Numerical Ship and Offshore Hydrodynamics
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Lecture - 51
Time Domain Panel Method - Code Development

Hello, welcome to Numerical Ship and Offshore Hydrodynamics, today is the lecture 51.

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Today we are going to discuss about the development of this of the numerical code of the Time Domain Panel Method. Mostly we are going to discuss about the linear part of it. I would say that this is not the other compared to other code that we discussed in this course I would say this is the most difficult code among all. So, it may not be possible to address all the all sorts of things, but; however, we are going to discuss some key aspect of it.

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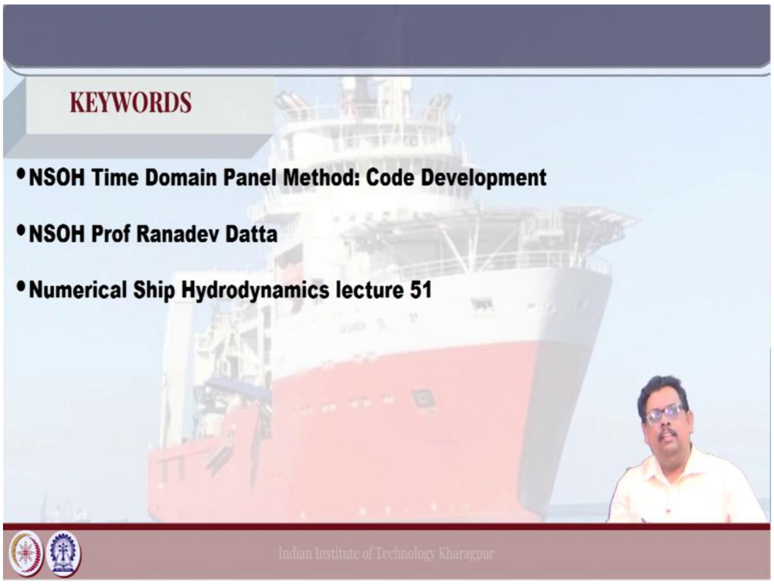

So, this is the key word that we have to use to get this lecture. Now let us start.

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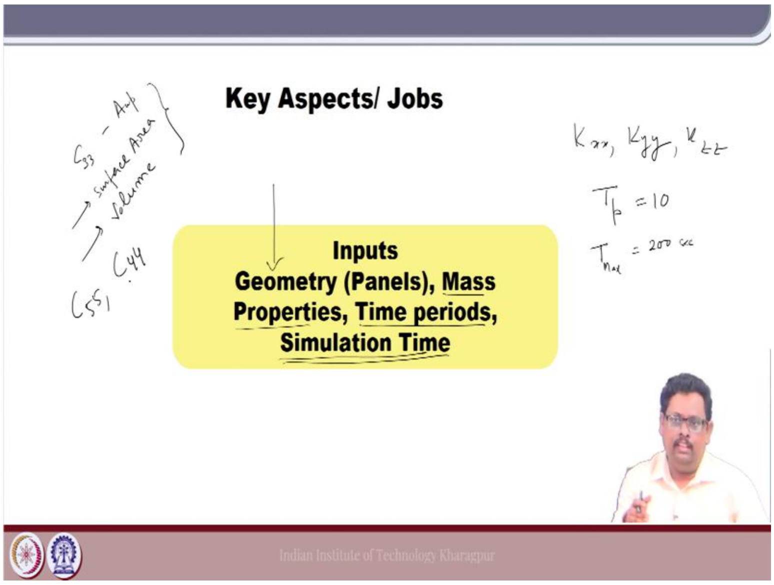

Now here as I said that in this class, we have only discussed some key aspect and also you know we realize that we have at this point after 50 classes. At least you have some idea how to generate the matrix, how to convert the integral equation into the system of linear algebraic equations, how to solve the algebraic equations. So, I assume that at this point you know all these things may not be you are expert, but at least you had you got the idea.

Now in any code definitely you have to have some kind of input otherwise, you cannot start. Now here the inputs are actually the geometry the ship geometry or you can say the paneling and also the mass properties; that means, the mass of the body and then the radius of gyration the K_{xx} K_{yy} those are the K_{zz} these all are the inputs. And also, you have to give the input that which time period you want to give so that you can get the response, so the time period let us say it is a 10 second or 15 second whatever.

And also, you need to give the total simulation time, so you can call this T max. So, it is you know how much second is 20 second or 100 1000 second or whatever right. So, this is the more general input that it is required to run this code. However, you know if you use some kind of software like max for other things some other kind of inputs, they prepare for you.

For example, the coefficient C_{33} ρjwp, so this A_{wp} you can get from some software like max are probably provide this; the surface area and also the volume. So, all these things that also it is possible to get from the other external sources and you can use this as your input like or may be this the C_{55} C_{44} everything actually you can get from some different software.

So, this is not the very big deal even if you have it is good if you do not have we already discussed before that how to get this hydrostatic coefficient in our code, I mean using the time domain panel method.

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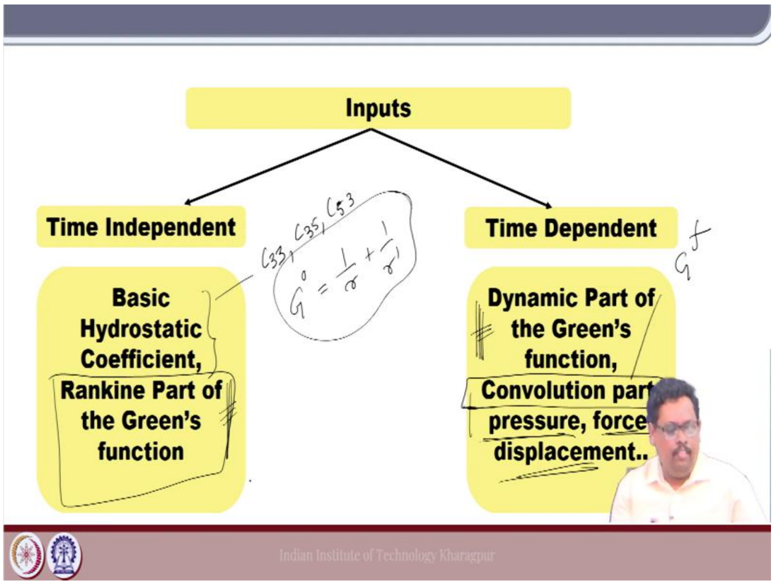

So, more interesting part is that from these inputs let us have this input, then how to start the code; like how we can think of. Now here one part is the time independent part, which part is the time independent part? Definitely, we are going to discuss. So, this after getting this input we need to understand that some part is the time independent part- and this-time independent part we have to you know calculate or compute before you start the original coding.

So, this original code definitely the time dependent part right it has to be there because it is a time domain simulation. So, definitely the major part is the time dependent part, but; however, there is a there is there is a lot of things that you need to calculate before you start the coding the original time part. So, now what are the thing? So, the as I said the basic hydrostatic coefficient you need to figure out like; that means, you have to figure out that the that coefficient that C_{33} or may be C_{35} or C_{53} all these things right.

And then second which is the important thing you have to find out the you need to do the integration of the Rankine part of the green's function. Now, if you remember this Rankine part or you can call it as G^0 this is actually this 1 + r plus you know 1 plus r plus. So, plus or minus anything, but this is the time independent part. So, we have to use this I mean we have to calculate this integral and we have to store it before we start the time dependent part. Now in time dependent part we have the dynamic part of the Green's function, so it is .

So, this dynamic part of the green's function we need to use you know we have to evaluate and actually we have to get this that convolution term. So, what is the convolution term? This is the one of the critical thing or complex things that actually there in this code. And also we have to find out the pressure the forces the displacement the velocity, so this is the main thing right. So, now in the next slide we have to figure out that you know how we can do this time independent that the Rankine part of the Green's function how we can do the integration.

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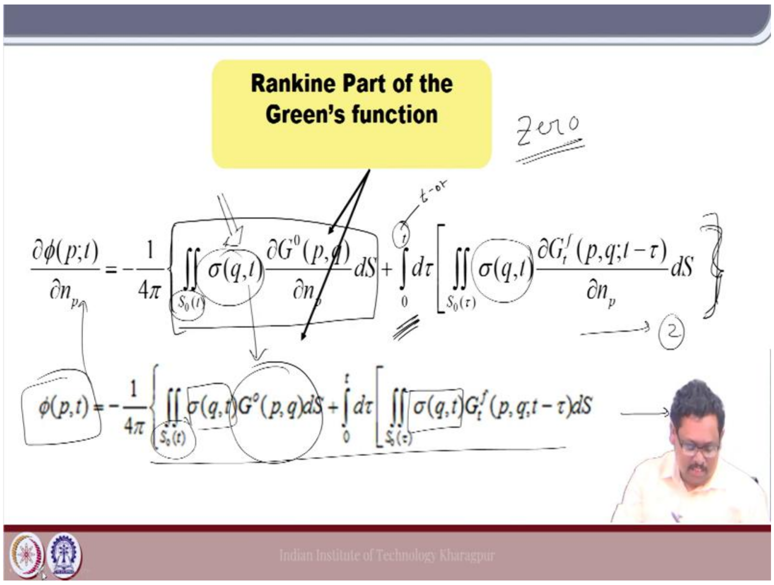

Now, this is the classical or the integral equation of course, this is for the zero speed. Why are using the zero speed? Because the forward speed only we have one term to discuss, but here this second bracket is missing anyway. Now, here you can see that this part actually we are talking about, now in this integral we have two parts. Now if you look at this part is integration from 0 to t now to be honest it is t is not the present time steps rather it is we can call a t minus you know in the delta t, but till the previous time steps ok.

But this part is actually the time independent part and also in the next equation which is phi t into this here also you can have this G^0 term which is again the time independent. Now, you might say why it is why I call this as time independent because in this integration you have S_0 t right you also have the S_0 t, so you might have asked like. So, that that S_0 is depending on the time, so therefore, at each time step the S_0 is changing, if S_0 changing then how this integration term is time independent right.

We are going to answer this question, but before that actually if you look at this carefully what I did actually you know I write this the way we are going to solve the integral or the way we are going to write the code. However, when I develop the theory you know that we write this equation first we give this equation number 1 and I give this equation number 2.

And we say that here in this equation number 1 I have this unknown is sigma and then the phi both is my unknown and then I differentiate with respect to n. So, I will get this equation number 2 and in this equation number 2 is everything is known to me apart from the fact that sigma is unknown to me. So, therefore, I solve this sigma first and then actually apply this sigma in the equation 1 to get the phi right, this is the statement right.

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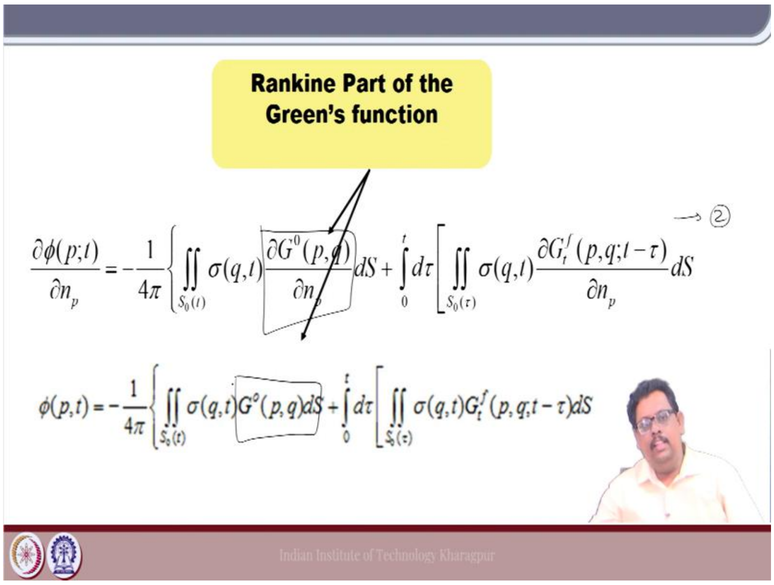

So, here since we understand that first we have to solve this the equation number 2 if I write it 2, so that is why I write this equation in the top. Now here I have this part I claim this part and from here this part is time independent. So, why I am telling so?

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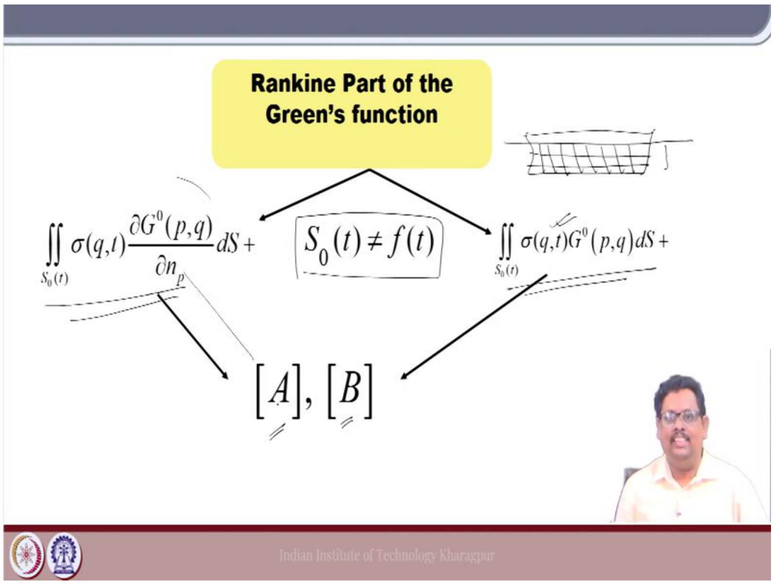

Now, actually these two parts it is only time independent when you do the linear analysis, why? Because in linear analysis the S_0 t which is the body surface the weighted surface is not function of time. If you remember that what we say that a that I mean level 1, level 2, level 3, level 4 all level we discussed. Now in a level one the thing that we discuss is in fact, in level 2 also this weighted surface does not change with respect to time.

Now; that means, this paneling actually does not change with respect to time only in case of a level 3 or in case of a level 4, that time only the geometry the underwater geometry it is changing with respect to time. So, you know we are not going to discuss about the non-linear part it will take you know another level, let us first understand at least the linear level. In this in linear level this weighted surface does not change with respect to time.

So, therefore, you know this integration and this integration we can do before actually we start you know doing the dynamic part of the course, so this is you have to do one time ok. And now after doing this we need to store the matrix A this part and we have to store the store it in matrix B for the second part ok. Now what actually we need we are having in this matrix A, let us see.

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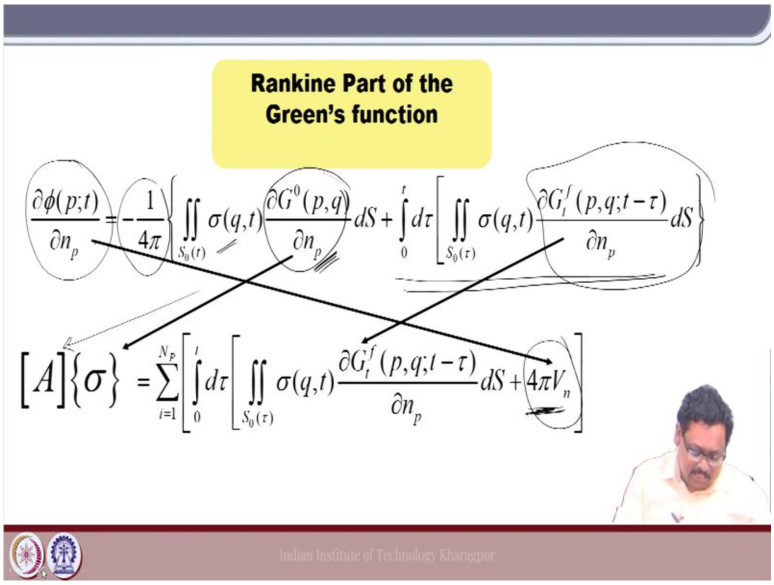

Now, in this expression this left-hand side this part is nothing but the velocity which is known to me and we can call this V_n right. So, this velocity component definitely you know I am taking that in the right-hand side right. Now if I look at this part here this actually $\frac{\partial G}{\partial n}$ that coefficient actually coming into the A matrix right. Now this you know already, so you understand very well why I am writing this it is simply if you remember this panel method code initially, we know that we call A as influence matrix.

So, how we are going to write this A matrix we know this right. So, remaining part which is this part now people will think that why actually this A matrix why the contribution from the second integral is not included in the matrix A. You know that is the fundamental doubt that everybody is having when they solve this problem. They say that ok no problem I know that this part actually is the you know the independent part and this sigma also is there.

So, this is the influence matrix A sigma, people know this very well ok yes I have no problem with this. But here why actually in the same matrix, why I am taking only the contribution from this part? Why I am not taking the contribution from this second part? So, we are going to answer this question. However, at this moment let us go with this ok to construct at least the construct the matrix the left-hand side, we are taking this part here and then we are taking this side over here and we are taking this part over here.

Now, since it is we have this minus 4 pi is you know multiplied throughout. So, this -4π multiply over here and I take this the right-hand side. So, it is $4\pi Vn$ here ok and we are just keeping it as it is here. Now, I am going to answer the question that why actually I do not take the contribution of this into the A matrix. Now if you look at this carefully, what is this sigma and what is this sigma ok.

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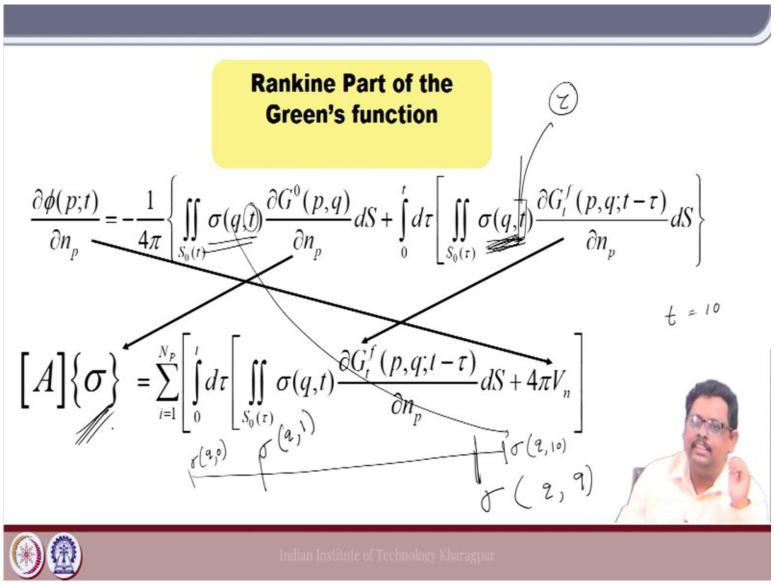

Now, here it may be confusing so normally we take this it is actually the τ and this is actually the t. Now what is the difference between the t and the τ? Now in time scale let us say I am evaluating at let us say t is equal to 10. So, now, this sigma actually if I look it at it is sigma the q at the time step 10. Now these sigma's are basically it is sigma of q starting from 0 ok let me write in bigger way, then we have the sigma at q at time let us take 1.

And then it actually ends of the sigma of the same point q at point 9. So that means, the sigma's are basically the you know it is the strength of the dipole of the previous time steps this sigma is not the strength of the dipole of the present time step, which actually I am going to figure out from this expression. I think that is I mean it makes sense right.

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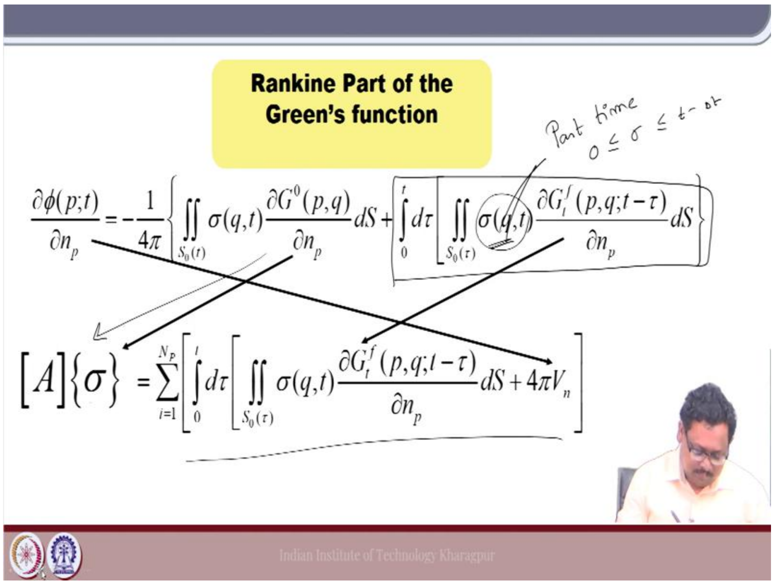

So, that is why we do not keep this sigma into the left-hand side, because this sigma are the sigma's of the you know past time. Now, this sigma started at 0 and this sigma is ends at t minus delta t. So, I know the value of this sigma is it not? Now when I solve the time step 10 sigma at time step 10, so I know that by that time I know sigma at time step 0 I know that sigma at time step 1, 2, 3, 4, 5, 6, 7, 8, 9. And then so therefore, the in this second expression all the parameter is known to me.

Because sigma is known to me because I know the sigma from 0 to 9 times step, I do not know the sigma at the 10th time step, so that is why I wrote I take this entire thing in the left-hand side. However, I know the remaining sigma's, so since I know the remaining sigma this sigma should not be the part of the matrix A rather it should be the part of this matrix right ok; fair enough.

Now, let us see about this summation thing, now here it is actually I written is a matrix form. Now in A matrix what is there? This A matrix you know if I if I write it somewhere I do not know where I should write? Let me write here this A matrix if you write this A matrix it I mean what is the element of the A matrix?

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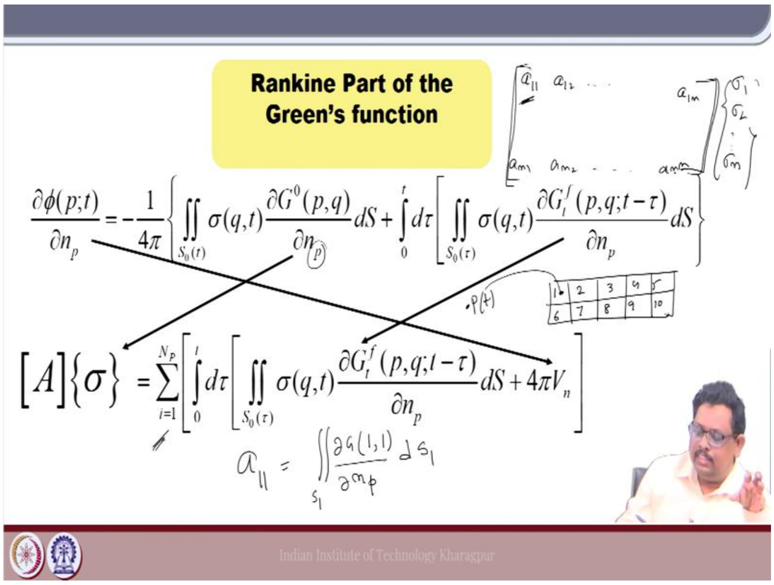

Now if I consider if I try to write the element of the A matrix, what is the element. Now it is a_{11}, a_{12} let us take a 1n into σ_1 σ_2 σ_n this is the thing right Now, what is a_{11}?

Now you know very well right, what is a_{11}? I mean you should know a_{11} the first term is referred to the to my source point and the second one referred sorry the first one is referred to the field point and the second one you know refers to the source point. So, what is that? Now I just again just for to remind you now if I have this paneling if I have this paneling if I take this number 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

Then if I put the source point P at time step t it is it should be the field point t is a arbitrary point, but if I take this as the first panel that is the idea of the panel method right. So, then corresponding influence coefficient becomes a_{11}. So, therefore, this a_{11} is nothing but it is you know in the panel 1 in case of a panel 1 right, we have the ∂G_I mean it is the source point now also 1 and the field point also 1, which is del n and now it is on the panel P.

Now remember there is a difference between the previous formulation where this normal we are taking at the source point here we are taking at the field point, $\dfrac{\partial G}{\partial n_p} \mathrm{d} S_1$ that is my a_{11} right. So, now when I talked about that influence matrix is complete it means that I am taking all the field point in the left-hand side right. Because a matrix has all the elements right A matrix have this an_1, an_2 and then an_n that element also there in the a matrix right.

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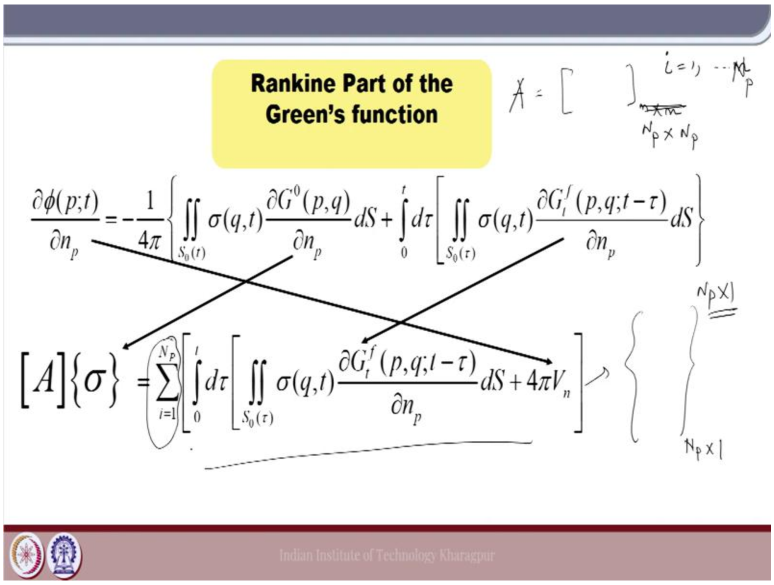

So, in case of this A matrix in case of this A matrix I am I am sure I mean I know that I take this all this n this is the n cross n matrix right. So, I am taking all this panel. So, let us take if the total number of panels is n. So, I am taking all the field point in the left-hand side. So, the same thing I need to do for the right-hand side also right. So, that is why I am having this summation sign because you know this right-hand side is nothing but the column matrix, this right-hand side should be the column matrix right.

So, then if I take n now ok, I just make it n p, so it should be let me correct it should be $np * np$ matrix right and i is going from 1 to np. Now, this should be the column matrix right it should be the np cross 1 right I am just writing about the term this should be the np cross 1. So, now each summation is not adding row wise now this adding actually the column wise. So, if I take the first point then actually you know if I write this, we have the less space over here. So, the only thing I can use here in theright-hand side corner.

So, I am always deleting thing anyway. Now when I just take i=1 then I can get only the column matrix ok. So, here now if I do that this i =1 then what I get.

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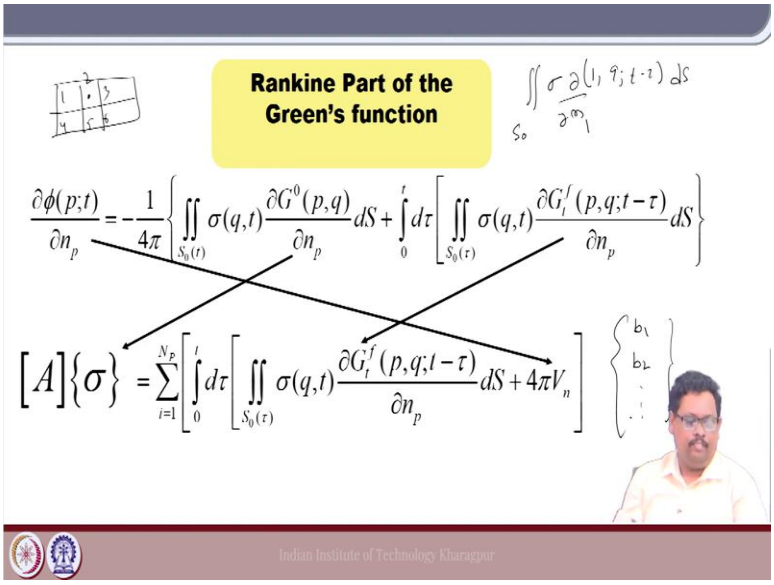

I get this integration of sigma. So, it is, so this integration over this body S_0. However, this $\frac{\partial}{\partial n_{pp}}$ is 0 and it is $(1, q, t-\tau)\partial S$. So, this is how actually we should do that ok fine. So, now, this one actually when I take i = 1, so I take 1 1 number.

So, then if I take i=2, so then actually in i 1 I take 1 number you get b_1. So, if I take i =2; that means, if I put my field point in let us say the second point it is let us say 1, this is 2, this is 3, 4, 5, 6, 2 then I get b_2 in that way it is going ok.

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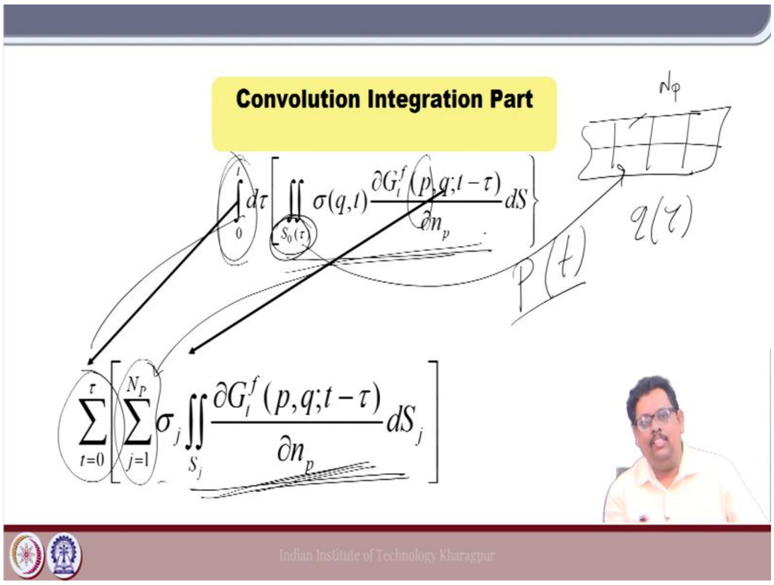

Now, let me this is the most critical part of this thing which is called the convolution integration. So now, here this is how actually I can write the convolution integral part. Now what I am going to do is this S_0 t is nothing but my body surface and this is the paneling. So, what I can do is this is now I know that this is the np number of panel. So, therefore, this integration part I just write in a summation term and this part also this integration is from 0 to t that also I can write as a summation term right.

So, for this integration I have 1 summation and then from integrating this over, now this is now this is the difference between i and j right i for the field point, but the j for the source panels right. So therefore, this integration this S_0 t actually I can split in the small number of panel and then from each panel actually I am going to do this integration. Now this is very clear if you know the omit type solution that time also we did that right.

So, there also we split this surface in number of panels and each panel locally I am doing the integration right. Now the part is the interesting part is how do the convolution integral I know now this, but I am not going to discuss here because as I said that let us keep this part right now. Maybe at the end of this course I can provide you the entire coding in MATLAB coding of this Green's function.

Let us now only formulate suppose you have this Green's function code how still it is very difficult to write this the other code. Now, here how actually you deal with this convolution part of it. Now you see it is actually not that easy to realize ok.

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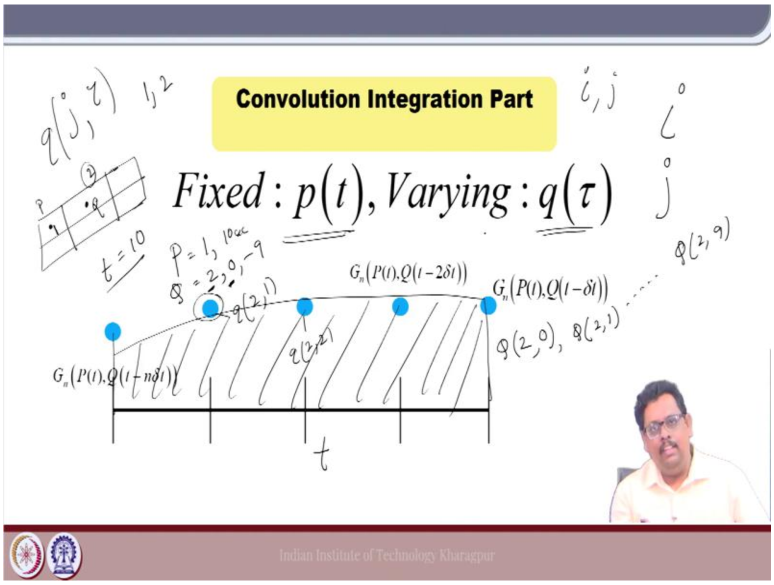

So, in order to realize it we need to understand this picture. Now here always this P is referring to this p is referring to the time step t and then this q is referring to the time step tau. So, q is the point on the previous time steps where is the P is the point on the present time step; that is also you need to consider. Now, see here now for a fixed p t like now suppose you fixing your i as I said. You fixing your i and then you are actually fixing your j also for a space coordinate, but you can vary now this q point is it has two variables.

One it is varied over space, so it is run over j also it varies over time scale done over tau. Now I am only varying the tau, so I am fixing the i and j for example, now let us try to do this integration. Now, suppose I am having my panel p in the panel number 1. Now I am having the source point q at the panel number 2, so I am fixing 1, 2. Now although you fix your 1, 2 still you see you have to do, now let us take that your p that t is about the 10 second.

So, now, what you need to do you see it is not that is why it is so complex you have to do that q for the panel 2 and not only for the you have to started with the point at t = 0 then you have to take the point at 2=1 and so on till the q point at 2, 9. So, you have to take all this point. Now, in time scale, so now, in time scale also you see you have so many points. It is in a space scale you have np number of point now and each np each j again you are having a time scale.

And that is why you have so many complicacies here, you have first overall you have i which is run over the field point. Now you have the j, now which is a run over the source point. Now this in a if you fix your j also then it runs over from 0 to t Δt. Now, here as I said I fix my p equal to let us say the first panel and 10 second. So, again I fix my q now let us the it is in the space coordinate in the second panel; however, the time coordinate should run from 0 to 9 second. So, then actually I have to compute that what is the value for Gn at you know.

So, we have to figure out that Gn at q = 2 and τ = 0. Then you have the next point, when that it is this point is basically when q = 2, 1 this point corresponding to q = 2 , 2 in that way it is going right. And then you need to integrate the entire curve under 0 to 2 you need to integrate the entire curve to find out the integration, which is the integration over the time which is this integration over the time.

You see you have first the space coordinate you each space coordinate; each space coordinate like you fixing your j and then you are running the time scale from 0 to τ -1 and then you integrate this right. So, this actually most critical part of this time domain code really, I try my best to give you some essence of it, but still, you need to do a lot you need to think a lot to write the algorithm for this particular convolution integral part.

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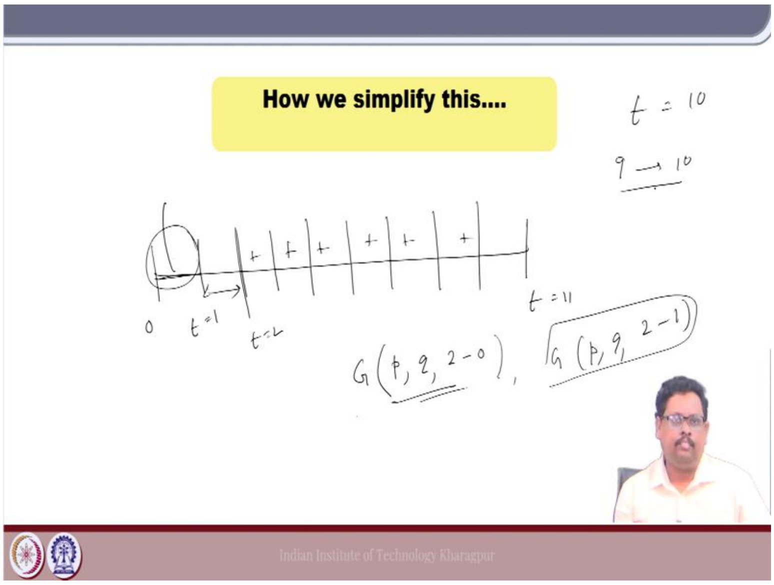

However, once you do that; once you do that you know ok how we simplify this let me also I forget this. Let me quickly I will tell you that here you know at each time step actually repeat you need to repeat this like.

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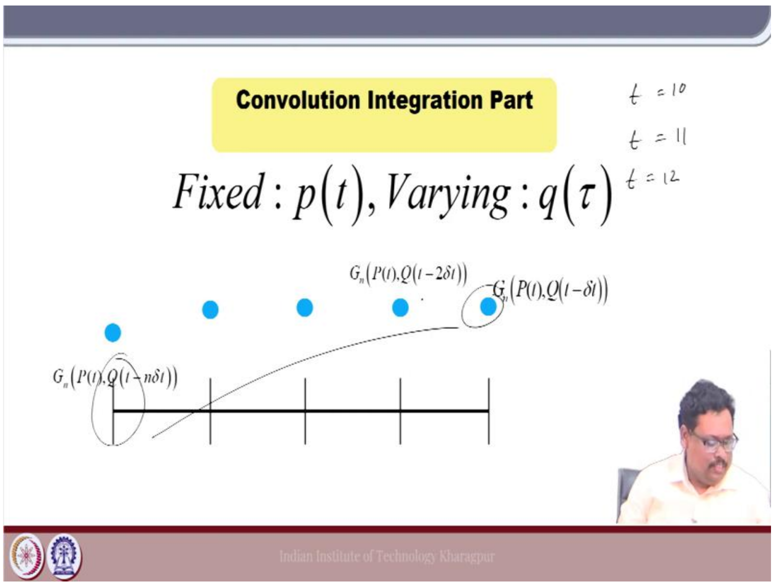

What I say that when t =10 you need to you need to do from 0 to 9. Now when t = 11 you again you need to do from 0 to 11 0 to 10. Now when t= 12 again you need to do from 0 to 11 is it not. So, all the time actually the convolution starts from 0 here and it goes up to the $t-\Delta t$ right. Now, this is very time consuming. So, how we simplify this as follows now what actually we are doing it may not be that accurate, but still it is fine now I just split it into the time scale let us say it is your t = 11.

So now, I know the value like let us start from the 0, so 0 we do not have the memory effect. So, we not; we are not going to do anything. Now when this t = 1 we have this integral right, so we store it we store the value. Now, when we do t = 2 we need to start from 0, but we have already, we have already stored this value we are only integrating this 1 and then we add this plus this. However, frankly speaking you have to take from this because you have to take G which is p which is q you have to do the t- τ .

So, it is let us say 2- 0 and then you have to do $G(p,q,2-1)$ that also need to do, but we simplify this we only store this value and this value we can get from the previous data that we have storing and we can simply keep adding. So, we really do not do this integration when t equal to 10 we not we are not going to do from 0 to 9 we only do the integration from 9 to 10 and then remaining thing we simply add with the previous thing.

So, this simplification we do and it works nicely; however, you know if you want to really have a robust and very high computing machine you can do from the 0 to the $t-\Delta t$ all the time.

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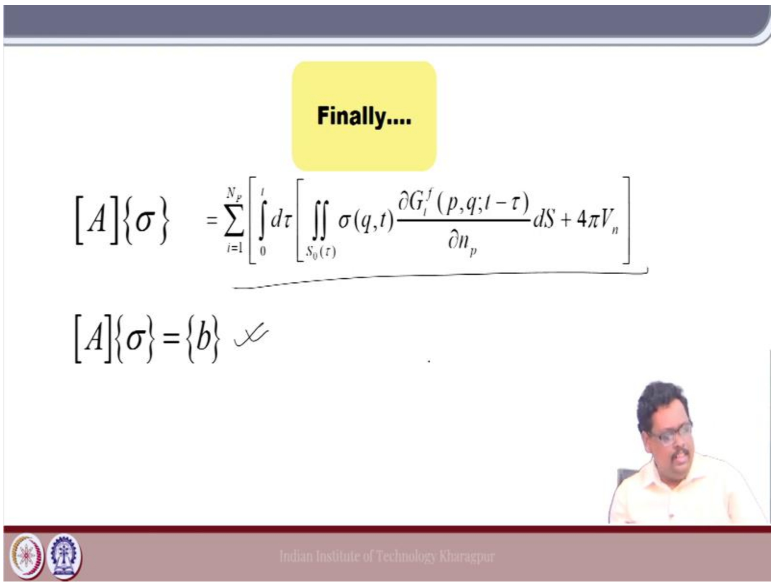

Now, when you do all the exercise and then this term also now you can write in terms of a column matrix B right. Like I just discussed for i is equal to 1 right now the if you repeat for i = 2, 3, 4, 5, 6 do all this convolution integration everything then each time you are getting b_1, b_2, b_3, b_4 a column matrix and finally, you are having the b and once you have this b then the remaining part you know right So, this is the critical thing that we discuss.

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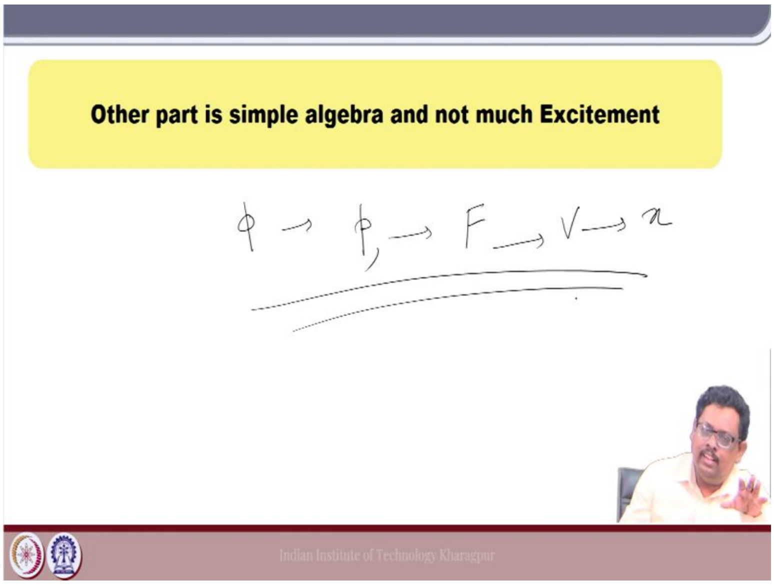

Remaining part we discussed a lot like other part like once, you know the phi know how to get the pressure, from the pressure how to get the force, from the force how to get the velocity and from the velocity how to get the displacement. This part we have discussed many times, so I am not going to discuss here the whole idea just to you know give you some kind of light I really do not know how you know how I able to do this.

It is so complicated as you know that the writing algorithm is really complex. But you know as I promise at the end of the course at least the Green's function part in MATLAB code, I have the Green's function that I can provide and then you can just write this algorithm. And once you done with this algorithm definitely you can able to write the code this time domain panel method code ok. So, thank you very much from the next class onwards we are we are going to start the hydro elasticity.

Thank you.