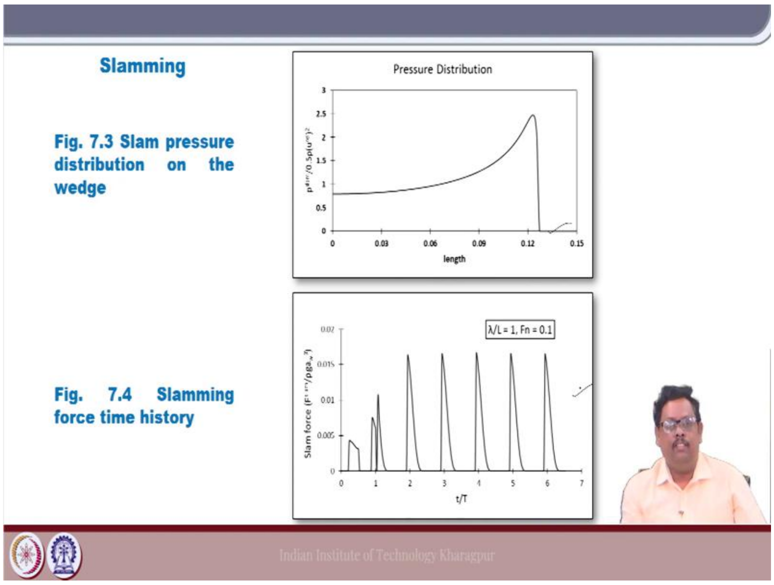

Now, similarly for the slamming load also this is how actually the pressure varies if you know see some paper or some published paper you can see that the slamming load normally varies along the wedge in this fashion it is from 0 it goes max and suddenly dropped and that is how actually we can get the that pressure history of the slamming load also.

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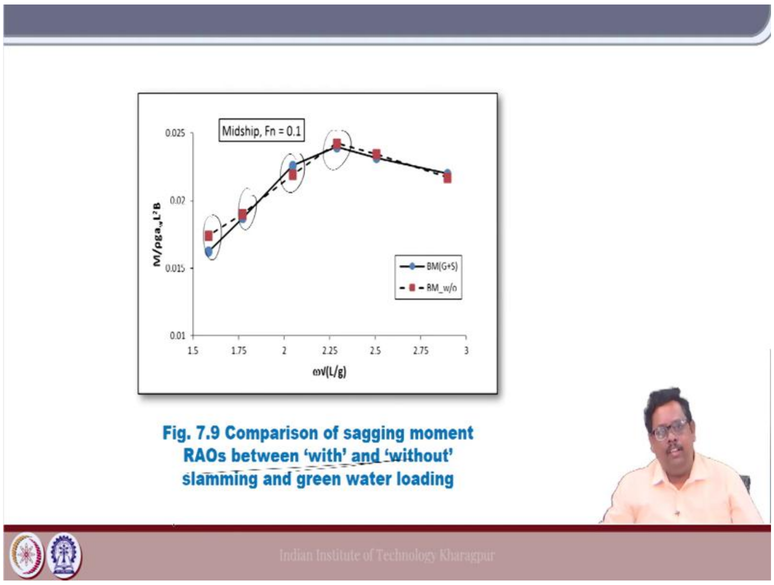

So, you can see that at least you can now you can see that there is some effect also some visible effect also one can see. Now it is actually on the you know that some RAO's of the sagging moment. So, you can see that it has some kind of effect right ok.

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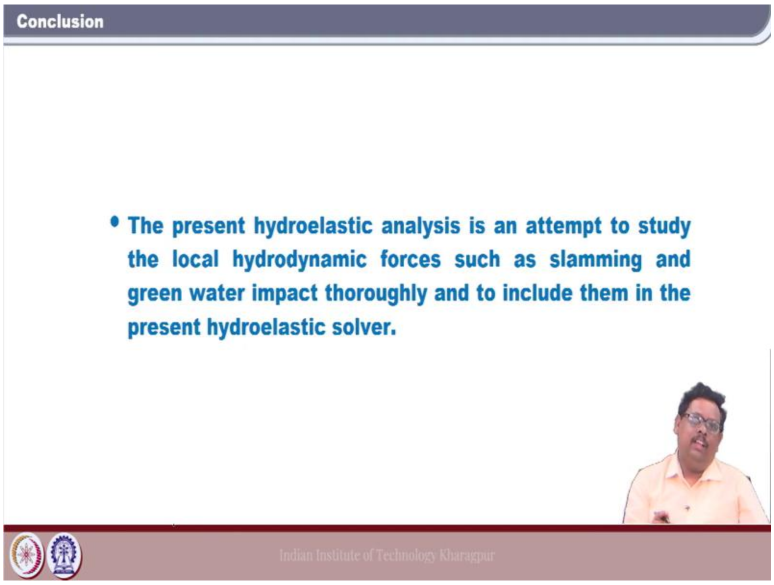

So, now, later this present hydroelastic analysis is just attempt to study that how we can incorporate the hydrodynamic load into the, you know into this hydroelastic solver right ok. So, let us move into the next problem.

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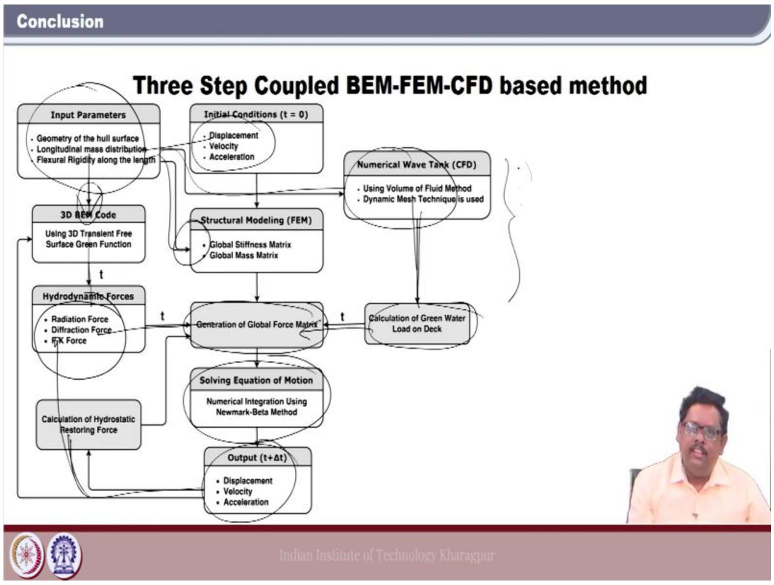

Now here let me discuss very quickly I will discuss about the three-step coupled BEM FEM CFD based method. Now this is the flow chart now here I just go quickly that we have this input parameter over here and then we initialize all this data right. And then actually from here we can go in three different solvers, we first move to the structural solver we go to the boundary element solver and again we go to the CFD solver.

Now, from this boundary element solver I calculate the all these global forces which is radiation, diffraction, Froude-Krylov and we pass into the JLIS force matrix from here also we can calculate from CFD the green water and I mean that green water load and then we can find in the store in the global matrix.

Now, then we solving the equation of motion we get the displacement velocity acceleration and again we can back to the BEM solver, but here it is a three-step method. So, this whole exercise actually we are assuming the body is rigid and we are calculating the green water load. So, here we are not coupled it that is why we call the three-step method; that means, initially you give some rigid body motion to the solver.

And you calculate separately the slamming load and then that slamming load we incorporate into the finite element solver ok. Why it is justified? Because we assume that that you know that elastic mode does not affect the slamming load as such it is only the rigid mode which affects the slamming load.

So, that is why we did not consider the flexible mode only consider the rigid mode and we calculate the slamming load. Then, however, this slamming load influence the structural deflection. So, that is why we are using this three-step method ok.

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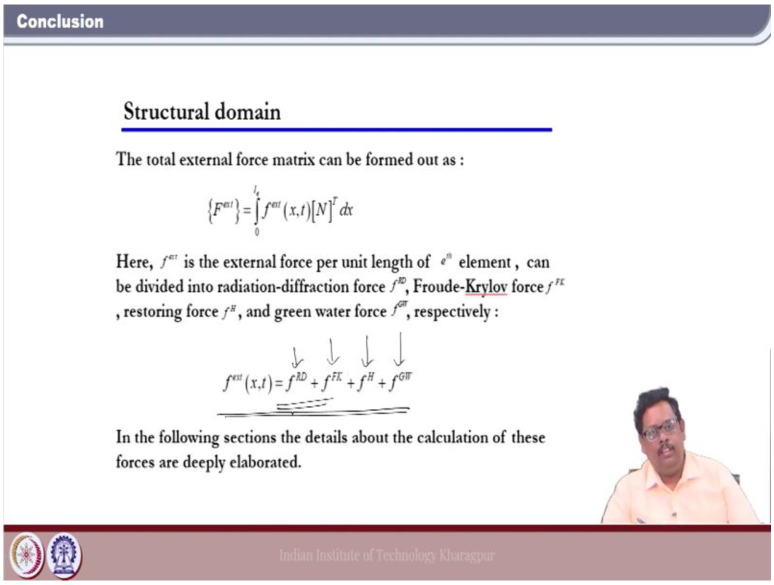

Now here we can see that the total force here it is the due to radiation, due to Froude-Krylov, due to hydrostatic and due to green water right. Now here the radiation and Froude-Krylov is directly coming from our BEM solver, right.

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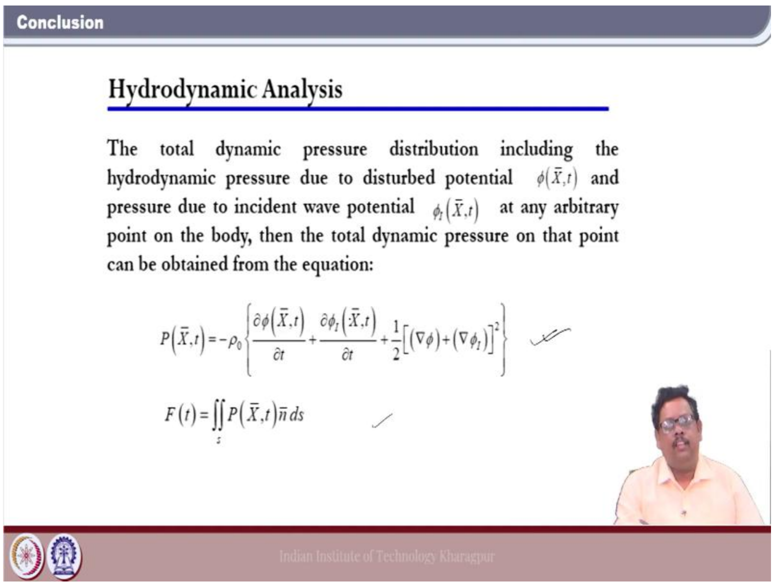

So, now you know that this is the pressure and we know how to get this pressure from the hydrodynamic code. So, we discussed a lot. So, this is how we are getting it.

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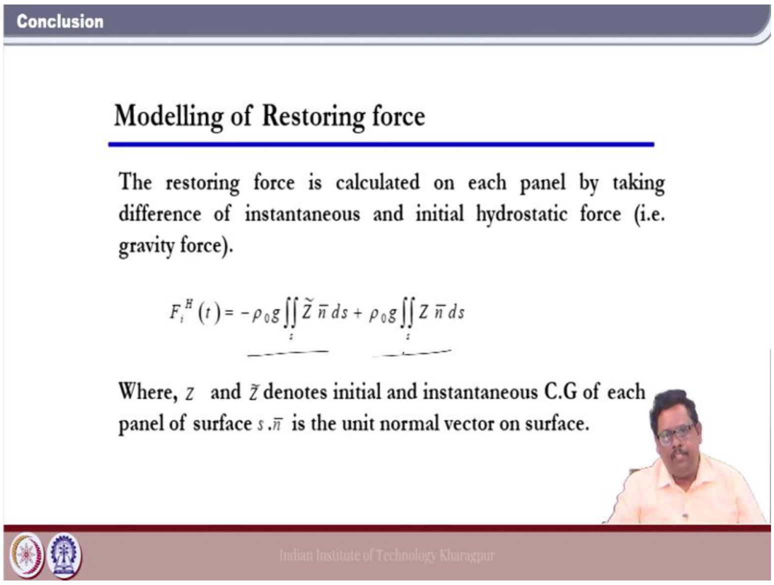

Now the restoring force also very important right in case of hydro elasticity it is not as same as the rigid body. So, here actually we can calculate the hydrostatic force is the difference between the instantaneous hydrostatic force minus the initial hydrostatic force right. So, this is how actually normally we calculate the hydrostatic force at that particular time.

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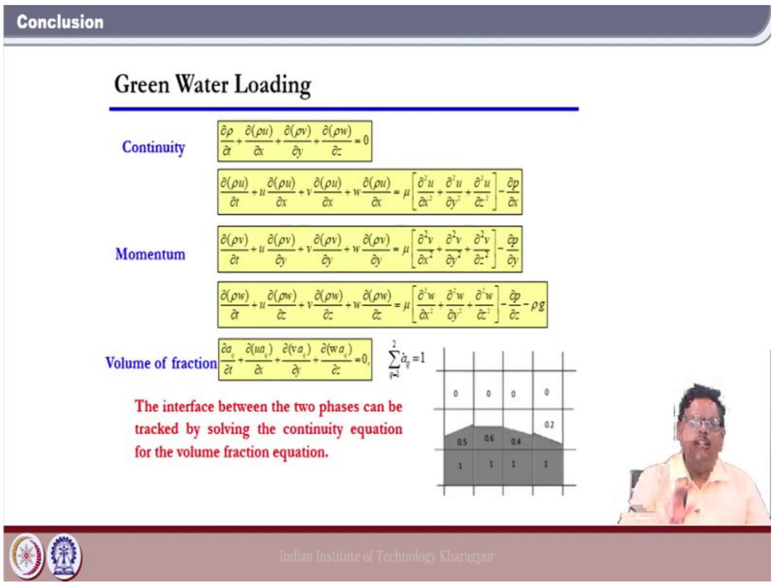

Now the green water load we use the now we can use the Navier-Stoke equation together with the volume of fraction vof method. Now here that is what my point like and that is the whole point of discussing this here because this is the out of the scope of this particular course, but you know we have to be very well aware of the fact that if you want to calculate this green water and slamming load with proper detail one has to calculate this using the Navier-Stoke equation solver or classical CFD solver ok.

So, this is the basic equation that you are going to use to get the green water load using the CFD. Now really, I am not going to discuss in detail what is this, but maybe as a researcher if you want to do if you have this the standard software, you can incorporate the green water load using this Navier-Stoke equation as well as the volume of fluid method, ok.

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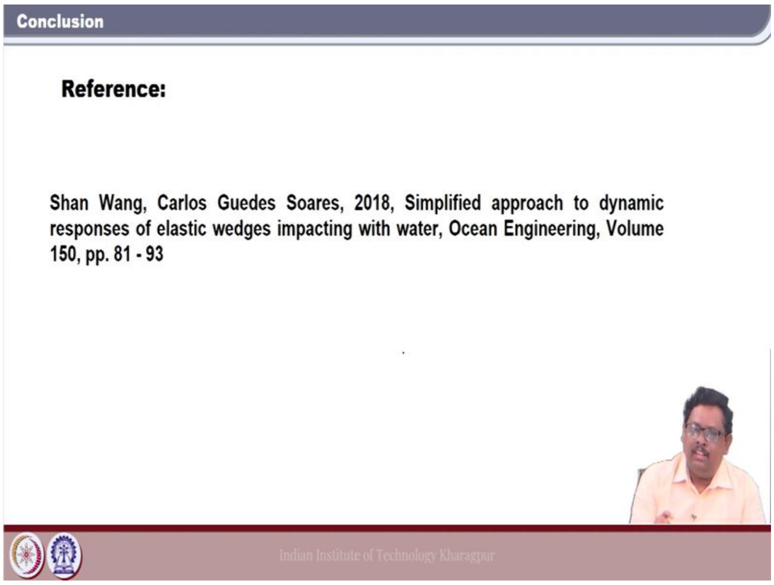

And now this is the reference that you can use to find out that how you can get the slamming load into the solver ok. So, now in this class we discussed how we can incorporate the non-linear slamming load and also in the previous class we discussed how we can incorporate the green water load into your boundary element solver ok. So, this is the advantage of the time domain boundary element solver, in frequency domain solver you cannot do this right.

So, therefore, it is better to have a time domain code because such non-linear force actually you can include into the solver and I think by this time by that time you have the boundary element code based on you know impulse response function right. So, try to write this dam breach model and this Wagner model and get a more realistic solver for you ok.

Thank you very much.