Design of offshore structures
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Lecture - 04
Loads on Offshore structures 4

The purpose here, so today we are going to see the wave loads on offshore structures. I think earlier we have already learned load calculations for wind and load combinations and the gravity loads associated with production and drilling. So, if you if you look at this subject the wave loads itself it is a very large subject.

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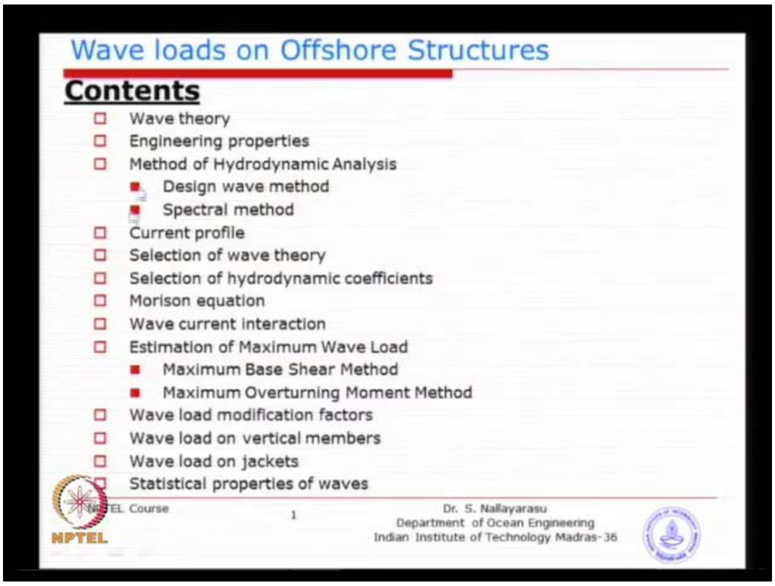

It requires extensive understanding of fluid mechanics and the interaction of the fluid with the structure. Now, the basic fundamental behind the wave generation needs to be understood. Hope you are going through that basic fluid mechanics in the other course just now.

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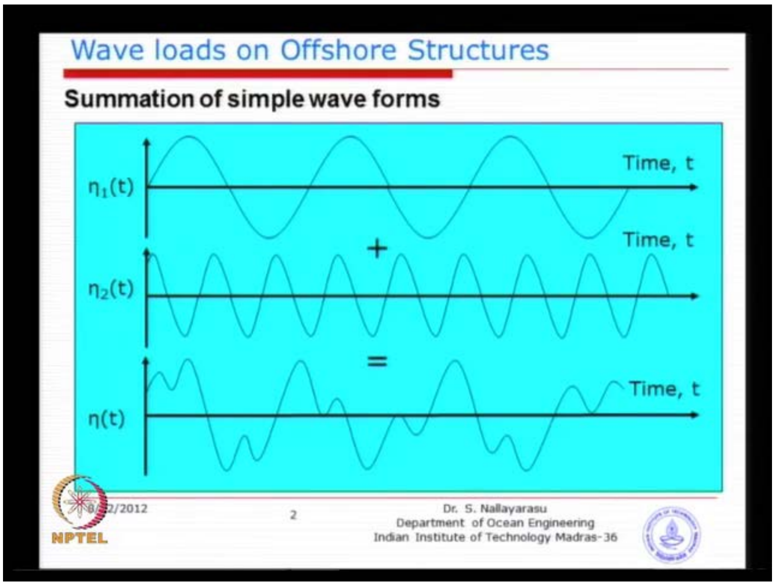

So, you see this picture what you could easily understand is the complex waveform, in the real field is the summation of various known waveforms. You know basically that we can breakdown using Fourier transform. That is where the first principle we are going to solve the problem by breaking down the complex problem, into simplified known problems. So, that the solution can be arrived and then can be summed up. So, the linear superposition is the first principle applied in the wave hydrodynamics of this structure wave interaction. Basically, all linear superposition that means the responses are also going to be linearly proportional to the waveforms. That you are going to breakdown from the complex situation.

So, if you go to or if you have gone to beach or gone to offshore conditions you will see the waveforms are not going to be, so nice and clean sine or cosine wave. You will see a random picture of the surface elevation changes. That is where mathematical representation of that could be potentially difficult. That is where we look for a simplified solution.

So, typical example I have just given you a two frequencies basically one two with a different amplitude, which could form something like this, but in nature you may have many more. So, you will you will have a range of frequencies from the bottom to top, which could be defined. If you have a specific site you do a measurement you will find certain range of frequencies. It is not always every frequency is available in every site.

You go to elsewhere you may find some certain range of frequencies. So, it is again site dependant and season dependant, you could see one particular site. You may have a particular range of frequencies. The next season you may have a different frequencies or periods of waves arriving at the site depending on the location.

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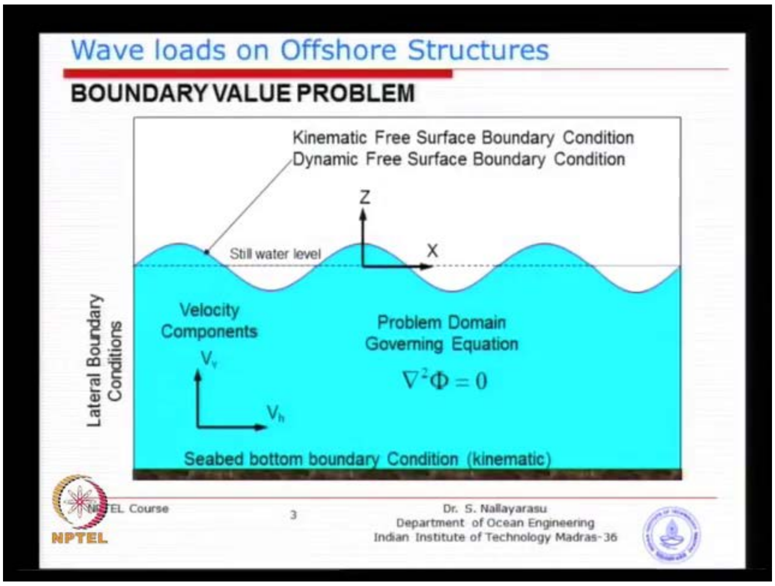

So, what you just need to solve is the domain basically the you see this two dimensional domain described by fluid flow or this is what you are just going through. Just now using your basic continuum mechanics from continuity of maths. Various conditions applied you can derive a Laplace equation to describe the fluid domain. Then apply boundary conditions at the surface at the bottom sea bed and at the both ends. So, taking a finite domain like this could solve a problem using various mathematical principles. So, basically the surface at the top has two boundary condition. One is kinematic boundary condition. The other one is dynamic boundary condition, which is changing all the time.

Sea bed boundary condition you have the no flow condition, basically impermeable sea bed. That is what normally we assume most of the conditions, but if you have a permeable sea bed, then the problem changes to slightly complex. So, the starting time simplified problem we assume there is no flow through the sea bed. Basically, at the two sides you have that mass continuity equation. So, if you do this you could solve this problem to find out what could be the profile of the surface, which is what we are interested. You know basically the surface elevation changes due to the boundary conditions. So, that can be derived that is what is called wave theory, which is something you will go through in the hydrodynamics course.

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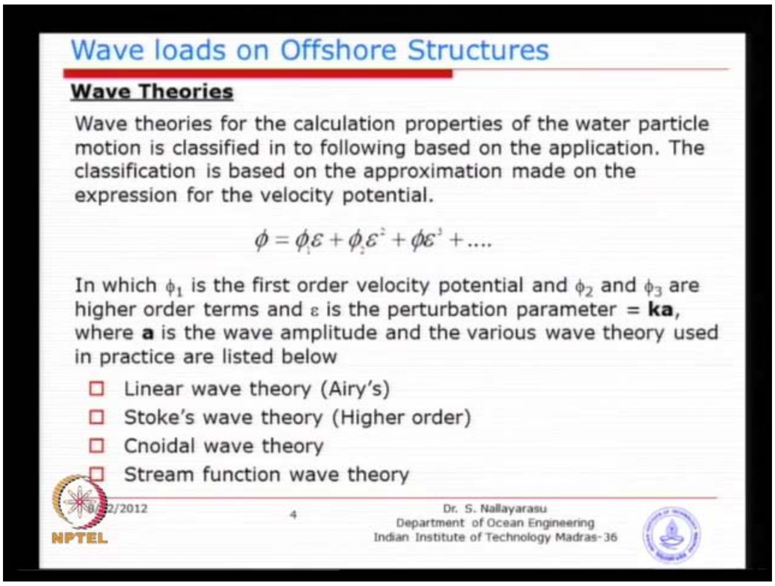

So, ultimately we have got several wave theories developed over the several years of like 30, 40 years quite a number of wave theories have been developed. It is again approximation wave theory is an approximation to reality. We cannot derive exactly what is the real field. So, that is why you see many theories basically starting with a simplified and too many assumptions. Try to remove assumptions by going closer to the reality. So, that is why the improvement over the number of years.

So, starting with linear wave theory, which could be a potential assumption. That the amplitude is too small. That means the boundary condition is applied at the flat surface, rather than the undulated wave surface. So, basically similar to your applied mechanics. You might have studied in your basic degree that small amplitude beam bending theory. You know we assume that the deflection is too small compared to the structure dimensions. So, when you do that their geometry does not change during the course of response, how that is possible that is exactly the situation here. The small amplitude wave theory or linear wave theory is assuming, that the surface is not changing or it is too small to be visible.

So, that is how the original wave theory was developed by airy professor airy has developed this, which is very simple very handy for the purpose of computation of loads on structures, but later for to apply. That theory what are the limitations. So, if you look at one by one some of the limitations. You may not like it, because you are violating in the real situation. So, you go for that incorporation of those violations in the theory. Then you find other forms of wave theory basically improvement over the first order. So, called simplified or linear or airy all the all the names pointing towards the that basic theory, which assumed too many assumptions, which may not be true at all the times.

So, you see this equation at the top basically the first order or so called linear wave theory is the five one, which is the velocity potential. You might be going through this just now in your fluid mechanics the potential function, which is proportional to the velocity of the fluid. So, basically the first order will comprise of the first term using the Taylor series expansion and the second order third order fourth order. So, as the order number increases, you can see the epsilon is a parameter associated with the wave number and the amplitude.

So, the first order or linear why we call it, because the first term is linearly proportional to the amplitude of the wave. Basically, you see this epsilon is nothing but k a k is the wave number a is the amplitude of the wave. So, it is proportional to the wave amplitude the second term is proportional to the square of the amplitude. So, second order and third order and so on. So, basically as you progress at additional terms the profile could be as close to the real wave profile in the field. That is the idea behind like if you want to develop a polynomial function a straight line. Can be defined by a linear function, isn't it? y is equal to m x plus c. Whereas, if you want to have a second order third order polynomials. You keep adding additional terms in the curve linear profile.

So, that you can define any profile you want that is the idea behind. So, that is exactly what is called linear wave theory to non-linear wave theory and non-linear is developed by this Stoke. So, that is why we call it sometimes Stoke's wave theory of order 3 5 7 and so on. Alternative wave theory is also available after the linear and stokes wave theory basically a cnoidal wave theory, which is a specific form. Also, stream function wave theory just an alternative to stoke wave theory, just exactly similar principle. So, you could see that these wave theories could be you could spend several hours deriving this. Then trying to figure out and you could take it on your own or during the course that you are going to go through. So, we do not have time in deriving this just now.

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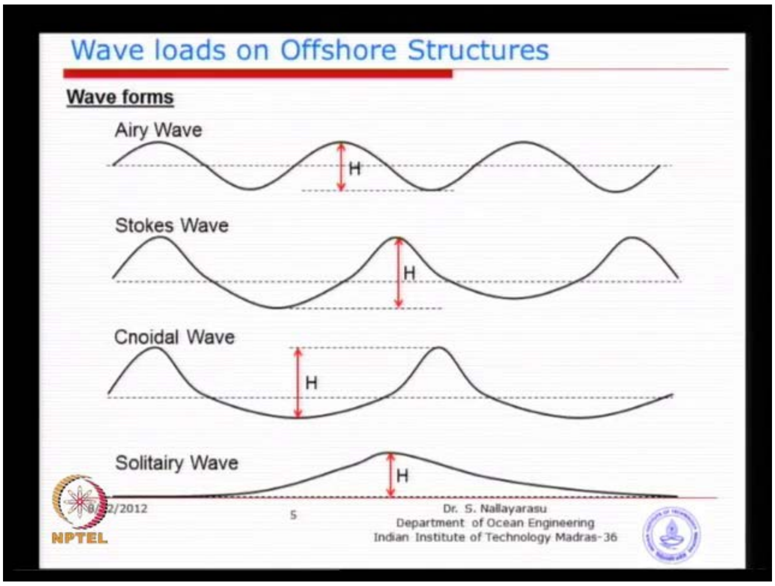

So, typically you could see a I would like to explain one important aspect of this various waves. You see the first one is Airy's wave or so called simple sine or cosine form what difference it makes. Basically, the amplitude at the above the mean water line and below the mean water line is equal. So, that means it is a symmetric waveform isn't it? Whereas, you look at the second one stoke wave you may see that the crest height. The trough height that means the top this height.

This height is not symmetric, isn't it? So, this is basically the idea behind. If you use a linear wave function you could only derive or you could only generate this kind of wave. Whereas, in reality you may see that the waves maybe of this kind of form. In fact if you go and measure in the field you will see such kind of waves that is why, we call it non-linear wave.

Basically, this non-linear means does not mean that it does not have the linear form. So, basically if you go back to this equation it contains this plus this. That is why you are able to get the crest and the trough are unequal. So, you could actually split into two components or more depending on what complexity the real waveform is. So, that is why the stoke wave is quite useful in going closer to the real wave in the actual field. Then there are few special forms like nodal wave or solitary wave, which is if you look at the solitary wave, does not even have the trough.

It just a build up of water surface and accumulation until it breaks. Similarly, the cnoidal wave has got very high crest and very small trough these are special forms, which you could find equations in the textbooks. You maybe taught in the classes to derive similar ideas will be there, but what is the meaning of this wave height is actually the height from the trough to crest, is called wave height. So, you must remember because this is what we are going to use it for our design purposes. So, basically the elevation difference between the trough to the crest. So, if you have gone to beach you will be able to recognise, what is trough, what is crest.

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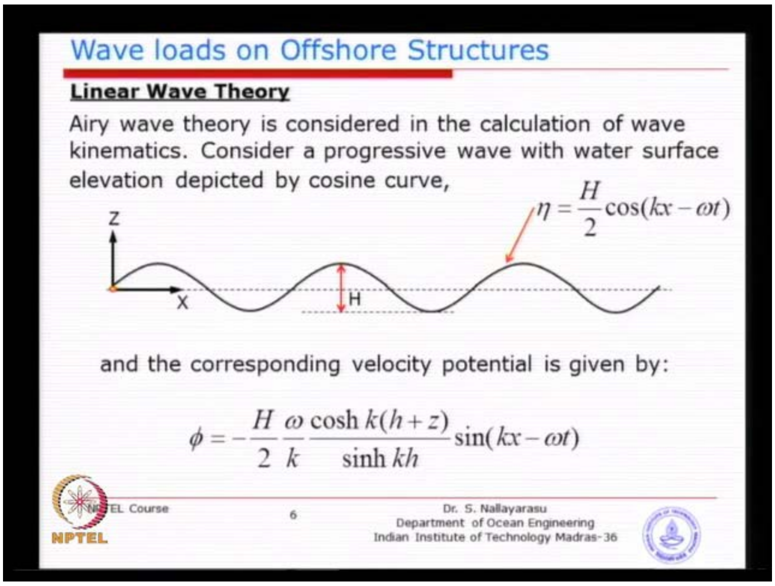

So, typically if you look at a linear wave theory you could describe this, because of a sine form or a cosine form in this simplified equation. Why we have put H by 2 instead of amplitude? Because, H by 2 is same whether it is crest or trough. Suppose, if you have not symmetric waveform, then basically you cannot write you have to write it as amplitude here because, that amplitude differs at different locations, whether it is trough or crest it differs. So, you will see that for non-linear wave you would not write H by 2. You will write a or other notations accordingly and the corresponding velocity potential. That you could derive using the either a linear waveform or non-linear waveform, which is something that you will learn over the period of time in the hydrodynamics course.

How to derive this potential function, basically the velocity potential is in the linear proportion to the wave height other variables of interest is the wave. The water depth the elevation and the horizontal spacial distribution. The time different timing and the frequency and the wave numbers. These are some of the variables involved in the derivation. So, basically the most important is the wave height you can see that this is the first term H by 2 is the half the wave height or amplitude of the wave in this case. The second term is the ratio of the frequency to the wave number. The third one is the depth variation basically the cosine hyperbolic term along the depth. How the changes in the velocity potential along the depth the last one is the variation with respect to horizontal distance and the time.

So, during the period of the waveform propagation, how the change is happening? So, you could see each one is representing one particular aspect. So, if you are looking at a variation along the depth you simply have to see, what is the coordinate, which is z. Because, normally we take the coordinate from the mean water surface. You could derive this with respect to even sea bed. Sometimes, you will find some textbooks with the coordinate z starting at the sea bed some of the textbooks will be at the water surface does not matter.

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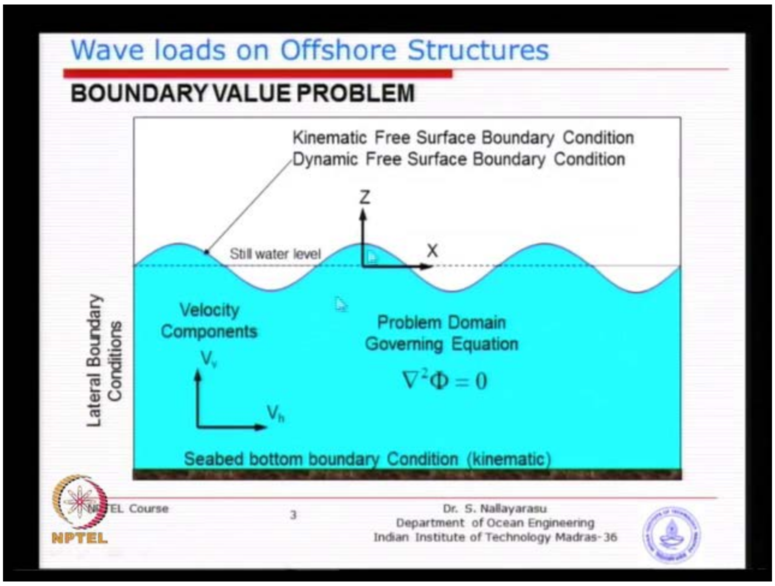

You know you could have this anywhere basically the final equations will be same only the substitution has to be accordingly done. In this case for sea bed location, we will put minus Z equal to minus water depth. Whereas, if you have the coordinate system starting at the mud line then Z equal to 0 will be representing the mud line. So, it is just a transformation. So, this potential function could be used to derive various parameters of interest for the structural design. Because, what we are looking at are the velocity and the acceleration of the fluid, while the wave is propagating. So, that is what we are interested. So, basically we will find the relationship between the velocity potential.

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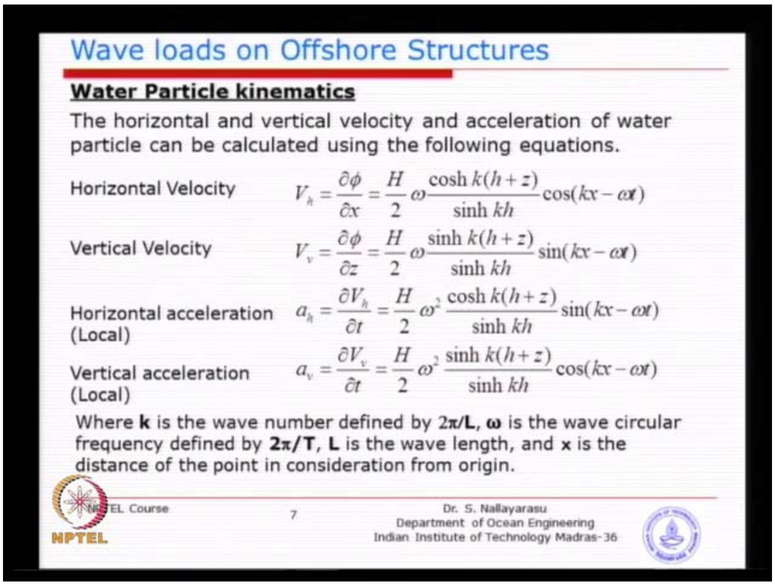

The velocity potential is defined in such a way, that the horizontal vertical velocities could be computed using the velocity potential by the first differential. The acceleration could be calculated by differentiating the velocity with respect to time. Basically, this is the local velocity local acceleration not the conductive acceleration. Because, we are looking at the particular location, rather than the propagative or the conventional acceleration. That is why we are differentiating with respect to time you understand the idea.

So, basically we took the potential function, which is described by solving a two dimensional problem of this kind, with the boundary condition. At the top boundary condition at the bottom boundary conditions on the sides we derived, so called the velocity potential using the velocity potential. Basically, the relationship between the velocity and acceleration of a particular water particle is defined by these functions. Because, this is what we are going to use it for our drag and the inertia force calculations later on. So, that is that is the idea behind.

So, the horizontal velocity is del phi by del x vertical velocity is del phi by del z. Then the horizontal acceleration vertical acceleration by associated velocity differential by time. So, basically it is a very simple idea and as long as you know this equations all of this terms will be known to you. Like, for example, wave height wave frequency if you know the wave period, we can calculate the wave frequency. Then the wave number can be calculated as long as you know the frequency and the wave period and the wave length.

So, you can find out the wave number and then the water depth is also known to you elevation at which the wave load is or the velocity is required. Then the time at which propagation of wave. So, all the parameters are known to you. So, as long as you know this relationship this particular one, this you will find different forms. I have taken velocity potential like this you will find few different forms.

It could be a cosine form here it could be a cosine form here depending on which boundary condition type you have applied, you will get different. So, do not get worried either one you use ultimately the values of your velocity and acceleration must be same. So, you will find in different text books different type of formulas form will be same, only cosine form sine form will be different. So, do not have to be unduly worried you will ultimately get the answer exactly same. So, what is defined as here is a wave number it is 2 pi by L, L is the wavelength. Basically, omega is the wave circular frequency defined by 2 pi by t. X is the distance from the point of consideration from the origin, you must remember the origin is defined at the centre of the domain from there, what is the..

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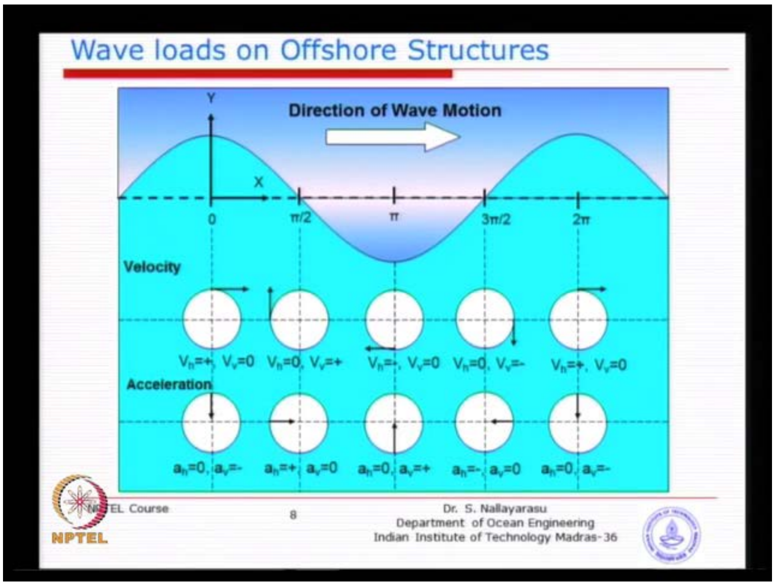

So, typically if you go through one wave cycle you will see that the velocity. The acceleration is basically ninety degrees out of phase. So, you look at one of the crust for example, this point origin point the horizontal velocity is maximum, but the vertical velocity is zero. You could go and take this equations what I have given you and just try to substitute. You will find this by observation itself and then acceleration is zero and the vertical acceleration is negative downwards.

So, that is something that you need to remember, because what exactly is happening when you are trying to do computation of wave force. You will see that wave force could be found out at each of the time step. Then you need to find out where is the maximum wave force will happen, because this is a dynamic force change with respect to time, because wave is not static. It is progressively moving and that is why you need to find out at what instant of time

That structure will be subjected to maximum force that we do not know of priory. So, that is why we have to just look at various time shifts along the wave propagation, find out at particular time step. Where, the in order to do that you should understand how the wave propagation going through. So, this picture will give you a clear idea that always there are there is a out of phase. Just, because you are differentiating the velocity potential one time for velocity and the second time with respect to time for acceleration. So, you will always see that there will be a out of phase. So, this picture you could find in the textbook also, but only a understanding is required at which phase, what is happening.

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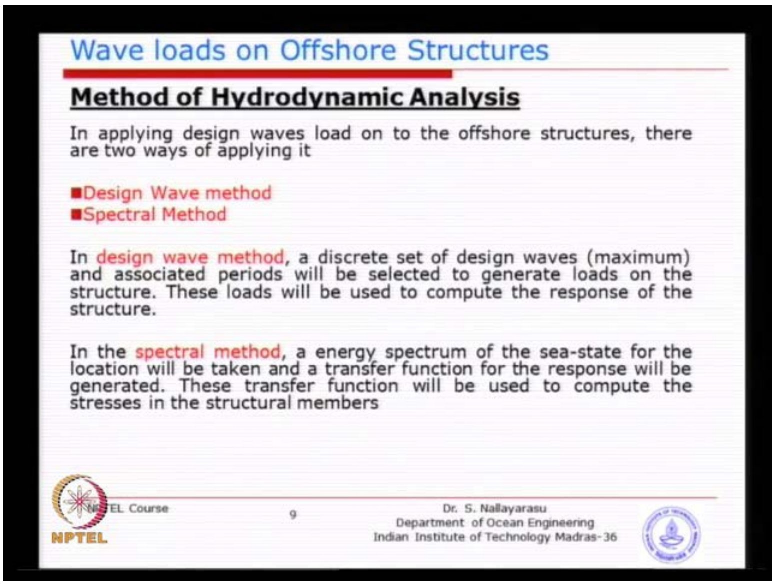

Now, we will go to the hydrodynamic analysis for the structures there are variety of ideas as you see from real sea field. You know you will find many wave heights many wave patterns and going to be a highly random. If you actually go by boat in middle of the ocean you will see that you would not be able to see a nice wave, like what I have shown in the picture.

That is where we need to describe that scenario by mathematically. So, that the mathematical transformation can be taken to structural design is not it. So, that is the idea behind there are few perceptions. Like, we could take the maximum wave over a period of design life. For example, if the design life is twenty years you try to find out, what could be the maximum wave that could occur during the design life and design for the structure

Once you design it there is no necessity that you need to design for the lower waves. For example, at that particular site you have a twenty meter wave height probably may come once in hundred years. If you have designed for the twenty meter wave height there is no necessity that you need to design for ten meter wave height. Because, it is already designed for a higher forces. That method is normally adopted, because you cannot take a chance for one bigger wave, which is going to come one in hundred years because, that is also going to fail the structure.

So, the design wave method basically going by the design for the maximum wave that may occur at the site during the design period of the or the life of the structure. That is called design wave method, which is slightly conservative, because you are not taking into account the probability of the occurrence of that particular wave. You may have a probability of one in one thousand that means 10 power minus 3, which is so small. That you do not even want to take that risk. Whereas, it may be prudent to consider a slightly reduced wave height, which may occur maybe a higher probability, but just do not design for the highest all the all the time, but then the last twenty thirty years, this design wave method is seemed to be comfortable with the designers, as well as with the owners, which has given in fact no alternative.

The other method of design is basically using the spectral method. That means you observe the waves at the site collect as much information as possible. Then describe the wave scenario at the site by a frequency versus the energy function. Basically, you can plot this particular wave period has got this much of wave height and that much of probability. So, a, b, c three functions you need to generate that means you can describe the site by a frequency function, with wave energy plus your probability. So, that you can take a decision I will design for ninety percent probability of a particular sea state. That means you may take a ten percent stance that the waves may exceeded, but at least you know what is being designed.

Unfortunately, this spectral method is still not being practiced for at least fixed platforms for floating structures. There are few instances the D N B codes does allow spectral design method for floating structures for response transfer function. Whereas, for fixed structures A P I on any other code does not permit the use of that. So, in this course we will use only the design wave method, where we will take the maximum wave. Then determine the wave forces design the structure and be happy.

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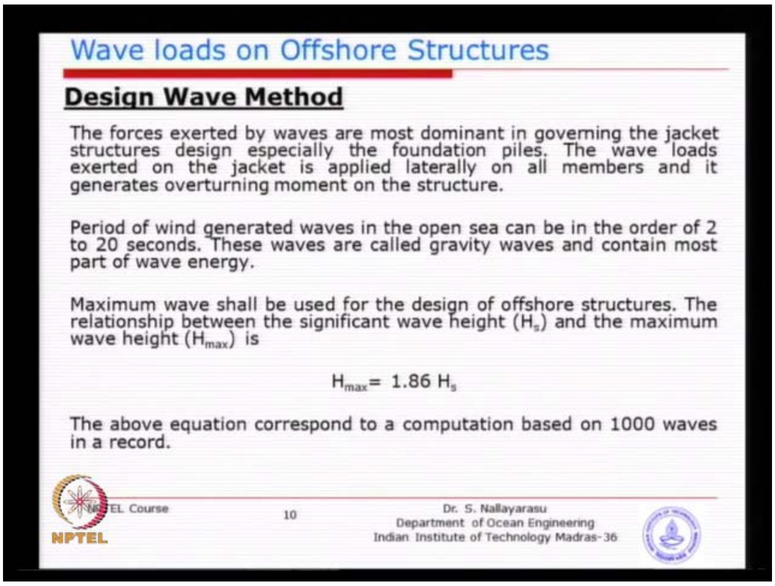

So, what is the method of design in the design wave method is basically the design wave height. You know the maximum wave height that may occur needs to be extrapolated. Sometimes, we do extrapolation because we may not know what could be the maximum wave height. Basically, this relationship between the significant wave height and the maximum wave height is 1.86. If you have a one thousand waves in the measured record in a depending on the strong duration, that you have measured. Typically you can vary this number this is not a fixed number for a particular record of one thousand waves. You could calculate the ratio between the significant wave height and the maximum wave height.

So, what is the meaning of significant wave height? Basically, the average of top one third of the waves recorded at the site. That means if you have one thousand waves you arrange them in the descending order. The top one third you take an average, which is called significant wave height, which is basically a simple idea, that the energy content is more on the top one third of the waves. That is why it is called significant the energy content is higher at the top. So, if you have one thousand waves starting from 20 meter all the way to say 1 meter the top one third number count you just take and average it. That will be called significant wave height, if you take the maximum of one thousand waves that is called H max.

The reason why we need this relationship sometimes you may have a significant wave height in the information. So, you want to calculate back without measurement you do not want to go and measure it. Then you can take this type of relationship. So, we should design this for such wave heights. Also, I have mentioned here typical waves generated all over the world. You go anyplace the wave periods the successive the time difference between the successive crest or the trough is called wave period, which is typically between 2 seconds to not 20 seconds. Sometimes, you get less than that you know most of the places you get maximum is 12 seconds or 14 seconds, but 20 seconds is almost like a tsunami. You know basically it is almost no trough will be there it is moving water most of the east and west coast.

We get wave periods of about 12 seconds maximum waves in 14 second wave during cyclone period, but other than that normal periods are around 10 to 12 seconds. So, if you go to beach you will see that every 3 seconds on a on a waveform is approaching and breaking. They are all just you know the seasonal waves, but if you look at the storm wave. It may take maybe 10 seconds 12 seconds, before you see the second successive crest come and break. So, that is the difference between seasonal waves versus the storm waves.

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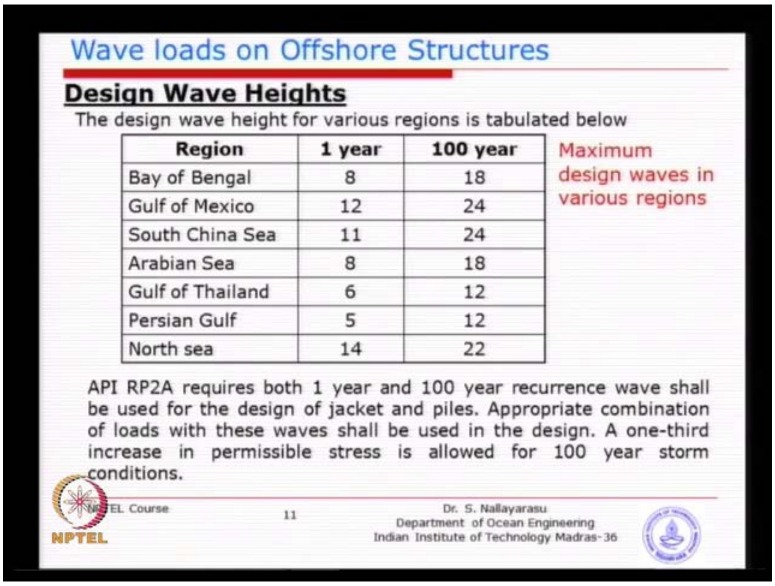

Region	1 year	100 year
Bay of Bengal	8	18
Gulf of Mexico	12	24
South China Sea	11	24
Arabian Sea	8	18
Gulf of Thailand	6	12
Persian Gulf	5	12
North sea	14	22

Typical wave heights just to give you a idea about what would be the type of variation you can find from location to location. For example, Bay of Bengal on the east coast and the Arabian sea on the west coast. You could see here the difference is very small both are open conditions both are subjected to cyclonic storms. In fact east coast is more prone to cyclonic storm. In fact the recent observations we find that this 18 meter is not correct. In fact last three years, in fact few cyclones have crossed in this east coast. You find that the wave heights could be as much as 23. In fact the new developments we are using 23 meter wave height, rather than 18 meter.

Whereas, if you go to west coast it is basically the data from last thirty forty years. Still, we use 17.8 meters about 18 meter is the wave height, which did not change. In fact west coast is less prone to cyclone than east coast. So, you could see elsewhere you go several other locations. For example, Gulf of Mexico the storm waves could cross as much as 24 meters. So, the structures that we design should be able to sustain such type of forces. So, the difference between one year and hundred year, I think we spoke about it the other day is a recurrence interval or the return period. At least one time it will occur during the design or the period that you are taking. So, one year wave means it is going to occur more often within the design life compared to a hundred year wave, which could occur one time or less.

So, this requirement of one year hundred year, why we take is. Basically, I think we discussed about the load combinations, the other day during the operating conditions or the platform normal operations. You may have to design for the one year wave whereas, a special case, where you may shut down. You may actually reduce the activities during the hundred years storm condition increase the stresses or allowable stresses in the structures. That is why we call it the two different design conditions.

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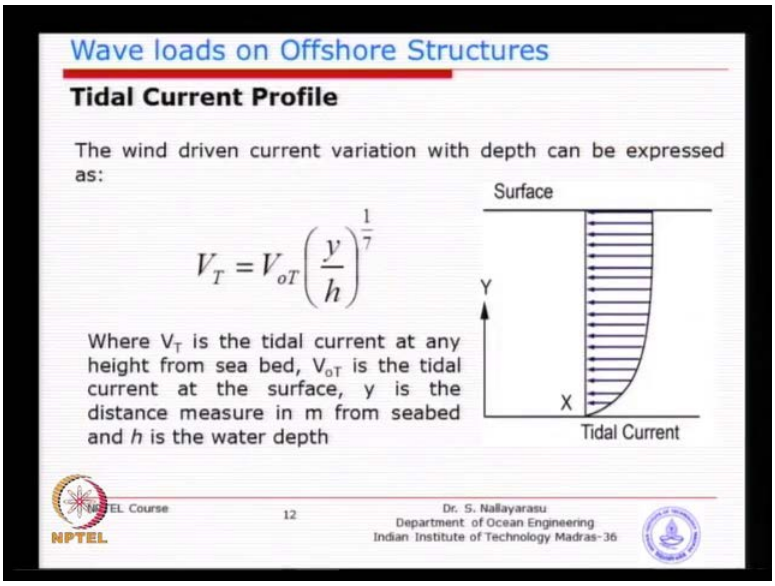

The next one is the current, I think wherever you go you will have sea current. Basically, these sea currents are the cause of several issues I would say. For example, simple sea current could be caused by wind as much the waves are generated by the wind. You could see that the sea current surface current, could be produced by wind by dragging shear on the surface of the water. So, the first one is the wind the tidal current is potentially possible in areas, where the tide difference is very high. For example, if you go to west coast the tidal difference is quite large in some places, like say Gujarat or the mouth river like Tapti. Basically, there the tidal difference is 11 meter during high tide and low tide the difference is 11 meter.

So, you could see that at certain places low tide certain places high tide. So, because of the potential difference between the water levels water can flow from high tide zones to low tide zones, almost like a river. If you go to some places in Gujarat you will see that water is flowing like river during tidal changes morning to evening. You will see that the water is going like a river and that could be high as much as 3 to 2 to 3 meter per second, it is like almost like a river.

So, the tidal current profile is almost like a wind profile you can see, I think we discussed about the wind profile. It is almost similar and using a power law formula, basically can be calculated to interpolate between the various steps. If you know the surface velocity say 2 meter per second you could calculate what could be the velocity elsewhere along the depth, so typical measured profile.

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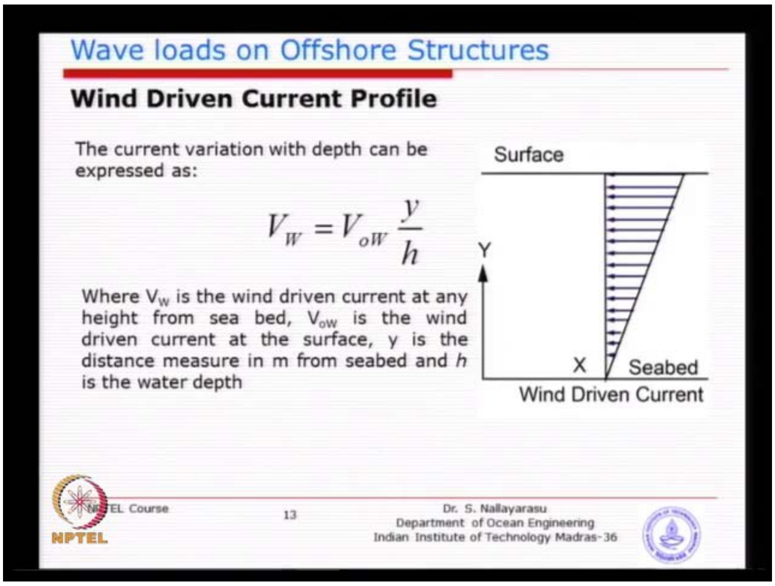

Similarly, the wind driven profile basically as you can see the wind shear is diminishing as we go down. So, you could have a linear profile instead of a non-linear profile in this kind of order. So, the difference between tidal and wind is only the variation with respect to depth.

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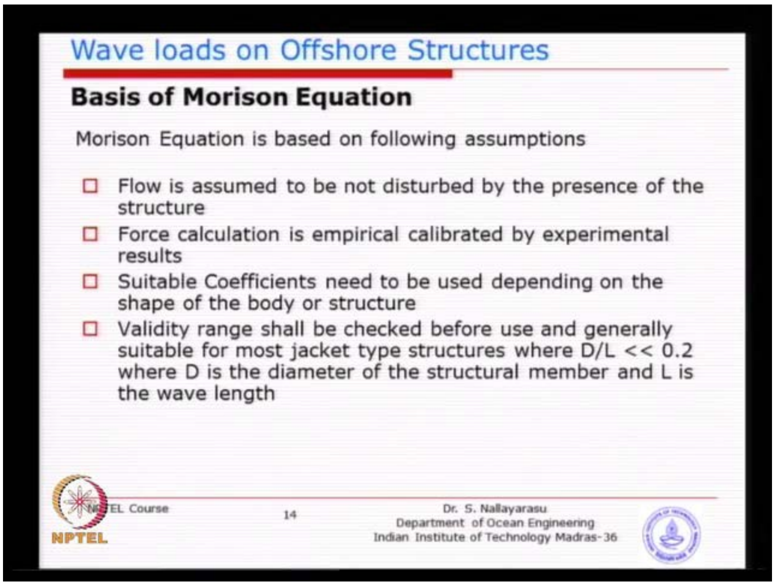

Now, we will introduce so called Morison equation, how do we calculate the forces on the structure? As you can see that when you place a structure inside the moving water whether it is wave or current something is going to happen isn't it? So, for example if you have a steady stream of current like river. You go and place an obstruction there by constructing a pear bridge pear or a column or a pile. What happens is the moving water is trying to cross the structure by diversion, isn't it? Automatically it will get diverted flow past and then it generates the surfaced friction drag. As, long as the larger the size you are going to create drag force. Basically, by the fluid drag on to the surface of water.

So, for sure you could see that the steady stream of current is going to create a the drag or the form force on the structure, which is very similar here. This doctor Morison has proposed a simplified formula, which even today we use it to extensive extent. Because, it is very good very easy and very simple. Only complexity comes arise in the use of the formula at various situations. So, we need to understand how we can calculate.

This formula is based on semi empirical method. It is not basically derived from first principle. Basically, his assumptions are of quite a number of them. Sometimes, they may not be able to satisfy first example is flow is assumed to be, not disturbed by the presence of the structure. So, this is the first assumption he has made that means when you construct a structure on the river the flow pattern is not getting disturbed. That means maybe acceptable maybe not acceptable depending on the type of structure, the size of the structure. For example, you might see if you take a small needle and put it in a river flow the flow may not even get disturbed. Because. it is the needle is too small, but if you make one big pear 3 meter diameter, what will happen? Definitely the flow will get diverted.

So, vice versa depending on the flow velocity if the velocity is too large. You may see that something may happen in the vicinity of the structure due to the boundary layer conditions. So, there will be an interaction between the structure and the fluid depending on the size and the structure and the velocity of the flow or the type of flow. So, this assumption basically flow is assumed to be not disturbed. That means the structure is unable to see the presence of the structure. The fluid is not able to see that there is an obstruction. That is what the first assumption made by Morison. That the structures are transparent to the flow, which we may see that. You may not even agree with this idea, but then mathematically trying to describe this flow he found that this is very easy, but he later made corrections to this assumptions. You know basically that is the idea behind.

Force calculation is based on an empirical or so called semi empirical some sort of explanation is given to correct the forces calculated by experimental results. So, what he did was he proposed a formula. Then calculate the force on a known geometry of the structure. Then go to a laboratory do a measurement and make a comparison. If they confirm hundred percent, it is good. If there is a difference make a adjustment to the calculated force until your measured force matches with the calculated force. So, adjustment means correction factors you get the idea. So, basically these correction factors are called the empirical coefficients termed as the drag coefficient or inertia coefficients, whatever we are going to term.

So, those correction factors needs to be calculated from the experimental studies. That is where you will find, so many of us our students in our laboratory M S scholars or the P H D scholars. They are trying to do so much of experimental studies, but not trying to find out the C D C M, because C D C M has been established several decades back by so many experts.

So, basically most of the fluid structure interaction problem requires experimental studies because the interaction is so complex. Without such studies trying to simulate by pure numerical means or by analytical means you may not be able to do so. If you can do so by making some simplified assumptions. Then correct that results by the comparison with the experimental studies. That is a practice because, as I mentioned fluid structure interaction problems always complex.

Especially, because of the viscous effects. That is why back in nineteen fifties this Morison proposed such as nice and simple formula, which even today we design complex structures for offshore applications. So, when this is applicable when the diameter to the length of the wave ratio is less than 0.2. So, as long as the size of the structure is less than 20 percent of the wave length, so what is the wave length? We just go back to this picture.

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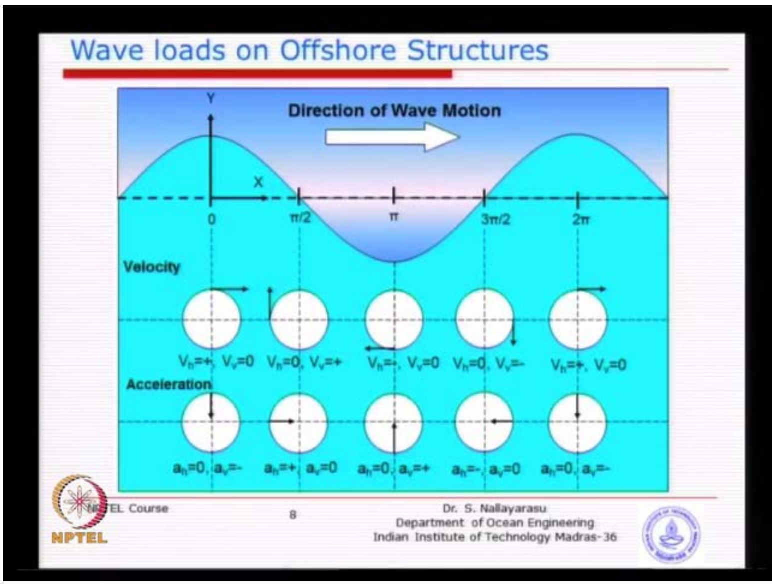

The wave length is described as either crest to crest or trough to trough one wave length can be calculated, which equivalent of the wave period successive wave crests is passing by. So, wave length is defined as one length from the crest to other crest. So, basically you can calculate that wave length. You know the size of the structure as long as the size of the structure is less than 20 percent of the length of the wave.

Then you could consider that this the last three points are satisfied. In fact it has been proved that this will be the case by several researchers. Even our students have done, so much of studies in the recent past, that this is true. That the wave forces predicted by Morison equation conform very well as long as the size is less than about 20 percent. Now, what is the formula he proposed, basically of the form the first component is the dragged form the second component is the inertia form.

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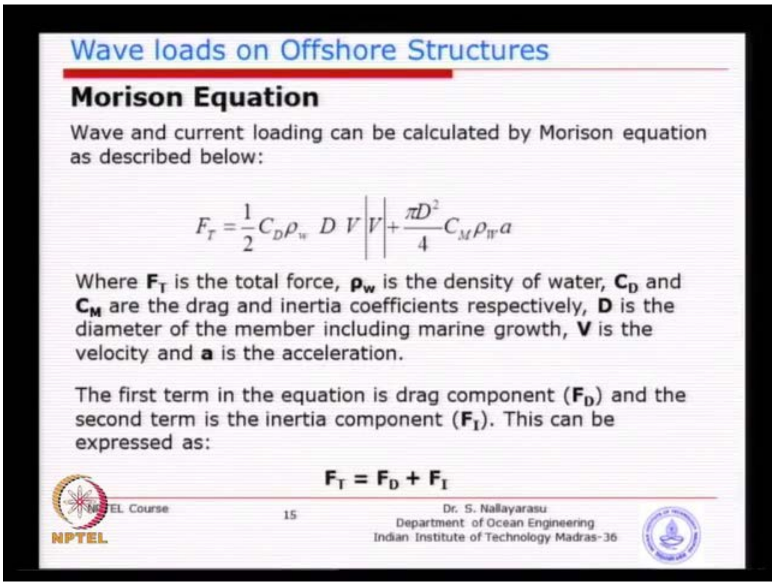

So, the first component is basically proportional to the square of the velocity like your kinetic energy. I think you might have studied very similar idea. The second form is basically the volume times density times the acceleration. So, volume is calculated by the cylindrical structure, this is basically for a pipe, that is what I have written here. For the other forms you will find the formula different here. I am just using a circular section like mostly we use for jacket type of structures. So, pi D square by 4 is the area multiplied by unit length that is not given here. Basically, the force is calculated for one unit length multiplied by the density of water.

Basically, that is the displacement multiply it by the coefficient called the inertia coefficient, which is comprising of the self volume plus the volume of fluid moving together, when the structure is trying to displace. So, that is why it will be always greater than one and a is the acceleration of the water particle fluid, at the surface of the structure, which we already have the formula to calculate. So, you could calculate the fluid velocity and fluid acceleration. This is acceleration this is fluid velocity and then substitute here.

So, if you go back to those formulas four formulas we had H V, V a H and a V. You could calculate those and substitute here and try to find out the force on the structure, but unfortunately that formula if you look at the it it is varying with space varying with time. So, that means it is not one value you are going to get you are going to get several values. So, we need to find the methodology which value to be used for design. That is where little complex scenario will come.

So, you see here the terminology C D is called drag coefficient associated with the fluid velocity. The projected area or the so called force on which it is generated is the diameter. Basically, C M is called the inertia coefficient always, it is greater than one because, the volume of the fluid displaced by the structure. Plus the volume surrounded or in the surroundings will also move when the structure is trying to move. So, we call it added mass coefficient as 1 plus C a. That C a will be calculated basically depending on the geometry. For example, if you have a circular cylinder moving in fluid versus a square cylinder. You know you will see that the volume moving together will be different. So, circular cylinders is basically streamlined body, whereas rectangular cylinder is a sharp edges. So, you will see that slightly higher.

Basically, we need to find out at what time this will be maximum, because you take one wave cycle wave period of 10 second. You monitor the force every point 5 second or 1 second. So, you just calculate for example 1 second ten times you do the computation. So, 0 second to 10 second you have ten computations ten different values will be arrived for the total force.

Now, whichever is higher that will be the design force, which I am sure you will all agree, because we want to design for the maximum forces. So, that the response is maximised and the structure is safe. Now, we want to find out at what instant of time drag will be maximum. We do not know, because when the drag is maximum the inertia is 0 because, you saw that your the equations for velocity and acceleration. The horizontal velocity is will be maximum at the crest that will be the maximum velocity. You will see that you can just calculate at that time acceleration is 0. Whereas, when you go to another place at the trough or at the quarter point, the acceleration could be maximum, but that time velocity is 0.

So, there could be a potential place where the combined effect of velocity. The acceleration will give you the maximum force we do not know. So, we need to find out at what is that time instant. Because, when you use maximum velocity you may have a maximum drag force, but that may not be the absolute maximum total force. Because, this other component has become 0. Whereas, when you use a maximum acceleration that time velocity is 0, but that may not also be the maximum force quoted, but when you have a combined effect somewhere else. Neither, velocity nor the acceleration is maximum, but the combined effect could also produce the maximum force, which is what is of our interest.

That is the point of consideration, which we need to device a method. So, that we can automate the process, because one it is not one member we are going to calculate, because we got a lot of members. I think I have shown you pictures of jacket structures, so many of them many of them and that is where we need to device.

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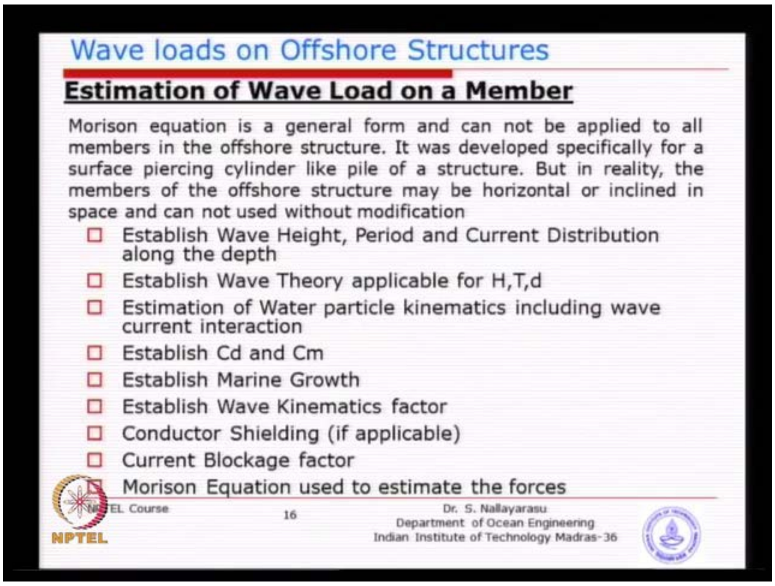

So, in doing so I think we have got a procedure established by A P I or other codes. In fact it could be easily seen by this flow chart we will see this.

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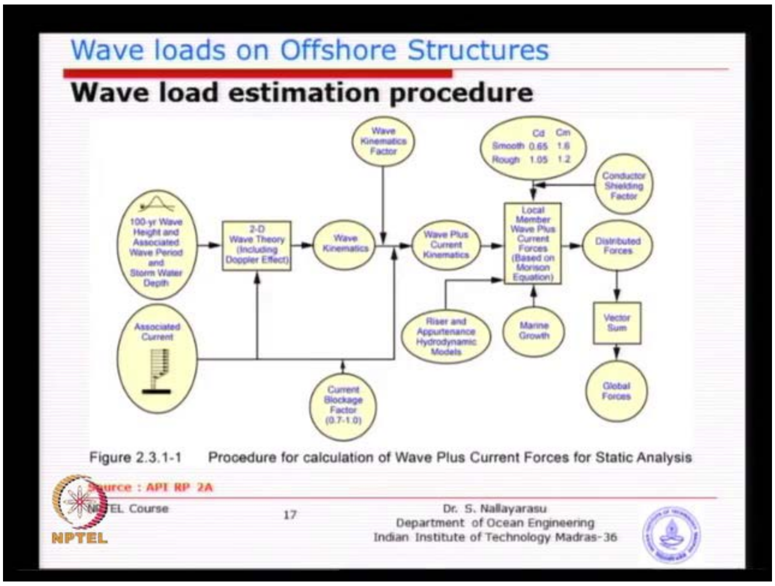

In the next class the procedure behind is basically establishing various data. Like, wave period wave height and the wave direction. Establish a particular wave theory, which is to be selected by us just now. We were talking about linear wave theory non-linear wave theory and then the special waveforms. Now, we need to find out for the given wave height given wave period.

The water depth at that site, which wave theory is suitable depending on the wave height, to wave water depth ratio or wave height to wave length ratio quite a few parameters need to look at it. Whether the assumptions made by airy is correct or not. For example, the amplitude is too small that is what he has assumed. So, we take a parameter and look at it. If that wave theory is not suitable, then we go to Stoke's wave theory see whether that wave theory is applicable.

So, fortunately we do not need to struggle a lot, because over the period of time people have devised a simplified procedure to select a wave theory. We will use the chart there is a design chart available. So, that you know the wave height you know the wave water depth we just simply go there and select a wave theory of suitable to the site. Establish water particle kinematics basically your velocity and the acceleration, which I think the wave equations could derive. Whether it is Airy's wave theory or the other wave theory establish C d and C m, which is definitely available nowadays, because you do not need to go and do research yourself.

It is already available in the literature or in the code books establish marine growth wave kinematics factor conductor shielding. Each one of them have got certain effect on the wave force calculation. Finally, you substitute each one of them will be looked at in detail, over the next few classes. Then finally, come back here apply all that information into the Morison equation arrive at the design force. I think we will stop here and then look at it tomorrow.