Design of Offshore Structures

Prof. Dr. S. Nallayarasu
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module - 01
Lecture - 06
Loads on Offshore Structures – 6

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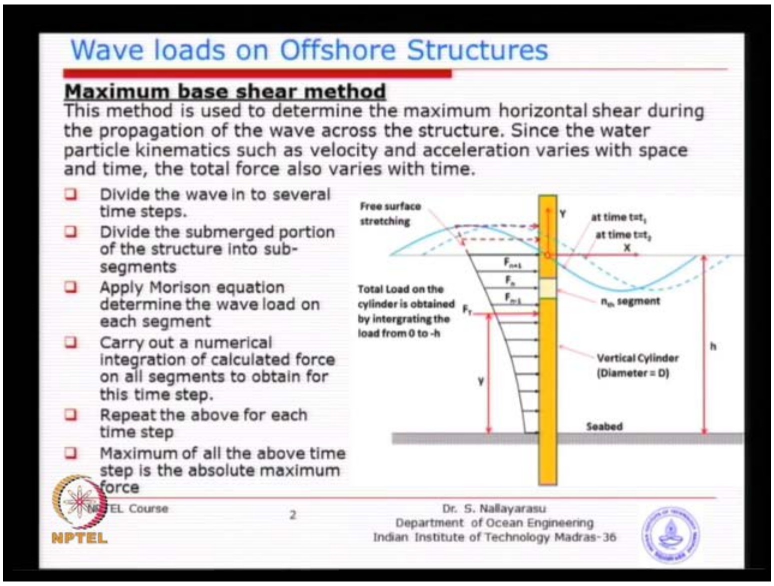

So, let us continue with what we were discussing yesterday trying to find out the maximum force on a structure. So, if you see this picture you could easily understand what is the principle behind, divide the wave into several time steps. That means one wave cycle is divided into so may be 8 subdivisions or 16 or 32 or 36 depending on the time that you would like to spend, but now a days because computer is calculating all this you could have as much larger sub-divisions. So, may be most of the time we take 36 steps or 72 steps so every one degree or two degrees.

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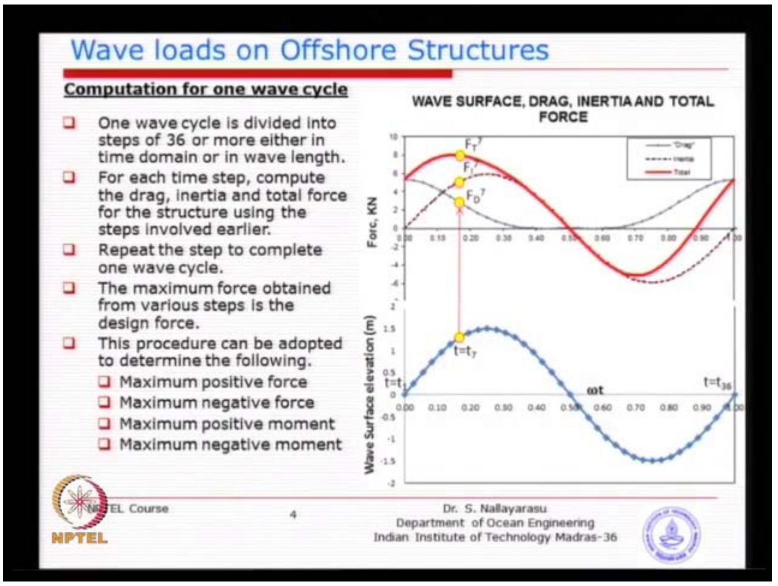

Basically if you go back to this particular picture for each time step you are going to do the computation in this step.

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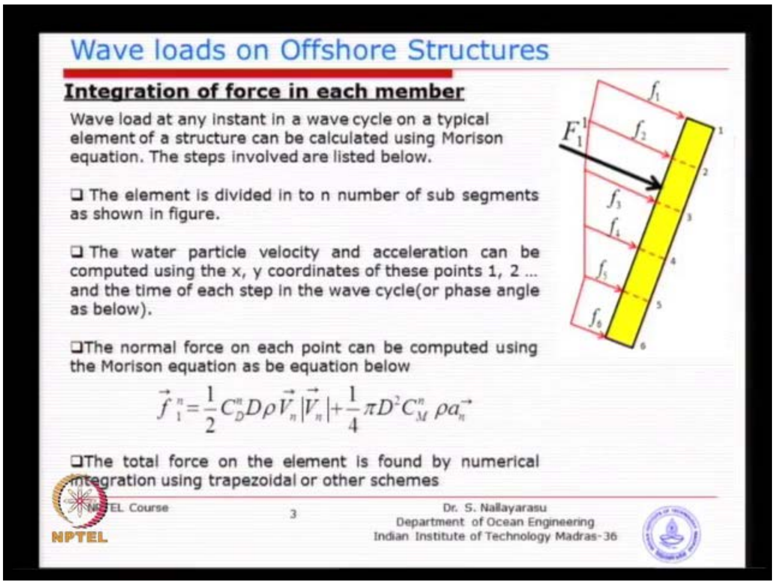

That means the wave force on one member is found by dividing the member into several sub segments each of the segment you have a coordinate and each segment with a x y coordinate. And time you can calculate the Morrison's force and then plot in this equations basically f 1 to f n depending on how many number of sub-divisions you have made for one member. So, basically again going back to this picture so that particular each time step you divide the member into several subdivisions, each subdivision is having force calculated from Morrison equation. And then do a numerical integration or simple averaging you know each segment and summation will give you the total force on that structure at that instant of time.

That is again explained in the next stage after doing one time step you go to the next time step so starting with t c equal to 0 t 1 t 2 t 3 until the full cycle is completed. For example, if you have a wave of 10 seconds divide in to say 72 steps then you will have 10 divided by 72 is the time step every time step. So, when you do this you see this picture the lower portion shows the wave profile the simple wave profile divided into so many time step each blue point you can see.

Here, is a time step so I am just typically giving you one particular time you calculate the drag force calculate the inertia force calculate the total force which is the summation of the drag and inertia force. For that instant of time the t equal to t 7 we go to Morrison's formula find out the acceleration and velocity from the water particle equations and then go to Morrison equation, substitute there because cd cm diameter everything is constant so you calculate that and basically calculate for the whole structure.

So, each time you have to remember every time step you are going to do the calculation for not only one location you are going to do for complete structure. And then only you can get this F t, this F t corresponds to 1 particular time step and then repeat that for several time steps you will get such a plot. Now, you can see the variation of in this picture you can see here the dotted line shows the inertia force, the inertia component and the blue line is basically showing here the drag force and summation is shown in the red colour you know basically. So, that is the profile of the total variation, the total force variation from time t is equal to 0 until one wave cycle is completed.

So, if you go to next wave cycle you could ask why we cannot or we do not need to do it because it is going to vary the same fashion it is going to be repetitive because we are using simple regular sine wave, cosine wave so it is going to be repetitive. So, if you can concentrate and get the force within 1 wave cycle it is going to be repetitive so we do not need to waste our time. So, what we are interested is what is the maximum force in this red line so we just use a simple searching technique go one by one compare with the previous one whichever is highest you take that as your maximum force.

This is how you could do a computation of maximum force on any structure for example, if you have only 1 element which I think it was very easy isn't it, but you imagine in a structure it is not going to be 1 you are going to have many of them so many of them. So, you have to repeat the same thing before going to the next time step you complete one structural element. Go to the next structural element go to the next one, next one complete the complete the structure before you go to the second time step so that is exactly the idea behind.

So, in doing here you can actually make decision on several things not only the maximum force, maximum positive force maximum negative force you see here in the red line, the red line has gone up and then come down and then again going up. So, if you look for the absolute maximum then it is only 1 value, but if you look for maximum positive force that means along the direction of propagation is the force acting and along the negative direction. That means opposite to the direction of wave propagation makes the force canal so, occur because remember the water particles are not just linear they are cyclic and it is going to go back and forth.

So, you can have the force in the opposite direction as the wave propagates forward direction only the magnitude differs. So, that is why you see here when the wave is starting it is this value goes higher in the positive x direction and then comes down it becomes negative x direction. So, you can have a wave force when the wave is propagating forward you can have a because it is a oscillatory it is going to be a cyclic force. So, you can have a maximum negative forces is this means what the force is acting opposite to the direction of the wave propagation this is basically force is acting along the direction of wave propagation.

So, you can either find out both if you want to see whether the force is positive this way or positive or negative the other way and basically either one of the concept you can use because you are the one doing the summation so, you can do a plot like this and find out using a simple search technique. The other one also you can find out instead of finding out only the force you can also find out maximum positive momentum about a particular point of interest. For example, in this structure instead of summing up only the force every force you sum it up after multiplying with the distance from same mud line you take say f 1 multiplied by y 1 plus f 2 multiplied by y 2 so on, until you complete your complete for one member.

So, that gives you moment about mud line which I think sometimes very useful because you want to find out what is the maximum force on a structure due to applied horizontal load. For example, you have 4 columns you want to find out what is the maximum force on 1 column it depends on the overturning moment not the horizontal force so you could find out the maximum over turning moment. Basically, you can do all these 4 cases what is listed here either positive moment negative moment positive horizontal force, or negative principal is same only the multiplication factors. And the point about which you want take a moment you could decide yourself you can.

So, I think all of you are very clear on how wave force is calculated for a simple 1 single element vertical column isn’t it. Basically, the steps involved is very simple divide the member divide the wave each time step complete 1 structure by dividing each of the member each sub segment carry out the wave force calculation per Morrison equation. After finding out the water particular velocity and acceleration substitute go to next element and complete one full member do a numerical integration or method of averaging and go to the next time step. And then complete one wave cycle, look around basically for the maximum values positive negative and then decide which one you want to use. This is how you make a decision to use this method because the force is varying throughout one wave cycle.

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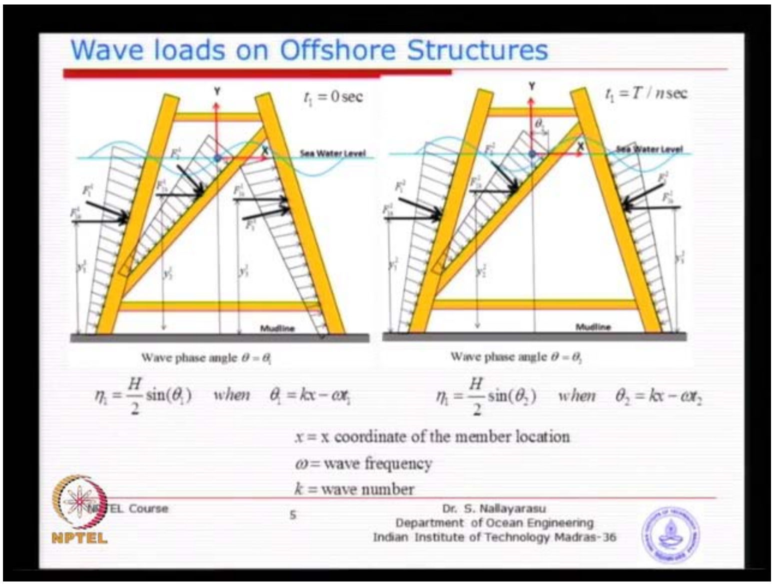

Now, if you go to a multi element structure so if you have understood that I think you can move on to a multiple element structure procedure is exactly same there is no big difference except before going to the second time step. You need to complete the whole structure, you know it is not only 1 member here you divide each member into several time steps like.

For example, this member you divide them into several sub elements do a computation keep it one side that will be not the total force that is force on 1 member and go to the second member divide them into several sub segments and then complete that force and then keep that. So, when you do this for the whole structure sum the whole number of elements into one force that is called a the horizontal maximum force that will complete the 1 point on the wave cycle. Then go to the second wave cycle do exactly the same procedure like what I have shown here t equal to 0 and t equal to t divided by n seconds you keep incrementing.

So, basically instead of 1 member you are going to do several members in a time step. Now, you can see here because we have only one vertical member in the previous example here you got members in any space in any direction you know. So, what we need to find out is the interest is whether normal force or tangential force so we need to just decompose simple geometry based on your orientation of the member, which could be easily programmed now a days so many computers and software.

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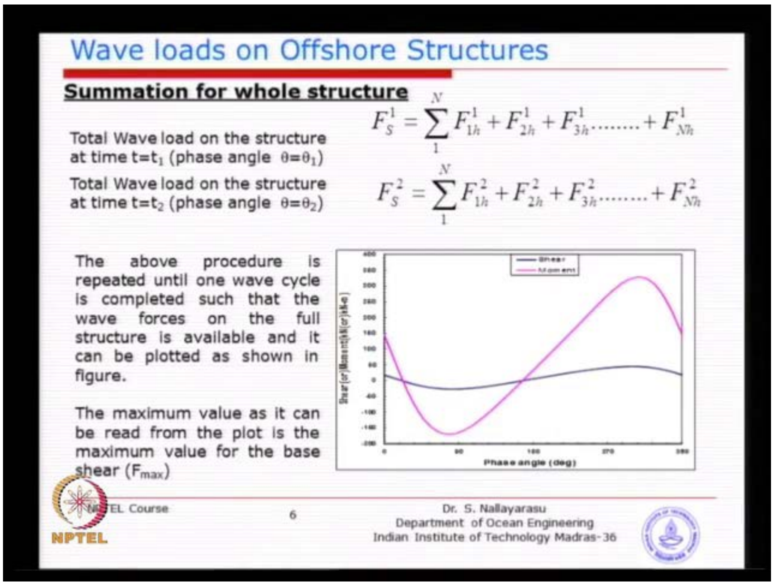

Finally, for the whole structure what you are going to do is take each member at one time divide add and calculate Morrison force again go back to. So, the total force at the time step this super script given here is a time step and basically that is the summation for first member second member and so on. So, you could do that for second time step for third time step so when you plot basically you will get something like this the a pink line. And the blue line, the blue line shows the horizontal force the pink line shows the moment taken about a particular point. In this case most of the time we take moment about mud line.

So, you could see here the maximum over turning moment is this one maximum shear forces somewhere here you know. So, this is what we are interested we are looking at the maximum value for the whole structure because that is, but if you look at 1 member at that time when the wave was propagating at this point. When x is equal to 0 for that member probably maximum force would have occurred for that member for us at that instant of time other members may not be having maximum force you understand the idea know.

Now, every time the wave propagates on a large structure each time 1 member may get maximum force at that instant of time, but the remaining member's maybe the magnitude of force will be smaller because your acceleration velocity is smaller or bigger. Elsewhere, it could be maximum for 1 member, but at that instant of time it could not be maximum. That means the maximum force for 1 member something like this may not happen for all members at any instant of time, 1 member may be maximum. So, that means it is not a simple logic that I will find out maximum force on 1 member and this multiplied by all the members or add the all the members like that because depending on the wave position on the structure you are going to have the maximum magnitude at 1 member or the other.

So, that is why this method needs to be adapted realistic, but what we are missing for example, just you need to carefully understand when this for example, take the left leg at one instant of time that leg is going to get maximum force for that member. Another, instant of time the right leg may get actually highest force on that member, but when we did using this method. For example, we are trying to find out the total maximum you may not actually maximise the individual maximum you may actually miss that.

So, that means the global force is right, but the local force maybe not right and this is one of the deficiency of this particular idea because you may design the whole structure and pile system like everything is correct, but when it comes to localised forces you may actually may not have generated every one of them getting maximum which is the deficiency of this method, but then we have to have some idea to solve the problem.

So, what we normally do in complicated projects we do a initial screening only maximise for each member and just look at the magnitude and if it is larger and cylinder members like. For example, this particular bridge is very large and if that member force is only local member force is maximum it may fail. So, only for such type of specialised members we do a screening, but the overall principle is basically to try to find out the total force maximum for overall structure.

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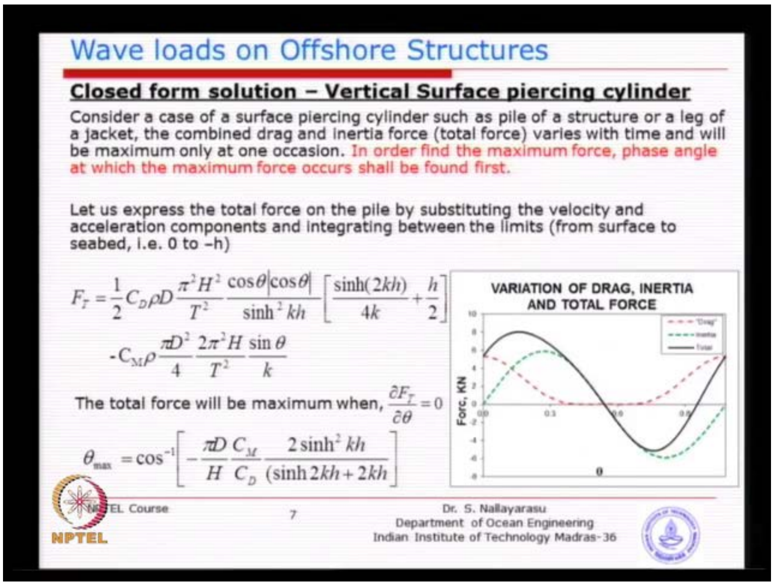

Now, for that simple problem what we had here we could also do a analytical solution using imperical formula proposed by Morrison what we are trying to do is instead of making a computer program. We could also substitute the velocity and acceleration formula, which we describe yesterday velocity is obtained from first differentiation of your velocity potential and then the acceleration.

So, you have the equations there your complete mathematical formation you simply substitute inside the total force equation which is a Morrison formula 1 by 2 rho C d and v square plus. So, you just substitute the equation for velocity and equation for acceleration because using that formula only we are trying to compute. So, our idea is to find out the maximum force you might have studied in your mathematics how do you find maxima minima isn't it use the same mathematical principle differentiate the total force with respect to the variable. Which is of vary for example, in this particular case wave force is varying with what the time or in other words the phase angle of the wave.

So, differentiate with respect to this force with respect to del f by del theta and equal to, what is the definition of maxima minima equal to 0. So, you can find out what is the theta at which this force is going to be maximum and substitute back you could get the total force. So, that is a simple example wherever the structure is very simple easy to do integration and differentiation you could do that.

So, basically after substitution what I have done here I have integrated not numerically simply by substituting the upper limit and lower limit this 0 to minus h because the force is on that element. So, you have the Morrison equation you have the equation for velocity and acceleration, substitute integrate and then differentiate with respect to the variable which is theta which is varying. And then make it to 0 you find the theta value and after finding the theta value you can substitute back into your force.

So, you can simply calculate so you can simply go and a write a simple computer program and plot. So, basically I got the same answer almost not a big difference. In fact if you compare this result and the result shown earlier almost identical because same equation only, but this can only be done only for cases where 1 element or 1 structure simple form used to integrate. If you have a 3-dimensional or 3 d space element difficult because you cannot do the integration that easily. So, for simple forms you will find this type of things in textbook you will find out.

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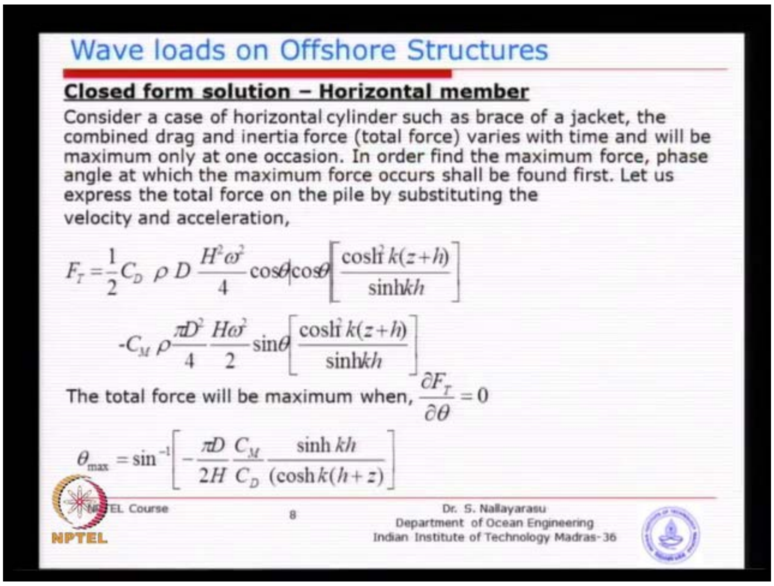

So, you can do that given for horizontal member you have 1 member in this fashion not going vertically up you know surface piercing just submerged below and basically can also do the integration here even very easy because it is not very. If the member is horizontally oriented the velocity particle is same as the position perpendicular because the wave is 2-dimensional. So, in that case also we could substitute the velocity and acceleration integrate for the whole member which is simply multiplying by length because it perpendicular to the wave propagation you could also get. So, if you have such a simplified a circular cylinders vertical or horizontal using this formula very easy to get.

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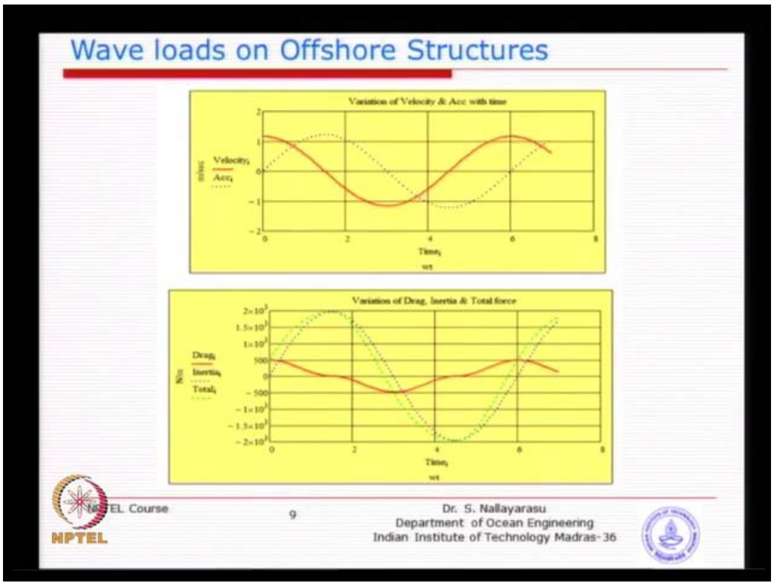

Typically if you look at the variation of in fact yesterday or day before yesterday we were talking about variation of velocity, acceleration and associated drag and energy of force you could just see the comparison. Wherever, the maximum the velocity is redline whereas, the dotted line is acceleration so you could see the velocity maximum acceleration is 0 acceleration maximum, but not necessarily velocity is 0 you see here this acceleration is maximum, but may be 0 also.

And then correspondingly you go to elsewhere you can see here maybe not 0 so if you come to the total force which is the green line is somewhere around. Here, somewhere around here you go just up here neither the velocity is 0 nor the acceleration is 0. Basically some intermediate value and that is what we want to see how the correlation is in fact we could have seen this one from this picture also.

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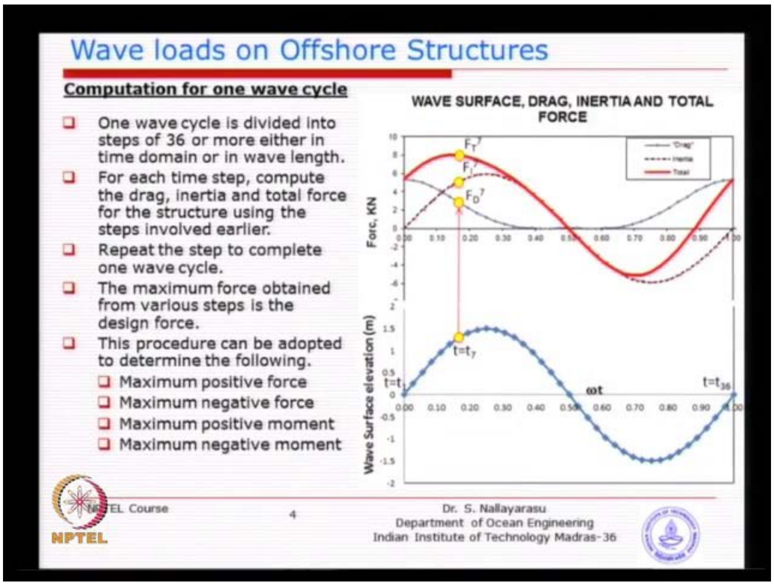

You see here when you look at the maximum force somewhere here you would see that none of them is 0, but none of them is maximum isn't it. So, you got an intermediate value because of the combination makes the total force is maximum and that is what of our interest. So, basically I think that is the idea behind how we evaluate the structure, but you should have understood hopefully the deficiency I was trying to explain you know. For example, I will repeat again you take this one structure put another one on the few another metres away this particular 2 columns may be I will draw a picture something like this.

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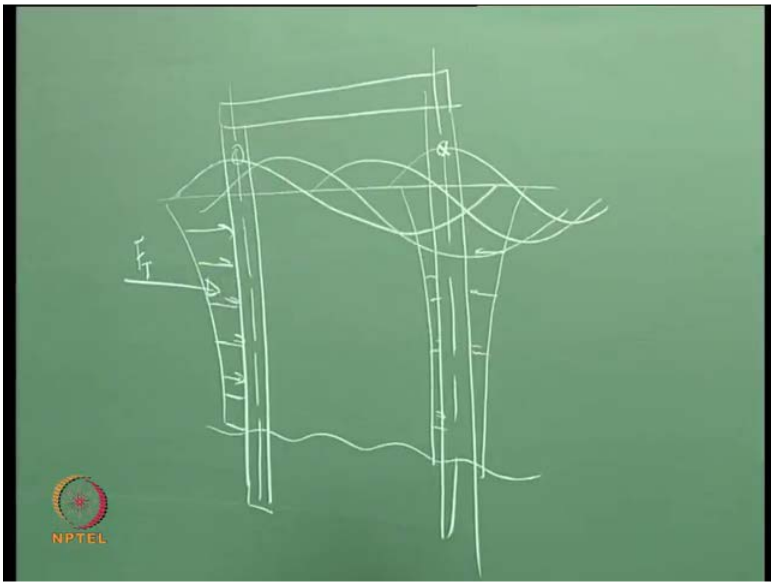

If you have not understood you better understood because maybe you have a portal frame. When the wave is positioned with respect to this structure or this part of the structure you might have got at that instant of time. The total force could be this much this is what we have found, but at that instant of time and we do not know whether what is the force this could be smaller. Or this could actually be opposite depending on the length of the wave because in this position water particle velocities might have produced maximum force here.

But as the wave propagates further at one instant of time it is going to reach exactly the same position as it was done by this member. So, you will get the maximum force at that time for this second member, but we are not interested in that because we are only interested in what instant of time the combined force is maximum. So, that the target is different we are not interested in maximum force for one member maximum force for second member what we are interested in maximum for the combined of the 2 members together. That means we may miss out both of them taking maximum, but what we will not miss out the total combined is maximum.

That means in reality when the wave propagates through we may actually miss this member in designing for the maximum local force which is what is the little bit of deficiency. Lot of studies have been done in the past to prove that is not a substantial problem and for the last 50, 60 years, we have been using this method of total maximum successfully no problem so far. So of course, we will introduce lot of factor of safeties, which gives us comfort level to, but if you are worried about that local maximum individual maximum sometimes we do investigative it and find out whether the member is susceptible to failure or not.

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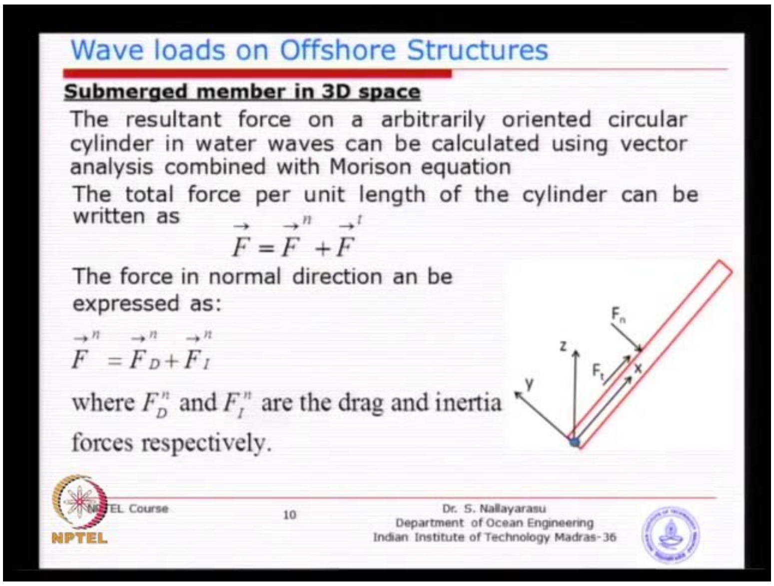

So, I think with that we could move onto the next 3-dimensional space just extend the same principle what we have discussed if you have a structure or element in a 3-dimensional space what we are interested is not only horizontal force we are interested in all 3 directions. So, in here we are going to do a simple geometric transformation you know basically you have the coordinate of 1 member starting coordinate ending coordinate using that you can find out the normal's.

You might have studied in you analytical geometry normal's and parallels to a particular surface and then you find out the normal force and the tangential force transform them into global xyz coordinates. Simple transformation matrix can be multiplied for the each member, but of course, the principle is same again you are not going to find a new formula. You will be using the same Morrison formula only you are doing a simple mathematical transformation from normal tangential force to a global xyz force for each member because after all you are doing a structural analysis, you will need a global forces to solve the equations of response.

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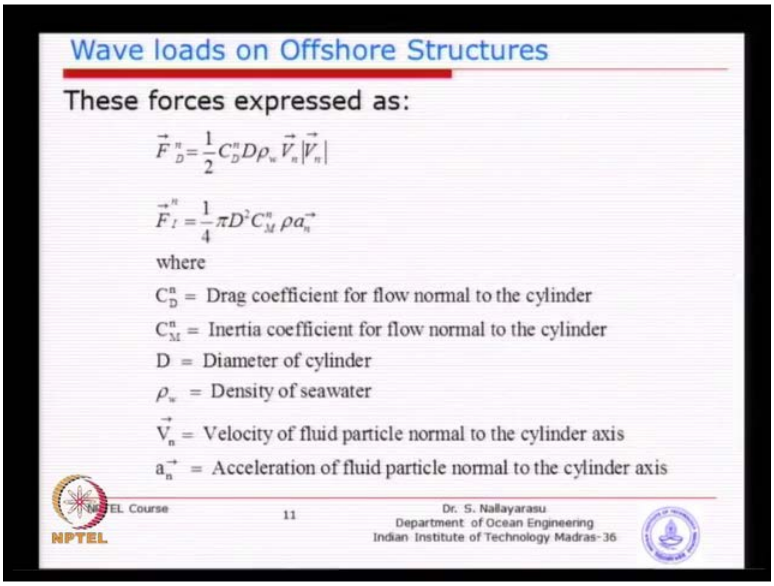

So, basically what I have written here is a drag force and energy of force fortunately what we are interested if we have 1 member the normal force is very much important. The tangential force is only acting on the surface, but both ends of the member is not dead end.

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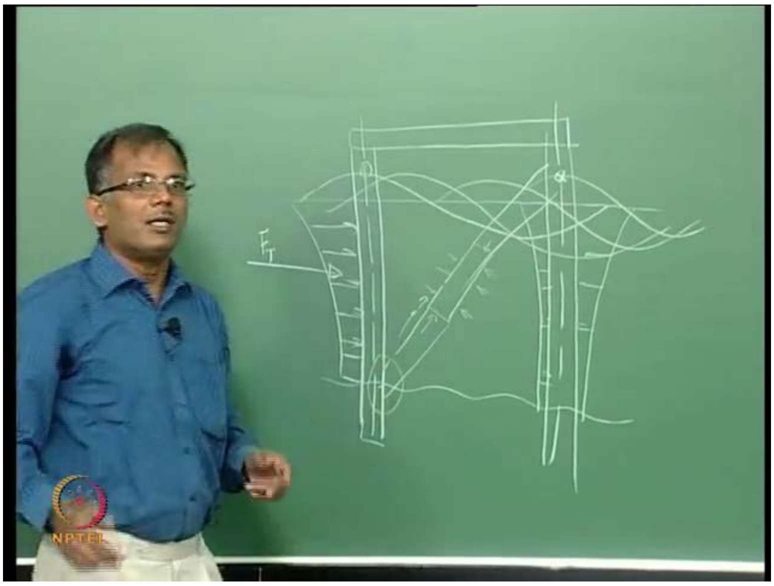

For example, you take 1 member in this free space if I put 1 member like this I will get the dead-end whereas, this member if it is connected here. For examples there is no way any wave force can act because that member is connected to another member. So, there is no dead-end only the frictional or surface friction will cause some drag, but that will be very small. So most of the cases we ignore the drag force due to the frictional surface because that will be too small.

And that is why we are not very much interested in the tangential force what we are interested is the normal force normal to the member axis because every member no member will be suspended. In this fashion it will be always be connected to something like this unit typical jacket structure, but if you look at the floating system. For example, you have a semi- submersible or you may have a submersible vessel then you may have that end force which is different case what I am talking about is only for fixed structure, you will not have the dead-end of the member exposed to any wave action. So, that tangential force is not much of importance what we are interested is the force normal to the structure axis or member axis.

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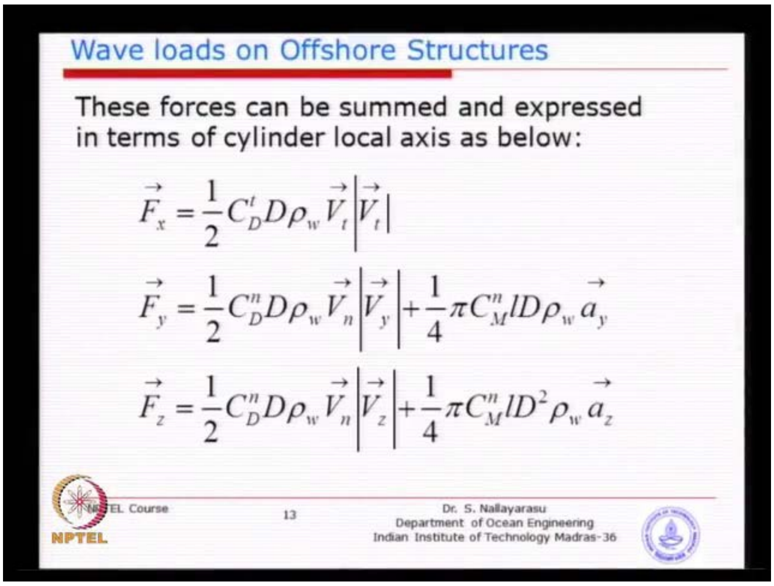

So, basically I think the same the force can be transformed into normal tangential and then to xyz directions so if you look at the actual force or so called F x.

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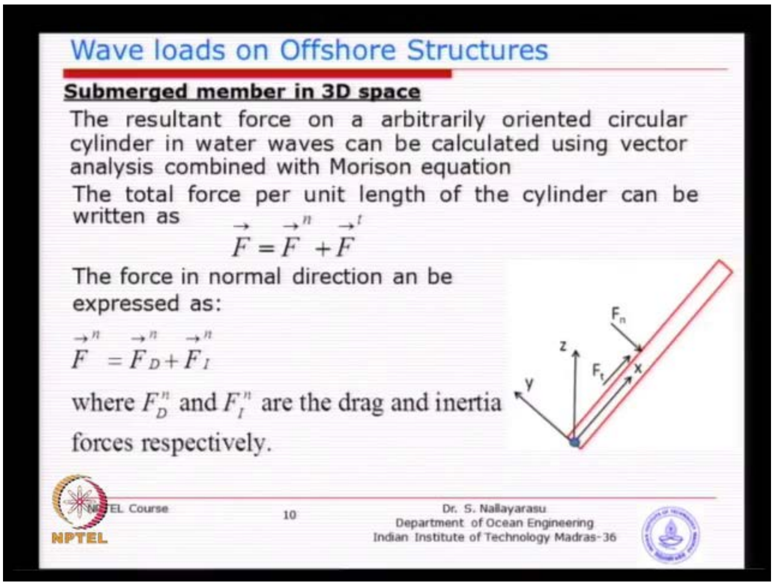

F x is nothing but x is always this is the notation followed by many software always the x-axis is along the member a longitudinal axis you know. So, you can see that the remaining two axis z and y could be perpendicular either in the plane of the paper like that depending on the software. You know it is not that that every software is the same coordinate system I have just picked from one the right hand system. So, you could see that what we are interested is z component and y component the x component is going to be quite small.

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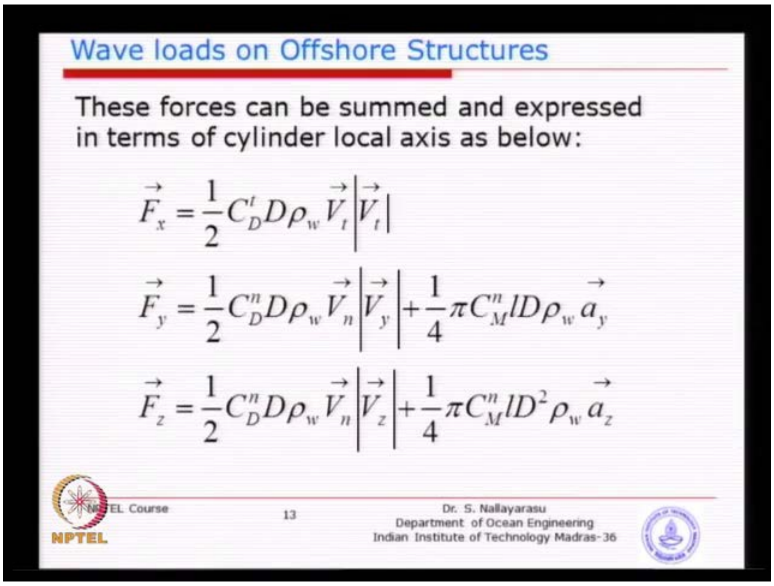

Only inertia drag will be there that too it will be very small the reminder y and z will be same as what we were doing for the single-member multiple member both will have normal and tangential components, sorry y and z components drag and inertia will be added together.

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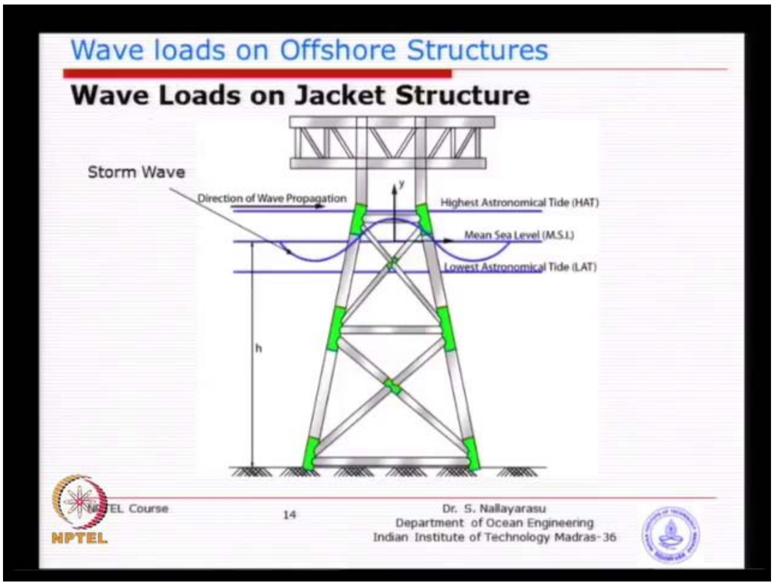

I think this picture will give you.

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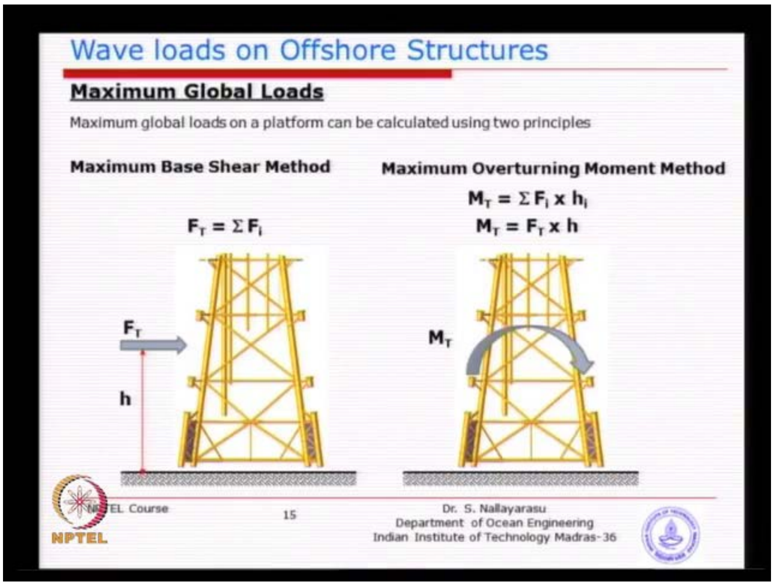

So, basically ultimately why we are looking at this is to find out the maximum horizontal force and when we want to design the pile system we are looking at the total moment which will be decoupled between this leg and this leg. For example, I want to find out the maximum pile force so what I need is the total maximum moment so I can divide by displacing of the piles to get the maximum pile load. Whereas, when we want the design for the local structures the maximum horizontal force may govern because that is going to be produce local bending of each of the member so we may actually do both and find out which is governing.

So, there is absolutely not possible for a given structure no one can make a decision this will govern the design or this will govern the design which is impossible unless the structure is having only 1 element. Like what we had one single element you could decide by simple decision-making because you know the equations you can say that for that single structure only maximum horizontal share will govern because that is going to produce maximum moment for us the base.

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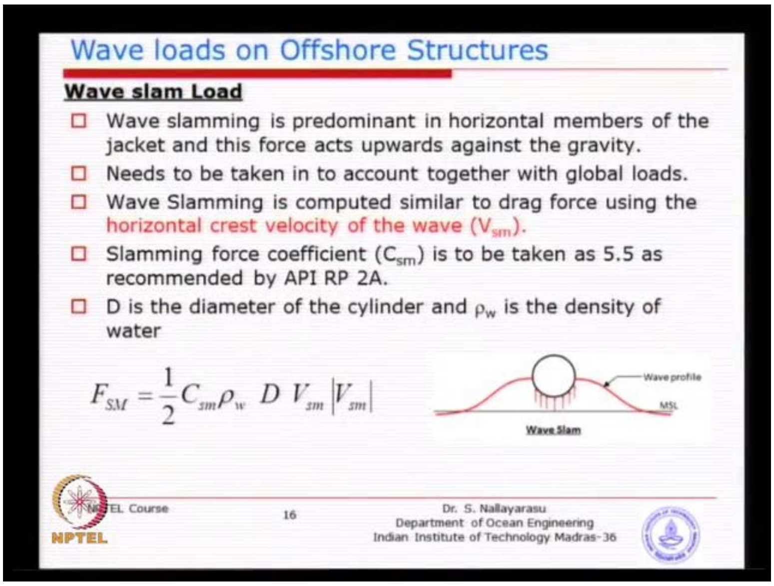

So, I think computation of loads arising from progressive wave is very clear from single element to multiple element to 3-dimensional structures. Now, what we are going to look at is if you look at the jacked structure I will just make one sketch.

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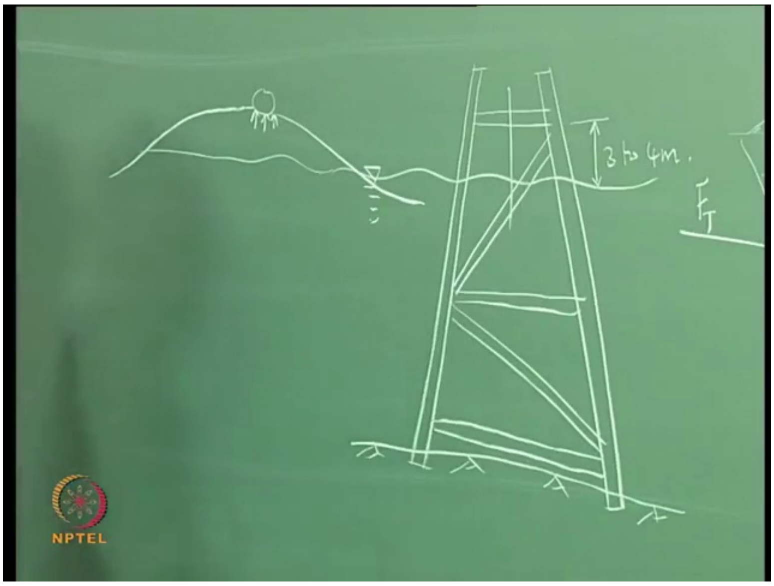

Basically, if you just look at, that is your water surface seabed something like this you see here the clearance between this and this normally we keep out to 3 to 4 metres. This is your water level, but you can see if wave height is 10 metre what will happen the wave will rise up if I do a cross section. This way I will see this member something like this and big wave comes that is what the cause of concern the wave will just impact against the bottom surface of the member that is what is drawn in this sketch which we call it wave slam force.

So, you could see that the wave is trying to pass through the member, but that because the member is half way through the crust so the wave will just impact. And then progress and this force could be substantially bigger as we know very well the crust velocity remember, we were looking at velocity and acceleration at various phase angles the horizontal crust velocity is very high at the time just before passing through.

So, you could see that the velocity can come and because of full obstruction it can just slam at the bottom. Though the velocity is not vertical the velocity is horizontal, but the water particles are not allowed to go beyond because it is a solid circular section preventing it from happening. So, it can cause good amount of force and many times if you have small things. For example, a hand drill typically I think that is what gets washed away the reason why the structures in that vicinity especially in this area.

If you remember any cyclone or a high storm coming during that time you will see that the small structures are associated attachments. Normally, they disappear because of this effect the local slam forces could be substantially higher which if you have designed for probably not a problem, but if you are not designed for you will see that after the cyclone many things are missing there.

Basically, this is called a wave slam force which needs to be calculated somehow because at this instant of time the main problem is the behaviour of the wave could not be mathematically modelled. Like what we have done we have just corrupt wave theory selected a wave theory and then we have got potential function and then first derivative velocity. All those things are not going to work because is not any more a propagating wave it is almost broken at that instant of time the water particle velocities could not be protected by the conventional wave theory.

So, what people have done the experiments to stimulate this scenario and trying to back calculate what could be the correction factor if I use the propagating wave theory because I do not have any other tool I do not have any other method I will still continue to use that, but then I will do a correction factor to account for the unknown things. That is happening there basically that is called the slamming force coefficient which is very simple same like our drag force coefficient instead of smaller number you are going to have a bigger number.

So, basically if you see these numbers depending on type and shape of the body it could be different for a simple circular section like this you see five and a half I think if you remember yesterday what we were talking about what is a drag coefficient. So, it is very small so it is 3 to 4 fold increase because the structure is just oriented very close to the surface and just trying to come and hit vertically upwards. You can imagine this is actually going against the gravity still jacket members are not having too much of gravity loads especially this type of horizontal members so it could actually be failing the member by bending upwards.

So, that needs to be taken in to account while designing any structural elements in the vicinity of water surface. Imagine if this is submerged for example, this member we have no worries there because there is always going to be a submergence number one, there is nothing like slamming going to happen because the wave is not going to go down to that level. So, this is only a problem wherever the structure is especially the horizontal members located in the vicinity of plus 5 metre minus 5 metre in that kind of scenario. So, the wave slam is not only a problem to jacket you can also go to port and harbour structures you know if you have gone to some places you will see that deck where you stand to board a ship or a boat.

It can actually get slamming from bottom and the larger area more the problem because the impact area is big the force could be substantially high. So, we got to be careful in constructing coastal structures very close to the water level. And when a cyclone happens the reason why they disappear is because the amount of force introduced this so large that it can just take away the structure. That is why you see after a cyclone several structures have been disappearing because it was not designed for so you should design this kind of uplift force otherwise the structures could be easily uprooted and then disappear.

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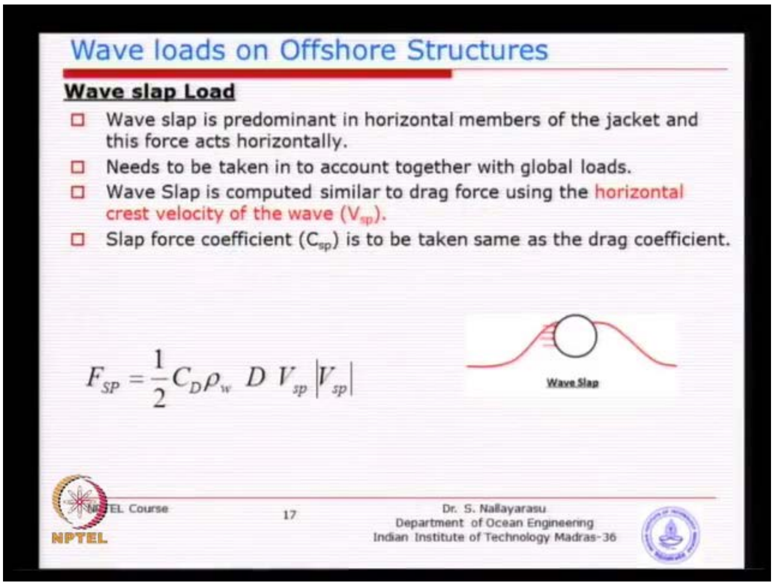

The second problem is the horizontal impact whenever such a scenario happens also can be followed by as the wave propagates you can see that there could be a potential horizontal impact. And especially, if it is a vertical wall instead of a circular cylindrical you have a rectangular prism.

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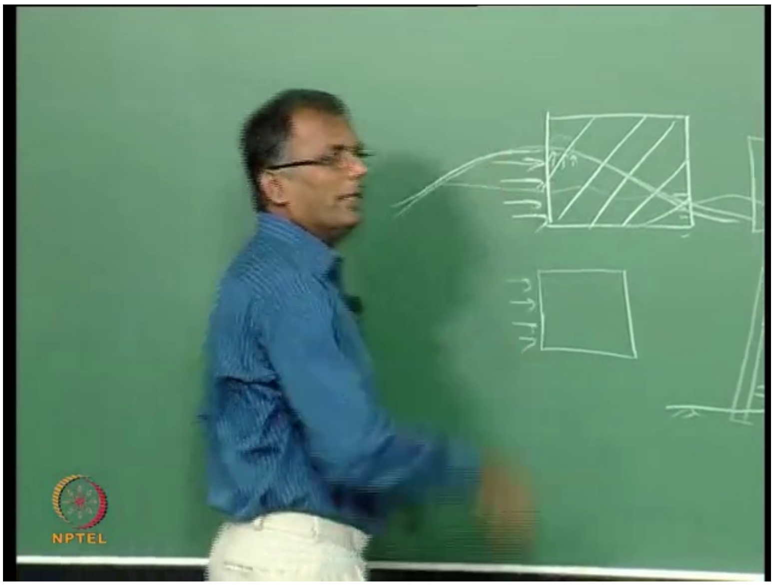

For example, I will just put one obstruction here like this a structure like this you could easily see the amount of force produced because of the wave impacting at the point of this contacting the structure could be substantially higher, compared to a propagating wave the same structure. If you place it underwater something like this when the wave is going through like this you will still have forces on this, but the magnitude could be smaller this could be substantially higher because it is an obstruction to surface flow. So, that is why we need to find out this so called so technical we call it a slapping waves slapping the phase of the body and slap load.

This could also be substantially higher, but not as bad as we were thinking normally you can take the drag force and the crust velocity and basically use a simple drag formula depending on the shape. We could find out what is the drag coefficient and horizontal cross velocity remember both times we have used only horizontal crust velocity. There is no vertical crust velocity you know at the crust always the velocity is horizontal not vertical so do not go. And think I will put the vertical velocity because the crust is only hitting the bottom or crust is only hitting the sides.

So, you will take horizontal velocity and that is why in this particular case though the force is vertically upwards, but we have taken the horizontal crust velocity, but multiplied with the larger coefficient which is called a slamming coefficient. The slap force also similar only thing is it is proved that is substantially higher it is very close to the drag force. So, this also needs to be taken into account as the wave passes through so that it could design it properly.

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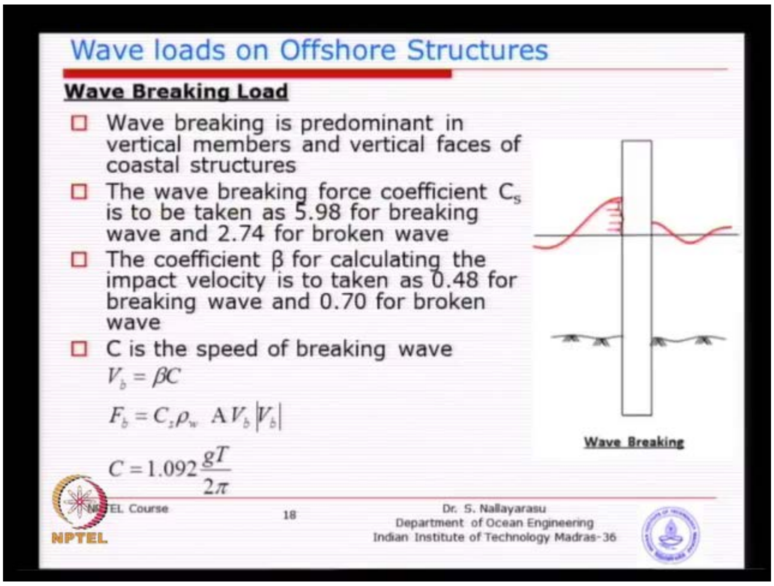

The last one before we complete is the wave breaking load you know as the wave propagates shallow water you see that the waves will start breaking because it is unable to propagate any further. The increase in the wave height because of the steeping is making the waves to break away water particles are disintegrating and not able to stay together. So, that instant of time what happens you could see that a slightly different from slapping, slapping still the water particles are going together. Whereas, here is almost going faster than the speed of the wave and that type of incidence normally happens in this kind of vertical cylinders. If you see some of the structures constructed near the coast men are happening in the jacket structures, but it will happen in the coastal structures.

So, this again empirical formula proposed again very difficult to simulate analytically so the wave breaking force is computed by similar drag formula, but then the coefficients are given as C s is your basically the breaking force coefficient which is varying between 2.74 and 5.98. Depending on just about to break or already broken some time what happen you have got one pile here another pile here another pile. Here, the wave is breaking on this pile, but after the breaking you will see that the wave will still propagating with the smaller magnitude it will just propagate for next few piles before it becomes flat water isn't it.

So, basically breaking wave and broken wave and then you have this computation of velocity is almost equal to salinity of the wave which computer using this and multiplied by a factor beta to account for 3-dimensional effect. So, the breaking those computation is also a quite an approximation I would say, but somehow we have to account for especially for coastal structures which is several experiments have been done in the last several decades to account for these numbers. If you go into the internet or literature you will find large variation of this coefficients for different types of structure. For example, this is basically a surface piercing cylinder typically like a pile structure for a coastal structure. Whereas, if you go for other forms of seawalls or breakwaters you will find different coefficient which have to be little bit careful.

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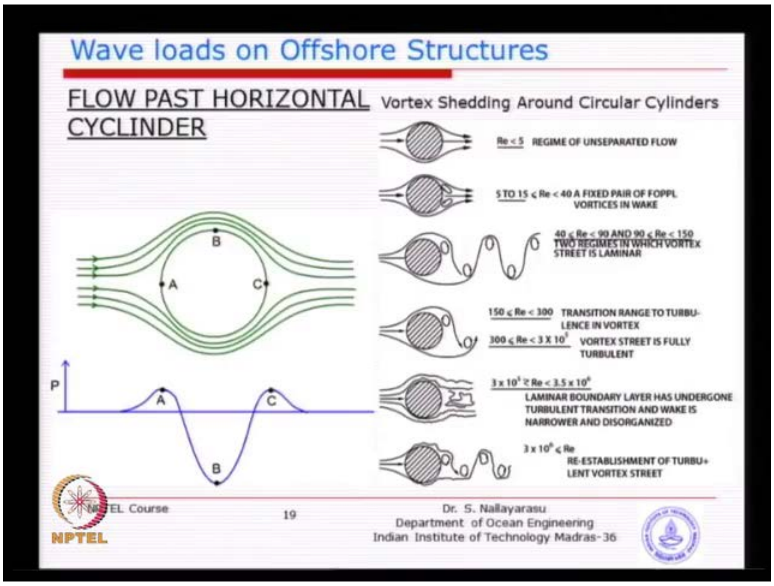

The last one is the flow separation which cost us a little bit of different types of force before we go into this you need understand the various flow regimes, flow in relation to the structure. If it is flow what will happen if it is fast what might happen we just need to think about if you place a cylinder like this. For example, if the velocity is very low you will see that the wetted perimeter of the cylinder is 100 percent isn't it.

That means the fluid will be in contact with the circular cylinder rectangular body whichever they say will be always in contact, but as you increase the flow velocity higher and higher what will happen it becomes a jet. You may actually not have a the contact between the fluid and the structure or the body may be last at some locations because the free particles are trying to go fast pass the cylinder without coming back and getting contact. All of you should be able to remember this phenomena in your basic fluid mechanics a basically called a vertex induced or vertex shading.

So, basic idea is when you have a water shading happening you see on the right hand side several flow regimes in terms of Reynolds number small to higher larger the Reynolds number indicates the faster the flow. So, you could see that there is a potential behaviour changes from full contact to a typical break formation. Basically, when you have no contact what happens is the pressure difference exist between a faraway point to the point near the surface. That means there is a low pressure here there is a high pressure elsewhere so what happens is the fluid particle tries to turn towards the low-pressure location.

So, high pressure to low-pressure this to come and you will see that some kind of pattern like this and this depends on the shape of the geometry of the body size and the velocity of flow and type of fluid whether it is water or other forms of fluid. So, lot of things could be investigated, but not now lot of things have been already done you do not need to spend time on this.

So, this phenomena of flow separation which we call it flow separation basically between the fluid and the body which causes vertices to form and said either downstream or some time upstream. You know if you look at some of the flow conditions even vertices are formed at the upstream itself because you see a same condition here in the flow may not be coming here it may just get diverted like this. So, you may have a low-pressure zone which makes the flow to circulate in the upstream or maybe in the downstream.

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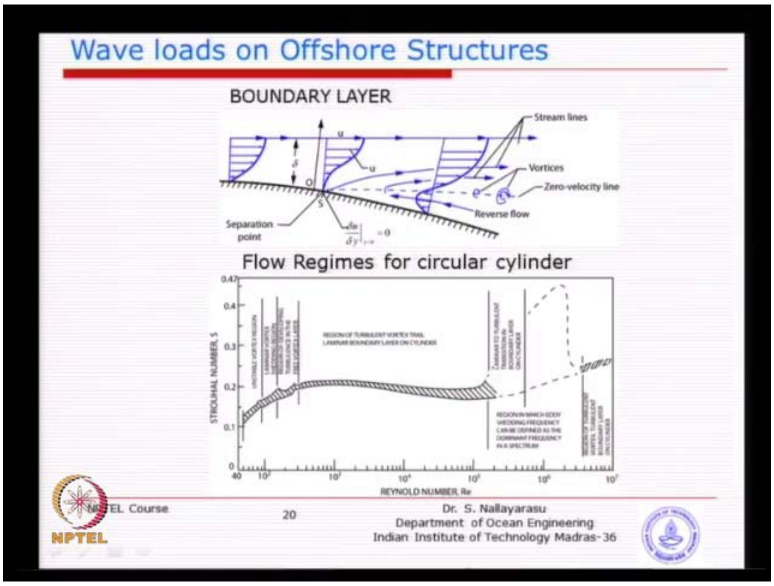

Now, when this circulation happens nicely symmetric for example I might have a picture of a symmetric or I do not have. For example, if you go to the second case a symmetric circulation happening that means the unbalanced force is not there. This force can be completely coming out of this pressure difference because you see here if this vertex is symmetric the force acting upwards and force acting downwards is same. Whereas, if you asymmetric for example, like this the force acting upwards may be higher or smaller depending on the strength of the vertex. And basically you can have a unbalanced force because of the asymmetry in the vertex formation.

Again how the force comes again because of the pressure difference here and pressure difference here so there is a so this force is called a lift force because this is always going to be perpendicular to the direction of flow. You might actually think why the force is coming when the flow is in the horizontal direction, but why the force is coming because this is caused by the vertex induced, or vertex shading phenomena not due to either a drag or to inertia force which we have already described by Morrison formula.

This phenomena is basically because of the pressure difference between the surface of the body and elsewhere. And the flow tries to come back and that pressure will be giving you the pressure induced force which could be different because of that small vertices here and big vertices here. So, you could now see here there is additional force coming depending on the relative velocity of the fluid relative to the size of the body or type of body which is called a lift force.

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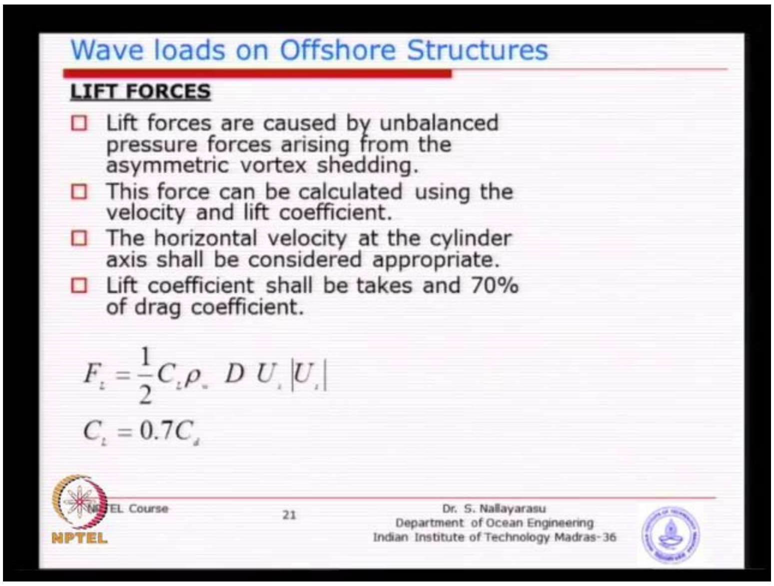

The lift force could be computed basically similar fashion to our drag force only by changing the drag coefficient to lift force coefficient which is taken as 70 percent of again by several experiments lot of studies. Finally, proved that this magnitude would be something around 70 percent only thing is we will be using the horizontal velocity corresponding to the point of the structure element. It is not the crust we will be taking where ever this structure is located you take it the horizontal velocity and then find out the equivalent lift force coefficient and then compute it. I think that gives you a complete spectrum of several types of forces from propagating wave to breaking wave and basically the vertex induced forces.