Numerical Ship and Offshore Hydrodynamics
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Lecture - 28
Frequency Domain Panel Method (Contd.)

Hello, welcome to Numerical Ship and Offshore Hydrodynamics. Today we are going to have the lecture 28 and this is the closing lecture for this Frequency Domain Panel Method.

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So, therefore, today we are going to discuss this overall discussion, this frequency domain panel method, what is the advantage, what is the drawbacks and what the things that one needs to take care when actually you are going to use this software.

Now, frankly speaking in present days, there are in offshore industry almost everybody have some kind of this frequency domain panel method; but the problem is that people really do not understand that when this code gives reliable results, which is most of the time they give. But, however, there are some critical time, where it might not be that reliable and one have to understand that if something goes wrong or everything is fine.

And if we do not have the sufficient knowledge on this frequency domain panel method, the behaviour of the Green's function and the behaviour of the other parameters, when we can go wrong, where this panelling is not correct, may be sometimes its solution is not convergent. So, then it is very difficult to assess the correctness of the code and the goodness of the results. So, those things let us try to cover up today in this final lecture.

Now, by this time we all know the basic principle of the frequency domain panel method, how it discretized the whole domain and how we can perform the integration of Rankine part, which is 1/R. And also you know how we integrate that other part also right; some slides are still today also there we are going to see, because those things are key things of this frequency domain panel method, ok.

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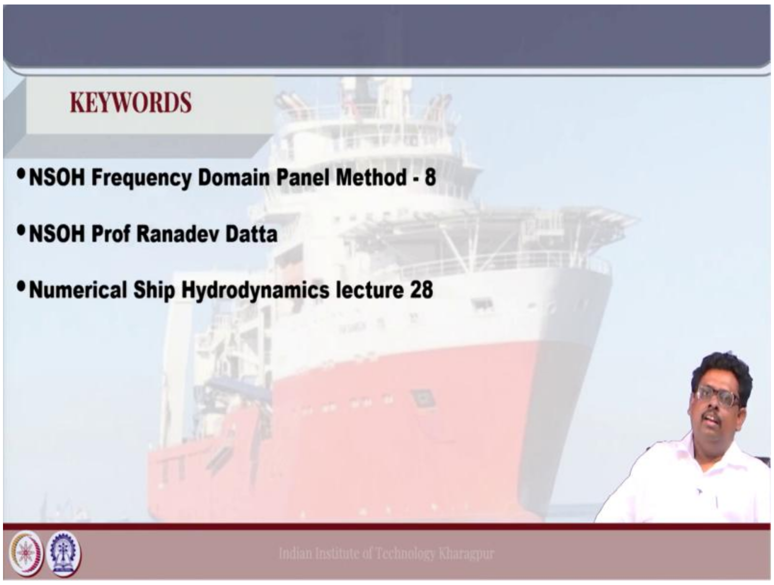

Now, these are the keywords that we are going to use to get this lecture, so let us start.

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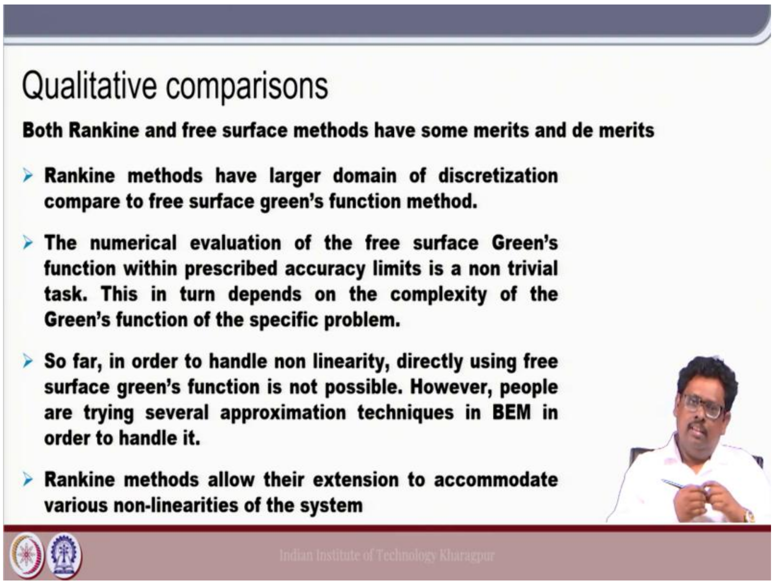

So, now, let us do a qualitative comparison with the frequency domain panel method with Rankine panel method.

Now, if you remember in our first slide, there are various methods I said that are available right; for example, time domain panel method or FEM or let us say CFD based method, like CFD means when I say the CFD definitely all the time I am going to mention that it is, when I say CFD I meant that transverse solver, which is finite difference or finite volumes. And I said that all methods are have some merit, demerit; but main advantage of this panel method, particularly it is very successful and very popular when we are going to deal with the sea keeping analysis.

That is simply because that domain discretizations become very easy. We know we do not have to discretize the whole domain; it is necessary to discretize only the body, if I use the frequency domain panel method or maybe only the body plus the free surface, if you want to use the Rankine panel method.

So, so then and then we saw that that it could be even if you even if you use the panel method; then there is something called the time domain also, something called the frequency domain also. Now, since if you are going to do with the linear model which normally everybody is interested to get the force; because of the linear part of the waves or so because frankly speaking this is the larger part of the force which gives you the 90

% of the total force, the contribution more than 90 % may be from the linear part of the force.

Of course, there are certain areas where actually the second order forces are very important, especially for offshore structure; but let us this course let us focuses only on the linear part of it for this linear, I mean frequency domain panel, I mean the zero speed floating body problem. Of course, we are going to discuss when we deal with the ship in coming days, we try to find out the motion of a body when it is moving with some velocity u, so sea keeping problem for the ship.

That time we try to discuss some non-linear part; but at least for this purpose floating body problem, we are stick with the linear problem. So, therefore, if you consider this linear problem; so therefore, only difference between the frequency domain and the panel and the time domain is just the Fourier transformation. So, therefore, really there is not much merit to go with the time domain panel method.

So, therefore, this qualitative this comparison is only for Rankine panel method and frequency domain method; because the Rankine panel method, you can solve in frequency domain or solving in time domain does not matter, because only the difference is the for Rankine you have only 1/R and for other part you have the 1/R plus the regular function, harmonic function.

Now, if I see over here that for the Rankine method, it has larger domain of discretization compared to the free surface Green's function method. In free surface Green's function we have to discretized only the body; however in Rankine method, you have to discretize the body plus the free surface, right ok. So, the numerical evaluation of the free surface Green's function is a very is not a trivial task, is fairly complicated.

So, this is something that is more difficult compared to the Rankine part because in Rankine panel method though we have to discretize the free surface as well as the body, however evaluation of the Green's function is little bit simple, because here you are only deal with the 1 / R part. However, here we have to deal with the complex, the free surface Green's function part also, right.

So, therefore, we can have some advantage, some disadvantage both are (Refer Time: 07:17) here, right. Now, so far in order to handle the non-linearity directly using free surface Green's function is not possible; because if you solve the Green's function, we know that linear free surface boundary condition has to be satisfied.

We cannot use the non-linear free surface Green's; I mean non-linear free surface boundary condition to use this term Liouville problem, it is strictly linear, ok. So, this is this is you know that is the limitations of the free surface Green's function. However, the you know there are several approximation techniques are available in BEM to overcome this problem.

And in later stage as I said when we discuss the forward speed problem, so that time we are going to discuss that I mean in how we can handle it in using the linear time Green's function, but still we can manage to include some kind of non-linearity in the panel method solution. Definitely, we are going to discuss this in the future days, ok. However, if you use the Rankine panel method, then this limitations actually we can overcome, ok.

So, therefore, in a way in a way it is better to say that, if you interested to do the linear analysis and then you know that how to write the complicated free surface Green's function. So, always this vomit I mean we normally very popularly sometimes call is a vomit type solution, right. Though there are many many people who wrote this frequency domain panel method, but it is very popular; like people loosely say it sometimes like it is a vomit type solution ok, anyway.

So, this frequency domain panel method with this free surface Green's function, it is more acceptable in that way. However, if you are wanted to include some kind of non-linear solution into I mean for non-linear free surface etc. then it is better to use the Rankine panel method, ok.

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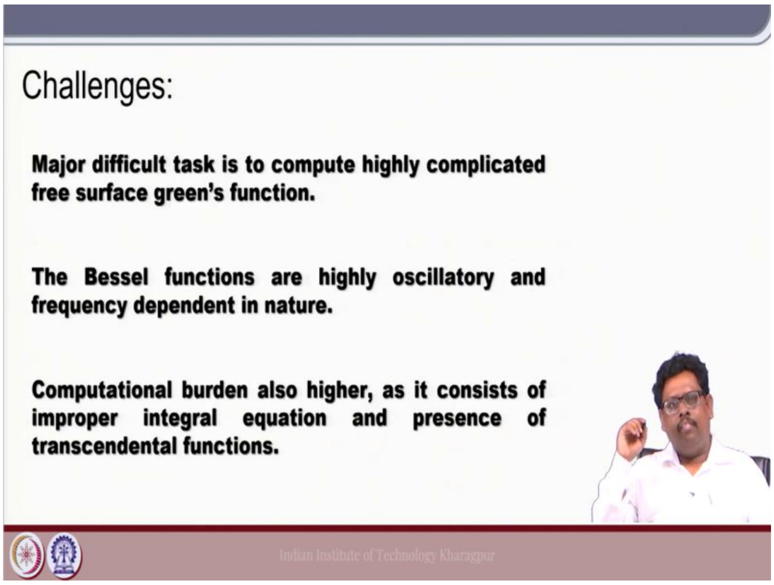

Now, the challenges again as I said that sometimes I am hammering things, you know again and again and again just to realize you that, I am really wanted to tell you something and I was just wanted to, I wanted you to understand it in that way. So, here the challenges again and again and again I am saying is the highly complicated free surface Green's function. And why? This is also we have discussed before.

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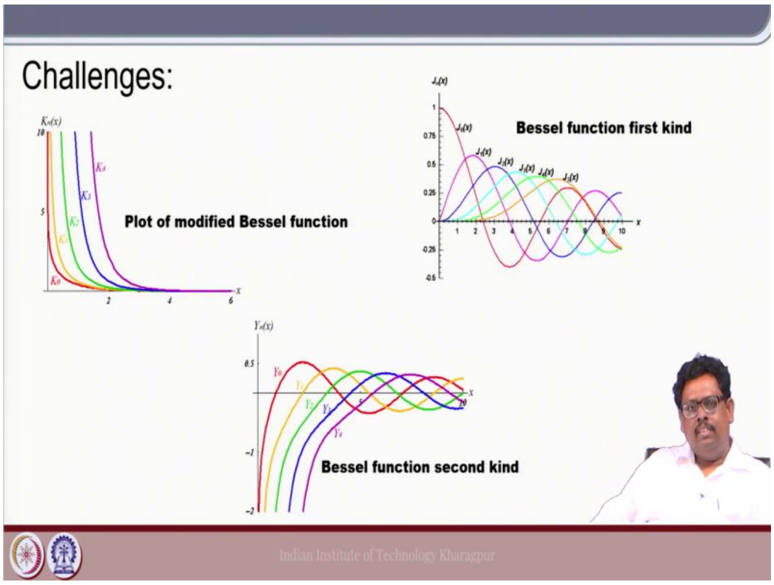

This is the thing that it is a highly oscillatory in nature.

Secondly this K_0, this Bessel function which goes to infinity asymptotically, ok. So, these are the complex part, not only that also we have to have a improper integral; improper not only improper, improper transcendental equation, which also extremely complicated to compute numerically. So, these limitations are there, I mean this complexity are there. So, before we start coding this panel method, we have to make sure that yes we can handle this complexity, right.

We can handle the solution for Bessel function, the improper integral, solving the transcendental equation, right fine ok.

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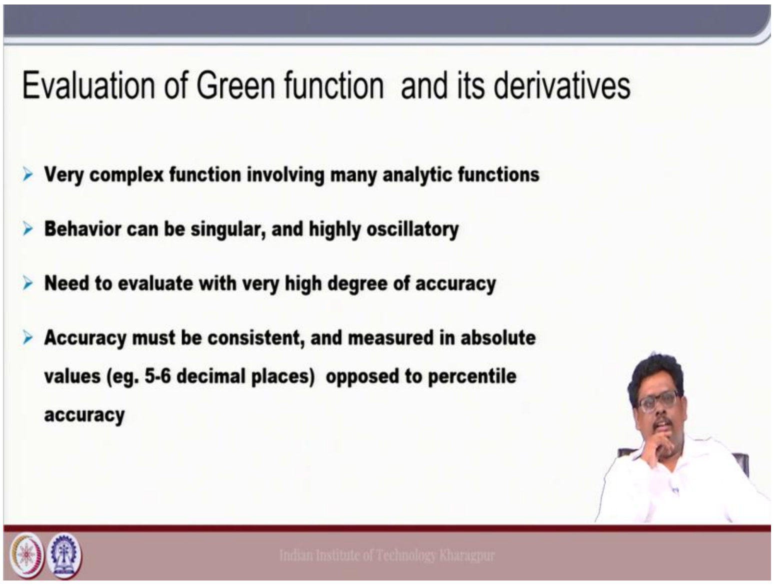

So, now these are the key things that one must understand that, first thing this very complex function involving many analytic functions, right this is one; that you have you saw this. Second was this behaviour can be singular, especially when field point equal to source point; then this behaviour is singular and also when this panels are close to the free surface and then this solution also become highly oscillatory.

So, and third one, this need to evaluate the Green's function very accurately; if you do not do that, we mentioned it that it should be accurate for the 5-6 decimal places. So, we really do not go for the percentage accuracy like it is 1 % correct or is 0.1% correct, not like that; it should be accurate that 5 decimal places. So, it is always the absolute values that we are going to you know take and we are going to consider; we really do not consider the percentage value, right.

So, these are the things that when we evaluate the Green's function, these are the thing you need to you know consider very very accurately and very carefully. Now, if you ask me how you know that is correct or not. So, the best way of checking this is manually at least one, two cases manually you solve it; you put these values and then you calculate manually, right for one and two cases some critical cases, you calculate manually and then you compare with your coding value, ok.

So, this is the only way to check at some way ok that it is coming correctly or not, ok.

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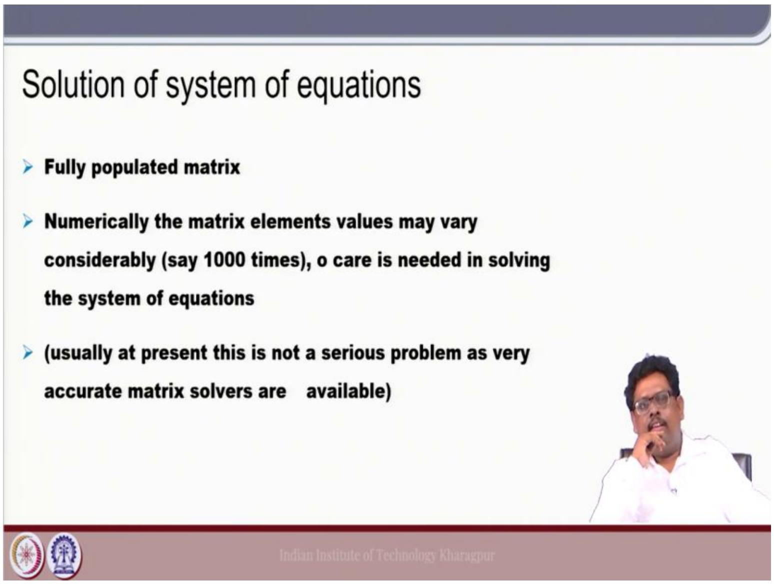

Next that the most another thing is that, actually this is nowadays this is not that a problem; but earlier that we have the fully populated matrix, it is we cannot say it is a diagonally dominant matrix right. Because you know in case of FEM and all since this is a diagonal dominant matrix; so solution for the matrix is less complicated, but here this i and j, the source panel and field point it is everywhere.

So, it is not diagonally dominant, you cannot say here; because if i and j very close to each other, then also the value will be very large, ok. So, therefore, that all the element is important here. So, when you solve this system, definitely it is much more complicated; because it is fully populated all this a_i and j has non zero values and specially not necessarily the diagonal elements are the having the high values, because we understand when i = j, then it becomes a singular point, right.

So, it is not like that, it is even if the i and j very close to each other, then also value can be very high, right. So, that thing also we need to take care, ok fine.

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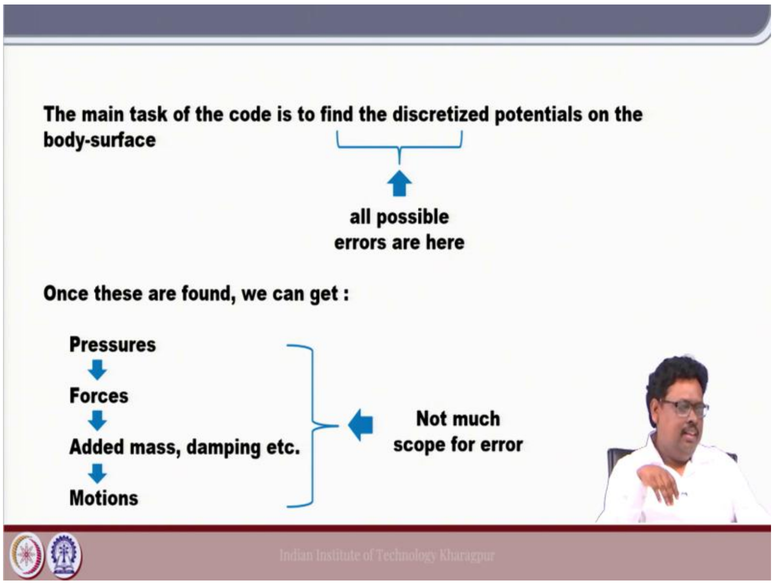

So, now here actually I mention that you know which part actually we have to be very careful and which part actually it is there is not much scope for an error. Now, as I mentioned that the main task of this the code to find the discretization of the potential function on the body surface and get this influence matrix b_{ij} and a_{ij}, I mean b_i and a_{ij}.

These are the major difficulty ok; that means essentially I am saying that, only the evaluation of the Green's function is the most difficult part of this whole code. However, once you get this that a_{ij} matrix or b_i matrix; then the remaining part are the simple algebra, like you know you have this a_{ij} or the influence matrix and then the solution of matrix nowadays also not an big issue.

So, once I get, I mean when you solve this matrix and get the solution for ϕ and then you see the rest part is simple algebra; because you have the ϕ, you need to multiply this ϕ with the ρ and then the normal component which is n_i and then the area of the panel which is DSI. So, it is simply $\sum -\rho\phi_i n_i s_i$, I mean DSI. So, these are the simple algebra to get the force.

Now, once you have the force, then actually you have the analytic solution, right. So, added mass you know that when you have this value; so a_{ij} is equal to the real part of that values and then the damping is the complex part of the or the imaginary part of the values of the forces, right.

And once you do this get this a_{ij} and then b_{ij}, then motion is now you; since it is a frequency domain, you do not have to do the even time marching algorithm also, that is also not that is also not required, right. It is again a analytic expression is there to get the motions, right. And once you get the motions, you know that since this is a harmonic wave always assume; then it is $i\omega$ multiplied by the motion gives you the velocity.

So, these are the things is really there is not much scope of error; however, all possible error comes, when we integrate the Green's function and the normal derivative $\frac{\partial G}{\partial n}$, ok fine.

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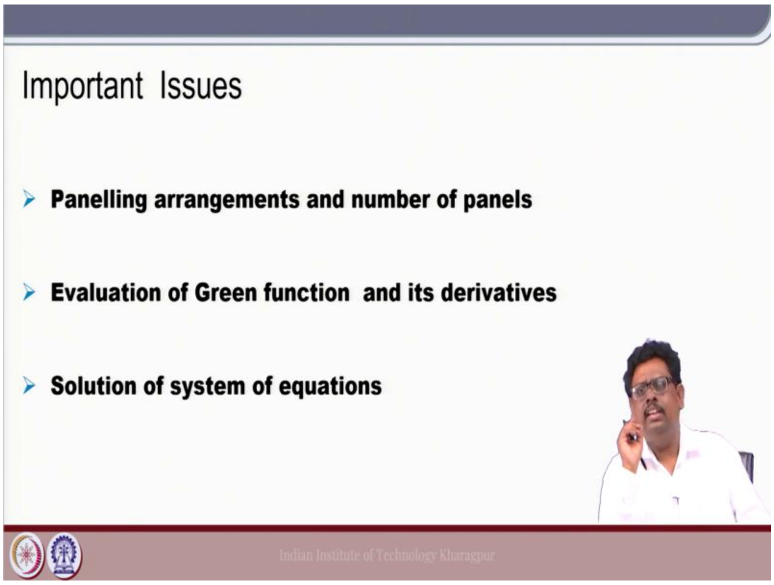

So, the important issues is here that, the panel arrangement and the number of panels; like for example, now if you have here also is a very interesting thing compared to the so called RANS based solution.

Now, there you have something called the convergent criteria. So, you have to make sure that, your mesh should be fine enough to get the convergent result. So, this is the standard norm, I mean norm to get the convergence solution for any system right; because always you are looking for the, I mean it is our general understanding right, it is our general understanding it that [F_L] if I discretize the grid finer and finer, definitely the result will be better and better.

Here this panelling arrangement here the issue, because that is not true for our this panel method always, not always true. You can think why it is so; because I will tell you that it is mainly because we have this singular function $\frac{1}{R}$.

Now, if you have this panel are very sufficiently small, ok. Even if you use the three point Gauss quadrature rule; normally how much you can go like go for, like normally we go for one point quadrature rule, two point quadrature rule, three point quadrature rule, may be four point quadrature rule, I mean it is not you can take you know n point quadrature rule, normally we do not go for it.

Now, this thing is that, suppose if your panelling is very fine; you are assuming that I am making finer grid, I am getting better and better results. Believe me there is if you get very very fine, then this 1/r. Now, if you look at this 1/r, it is asymptotically infinity if you going to close r. Instead if you have little bit bigger panel, then distance between r and j like the characteristic length if we mention over here; like if this characteristic length is you know not the order of 1, it is some 2 or 2.5 or something like this, then you can have very convergent and very good result.

So, therefore, now it is a lesson for you, it is unlike in a is not; that is what I said that it is not is anti-intuitive you can say, like in normal trend you are discretising finer grid getting better result not like that, this is not happening here. You have to find out that optimum panelling arrangement to get this panel. But now the question is how you get it, right?

Now, the only answer is the with experience; more and more you work on this domain, more and more you can understand that arrangement of the panel, more and more you know that what should be the you know that characteristic length should be between two panels, that minimum characteristic length what should be the between two panels, right.

So, this is one thing. Now, again this evaluation of the Green's function derivative we discussed a lot. So, we really let us not discuss it again and then we have the solution of the system of equation. Now, this nowadays as I said this solution of system equation also is not a big deal, because we have sufficiently stable solver available, right.

So, we can pick any one and then we can solve the equation; mostly the understanding of the panelling arrangement and then correctness of the Green's function will be the deciding factor that, whether code is good or bad, ok.

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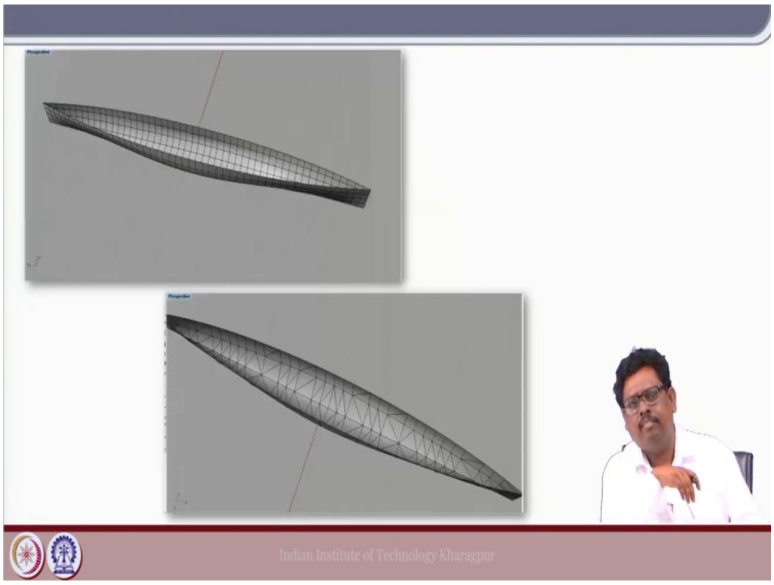

Now, here I just give one example, see you can see the top one that panelling is nice and then the bottom one is not that nice, right.

Now, you see it is a wiggly hull of course; let us see that what would be the corresponding results.

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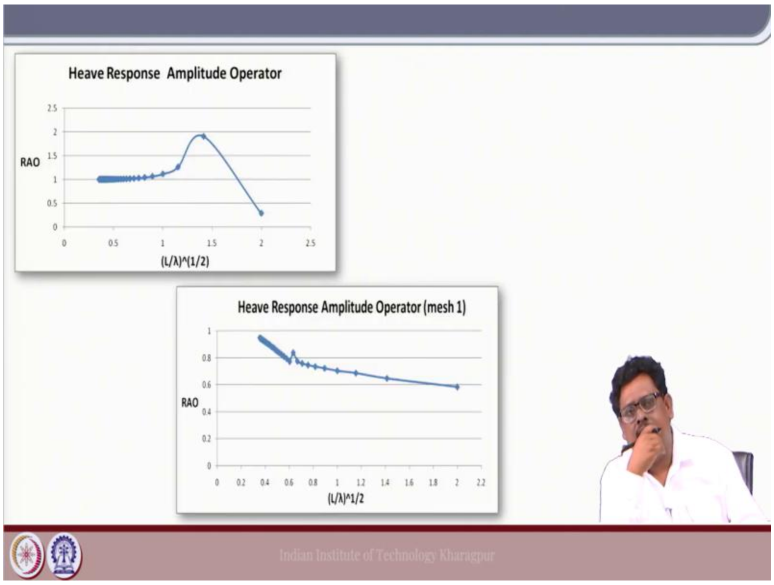

Now, you see here that result is entirely different; however interesting to note that you know that in lower frequency range, both are approaches to 1, I mean this is a heave response, so that is how it should be, right.

In the lower frequency range, it should be approaches to zero; because you know we discussed a lot in sea keeping also, in lower frequency range, then the body only the height, I mean that added mass damping does not make any big role, only the thing is that it is the restoring coefficient and the exciting force which is essentially the (Refer Time: 23:07), because at that point diffraction force also goes to zero. So, therefore, that it is the ratio between the (Refer Time: 23:14) force and the hydrostatic force.

In such case it should go with the, you know the moment this body is there the way we are we discussed that when we go for a bathing in ocean, like we just move up and move down with the waves, right. So, that is what going to happen over here.

So, it is fine; but however, you can see here, in some you know sometimes when it actually hit the resonating zone, may be here in this case the frequency is this non dimensional value is close to 1.5. You can see that we have some resonating thing that is showing in the top figure, but in bottom figure is not like that; it is showing, but there is a difference, there is a difference a lot.

So, this is only purpose to show you that, maybe you can see some physics still captured for the both the panel, but there is a difference, ok.

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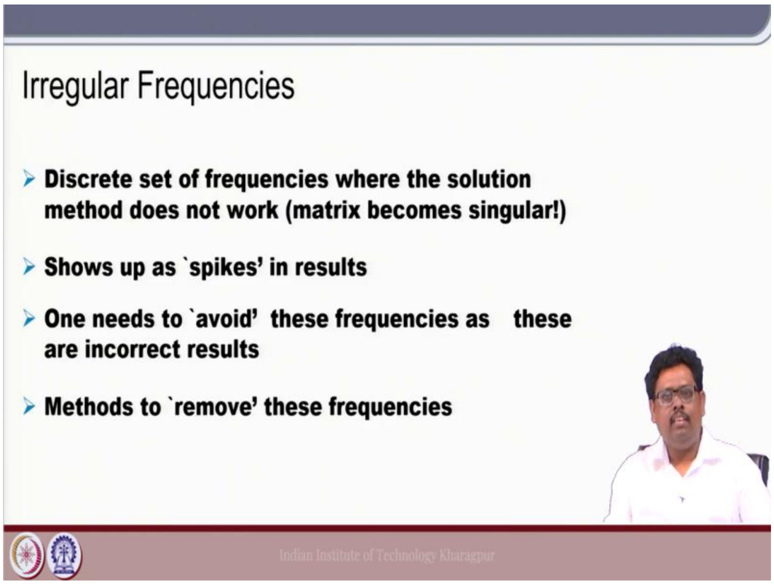

So, now, this is another very important concept that one must understand that and that is how you have to have some good understanding of the theories, so that you can try to understand this sort of phenomenas, to address this sort of phenomenon.

Sometimes what is happening that, frequency that we are evaluating that when we evaluate the RAO's; sometimes we can have some sudden spike or some sudden peak. And then if we really do not understand that about like some knowledge about why what why this spike may come; so normally we can we tend to defend our result and we say that ok in this frequency that is what is going to happen, right.

And then what happening that, you are defending a wrong result blindly trusting the your software.

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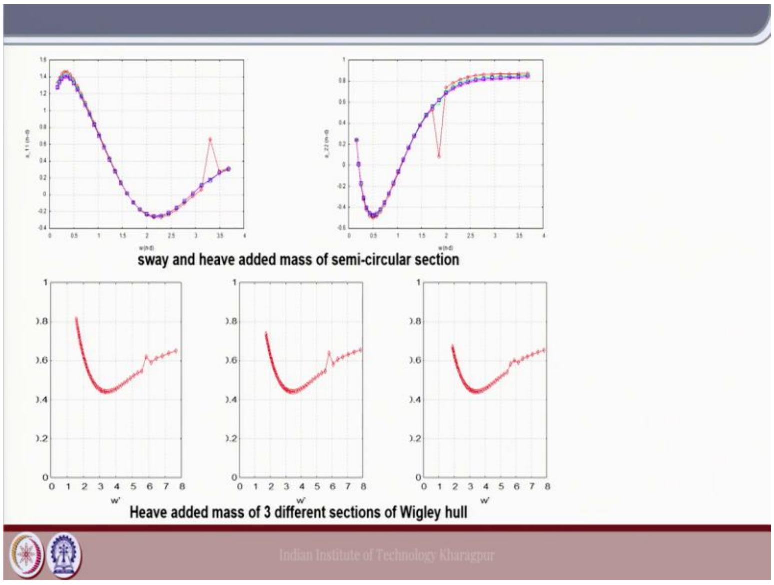

So, let us see let us see what I mean. Now, here in this result you can see that there are certain frequencies where you can have a spike. Now, thing is that if this spike is physical or non-physical, ok. Now, this we can say something called the irregular frequency, at which frequency this solution actually can go up to the infinity.

So, at that time, you can have this sort of spike. So, therefore, if you solve for a solution, you are getting a spike; it could be possible that it could be because of this irregular frequency. So, we have to understand there are certain frequency where this code, you know there is something we can get some what is called that that singular matrix is generated and then you can have such spike and then we must delete those frequencies.

We must remove those frequencies and those frequencies are called the irregular frequencies, ok right so. So, now, this is something if you do not have any understanding of this irregular frequencies; then definitely whatever you are getting from your software, you are trying to defend your result and then you are defending a wrong result, right. So, we have to be very careful on that.

Now, again suppose we are we must understand that when this irregular frequency comes and when this irregular frequency we have to think; ok this is the irregular frequency, it is not physically happening, because sometimes this physical phenomena also can happen. Now, let us see.

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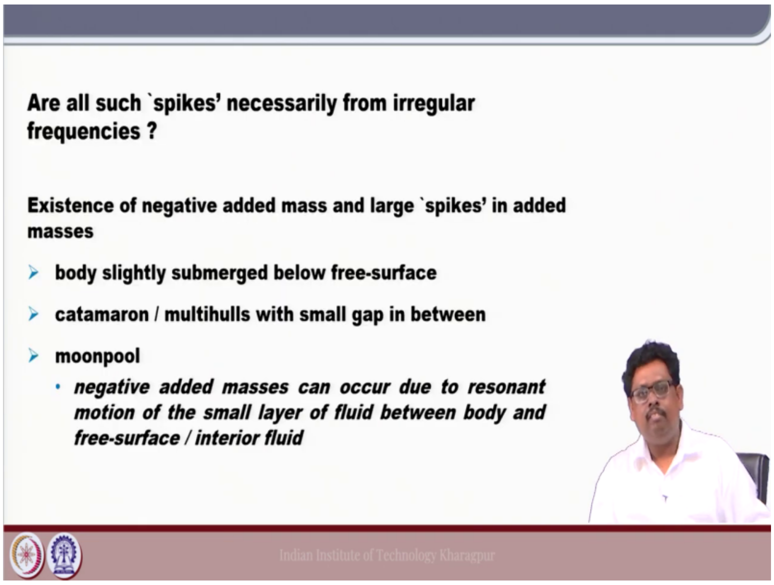

Now, all such spikes necessarily from irregular frequency there is a question? So, answer is existence of negative added mass and large spike in added mass there are certain things that I mentioned over here; when the body is slightly submerged below the free surface, then this spikes is possible. For the catamaran or multihull when there is a small gap between two vessel that mean you know the catamaran, there are two ships going each other.

So, in between there is a some the gap and that time also it is possible. So, in case of a moon pool also; you have a body and then you have a hole at the bottom, I mean below and then this water you know what is moon pool, right. So, in that case also it is possible to have this, physically is possible to have this the spike. So, therefore, so first of all we have to understand this existence of spike.

So, if it is not the catamaran or moon pool or something or not below the submerged body. So, then it could be a, it could be a spike; but however, if this happens, we really not sure whether is really spike is because of the irregular frequency or because of the physical phenomena. So, we have to be very careful to you know to assess this, ok.

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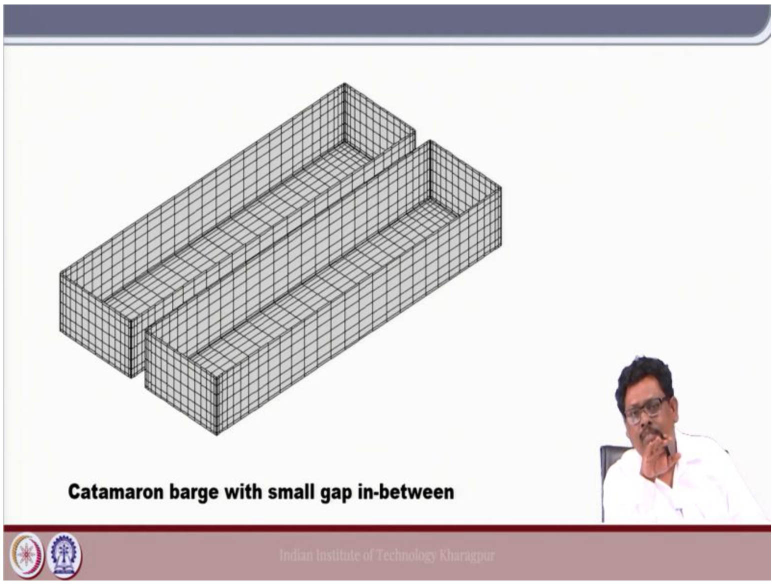

Now, you see that that is what this is the picture that, there is a there is two ship and then there is a gap in between.

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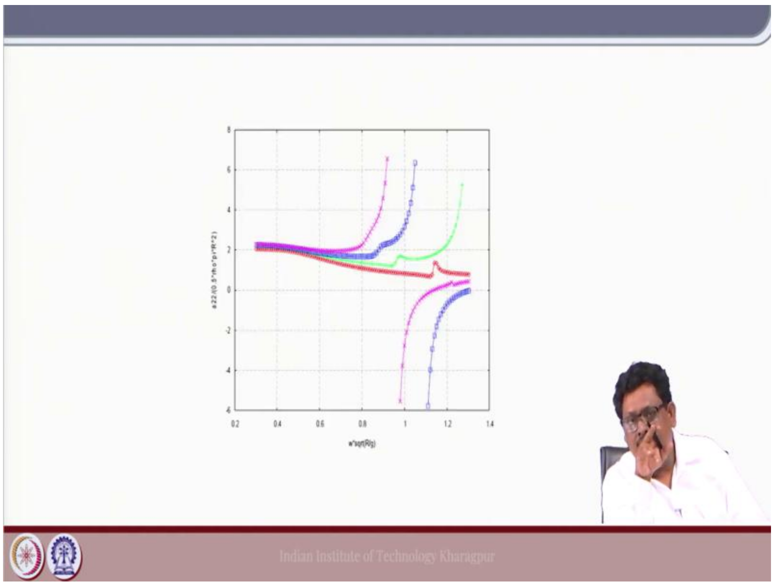

So, in that case it is possible right; it is possible to get such spike. Now, you see these results, right.

So, therefore, you can so now, you I confusing you, I am confusing you, right. Sorry, we are saying that it could be the spike could be for the irregular frequency; now I said some physical phenomena is also possible that you are having some spike. So, therefore, it is your experience, your knowledge and your way of thinking and your understanding of the physics will decide that whether it is actually a spike irregular frequency or it is a physical phenomena, ok.

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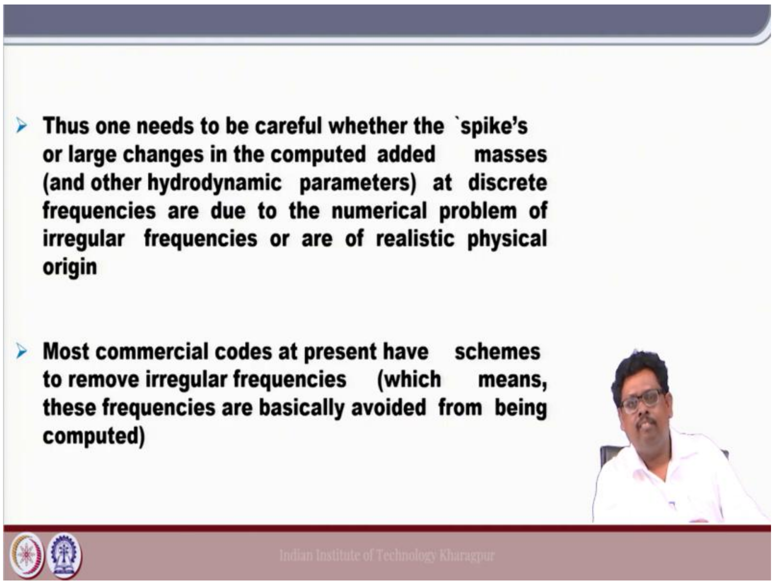

So, thus one needs to be careful whether this spike or the large changes is the computed added mass; it is because of this irregular frequency or it is because of the realistic physical origin. Now, most of the commercial code at present, they have a scheme to remove this irregular frequencies of course; so, but I am not sure like is if it is very highly accurately, it is executed or not, ok.

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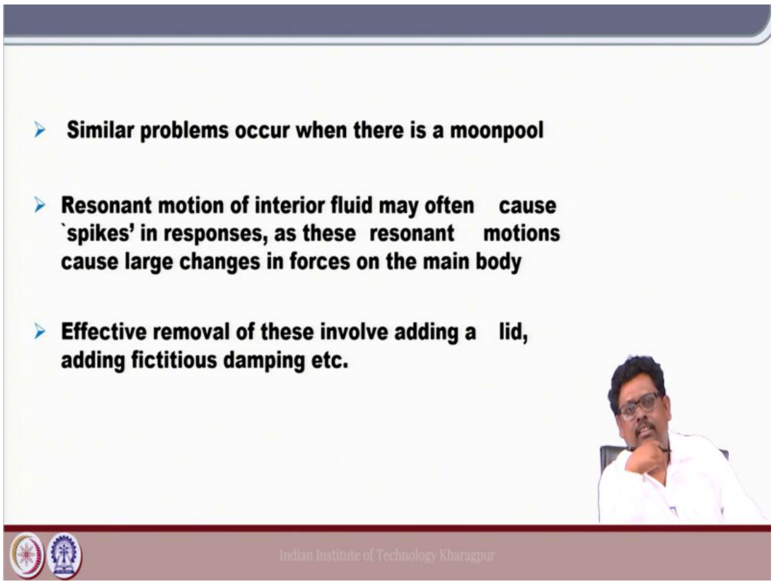

So, as I said the similar problem occur when there is a moon pool, in moon pool also you can have such phenomena. Now, suppose this is for the irregular frequency how to remove it? So, there is a popular way of removing is the putting a lid or adding a fictitious damping, ok.

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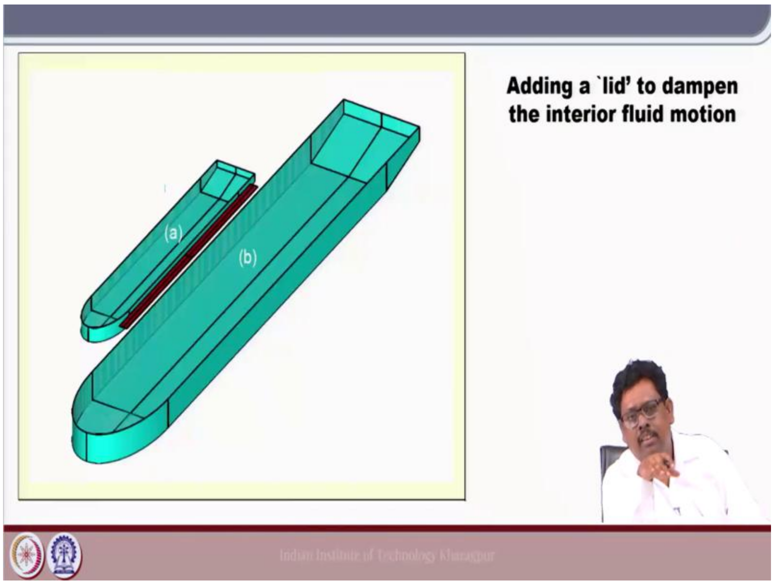

So, now here we can see that there is in between this that grey one is a lid. So, it is over the free surface. So, we are not considering. So, now, we are meshing the body as well as this part of the lid and that also is a move up and down like a wave.

So, this is one way to remove this irregular frequencies our internal fluid motion, if you want to suppress, ok.

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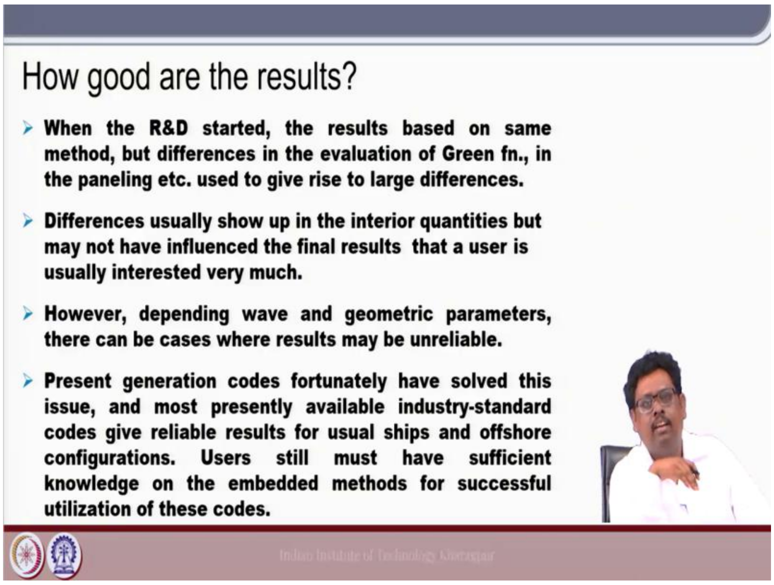

So, now we are just coming to the concluding slides, so how good or bad this result. So, now, you know nowadays in the last point I just wanted to emphasize; because these are the there you know everything about this previous thing that when we started that evolution Green's functions become very difficult, we struggled a lot. But nowadays the most of the available industry standard codes, they give the reliable more or less reliable results and; but still users still must have sufficient knowledge on the embedded method for successful utilization of the core.

So, that is what all the point, this is fairly complicated software's; you have to have some domain knowledge to assess your results to overcome the difficulties and when what is a good meshing, bad meshing. So, let us not go blindly, like making my image very finer to get very good results something like this, it do not work, ok fine.

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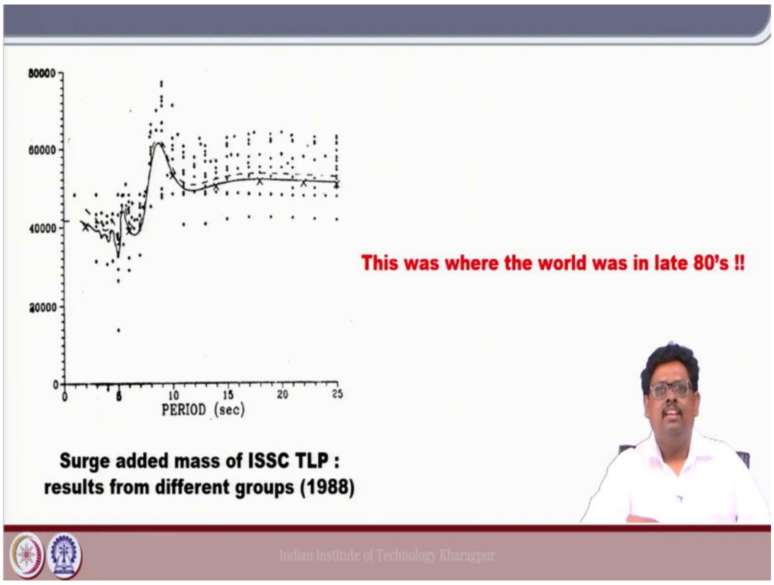

So, now, this is one it is actually early 80_s, now the position is much much better just; I just picked this one, it is from the 1988 some analysis it is giving many people theory is same, Green's function is same, everything is same, but you can see there is a still lot of variation in the final result.

So, this is early 80_s results, but nowadays you know the results are much much better than compared to when we started anyways.

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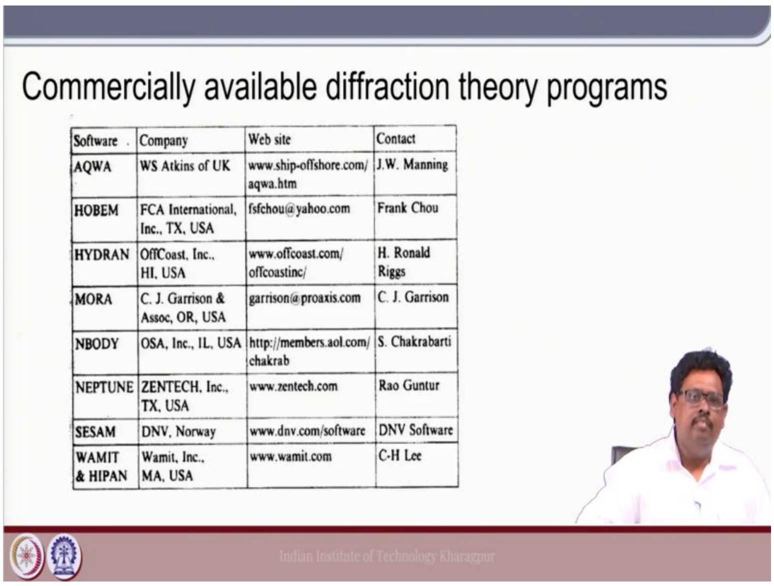

Software	Company	Web site	Contact
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NBODY	OSA, Inc., IL, USA	http://members.aol.com/chakrab	S. Chakrabarti
NEPTUNE	ZENTECH, Inc., TX, USA	www.zentech.com	Rao Guntur
SESAM	DNV, Norway	www.dnv.com/software	DNV Software
WAMIT & HIPAN	Wamit, Inc., MA, USA	www.wamit.com	C-H Lee

So, these are the some commercially available software; these all are based on this frequency domain panel method and these are the link that you can go and you can find out, ok.

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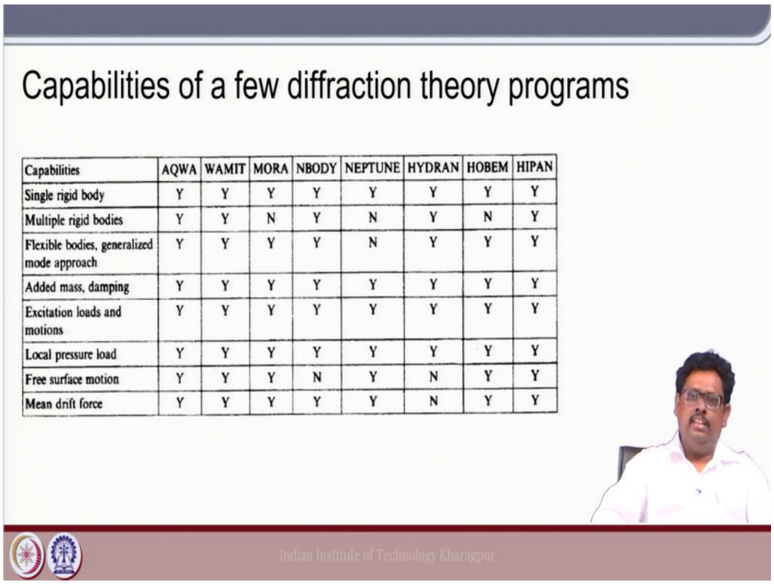
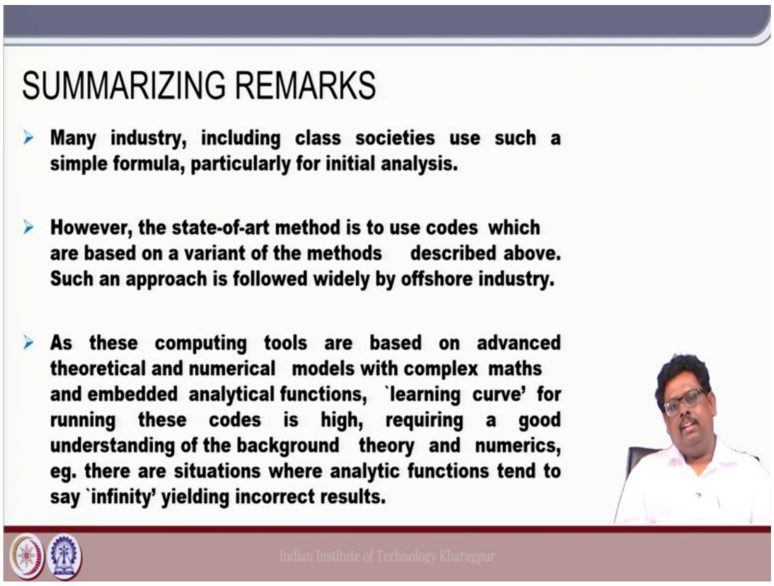


And these are the I mean I just make one comparative that a statement that which software do what; like for vomit it is a single rigid body, multiple rigid body, which is possible, which is not possible everything is listed out over, you can check it out this one, ok.

(Refer Slide Time: 33:07)



And then just as a summarizing remarks, this many industry including the class societies nowadays using this ok; but this as mentioned repeatedly the state of art code which you know mostly is a how to deal with the Green's functions, how this is all about of these things, right. And also there are lot of things are also involved; sometimes you can have spike, sometimes you have the realistic situation, you have moon pool, you have multi body, so many things are there.

So, one has to educate himself to use this code and get some you know realistic results, right ok. So, with this we stop this frequency domain panel method part and we start a new topic from the next class.

Thank you.