Seakeeping and Manoeuvring

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Lecture No. # 20

Derived Responses & Dynamic Effects - II

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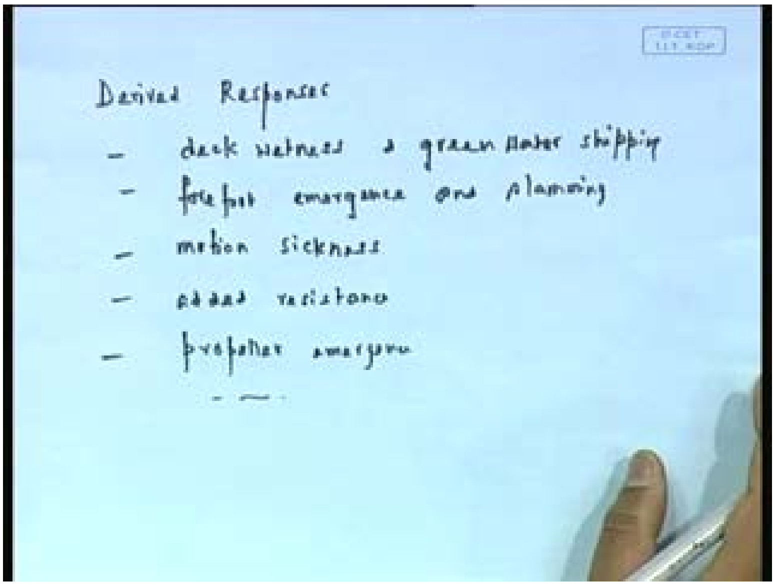

See, we are going to continue our discussion on derived responses and dynamic effects, as we had in our last class. As it was mentioned the basic 6 modes of motions, the rigid body motions are very important, but from practical point of view, some of the effects that results from those 6 modes of motions becomes even more important, which we call derived responses. Like we were telling about things like deck wetness and say green water shipping, we have mention all this, I will just for sake of continuation I am mentioning.

Then we have got forefoot emergence and slamming, then we had motion sickness for example, then we have added resistance, etcetera. Say propeller emergence, etcetera. See, so we were talking about this, so we will continue talking, maybe some of this aspects little more again, because what we would like to talk today is, not only how we can estimate them. Also, how practically important information can be derived for this quantities in irregular ship for example; slamming, you would like to know for a design in a given sea state.

How many times it slams per hour, how many times water comes on boat that takes per hour etcetera? These are the quantities, that maybe of more relevance then directly computing just the number. Now, let us continue this part little bit more to see this deck well deck wetness and fore foot emergence.

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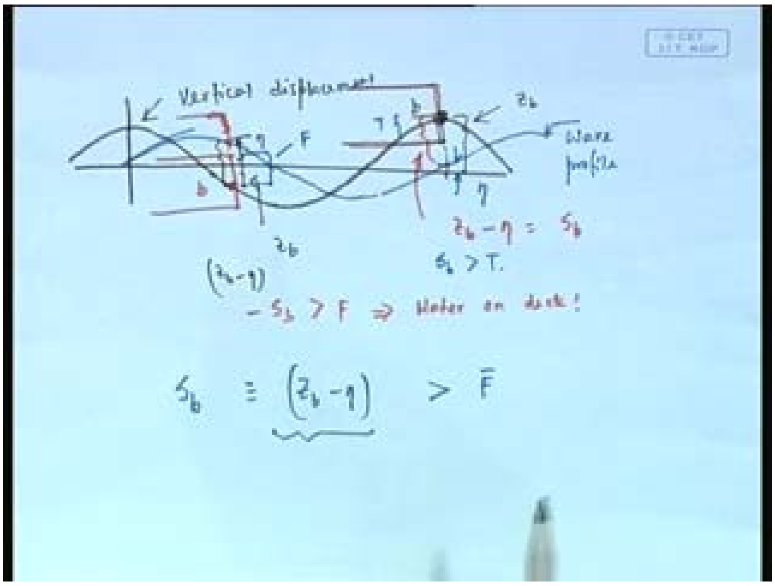

Now, let us just think of this relative motion concept. Now, if I had a wave or rather body, let us say, this represents the vertical velocity of the body, and I will take another pen, and this represents the wave, maybe smaller. Now, what is happening see here, now let us talk of a point, we will take somewhere here, say this lines represents this black line, the motional of the ship. So, supposing I take a ship here, bow point, say point b. Now, what is happing, see here at this point, this height is my vertical displacement of point b. So, let me call it Z at point b whereas, this blue line is eta at that location that is incident wave height. See, once again this is my vertical displacement and blue line is my wave profile, and this is my ship at this instant. So, this point b, see it has come up to this height, so that is this distance is my Z b whereas, this is my eta. So, what is happening is that this distance, again with the red maybe.

This distance is Z b minus eta equal to S b, what we can call relative vertical displacement of point b. Relative means, how high it is with respect to the water profile.

Now, obviously you can make out from here that if this is t, see this is the draft here. If S b is more than T, what happen? The fore foot has come out, the bottom would have come out, is not it? See, S b is this much and T is this much. So, obviously if S b is more than t, my bottom has come out of water. Now, exactly same way in a reverse case we can show here for example, if I were to take this red line here, some here. Now, this is my body point b no, sorry sorry I making mistake this is the point b, this is my ship here, this is my point b. Now, you see it has come down, so that means this is my. The point has come down, this is my Z b, this is my eta, so this is my, you can say Z b minus eta with a negative sign and this is my free boat. If now, obviously eta minus Z b is more than F, that means the water is come on the deck.

So, in other words I can say minus S b greater than F. So, what we are saying therefore, is that see, both this phenomena, actually can be found out by the quantity S b, which is given by Z b minus eta. So, if this eta at that location, eta at that point of interest, if this more than some value, say some threshold value, then I will say depending on how you take it, minus or plus, that fore foot has come out or the deck has gone down, essentially.

So, essentially what happen, what I need to do therefore, see I need to prepare a step in this is regular waves. So, in irregular waves if I want to study, I must make a spectrum of this, of S b. That is very simple to do a spectrum, because what we have seen last time, that Z b is nothing but, once again if I were to draw a ship, like a ship case with cross section, etcetera.

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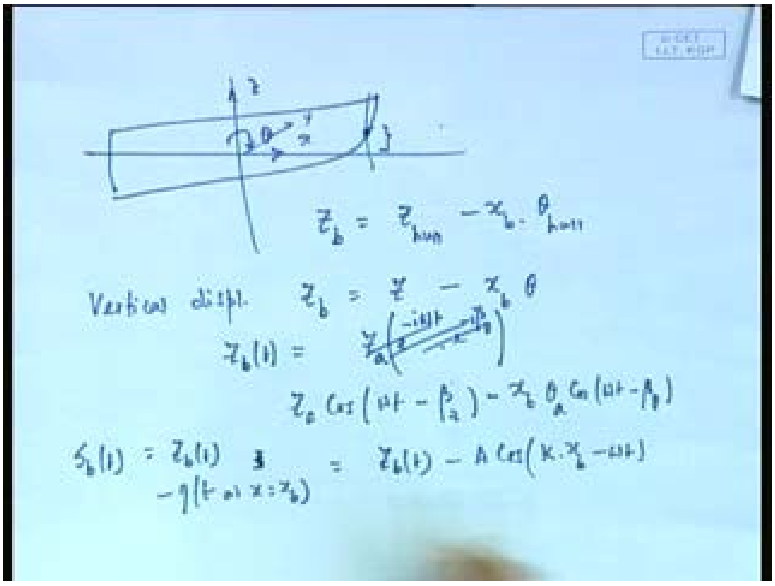

And if I take a point here, remember that they are this Z at point b is Z of the hull minus x of point b into theta of hull, that is pitch. Why because, remember that my Z is positive here and theta is positive here, like if you take the cross section, because what we have taken is you know x here, y here, so downward knows down is positive, so we find out this. So, you see that means that vertical displacement Z at any location b is equal to heave motion, I will just write Z at heave motion minus location of this point x location into theta. Now, this see Z b this is t, let me put this the full thing here right, this t it is going to be equal to Z. See, what is Z? Z is amplitude of heave into e power of minus i omega t, maybe e power of minus I beta, beta of e Z.

Essentially, it is a well sinusoidal function, real part of that or if you do not like it, let me put the other way round, let me put it this way, it is basically Z a say cos of omega t minus beta Z, it is something like that plus or minus of which, this is my phase, this is my amplitude and then I have got minus x b, theta is again theta amplitude a into cos of omega t minus beta theta. So, this full thing obviously of course, I can express this way as some quantity, maybe I will wait for the next level.

Now, if I were to took S b t, that is Z b t minus eta remember, minus eta t at x equal to x b, this becomes Z b t which is, but not minus, this is actually A cos K into x b minus omega into t. K x minus omega t taken at x equal to x b. Why I am doing all that? Now, if you see add this, this and this, this entire x b.

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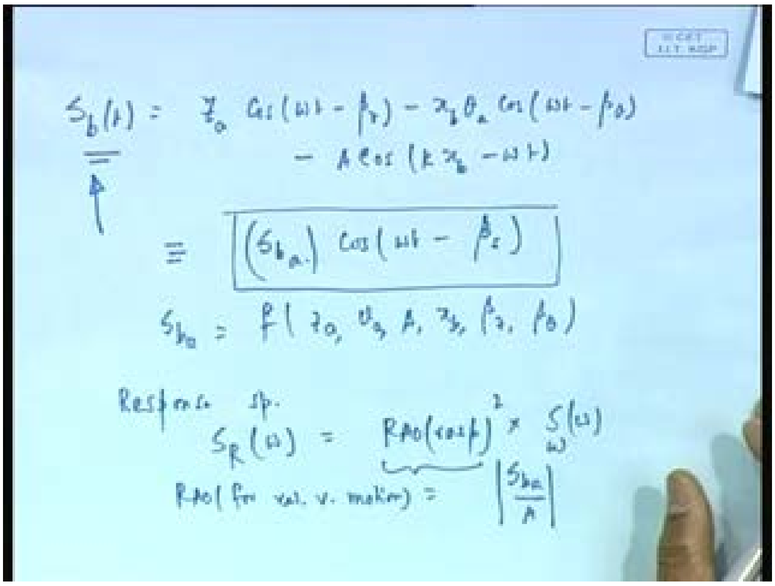

Go to this next slide that is I end up getting S b (t), if I were to write it Z A cos omega t minus beta Z minus x b theta A cos omega t minus beta theta, minus a is amplitude of A cos K x b minus omega t; omega can be omega e of course, in our case. This entire thing is equal to an S b amplitude into cos omega t minus beta S. You can write it this way, it is a sinusoidal function. So, here x b will be known, you will be knowing S b a, I will not the expression, but it is basically function of all this Z a, theta a, A, x b, all this beta Z beta theta will be an expression.

So, what I am trying to say see this S b t, this is relative vertical motion itself is a sinusoidal function with an amplitude S b a. So Therefore, I can very easily determine the spectrum for S b t, because my response here, the word response see here my spectrum, response spectrum if you remember, response spectrum that is S R omega is R AO of the response, square into S wave of wave. This is my R AO for the response square that is amplitude of the response divided by a square. In this case, I want to have the response spectrum for this particular quantity, which means I have to have R AO to be S b a divided by a square. That is it, there is nothing to it.

So, you see then my R AO therefore, here R AO for relative vertical motion is nothing but S b a by a. So, the point therefore, I am making is that all derived responses are also responses, and I can always determine the spectrum for those responses simply by taking amplitude of that response divided by a as R AO that is all; if were to for example, find out vertical motion spectrum, then I would take Z b a here that is I will take this quantity, find out the amplitude of this quantity and take that as an response spectrum, So, this part is straight forward part, so once I therefore, you know find out this response spectrum for say in this case

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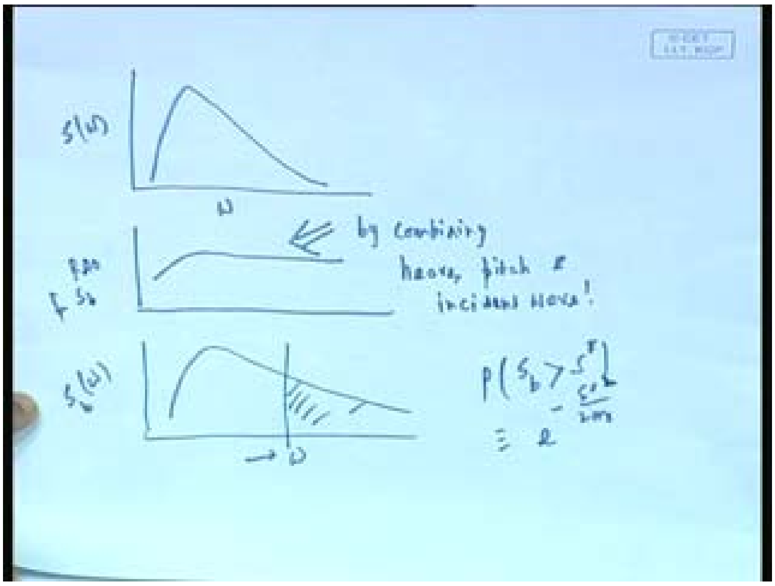

So, I end up getting here something like that, again I end up getting here wave spectrum is omega by omega, I end up getting here my R AO for S b, R AO for S b, whatever that is, then I end up getting spectrum for S of omega of S b verses omega. See therefore, how did I get that? Remember, how did I get it, by combining and incident wave, right. And remember, that while combining that here, the phase information was there remember, when I did that in, when I did this S b a this one, I had also phases there, very important. So, that is why in motion spectrum for say heave, roll, pitch, etcetera, you do not need phases. But, when you want o derive responses, phases are very important, because the phases must be properly added to find out the relative motions. Obviously, that is important, because you see the bow part is at the same it goes down and it pitches obviously, it will go down much more, so the phase is very important

That is why when we calculate R AO, remember that phase becomes equally important, because that is very relevant for derive responses. And derive responses are the one that is more important from the practical point of view, for our practical point that we would like no. For example, now we done this response.

Now, what we are doing, so this is let us say, my relative vertical velocity, so it is very simple, Now, I want to know what is the chance of probability of S b exceeding some value f, this will be given by exponential of minus half f square by m 0, when m 0 is basically, this is the by theory. Because the spectrum is again assumed to be a narrow band Rayleigh spectrum always, and if it is a narrow band Rayleigh spectrum, see this one, you can easily find out what is the chance of certain value exceeding some value. That is probability of S b exceeding some threshold value, always known, this is always given by e power of minus S plus square by 2 m 0, when m 0 is really under the graph

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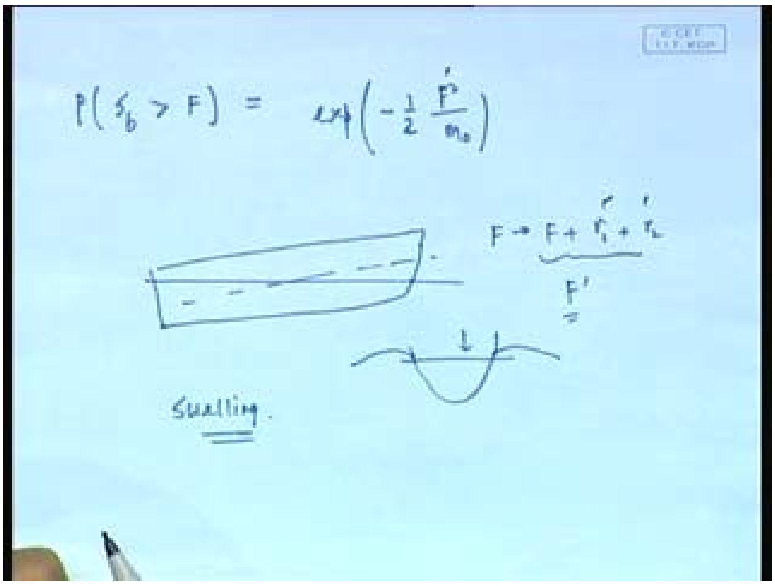

So, this is always known, so that means you always know this part, not only you know this part, see here my F dash is basically the threshold value, So, what I say is that if S b exceed F, then I am going to deck wetness. So, what is the chance of deck wetness then? Like this. Of course, I can modify if I will come to that part in a second, but from there I can find out all other statically properties also. For example, we will see in a minute how I can find out, how many times a deck will get wet in for example, in one hour, or per seconds how many times it can go up, all this part, or in 1000 cycles, how many cycles you expect to get wet. All these parameter becomes relevant from them.

Now, before I go to this threshold value, there is one more thing I want to tell you that, as far as threshold value is concern for deck wetness, see two more modifications are taken free boat. Because what happen, when I take a ship as it goes in calm waters itself, what happen? It actual undergoes a kind of a team and squad, because it changes the value slightly, because as it goes there it will actually parallel.

So, that modifies F to this F plus some value, some correction, say R one let me call. Therefore, effective deck like free threshold value that you get, may get modify. Second thing is that sometime when the ship goes down, then see for example, in this cross section it goes down, water tries to pile up. This is known as swell upper fit that water swells up, like if you just take calm water and push it, water tends to push up on the side, this is called swelling of it.

So, there are some empirical formulas for those swelling. So, with all that my this may be say some R two may be for swelling, so I end up getting this as effective F dash, so what I do is that I put here F dash. What I am trying to say take a ship, it has got a free boat of say 5 meter, but would happen is that effectively during motion, what you will get because of that quart, and because of the swell up effect it will be 4 meter perhaps. Therefore, we are going to say, if my relative velocity displacement exceeds 4 meter my deck will get wet that 5 become 4, that terms can be determined from empirical formula.

This is only a question of relation that is available, physically that is what happens. So, you end up getting that.

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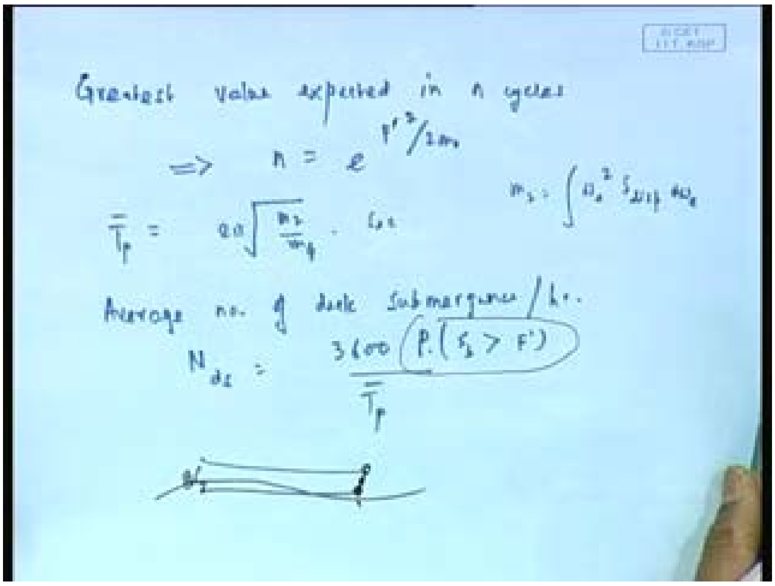

Now, for example, here from this relation also we can find out that, what is the chance that see for example, greatest value n cycles, this is going to become n Actually, this the formula is that n can be obtain e power of that F dash square by 2 m 0, rather this is not important, what is more important is time see. I will just come to this time part. See, we can find out typical peak period of this spectrum given by 2 pi square root of m 2 by m 4, second m 2 and m 4 are basically as you know, area under omega e, area under the velocity and acceleration spectrum, or you can say integration of omega e square m 2 S that velocity displacement spectrum and m 4 is power of 4. Essentially, this is the area under the velocity, see here relative displacement, relative velocity spectrum, relative acceleration spectrum d omega e, you can say. And the average number of deck submergences, this will be n deck submergences is going to be 3 6 0 0, of into probability of S b exceeding F dash divided by t p dash.

So, what I am trying to see from this relation you can find out, so what is happing is this part, this part we have done, this part, this is given by the expression last time that is this expression. So, what it means is that we are forming a spectrum. So, the procedure becomes very simple, I do a calculation, I have all the 6 modes of motion. Now, I want to do my lukewarm, what is deck green water shipping probability? So, I will first of all find out this RAO, I know my free boat, modified free boat dash, so I first find out RAO, one particular line find area under that m 0 and in next line I simply come back to those relation, this, this, and this. And therefore, I output the number of time the take we will expected submerge, per hour is that much.

Similarly, instead of take submergence I can say propeller emergence, the typically for example, the ship, it going like that, the propeller is here and if the water is here, the propeller can also get go outside, same thing I can do. Exactly, the same thing I can do for 4 foot emergence. That is, that 4 foot is coming out of water, same relation, because all that we will change is that F dash value will change, the probability will change, Different condition, S b must be more than these, must be less, whatever. All of them are, what we are doing is measuring this particular, some point. In this case, I will be measuring actually, this bottom point whether it is coming out of water. In the deck emerges I would trying to find out whether is coming below water, see all vertically. So, this becomes very straight forward procedure and this is what exactly we do.

So, when we do a calculations, see a typically a sea keeping calculations threshold, we would be doing first the RAO for the 6 modes of motion, that is the fundamental thing, So, I have this RAO for the 6 modes of motion. Then, I will immediately construct all the derive RAO that I want, like in this case, relative velocity RAO, and then I will find out whatever I want. So, these are very simple now let us talk about this part once more, see this one is the slamming part, because slamming part requires maybe little more kind of other like criteria.

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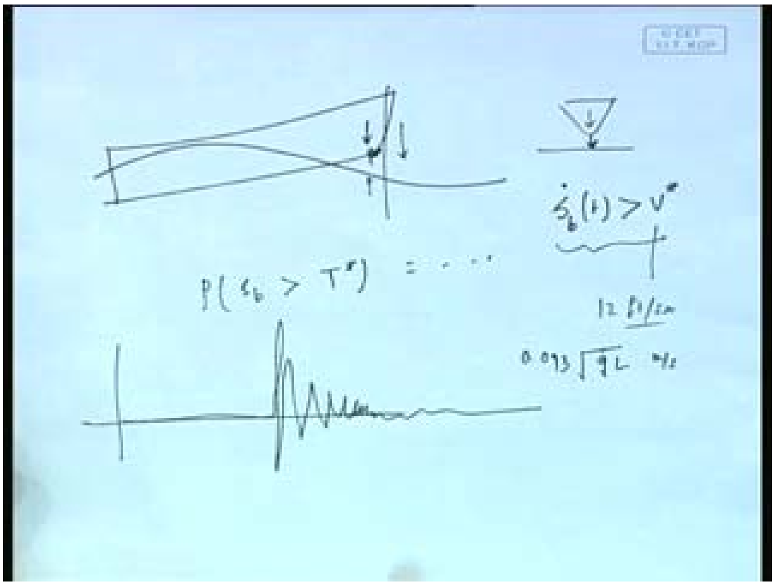

Now, say slamming, what here we are doing? Hull is like that, water is like that, so this bottom has come out. So, we know that what is the chance of this coming out, we know that. We have just found out what is the chance of a bottom coming out for example, this will also given by this more than some value, some value say T. This means, if S b is more than T star some kind of a mean draft at this location then the bottom comes out I know, but does it cause slamming? The next question.

Now slamming, what is slamming? Is very important for us to recognize this phenomena of slamming. See, when this goes up and this reenters, it will give a very large impact here and if you were to measure the forces here, you will find out the force with the pressure here will go like that, very large like bang, it is going to make a heat.

So, this bottom will be undergoing a large pressure, because it is entering here and it depends on the impact load. Now, this is impact load will obviously cause a very large vibration on the hull, like you are basically like an, like a hammer just banning it here. Now, when will it happen, we nobody knows it exactly. But, what we do know is that for it to happen this bottom might have to come out and reenter, reentering has to be also, well it has been found out, you define then that it reenters beyond a certain threshold velocity.

Suppose, it see the impact, we will take a waters. Now, if something is being dropped, now if you drop from much higher height, you will expect much more impact. Why? Because the entry velocity has something to do with it, see if you are very slowly entering a weigh from outside to water, you do not expect very large load, but if you enter it very fast, you expect. So therefore, statistically it is find out that there must be a vertical velocity, relative vertical that is S b dot T.

Relative velocity because, water can be going up you may be coming down, that must be more than some threshold velocity, some velocity say, some v star, we will come back to this v star, people have say it, this is the question of definition. People say that, well we will call slamming to have occurred, if this happens, as well as if the bow has come out. See, because otherwise, this is subjective. Well, when the ship keeps going it has got different kind of velocities and you cannot call it is continuous slamming, so there are some prescription. But, we do know that the load will be higher, provided or the load dependence on the relative vertical velocity of that bottom with respect to water, how fast the bottom is entering, at what rate? So, people have prescribed certain sensual value for example, at one time this had known to be 12 feet per second.

But there are empirical formula like this can be written as 0.093 root over of g L meter per second, so some norms are there. So, what we will say that slamming to occurred, if probability of this is more than this, as well as probability of this is more than this, people can say that. Now, the same spectral theory will work, because what happen, I can also find out the spectrum for this, right. So, therefore I have got now here 2 spectrum, now I will just come to that.

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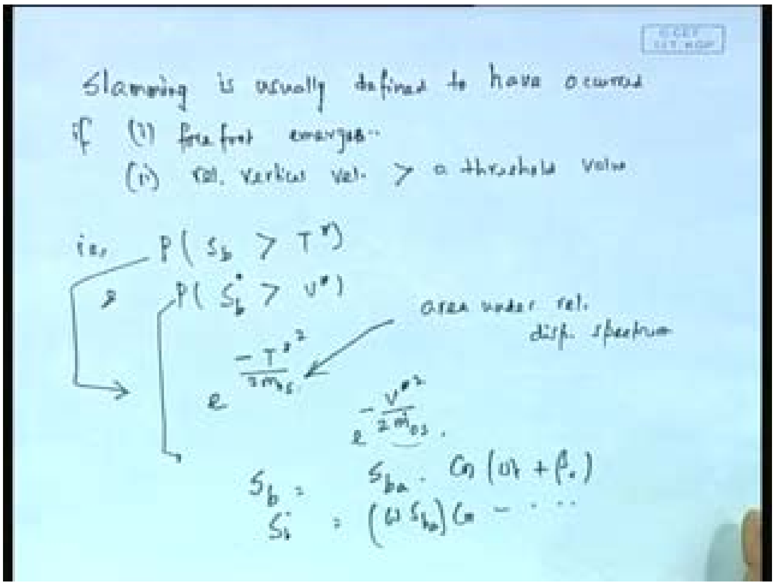

So, for slamming therefore, I will say that (No audio from 29:02 to 29:40) relative verticals exceed a threshold value That is, you can say, probability of S b exceeding some t star and probability of S b dot exceeding some v star. It is two together happens, we might define it as slamming has occurred. Like that one can say, now you see this can also be easily found out by the same probability function for example; this, we have seen this is given by e power of minus T star square by 2 m 0, going to put this S here as the relative velocity at displacement spectrum, this is displacement spectrum remember this one.

This one of course, will be given by e power of minus V star square by 2 m 0 dot, velocity spectrum, which are of course is, 2 m 2 S. See here, what is happening, probability at S b is more than T star is of course, given by e power of minus t square by 2 m 0 S and m 0 S is the area under that, under the relative displacement spectrum, and this is of course, probability of S b dot more than v is e power of minus e square by 2 m 0 dot S which is of course, area under the relative velocity spectrum.

Now, how do you find out? Again very simple, if I know S b, see when I went back to S b remember, the what has happen to S b? S b happen to be S b a into cos of omega t plus minus on beta. So, what is S b t? Simply omega into S b a into cos of this thing, so this is my velocity amplitude. So, what I am saying is that, there is no point of going further and further, when I add this two up I will end up getting simply a this thing.

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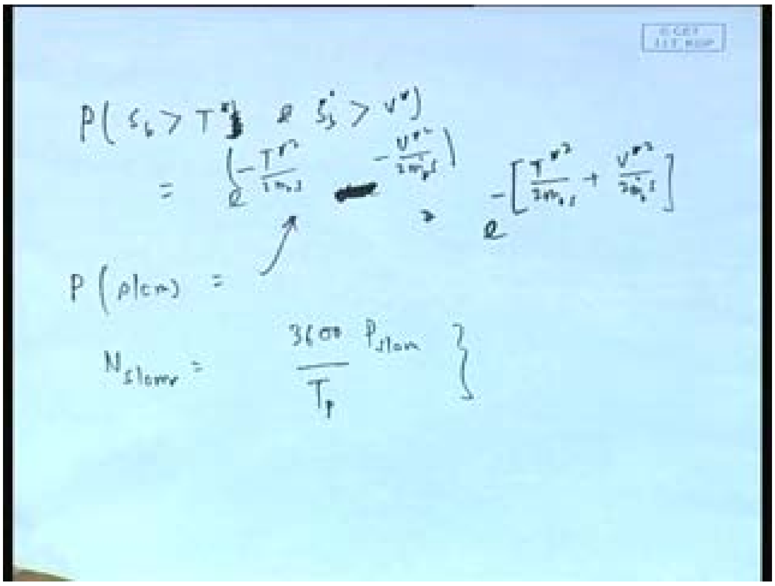

I will end up getting the probability of, if I want to find out slamming probability, that is S b is more than T star and like, sorry I should not put it this way, with not comma and S b that more than V star will be a combine probability it will be e power of minus T star square by 2 m 0 S plus e power of minus V star square by 2 m 0 dot s.

So, this I can find out once again, once I found out this probability of, so that therefore, I say probability of slam is this the chance of slamming is this. Then of course, I can find out number of slam per hour, exactly the same way 3 6 0 0 by p slam by T p or T p is again by that, like that period we do by that 2 m 2 by m one.

So, you see what is happening when this t p I can find out again by this m 2 and m 1, but I will just tell you that what yeah yeah yeah yeah yeah Now, that is what actually, no, what I meant is this, yeah this even you multiply it becomes that portion get added. Absolutely, right yeah yeah this is what I meant. It becomes this, like you add this up, the top, the portions up, yeah when you multiply.

So, basically let me write it again, probably e power of minus T star square by 2 m 0 S plus V star, yeah absolutely, so you know like that. So, what the point therefore, I am trying to say here is that see all these things are important, very important, but all this thing becomes fairly trivial to estimate as long as you have got all the basic motions right. So, fundamental point therefore, remains is that get the basic motions right, get all those 6 motions right.

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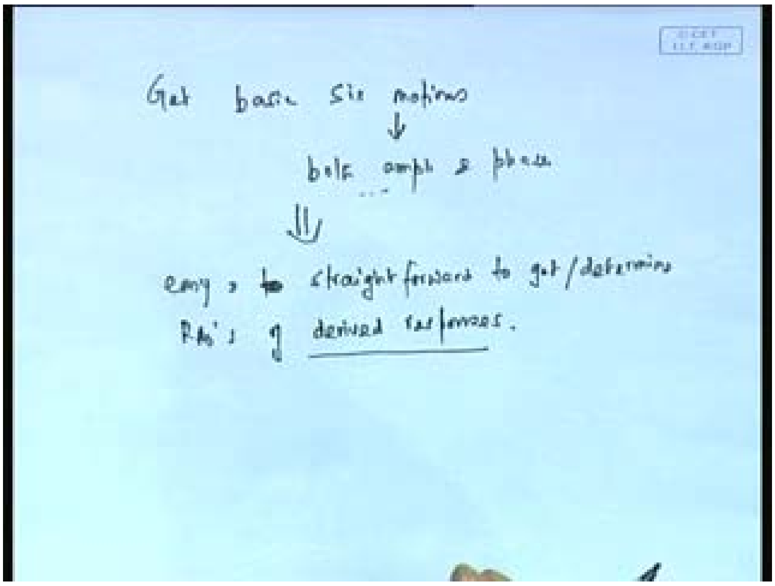

Now, here it means both amplitude and phases, then it is very easy and straight forward to construct all those derived responses. Specially, vertical like, what we say it for slamming, etcetera. Easy and because they are, because this derived responses are nothing, but combination of this, that is the point I am trying to insist upon you as far as practically it is concern, you can always find out the open up the book and find out the exact relationship. But, the point is that it becomes fairly trivial to obtain that, you see if I have this 6 modes of RAO and the phases, I can quickly, just by one line find out RAO for the particular motion, say Z b vertical velocity, or healthy vertical velocity, or whatever I want, from there I can find out whatever I want to know, again by just one line.

So, you know that the interesting point in therefore, sea keeping turns out to be that you see, what is important, practically are quantities like, how many times it slams, what is the chance of its deck getting wet? But, to get those numbers which is more relevant, the effort needed is very less. It is basically 99 percent effort to get to the RAO for the basic ship 6 modes of motions. Now for example, this we have talked about this two things.

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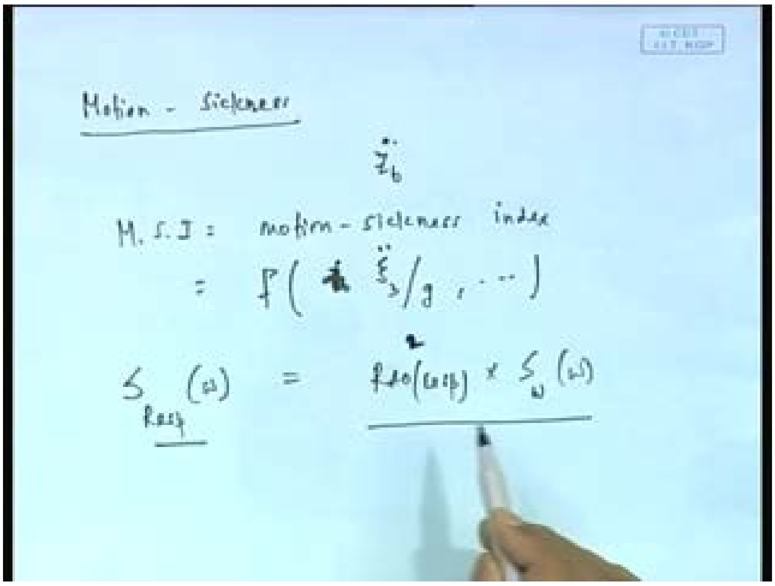

Now, let us talk about something else also, we will talk about the thing in a minute. See, motion sickness, again it turns out that motion sickness is connected to actually, rigid body acceleration at some location, vertical acceleration on this quantity. People do not know there are certain criteria, it says that if Z p t is within this to this range and omega is within this to this range, people define that there is some definitions of motions sickness index, M S I. I just take this sickness index, this is a function of essentially, like taken to be as some kind of a Z b dot not bow here of course, I should say vertical motion. Let me tell this vertical acceleration, actually acceleration, not maybe this acceleration divided by g and other quantities, you can define it.

My point is to say is that, it is not uniformly accepted you see, when you are going to feel sick and when you are going to throw up, it depends on the some kind of a criteria, it so happens, that ships represents the range of accelerations and range of frequencies, where you tend to throw up more. You do not do so in a high frequency, train for example, or in a car. It is a question of actually, a human bodies response. So, what happen, then why define that look? If my acceleration is within this range, and my frequencies are within this range, acceleration and frequencies get connected because it is omega square into psi three dot. Then I will call that people fall sick, so I will define m S I, then I can, if I define something then I can easily find out the spectrum for that. Then I can easily find out, what is the chance in a given see state that my motion sickness index exceed so and so.

So, you see application becomes straight forward for example, if I say that look, if my acceleration is within 0.4 g to 0.5 g or say point 2 g to point 3 g, then I am going to say that, I am going to fall sick. You can find out what is the probability of acceleration between this limit, so you can say that this ship would have, and then you can define that to be motion sickness index, that is that number of time that say sensual value exceed over the total time, say 10 percent time, so like that.

My point therefore, to say is that all this derived responses therefore, can be obtain more easily, but there is one and the spectrum become very simple, but there is only one which we will talk in a minute, where the spectrum cannot be constructed the way we have done for all other. See here, RAO square we do etcetera, so we are doing all that what again I am doing that this of response, this I keep on doing at omega, omega square RAO for that response, square into S wave of wave. That is what we are doing, so this square is important, this how we are doing for any response. Excepting one case that we will see in a minute, where we cannot really do this square part and that is what we call added resistance. Additional resistance that a ship encounters, we will just talk about it in a minute.

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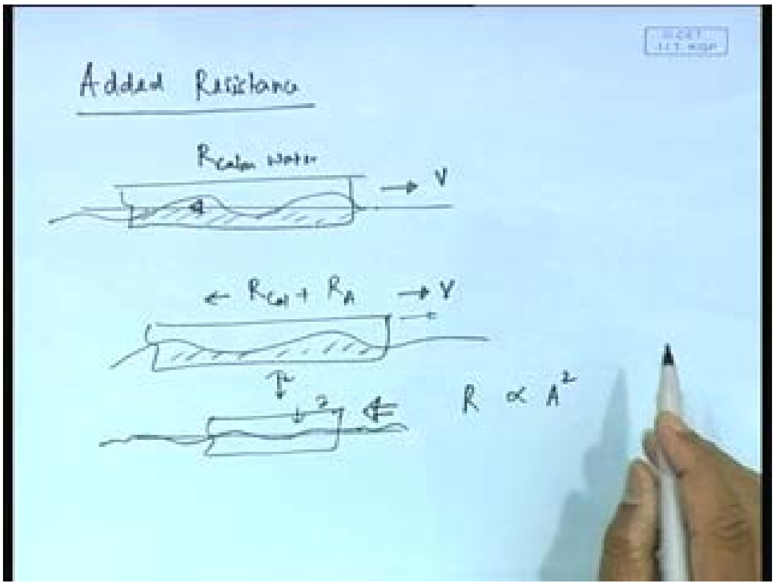

I just want to bring this out here, added resistance part. I will continue on this added resistance tomorrow also, but next class also, but I will just want to tell you today the some kind of this idea regarding this added resistance. What happens, see here that if you were to have a ship, going in calm water. We have an R calm water, that is your resistance that is coming, but if you were to go in a wave, then I get an R. Now, this R happens to be more than this R that is this becomes R calm plus R added. Basically, it is more and if you take this minus that, what you call is additional resistance. Why does it happen? Now, you see if I ask you this question, why, what is the physics behind this, that will be the answer?

Let me just try to understand from you, we have all done resistance course before. So, we know resistance dependence of course, on skin friction on this area and also wave making resistance. Now, the question is that there will be a temptation for us to tell, because it goes on the waves, my underwater this part is changing therefore, I will have additional resistance. But, that is not fully correct, why I tell you that. Remember, even I go on calm water, I actually have a wave formation, see even when I go on a calm water I got a bow wave formation around that, isn't it. Yet, what I have done? If you recall correctly, we do not consider that for R F calculation. Why so is because, this wave is up and down and the net wetted area, we think do not change significantly. Now, if there is a wave, like wavy kind of wetted surface, you say that wetted surface is more or less same.

So, here same thing will happen. So therefore, it is not because of the fact that I my wetted surface is changing. Then why, where is the physics for which the resistance increases, and why do we talk this in sea keeping course and not in resistance course. That is a point I was trying to tell. The main reason for that see and that we need to understand, see when the ship is going in waves, what it is doing? It is undergoing heave, and pitch and all the motions.

Now, you take a calm water, and you take a ship and make it make it move like that, what will it do? It is going to create waves, right. So, if I were to by force impose motion, it is going to create waves. This waves obviously, carry energy, just like in wave resistance waves. So, what is happening is that these obviously, show up as resistance, additional resistance. See, when the calm water I my ship was going, it is making a wave resistance wave, calm water wave but, now on top of that my ship is also oscillating, going like that, and if I do that it is going to cause further waves, because anybody in calm water which you want to oscillate, it will create waves.

So, this additional wave also carry energy, and this energy just like in wave resistance wave, calms or show up the rate at which the energy is spend, show up an additional drag or resistance. What is the origin? The origin of the of the resistance is purely sea keeping, purely the fact that it is undergoing basically heave and pitch motion or motions.

That is why it is taught in or it is a part of sea keeping additional resistance, you see because this resistance originates from the fact that the ship is creating waves, because of its wave resistance motion in the first place, because it is undergoing some oscillation.

So therefore, this resistance formula that we will find out will be all connected to heave and pitch and other modes of motions. Now, the question is that, this particular thing is normally going to be more significant, we will come back to that in head wave, but I can tell you one thing, resistance. Now, here there is comes the question, resistance is proportional to amplitude of wave square. Here also the resistance that has caused is because the waves it is creating, this waves it is creating would be having certain amplitude. Now, you think of this, I have the, let me because today I am going to just discuss this.

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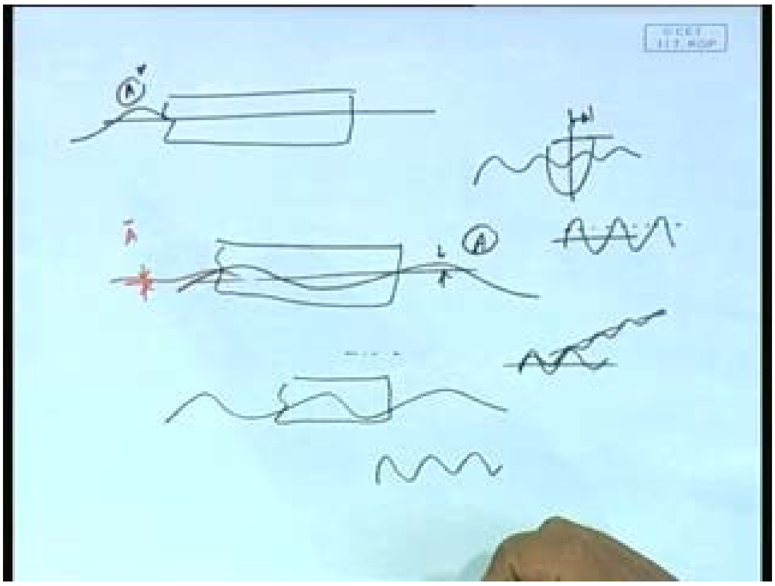

So, I have got a calm water here, let us say calm water here and it makes a wave of certain amplitude A, this wave resistance wave, we are not forget it A star or something, but now I have got A wave or certain amplitude ship is going.

So, now this incident wave amplitude, this is my A, this is my incident wave amplitude, remember. Now, this is causing me to move up and down, this move the body to move up and down heave and pitch. Which is causing me certain additional wave, where is the blue pen?

So, let us say this additional have has an amplitude of A bar. Now, this A bar obviously, is proportional to a, because if the A is more, see my linear if suppose a was twice, my heave would be twice, my heave is twice, A star will be twice. So, that means this and this are in proportion, but resistance is in proportion to square of this. So, therefore, it is an proportion to square of this. Now, here is where we differ in all other responses like vertical acceleration, motion, etcetera. The response was linear function of A, but here my wave resistance or additional resistance is a quadratic function of A and therefore, the spectral formula will not apply.

So therefore, what is happening? Now, I will just want to tell you, because it is actually a square function of A bar, this is basically, quadratically depending on the incident wave. If the incident wave was to be twice, you would expect this to be 4 times, because it is quadratically dependent. When a phenomena is quadratically dependent to be a physically therefore, you can think that it is a non-linear phenomena, it is a second order phenomena, because it is not dependent on A power of 1 but A power of 2. So, this is from hydrodynamic point of view, much more complex phenomena, because this is what we call a second order phenomenon. Why I am saying all this is because, we are going to tomorrow or next class talk about certain empirical formula. Empirical formula has to come, because or based on certain physics connecting heave pitch, etcetera, because there is no direct way or close form way to solve a second order problem.

This phenomena is somewhat similar to also the fact that in a wave, if I keep a body, you see here then if I just leave it, what do we expect? You expect it to drift slightly, you expect it to drift, isn’t it, Why should it drift? See, the first order response tell me that the surge motion is like that. That means, if it goes down one meter, it should come back one meter, it should be oscillating about one point. See, if you leave a body, a ship or a floating body just on the water.

Now, according to my first order theory, what has happen? If it went down this much, it come down this much, it is oscillating, So, it should not be drifting about a mean position, you agree with that. Now, it should not drift, but in reality shows that it drifts, because you have seen that it always drift, so you always put an anchor. Why it does, because what would happen in fact, if you see this body, it is not going to go like that, but it is going to go slightly like that, slightly drift would be there, oscillate but drift.

This drift force cannot be explain by first order theory, because first order tells me my psi one, or surge, or sway motion is oscillatory about a mean location, but reality shows it drifts. This drift is obviously occurring because some kind of mean force is acting on the body, so there is there the body here, waves are coming here, there is a net mean force acting and this is a second order phenomena, this mean forces you know.

What we call, if it is first order force it would have been oscillating, that means the force would have look like, but this force is having a mean value, so it would like as if on the mean it oscillates, that means there is a steadily and pushing, that push is equivalent to our added resistance.

The physical hydrodynamic phenomena is that, that push which is what we call the second order, force equivalent to all this added resistance. So therefore, my point of saying therefore, is that added resistance is therefore, is a phenomena that is not same as other derived responses, it is a second order phenomena therefore, it cannot be directly completed or found out as an you know as an simple motion combination RAO type. Therefore, you must have certain special formulas that would have been derived, which will be talking eventually.

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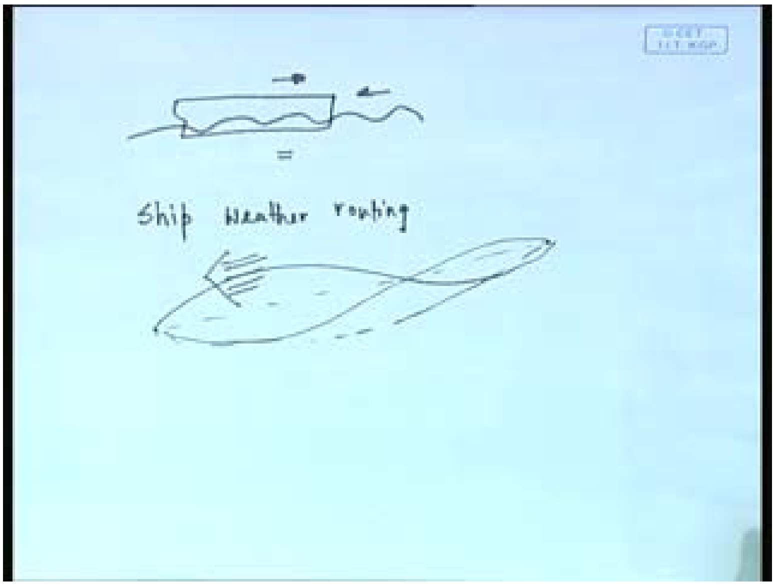

Now, the other thing is that, when is it most important for added resistance to occur? Obviously, is it most significant when heave waves are coming, waves are here and ship is going here; in fact, that is the only time, that you expect very large heave and pitch and very large added resistance in a heave wave. See, added resistance you expect much larger on a heave wave condition.

Now, I want to tell you this before I go into this formula, this added resistance has given rise to many important phenomena like, when a ship goes from here to here, open ocean, it does not go on a straight line or even if you take the, so call the arts curvature, it does not go on the line of minimum distance, typical line that somebody might follow.

It may follow some line like that or some line that or some line that, why? One of the reason is because in that line, see there can be waves coming in some direction. If it actually, were in this side, it might actually experience more resistance and slow down and might take longer time. So therefore, it actually takes it route where your total time taken might be minimum, this is what is called whether routing, depending on the prevailing weather, it actually takes a route along with, which it will have the least resistance, but what is the resistance? It is only for the waves, maybe for winds also, if there is a wind field there, but primarily waves, which means added resistance become a significant criteria for selecting which way you should go.

So, this is added resistance part and actually we talk added resistance conversely, because a typical ship would have certain power, now you cannot power up more, what would happen you are having a full M c r rating, so you are making 16 knots but because waves you end up making fourteen knots.

So, we can look at added resistance also as a reduction and speed rather than additional of resistance, so we will talk about it next class about certain empirical formula of added of resistance, and how you determine added resistance in a irregular sea, and we will find out that here in added resistance we are not concerned with one third significant value etcetera, but with average value, because its average value of increasing resistance that we are interested more, this we will discuss in next lecture along with you know like some idea on this sea keeping criteria for design and polar plot things like that. Thank you.