Design of Offshore Structure
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Module - 1
Lecture - 5
Loads on Offshore structures 1

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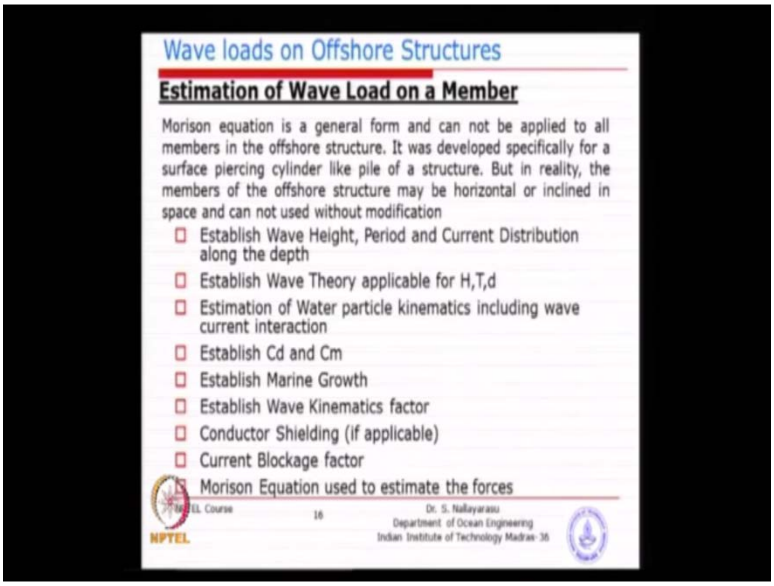

So, let us continue with what we were discussing yesterday, regarding the estimation of wave load on a single member. That means one single structure element is subjected to wave loads it is quite easy, but when you have multiple elements we will look at a procedure which we can find out. So, in this I think various steps we were trying to understand. The first one is to collect date on the wave height wave period and the direction and the associated wave theory for a given situation basically. We learn about little bit about the linear wave theory and the non-linear wave theory and where it is applicable, what are the assumptions are violated in case if you select a wrong wave theory.

So, basically we want to see that how do we select a wave theory and then the using a particular wave theory that you have selected estimation of… Note the word I am using estimation is always is not hundred percent correct all these wave theories are just near approximation of what is the natural phenomenon happening in the open sea conditions. So, always you try to estimate correct it adjust it according to what we think it is right so basically most of the wave loads are not calculated is actually estimated, based on certain ideas devised by past people like researchers, over a long period. And we keep updating these information and as we learn more and more. So, there is absolutely no question like this is right and this not right, still we keep updating because most of them are semi empirical. So, in doing so we also need to select a suitable C d, C m which is highly subjective to experimental evidence. And then they other three or four parameters we are just going to look at what are these correction factors, so you evaluate the wave force and do a correction to adjust to reality.

So, some of these correction factors like wave kinematics factor conductors yielding and then the blockage factor will tell you the story that the reality verses the theoretical calculations, there is an adjustment to be made. And the one more extra parameter is the marine growth you might have seen if you have travelled to coastal areas, you will see that the algae grow on top of the structure, where ever you have costal structures or even off shore structures. These algae grow on top of the structure making the structure slightly the dimensions bigger, but of course, it is not a structural element its basically a attachment that makes the dimension bigger. Once the dimension bigger what will happen your wave loads will be larger that means they attract more forces.

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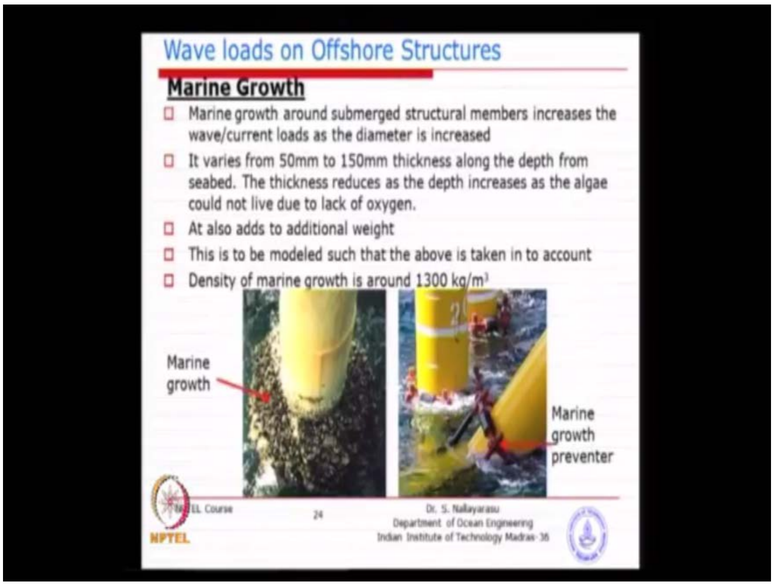

So you could see here that picture I will show you something like this you see this picture on the left side is a meter diameter structural element, which is of column of a jacket structure. You could see that how much algae grow on top of this could be 30 to 40 percent diameter increase you could see that potentially the wave loads on this, on this is definitely going to be higher because of the presence of such a additional dimension. So, sometimes we do use you know basically idea using the natural wave energy to remove this. So, you see on the right hand side we call it marine growth preventer, the idea behind is a sliding system by natural water oscillation just because wave is moving up and down.

So, this will scrub of top of this member making sure that there is no algae continuously growing on top. So, if there is little bit growing here it will keep moving up and down because we are not using external power. So, this is one good idea that we could come up, but then the reliability of this is little subjective, sometimes it may get entangled and then become very good place for growing further algae you know.

So, basically sometimes we do use this, but not hundred percent going to help us so basically if you look at this marine growth it is a it is a phenomenon, which cannot be prevented number one for sure you cannot prevent, it is going to grow. And then how we take into account is something that we need to think about it because the diameter increases, but it is not going to offer structural strength its only a burden for us. It increases the weight it also increase the dimension which will capture the more wave a current loads. So, that means we need to consider this as a separate analysis in the hydro dynamic load calculations.

Typical dimension or the thickness of this is about 5 centimeters to 20 centimeters. Sometimes I have seen in so of the locations 20 centimeter is a kind of thickness, so if you have one meter it becomes 1.4 meters 20 centimeter this side 20 centimeter the other side so, but this one varies most of the time along the depth you know algae is the living organism. So, you need defiantly oxygen, so as you go down what will happen? The oxygen content is lower and lower and that means the thickness or the amount that it can grow or bottom sea near the sea bed will be very, very minimum.

So, you can see that the near the surface it will be larger and slowly reducing down. So, this effect its actually not very good for us because the wave load is also maximum at the top only because of the water particle kinematics is higher velocity is higher, acceleration is going to be higher. So, you could see that this is an added effect which will produce more loads so this needs to be definitely take in to account, and also adds weight. You see here the member become so large even if even if it is light density, it is not very heavy like steel, but still it adds weight.

So, we will see that so much of members you have in the jacket structure every one of them had with so much weight you will see that the total foundation design load will be higher. So, that is the only effect which we need to defiantly address in a proper way and so that you know the loads are captured correctly. The other three parameters are generally a reduction factor wave kinematics factor and conductors yielding and current blockage.

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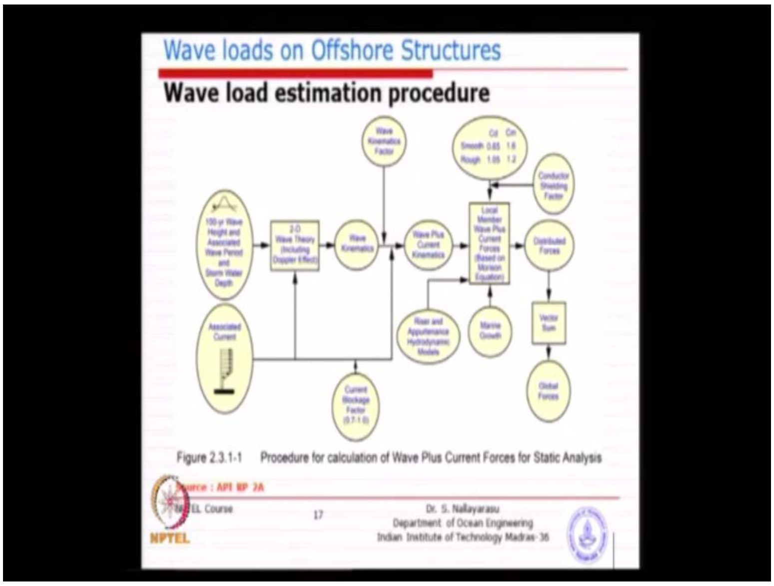

The same steps what you have just now seen is given in a chart form, which is given by a p i in fact if you see that the whole chart is developed by a p i just to make sure that you do not forget, it is not technical flow chat its basically an idea that you should keep everything in mind while doing evaluation of wave load on a structure. Basically the collection of wave data hundred, year one year, associated current. And then combine them and then the wave theory selection depending on water type wave height and the location including Doppler effect, we are going to just see what is a Doppler effect, we will just see in the next few slides.

And then calculate the water particle chromatics and then use the reduction factor like wave kinematics factor or current blockage factor. And then come up with a combined wave and current effect, you know we will see the non-linear interaction, as well as the Doppler shift. And then basically apply corresponding cd cm for a particular member whether its circular sections or rectangular sections or other shapes you will have the Cd Cm s different and the apply the marine growth on top of them.

And then if you have any secondary structures non structural elements apply there and then the conductors yielding and finally, you come up with a distributor forces. And then vector sum means you distribute into x y z directions for a three dimensional structure, if it is vertical structure its very simple, but we have a three dimensional brace or column you can see that then global forces can be competed. So, you see this the reason why this flow chart is given is to make sure that you do not miss any one of them because it involves several sub activities.

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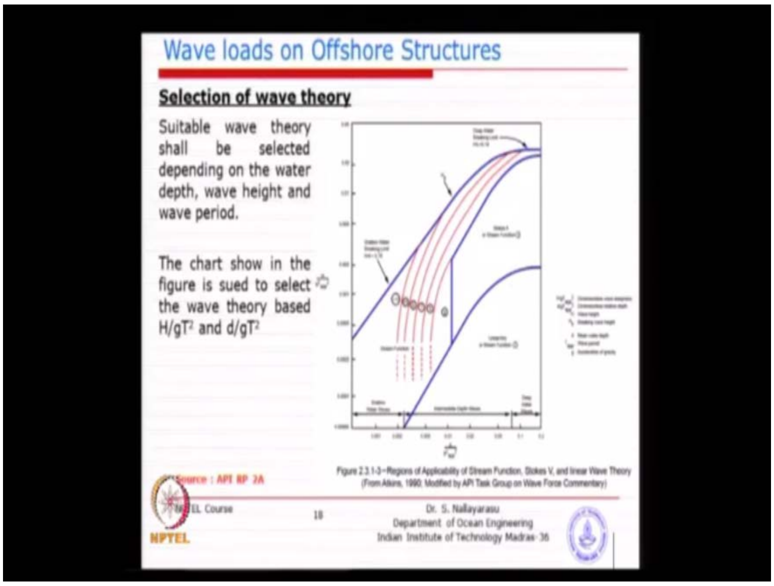

Selection of wave theory you see right side you have a chart made by task force set up by a p i quite some time back and basically came from atkins report its actually a laboratory in US they have got a very good set up, they have been doing hydro dynamic research for several decades. So, they came up with this in fact this chart originally and then the a p i task committee trying to identify what could be the best way of classifying wave theories for the purpose of computation of wave forces. So, this chart is adapted, but modified the a p i task group slightly modified the atkins original chart.

So, you can see here in the horizontal axis you have a d by g T square is a representation of the depth of the water depth at the location with respect to g T square is proportional to the wave length, you know the longer the wave period longer the wave length. I think you can see very easily to second means is once you go into wave theory calculation you will see basically the length is proportional to the period, for sure you can easily understand.

So, the g T square is the representation of the length of the wave and on the vertical axis you have h by g T square, basically the wave height verses g T square that means also with respect to so you could actually indirectly write this on the vertical axis is h by l. Whereas the horizontal axis is d by l so water depth in relation to the wave length and wave height in relation to the wave length. So, one is the wave stiffness the other one is the relative water depth how much is the water depth with respect to the length of the wave. So, you could see here this two parameters are playing major role, one is the vertical one is very easy to understand the wave stiffness, how big is the wave when compared to the length of the wave, the longer the wavelength smaller the wave height, the assumption made by aerie could potentially be acceptable.

Whereas the wave length is smaller wave height is too big probably the assumption is going to be violated to very simple idea that vertical axis is trying to figure out, how relative wave height to the wave length that is what idea behind. The horizontal axis is also very easy to understand water depth verses wave length, if you if you look at the wave decay function which we discussed about the sign and cosine hyperbolic functions that wave effect is going to be diminishing as you go down.

So, if you look at that you will be able to understand the deeper the water depth for example, one thousand meter verses one hundred meters, just take an example one hundred meter, one hundred meter wave length. The effect will be almost to the full depth where as one thousand meter water depth same one, one hundred meter wave you will see that the top portion will be have water disturbance more than when it keep going down. So, that you can see that the d and the length effect you could potentially identify probably, you will learn more in the hydro dynamics course that the water depth in relation to the wave length also play a major role, how much is the distribution of the wave load from surface to sea bed.

So, the d by l is larger means the depth is more when comparison to the wave length you will see that it is more like a deep water effect, means the wave forces is concentrated on the top one third or one fourth of the total depth, and that is the representation given by the horizontal axis. So, based on these two parameters, you could see here the theories have been classified and selection is made easy, you see on the on this side, linear or stream function wave theory just you can see on this, this blue line form here all the way. So, any of the points lying here you can simply select linear wave theory.

That means you could see that it is a lower h by l number one basically the wave height is smaller when comparison to wave length. And also the water depth is deeper because as we go on the horizontal axis on the right hand side is water depth is deeper in relation to wave length. So, that means its deep water no breaking, no build up so basically that is the idea behind that you will select linear wave theory on when the d by g T square is larger number. As you come smaller and smaller you will see that the shallow water effect that means, the wave will be effective throughout the full depth or as much as distributed to a full depth. So, that is why you will see a shallow water waves or you can even see sting function wave theories.

So, in here there is nothing wrong even if you use stream function wave theory, but also can select so you could see that this demarcation this line, beyond which you cant use the aeries wave theory. So, the linear wave theory cannot be used all the time unless you this parameters are such that they are below the first blow line, I think that you could easily understand. Then when you exceed beyond that line then you have several choices you can use Tokes wave theory, you can use stream function wave theory. And then you have the last upper line beyond which the wave does not exist because of wave breaking. So, you can easily see that as the height increases without changing the wave length, what will happen?

The height of the wave is higher and higher is unable to sustain its going to break. So, that we call it deep water breaking and you know basically the waves cannot sustain because of the water particle chromatics is so large compared to the speed of the wave you will see that the water particles jump in a head of the wave propagation. I think that you will learn in hydro dynamic course more.

So, basically that that gives you an idea about the demarcation of shallow water, deep water and breaking and non breaking waves. So, the upper line the upper limit what you see here as long as h by g T square is higher the waves will break. So, you may not be able to apply any of these wave theories because you can see there, when we derived or in fact you are the boundary conditions and the domain equations is for continuous or flow with in a domain. If you have a breaking wave the water particles get separated, non of these theories will be able to apply that is why you cannot calculate a wave force, for a structure when the wave is just breaking or just broken.

So, what we need is another idea, when the wave is breaking on a structure you will see when you go to many of the port and harbor structures, or costal structures many times waves come and break on the structure. So, how do you estimate, so we need to just see some alternative methods because none of these methods will work because they get separated during wave breaking. So, this is a very good guidance for us to select a theory because it gives up little bit of sense, you know wave height effect, water depth, and relative wave length effect.

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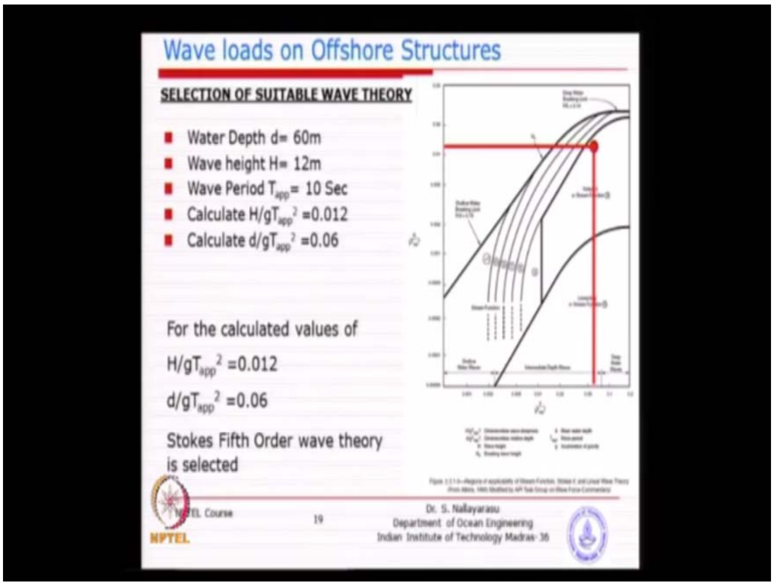

So, typical example for a location what you see here in this chart is a water depth is 60 meter wave height is 12 meters and then associated period is 10 second, calculate this both the parameters. And then you could see that straight away strokes wave theroy is applicable so for a typical jacket location of 60 meter water depth you could see that the wave height is potentially 12 meters, stroke wave theory. So, you cant use aharies wave theory because the wave height is at the same location if you selct two meter wave height you will see that probabily, it will come down straight away here isnt it automatically will be able to select aries wave theory so that is…

Similarly, when the water depth beocme ten meter for example, can we have a 12 meter wave height not at all feasible it will not be possoble to propagete because by the time it reaches 15 meter itself it it would already broken, because enough water depth is not available. But at that location 10 meter you may be able to get 2 meter wave height so 10 meter verses 2 meter you may still fall in either strokes or aries wave theory we do not know so is all relative rather than 60 meter is called a deep water, and 10 meter is called a shallow water, there is no such thing. Every time you have to see the relative effect of water depth wave height and the wave length or wave period.

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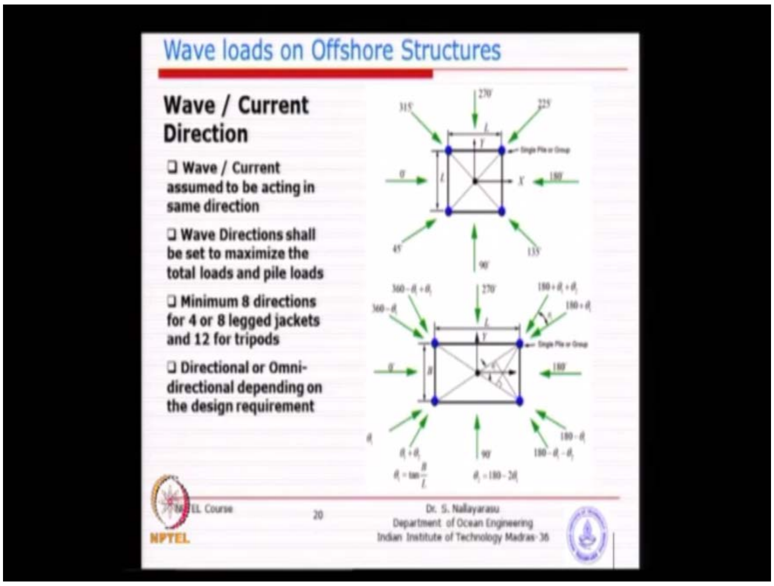

The next one is the selection of direction of wave which, I think is as important as what we are trying to do using estimation. Basically maximizing the loads on the structure the other day we were discussing about you know the diagonal direction could potentially be a proven to be the most effective, and higher forces could produce because of the de coupling effect. So, basically in here you can see several times we do also ask for a variation, instead of only directly doing diagonal you could do plus minus 5 degrees plus minus 10 degrees depending upon uncertainty at the site, not necessary that only 8 cases you can even do 16 directions because it could be possible at the site, but as the thumb rule minimum 8 directions for a rectangular structure. For a triangular structure minimum 12 directions which is mandatory with out which you wont be able to the design approved.

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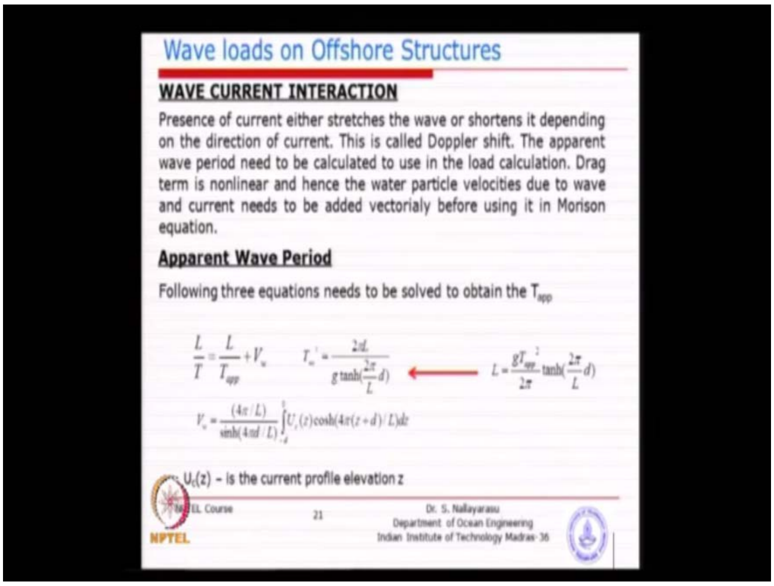

The next one is the Doppler effect which we need to just spend little time, basically now you have seen them the Morison equation which I think drag component, and you have the inertia component. In that the velocity is a combined velocity from the wave and the current, we need to add the current because every location every offshore field, you may have sea waves, you may also have the sea current. And potentially the a p i or any other code is asking you to actually apply in the same direction, though sometimes you may have different directions.

So, in order to maximize or take into account the worst possible scenario, we need to assume that the wave is propagating, exactly in the same direction of the current. So, imagine the wave is propagating in the forward direction and the current is also flowing in the same direction, what will happen? The wavelength will get stretched away it will increase in length because of the Doppler shift effect, if the current is coming exactly opposite the wave length will get reduced. So, this phenomenon is supposed to be taken into account as soon as you change the wavelength or wave period you could see here in this chart, the wave theory will get modified. That is why you see here I have put T apparent nothing but the modified wave period the original wave period is say T and because of the presence of current in the forward or backward direction, you may see that the wave period may increase or decrease accordingly

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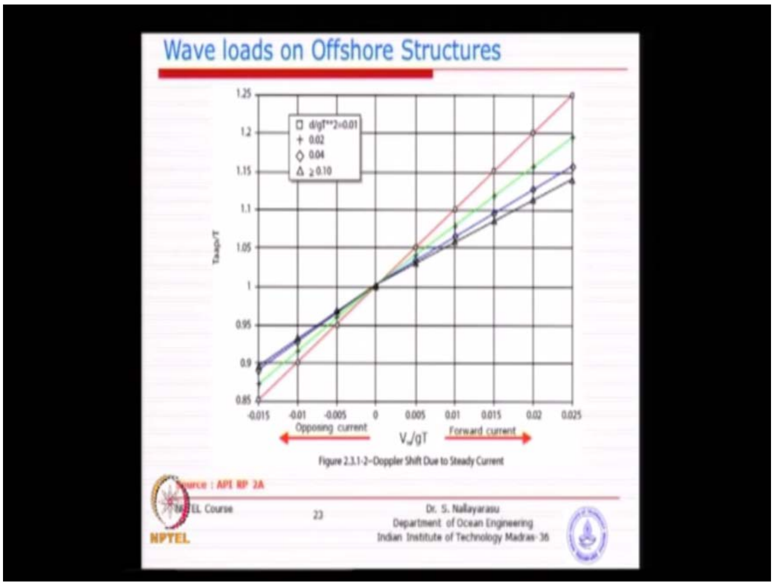

A p i has come up with the chart something like this so you can see here if it is a zero current, it is the current ration bw is the current speed divided by g T if it is zero the ratio is one is it not? Basically you just go up here and then just come here several experiments have been done and basically based on this that red line is something that we normally use. So, you could see here forward current, the ratio is always higher and backward current or reverse current in order, it will always be smaller than one. So, that means the wave period is ten second the current is flowing in that forward direction depending on the speed, the larger the speed. That means the number could go up to 20 percent larger or even 25 percent larger.

So, 10 second will become 12.5 so basically 25 percent larger so the wave period becomes longer or if it is opposing current, then you will have the so the same thing is calculated by a simple relationship called dispersion relationship. You will derive this one when you go into your hydro dynamics course, next few days the relationship between wave length and the wave period, which I purposely did not derive because this again a waste of time because will be deriving in your course.

So, basically that is the relationship that you can see relation between the wave length and the as long as you are given a wave period, you could find out what is a wave length using this. But unfortunately you see here this equation is a iterative equation because the wavelength appears on both sides. So, you have to assume certain length and then start iterating until both side becomes equal. So, basically or you may be given a table, wave table will be given to you in your class room exercises, probably once they give you that then we can do a example problem in our class, I think you will be given definitely. So, that you can if you are given a wave period, and typically you can use that table to find out wavelength.

Once you find the wavelength you can find out all the parameters like velocity, acceleration because if you go back there you need wave length to start the computation. And then once you have the wave length calculate the velocity acceleration substitute into Morison equation find out the wave force and then do further steps. So, basically how it is calculated basically the l by t is the wave speed length travelled by once wave cycle and that original is this, and the modified is this the effect of current is added. Again the current speed is going forward so if it is negative you will just detect it so, simple Doppler effect.

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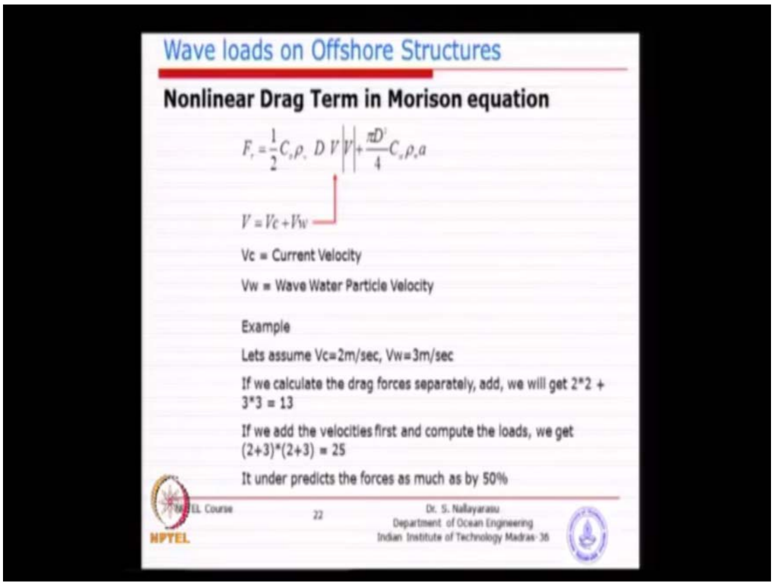

Now, comes the important so you all of you understand the idea behind the reduction or increase in the wave period or wavelength just because the current is flowing in the forward or reverse direction with respect to the direction of wave propagation. Now, the second thing is whether we should do wave force separately or current force separately or combined together. So, you see this equation the drag force is non-linearly proportional to the velocity.

Now, if you if you imagine we this wave is going in the same direction of the current, you could also think about I will do the calculation of wave force separately, plus add the wave force with the current force calculated separately. So, typical example you see here the all other terms are constant, you know like diameter, density everything is kept constant. So, the only changing is the velocity down here now if you take the velocity components split into two components, one from wave and other one is form current. So, you could see here if you calculate the forces separately, what will happen if current velocity is 2 meter per second. And the wave velocity is 3 meter per second.

So, if you do this computation 2 square plus 3 square will become how much basically 13 because computation was done separately for current and wave. Now, if you just add vector ally the wave velocity plus the current velocity together and then do the computation of the force, you will get 25 that is exactly the idea behind the non-linear drag term can not be treated individually for wave and current separately. Because since the wave and current is acting in the same direction, you should add the velocities before computation of the forces.

So, you must remember whenever you are trying to do, you cannot do separate calculations for wave forces and the current forces, you should add them together before you substitute them into the Morison equation where as you see here the inertia term is anyway linearly proportional so not a big deal. But however current will not produce any acceleration. So, you do not have a problem down there I think we have seen this marine growth again we should take in to account this effect.

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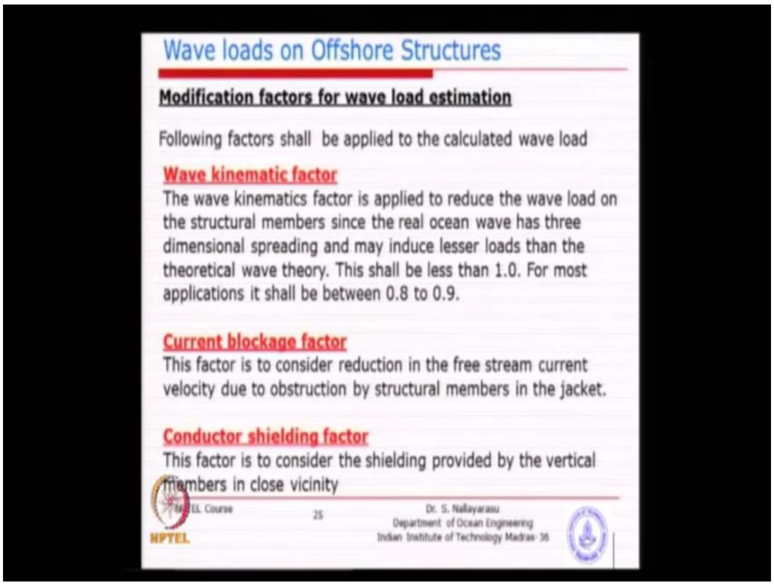

So, this other three reduction factors which I think I mentioned about it we should we should consider the first one is the wave kinematics factor very, very important you know what we have seen is a two dimensional wave, two dimensional wave theory which we have seen the equations. And if you compare with the reality you could see that the water particles are not going to flow in such a nice manner, because of the three dimensional effect of the wave you will not see a wave nicely. Like if you go to our wave room you see that the waves are produced almost close to the theoretical wave, like what you see in the text books.

But still there exist a distortion side wall effects and probably slightly different from even if you do comparison with your theory and the laboratory simulated waves, you will find some difference. But if you compare it with the actual open sea condition, you will see always open see condition is lower than the theoretically calculated velocities and acceleration. It was proved by in fact Morison time itself they have done proto type testing by doing measurements off shore and measurements laboratory, and then do the computation. They found that always the theory is giving you the larger value than the measured values.

So, what they were coming up is the reduction factor if I have a 12 meter wave height or 10 meter wave height I do computation, I simply reduce by 8 to 10 percent, irrespective of geometry remember the C d and C m was taken into account to modify because the Cd

C ms are only a correction factor again. Basically that is for particular geometry in addition for over all any type of geometry, you simply can reduce 80 percent or 90 percent.

So, this is recommended by the a p i task committee which was giving you recommendation because 10 percent of wave load could substantially reduce your design reasonable. So, that is why this reduction factor a wave kinematics factor is basically to account for the difference between the two dimensional wave theory verses three dimensional wave effects in the real version. The last two is basically the current blockage factor and the conductor shielding factor is again also to account for a kind of reduction only. So, always all these three factors will be less than one cannot be greater than one.

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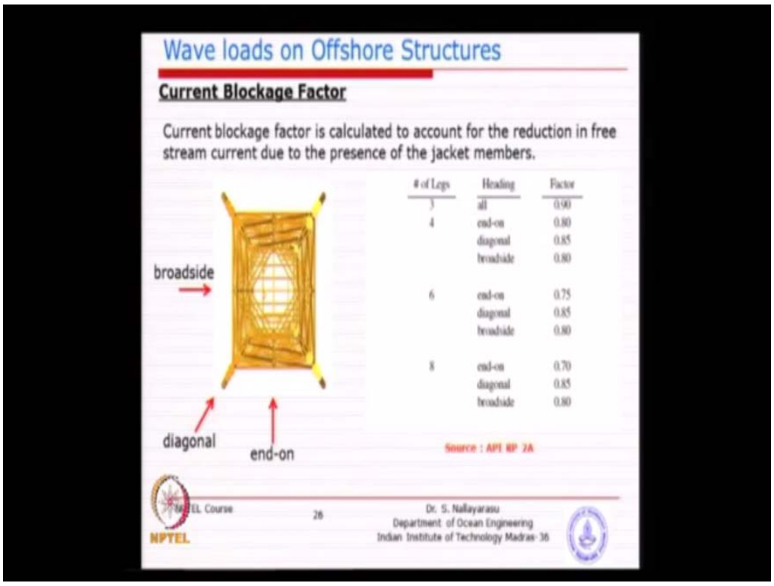

So, you will see this current blockage factor when you put a big structure in middle of the ocean, you could see the free stream current is unable to flow across the structure gets diverted, probably slow down and then go around. So, because of the defect possibly the loads on the individual elements could be lesser than what it supposed to be, if you have only one single element because it is a assembly of structures placed in the middle of ocean. So, you will see that the reduction could possibly happen, a p i has done lot of studies on this with respect and they have recommended for each type of jacket structure, 3 legs, 4 legs, 6 leg, 8 leg they got a reduction factor in the order of 15 percent to 10 percent like then the maximum that you can go here is 0.9 and the minimum is 0.85.

So, you could see that for broad side is given as broadside is given as 20 percent reduction. Whereas the end on direction the smaller dimension is given as also similar only diagonal direction has given just a 15 percent reduction. So, once you calculated the wave force you reduce by you multiply this number basically you just multiply by 0.8 or 0.85 depending...

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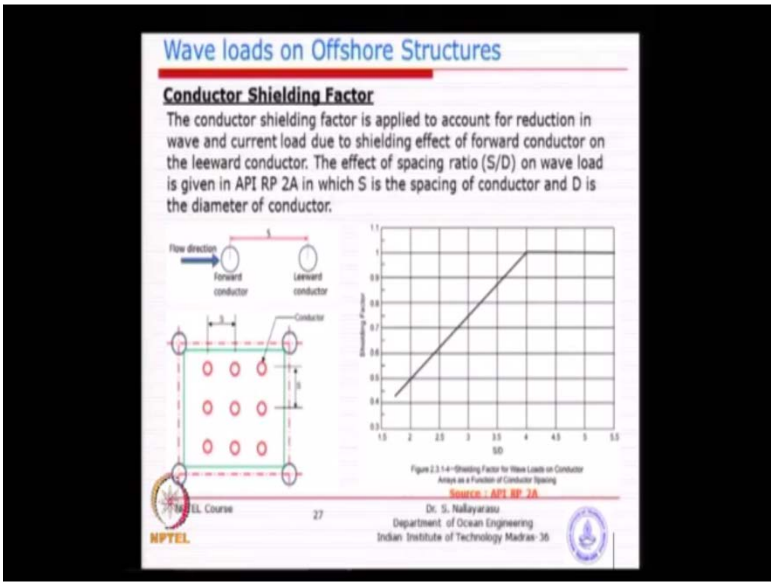

Last one is very interesting basically the shielding factor when you have one structure in from of another structure basically, the water flow the water particle velocity is an acceleration is going to be obstructed by the front one. So, you could see that if you keep them together just like side by side only the one of them will be receiving load, but if you keep them few meters away you could see that both of them will get because the water particles will get comeback to the original position after diversion, and then comeback. So, basically that is why we have this effect called the conductor shielding factor.

A p i does not recommend the shielding effect to be considered for all the members, except when you have vertical members arranged in sequence like conductors I think you I have shown you some pictures, what is conductor is a well protection casing. So, basically if the spacing is so small this spacing between the front one and the back one, you could see a chart developed here as long as the spacing is about four, the shielding factor becomes one. So, one meter diameter if you keep them four meter away, then there is no shielding effect, but if you bring them closer and closer you could see that potentially reduction in the loads because the second one does not get full effect.

So, if you see here if you keep it at two diameter it becomes almost half load only, so you take two cylinders, one cylinder calculate the force and the second cylinder receive only 50 percent of the load, it is a same diameter cylinder. So, but the second one only receives fifty percent because its close vicinity allow the water particles to move away from the second cylinder. So, that is the idea behind. So, if you series of cylinders the last one may get nothing because free stream is not going across the section. So, this effect will also be taken because sometimes each of the platform will have a many many conductors. So, you do not have to really take every one of them individually.

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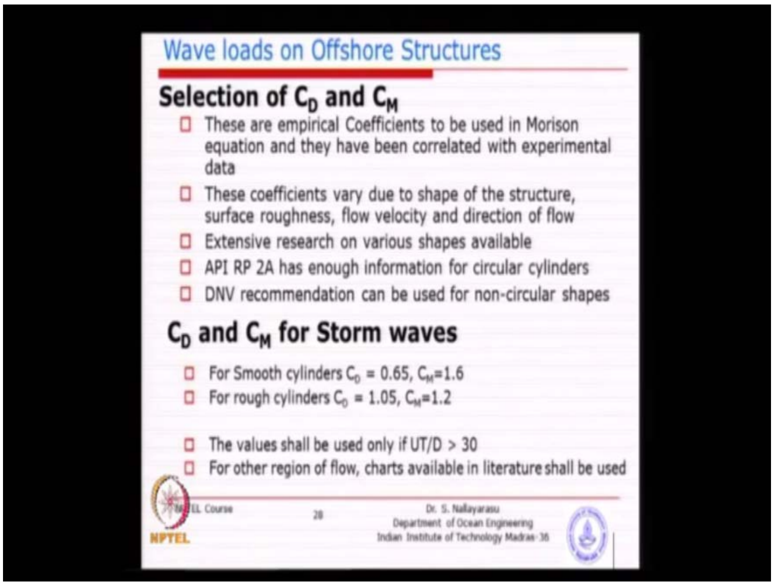

Selection of C d, C m again basically it is a empirical coefficient very similar to you might have studied selection of wind drag coefficients, for calculation of wind force on structural elements basically for rectangular, projected surface, tubular surface, stream lined body. Each one has got a different drag coefficient so similarly, here we have the drag and the inertia coefficients, which are correction factors to Morison equation. Remember these are the numbers you have to select according to the size, shape and the type of floor. That means whether the wave is 10 meter wave or 1 meter wave also will get changed so that is why lots and lots of researches happened over the last 50 years.

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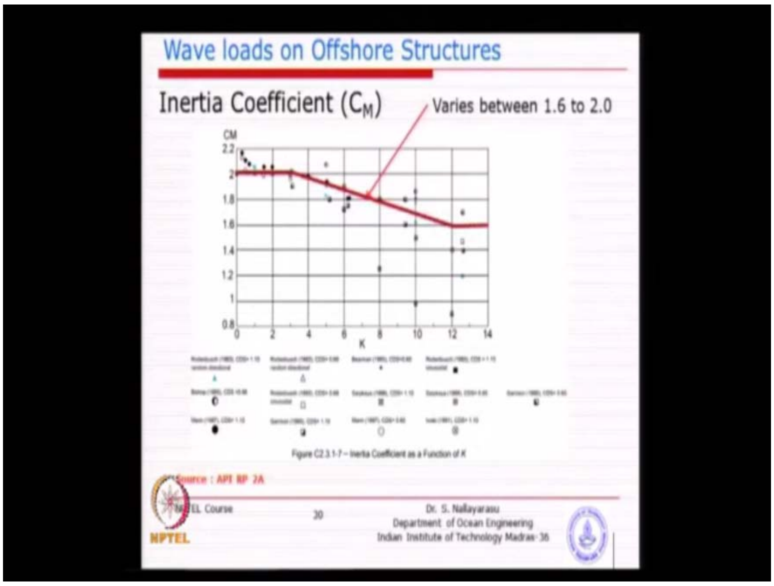

If you this chart before we go anywhere else many many people have done research, you see here at the bottom starting with where is this Morison (Refer Time: 32:21) he has done so much of work as early as nineteen seventies and eighties. And he has if you look at his book he got lot of collection of more data, but of course, the a p i task committee ahs take only the good work and collected and presented here, you could see the variation its very large some times its so low sometimes it is so high. So, what they have come up is they have come up with this red line, which is drawn something like this and presented with respect to the number called non dimensional number called collagen carbenten number in the horizontal axis and the vertical axis is C m.

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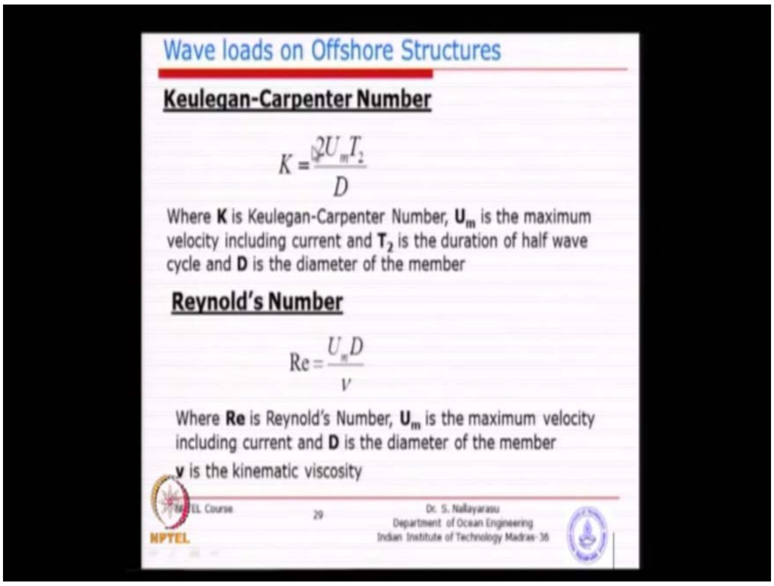

So, what is Keulegan-Carpenter number? Is a represent representation of the wave period with the diameter of the member. So, U is the velocity at the crust or the maximum velocity including current, T is the half or T 2 is the half wave cycle or period D is the diameter and K is a K c number which is to represent the type of flow in relation to the size of the structure. So, most the literature you will see that the presentation of empirical coefficient is for wave load calculation is given in terms of K, but in the recent times some of them have been modified to Reynolds number. I think you might have studies Reynolds number again integrate the type of floor whether it is slow or fast, or super fast

The velocity time is the diameter divided by your kinematic viscosity, so this is also a representation of how relative to the structure the flow conditions, which will give you an understanding, the larger the speed what will happen the negative pressure will happen at the tail end of the structure. Which means the contact between the fluid and the structure is very less so basically boundary layer effect will come into picture. So, Reynolds number usage of Reynolds number or Keulegan-Carpenter number depends on type of presentations, some text books will use Keulegan-Carpenter number some may use Reynolds number, but a p i have choose to use the K number as the representative to identify the flow conditions.

In fact most of the presentation in off shore we use k number and basically you see here starting with two and reduced to 1.6. So, that the range of values of C m so if you are asked to come up with cm values do not go a put some big numbers or small numbers it will be in very small range 1.6 to about 2.2. So, it should be between and this is for tubular members remember this is for circular section, either placed vertically or horizontally or in any three dimensional spacing, but for non tubular sections this could be substantially different it could be higher or more.

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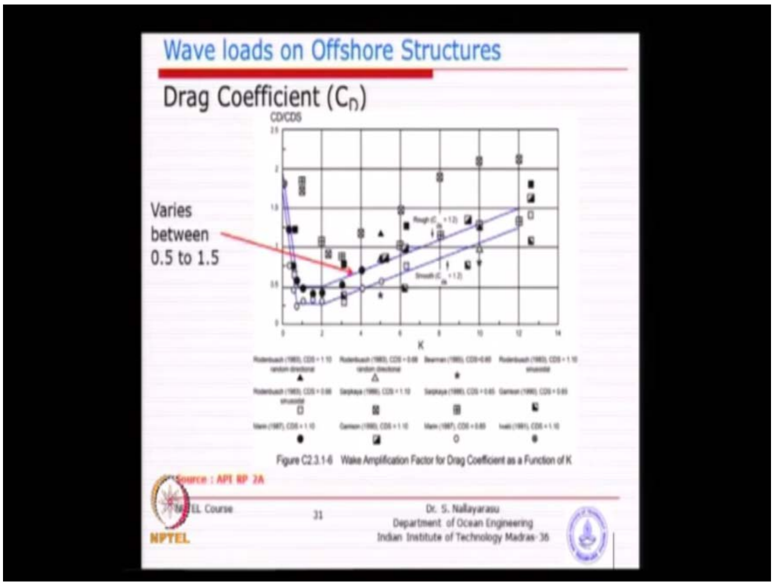

Similarly, you see here another chart for drag coefficient again presented with respect to K number, but instead of directly presenting they have given a ratio of drag coefficient with the C d's, Cds is a surface roughness coefficient surface roughness is to be taken as one for smooth cylinder like structural steel pipe, if you have marine growth then there could be potentially increased roughness because you saw that picture no, the marine growth is so rough. So, you have a increased coefficient may be 1.1, 1.2 so C d will be slightly increased, so in here what we are trying to say is you have to select C d and C m's suitably according to the type of structure type of roughness of the surface. And use it with the Morison equation.

And you can also use D and V codes because a p i does not give you or talk about non circular sections, they always focus on tubular sections. So, I have just summarized in the next few slides recommendations given by D and V for various non circular shapes, which could be potentially useful. Typically the C d, C m for tubular sections I have just taken from a p i 0.65, 1.6, 1.05 and 1.2 this is for smooth cylinder this is for rough cylinder, like what you have seen with marine growth. You could see that the drag is increasing and the inertia is reducing, and this is true only when you have this u T by d is greater than 30, this is the condition given by a p i this numbers are valid if it is not valid then you have to use the shorts to select your own coefficients and then apply.

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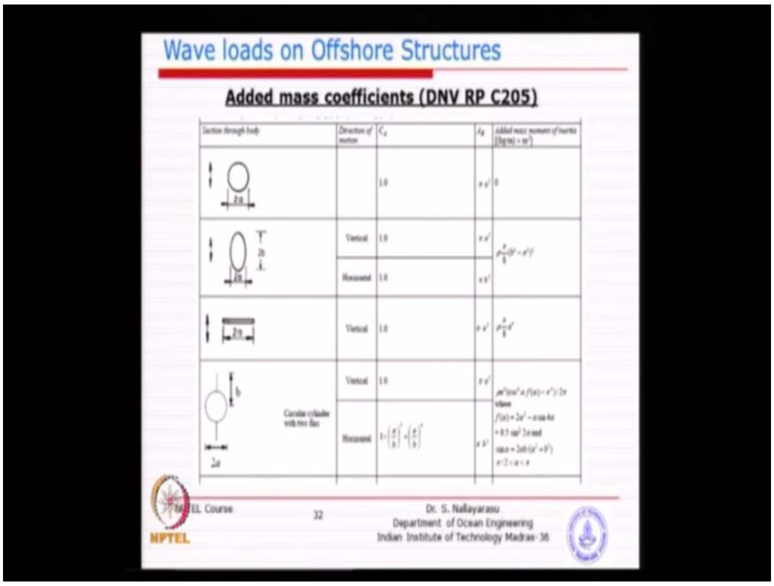

So, I just summarized from D and V code that you have large number of you can just go through you can see from there, you see here the added mass coefficient. Basically is 1, that means if you have one cylinder the structure is moving in water the additional mass moving with water is basically, the same as the displaced volume of the cylinder itself. So, that is why you will see one plus one you understand the idea no C m is equal to one plus C a, C a is added mass coefficient which is this. So, this C m whatever you have obtained from experiments could also be theoretically estimated by simple means, if you put a circular cylinder in water, and when it is moving horizontally, the amount of water moves together is almost equal to the displaced volume of the cylinder itself.

So, the cylinder volume plus additional volume surrounding the cylinder, so almost two that is why you see here starting with equal to 2 or 2.1, 2.2 and then gradually reducing as the flow speed increases. So, basically you see here circular cylinders to flat plate, all geometrically derivable dimensions given are recommended by d n v, but this needs to be verified by experimental conditions, most of the time we take this as a basis and then do the experiments to verify.

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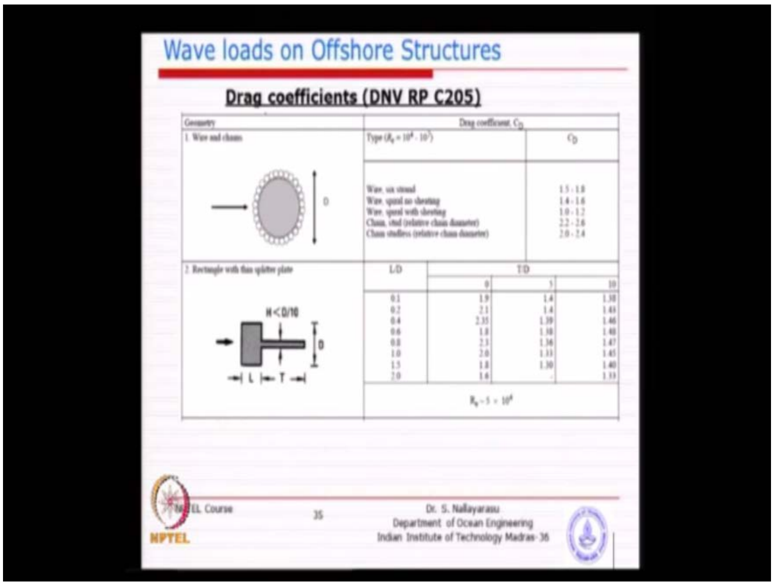

Similarly, I have given you the drag coefficient also recommended by d n v for non circular shapes like for example, wires and chains with rough surfaces. Most of the values are around 1.52 to 2.4.

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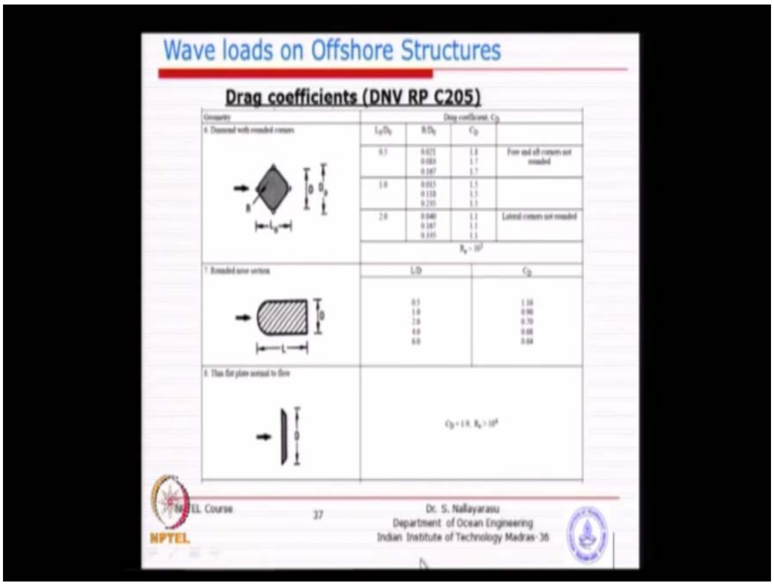

Flat plate is something that we are very much interested, you see there this kind of flat plates C d is almost 1.9. So, comparison to what we had was 0.6 and 1.2 for a flat plate so much of drag forces attractive, and other shapes you could use it for you reference, if you encounter in your design problems.

Now, comes the most important, so we have learned the summary of the whole thing is we know how to select wave theory right, calculation of water particle velocity acceleration. The components in the Morison equation is drag and inertia and in the drag we have to combine the wave velocity and current velocity together before we do that selection of C d C m's, application of reduction factors, increase of diameter phi marine growth so all this ideas have been understood. Now, we need to see how we can calculate the maximum force on a vertical cylinder.

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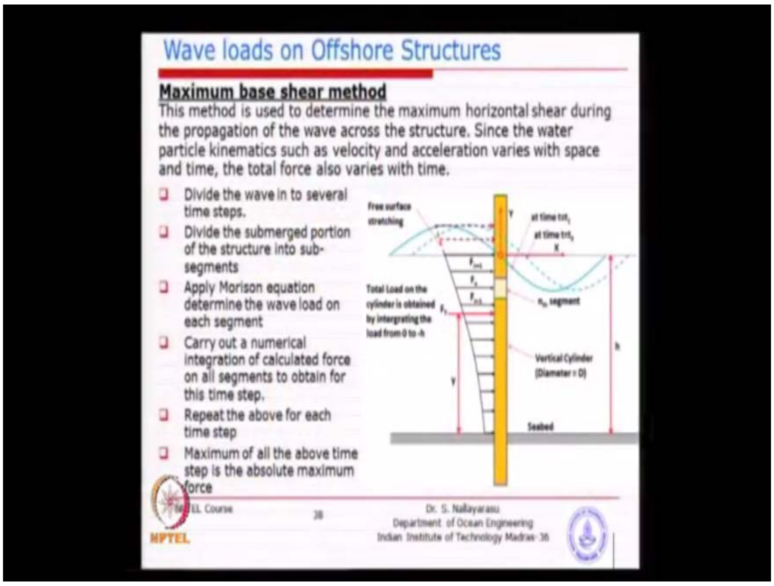

Just you see from this picture we have a vertical cylinder and the wave is progressing in a direction, perpendicular to the cylinder axis and just moving continuously. So, at what instant of time maximum force will come, which needs to be evaluated. So, what we can simply do is we can just take this Morison equation.

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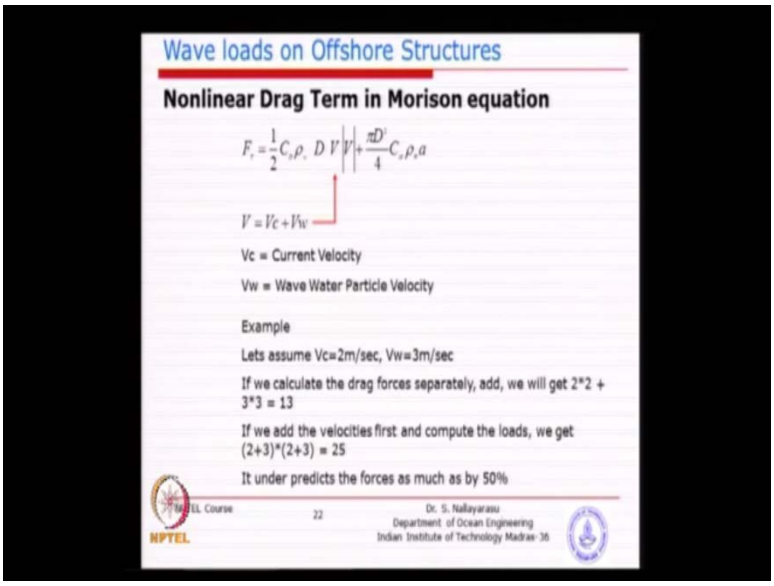

You can take this equation C d is a constant, rho w is a constant, D is a constant we is a variable depending on the location is it not? Location, means it could be horizontally or it could be vertically, but right now we have fortunately have only one cylinder vertical cylinder sitting on sea bed. So, we have go various points along the cylinder, x is equal to 0. We can set the coordinate system in such a way that the axis vertical axis becomes x equal to 0, only z will be varying.

So, you substitute that equation in this because you already have the potential function you already have selected the dell phi by dell x, substitute in this equation. Similarly, you can substitute the equation for the acceleration because everything else is a constant. For example, phi D square by four cm rho w and you substitute and you derive a equation for F t, the only variable will be the time and the depth because its going to vary along the depth, it is going to vary with respect to time because you go back and see the equations which I derived…

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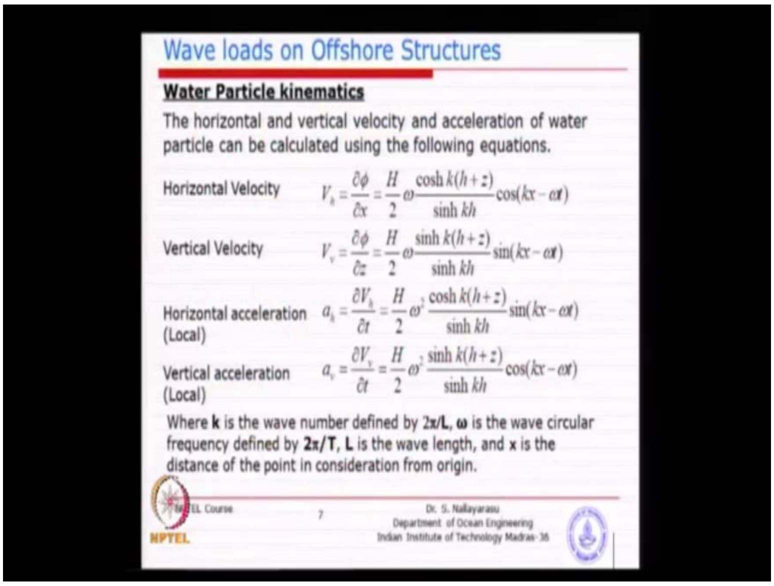

You see this equation you are going to substitute the equation for velocity you are going to substitute acceleration. So, if you look at this z is the variation with respect to depth and T is the variation with respect to time because x has become 0 because we have set the coordinate along the vertical axis your horizontal axis starts. So, if you substitute only two variables are there along the depth, you can see velocity is going to come down for sure you can substitute and check, with respect to time only we do not know, what could be the. But since is a cosin or sin function is going to vary something like this either a sin function or a cosin function.

Now, what we are looking at not that information because we want only the maximum value of the force at any one time, during one wave cycle because its going to be repetitive. The assumption that we made is a complex wave form is decomposed into simplified wave form like sin or cosin wave, so that only one wave form you look at it the reminder is repetitive. So, that in that one wave cycle where is the maximum force is our interest.

So, we go back here there are several methods of doing it, the easiest method the easiest method is divide the whole cylinder into several pieces, like you see here something like this. So, if it is 10 meter divide the cylinder into ten one meter pieces is it not? And each piece you take it, you have coordinate x is always going to be 0 because it is a vertical cylinder. And z is going to be 0 minus 1 minus 2 minus 3 minus 4 up to minus 10. So, each of this location you can calculate the velocity and acceleration because you know x coordinate you know z coordinate, use the formulas given there calculate these. And then substitute into morison equation is it not? Each of the location.

So, for time T is equal to 0 you take the equation find out the acceleration velocity find out the forces. So, you plot that and you will see that something like this because near the surface velocity is going to be higher because the exponential decay function because if you see the velocity at the bottom you have, sign hyperbolic k h and at the top you have cosin hyperbolic y plus z plus h. As the z goes down you will see that the function will be reducing. So, you could see that the velocity and acceleration is definitely going to reduce as you move downwards.

So, this kind of function you will see so when you calculate the force also you will see something like this so T equal to 0, you calculate one like this all of you understand this idea no. So, x is 0, z is varying and we divided the whole section whole member into several subsections and each of the subsection take the center coordinate z equal to what ever number comes, calculate the velocity, acceleration. All other terms are constant substitute you find out the force on each element multiplied by that one meter, if you design it to divide by two meter, then you have to multiply by two meter in this case we have divided by one meter which is very convenient.

So, each of the segment receives one force proportional to the diameter and the segment length because you have taken the central coordinate x and z and you calculate the force for all elements you plot them this way. Now, you see some pattern now you can do a numerical integration you might have studied several numerical integration procedure or you can do a simple weighed average, I think most of you will know in numerical methods. So, what is weighed average just add the each coordinate and divide by 2 for each of the blocks and then total summation, you will be able to get the total force.

So, you understand the idea the how we do divide into several sub segments each segment you calculate the force, each segment use the coordinate to calculate the velocity acceleration substitute into Morison formulae. And so this force corresponds to only one time instant because the wave period is 10 seconds. So, T equal to 0 you have calculated now you have to repeat this for several time steps from 0 to 10 second you divide every one second you divide every half a second it is up to you is it not? We will continue tomorrow.