Advanced Marine structures
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Lecture - 8
Environmental loads-IV

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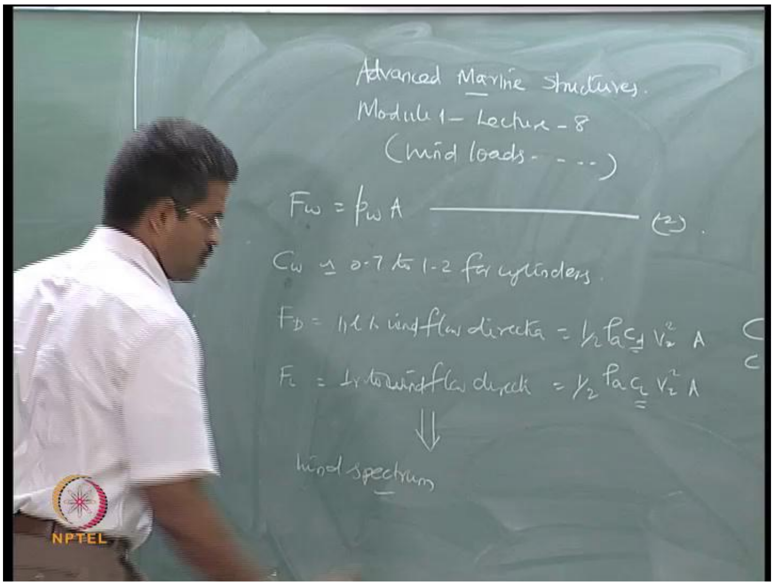

So, will continue talk about the wind force estimate and marine structures. So, equation two I already said that, the wind force normal to the surface, can be computed by rho w A, where A is a projected area, which is orthogonal to the wind flow direction. Whereas, p w is the pressure coefficient which can be pressure value, which depends upon can be computed from the equation number one. And the coefficient of pressure can vary from 0.7 to 1.2 for cylindrical members.

So, wind will generate two kinds of forces, what is called the drag force and the lift force; one is parallel to the wind flow direction, other is normal to the wind flow direction, so half rho c d v z square of projected area, which is half rho c l v z square projected area. The only difference is the lift and the drag coefficient, which can be computed based on experimental studies.c d c l can be based on experimental studies, which is essentially a wind tunnel testing, which is generally done to compute these values correctly. So, this will lead to what we call, what is the acceptable wind spectrum, as we saw the load spectrum for hydro dynamic loading.

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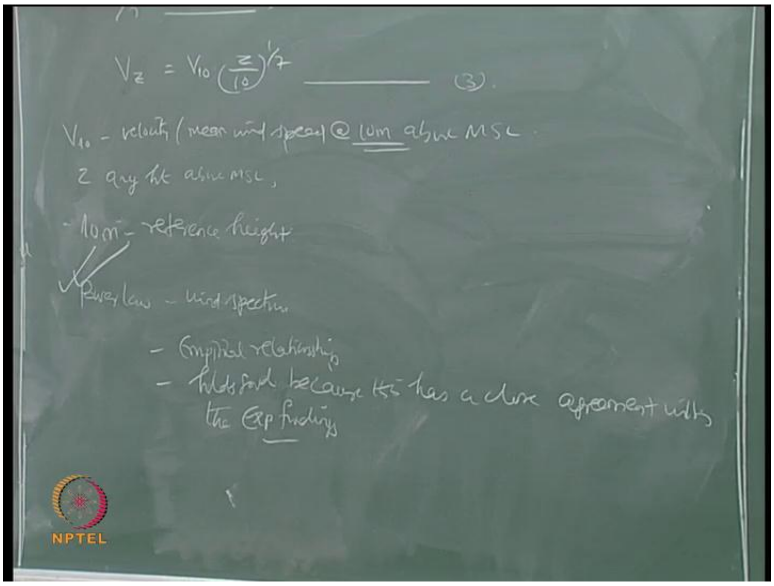

$$V_z = V_{10}\left(\frac{z}{10}\right)^{1/7} \quad \text{------} \quad (3).$$

V_{10} - velocity (mean wind speed @ 10m above MSL.

z any ht above MSL,

- 10m - reference height

Power law - wind spectrum

- Empirical relationship
- holds good because this has a close agreement with the Exp findings

So, the acceptable wind spectrum, which is commonly followed in engineering practice for design of marine structures is actually the one seventh power law, we says v z is given by v 10 z by 7 power 1 by 7; equation number three, where v 10 is the velocity or the mean wind speed at 10 meters above the mean sea level, z may be any value, any height above the mean sea level, where you want to find the velocity. So, since the exponential power here is 1 by 7, this law is called one seventh power law. So, this 10 meter is what we call as reference height.

Now, there is a very important comment, which has been made on the power law by the literature. The power law which is being used as a wind spectrum, for computing design forces on marine structures, is basically an empirical relationship, and this holds good, because this has a close agreement with the experimental findings. So, this law is favorably being recommended by engineers, for finding about the wind forces on members of marine structures.

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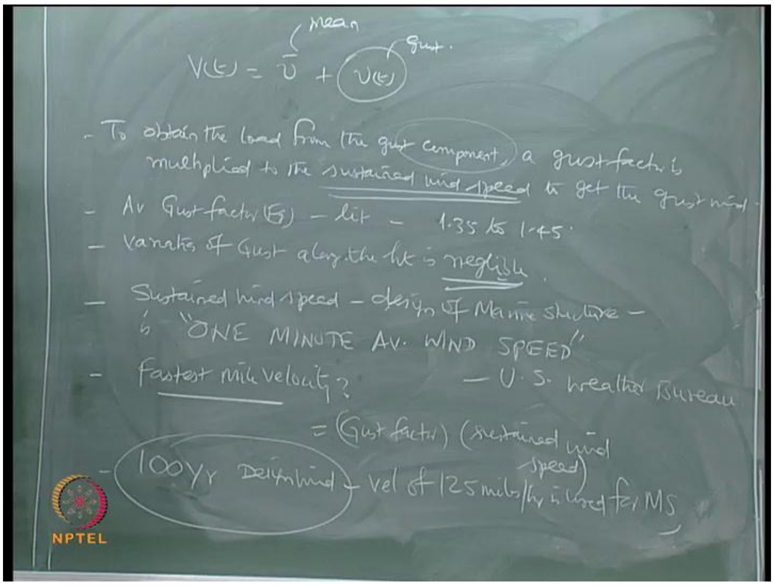

$$V(t) = \overset{\text{mean}}{\bar{U}} + \overset{\text{gust.}}{v(t)}$$

- To obtain the load from the gust component, a gust factor is multiplied to the sustained wind speed to get the gust wind.
- Av Gust factor (Fg) – lit – 1.35 to 1.45.
- Variatn of Gust along the ht is negligible.
- Sustained wind speed – design of Marine structure – is "ONE MINUTE AV. WIND SPEED"
- Fastest mile velocity? – U. S. Weather Bureau
  = (Gust factor) (sustained wind speed)
- 100 yr Design wind – vel of 125 miles/hr is used for MS

As I said, wind has got two components, which is the mean wind and the gust wind. This is the mean component, this is the gust component. This is static, this is dynamic in nature. This is fixed, this is fluctuating. So, far we have been handling the mean component, which can be computed using the power law. Now, how will you handle the gust component, where that is an important contribution. Now to find the load from the gust component, a gust factor is multiplied, to the sustained wind speed, to get the gust wind. The average gust factor, which I call as f g, as seen from the literature varies from 1.35 to 1.45. Most importantly, the variation of the gust factor along the height is negligible is very important.

You will see, the mean wind component along a height, is predominantly one of the varying parameter, it keeps on varying, but whereas the gust component does not vary with the height, it is negligible actually. Now, the question comes, the gust component depends on the sustained wind speed, what should the sustained wind speed taken by marine structures; that is again an argument, where is international course advise different sustained wind speeds. So, the sustained wind speed, to be taken for design of marine structures, is one minute average wind speed, as recommended by U S Weather Bureau. So, one must consider, one minute average wind speed, you must measure the wind speed, one average of a minute and use that as sustained wind speed, to multiply this, where the gust factor to take the gust wind in the design.

You will also find another important term in the literature which is called, fastest mile velocity. Now, what is called fastest mile velocity?This is nothing but the gust factor multiplied by sustained wind speed. So, generally a hundred year designed wind, with the velocity of 125 miles per hour, is used for marine structures; that is important. So, I used hundred year design wind speed, sustained wind speed, with the velocity of 125 miles per hour, to compute my sustained wind speed. So, what I actually try to say is this, look at the hundred year record, look at the wind velocity of going at 125 miles per hour, during that scenario take one minute average of the wind speed, and use that value, multiplied with the gust factor, which is given in literature as it is, which will give you the gust component of your wind velocity or wind force.

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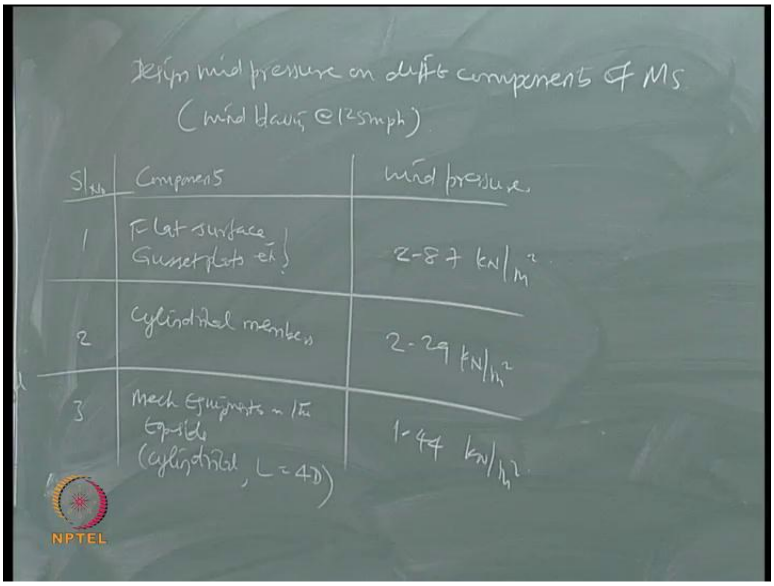

Design wind pressure on diff components of MS
(wind blowing @125mph)

Sl.No.	Components	Wind pressure
1	Flat surface Gusset plats etc }	2.87 kN/m²
2	Cylindrical members	2.29 kN/m²
3	Mech Equipments on the topside (cylindrical, L = 4D)	1.44 kN/m²

Interestingly, the design wind pressure, I am saying, the design wind pressure, on different components of marine structures, when the wind blows at 125 miles per hour, is available in tabular form, which is given in the literature.Let us see what is that. These are the components, this is the design wind pressure.Once you multiply this by projected area, which is orthogonal to the direction, you get the force.

So, different components; the components are let say flat surface, gusset plates, etc. Cylindrical members, mechanical equipments on the top side. So, some of the mechanical equipments will be cylindrical. So, we will say them as cylindrical only, when there length is equal to four times of the diameter. In such cases, the recommended wind pressure, which can apply on to these surfaces, which can be taken as the design wind pressure for marine structures are the following; 2.87 kilo meter per square meter 2.29, 1.4. So, if you know the projected area, which is normal to the direction of flow of wind, multiply these values on the surfaces, to find out the wind forces on this surface respectively, or for design purpose in the marine structures. Now, let us quickly talk about the realization of wind on marine structures. Where is the complexity, it looks as if it is very simple, but there are some complexities in this, because we are seeing both the components independently; that is the mean wind speed, and the gust component, independently so far we have been seen, but in the wind as a phenomena, they are acting together.

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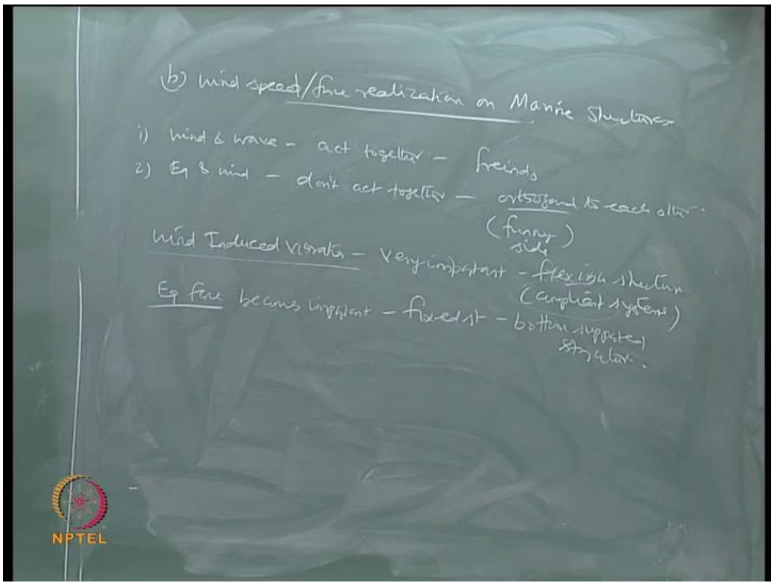

(b) wind speed/force realization on Marine Structures

i) wind & wave - act together - freinds
2) Eq & wind - don't act together - orthogonal to each other.
(funny side)

Wind Induced vibration - very important - flexible structure (compliant systems)

Eq force becomes important - fixed st - bottom supported structure.

So, let us see, what the wind speed is or wind force realization, on marine structure, because there have been two components, there has a important points, wind and waves generally act together, so we can say they are friends. Whereas, earthquake and wind, they do not act together, so we should say they are orthogonal to each other. I mean, this funny statement; saying orthogonally means there product will remain zero. Therefore, wind induced vibrations, becomes very important for flexible structures. I should say, compliant systems, because the moment structure becomes flexible, structure will start responding to the wave action or wind action, I address this as compliant systems and marine structures.

Whereas, earthquake forces become important, in case of I should say fixed structures, but I would say bottom supported structures. You can have many examples, like gravity based structure, fixed jacket platform, there earthquake force becomes important, where as wind induced vibrations becomes important in case of compliant structures. Let us quickly see, some of the important parameters, which are focused on wind force on structures.So, we will try to derive the aero dynamic admittance function, which in inter presentation of the random force of wind to compute the force on marine structures.

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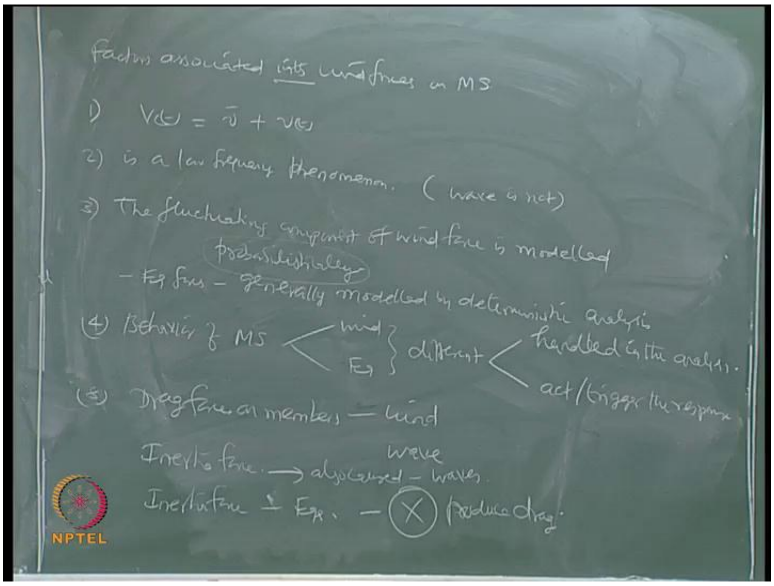

Factors associated with wind forces on MS

1) $V(t) = \bar{v} + v(t)$

2) is a low frequency phenomenon. (wave is not)

3) The fluctuating component of wind force is modelled probabilistically

- Eq forces – generally modelled by deterministic analysis

(4) Behavior of MS $\left\langle \begin{array}{l} \text{wind} \\ \text{Eq} \end{array} \right\}$ different $\left\langle \begin{array}{l} \text{handled in the analysis.} \\ \text{act / trigger the response} \end{array} \right.$

(5) Drag force on members — wind

Inertia force. → also caused – waves. wave

Inertia force ≠ Eq. – ⊗ produce drag.

There are some factors, associated with wind forces on marine structures. We already know that, wind has got two components; the mean wind speed, and the gust component. Wind is a low frequency phenomena.Wave is not so low frequency phenomena. The fluctuating component of the wind force is generally modeled probabilistically, whereas earthquake forces are generally modeled by deterministic analysis. So, therefore the behavior of marine structures, in wind and earthquake are different, in terms of two; one how are they handled in the analysis. The way they are handled in the analysis they are different. Two, the way in which they trigger the response, we have just now seen here, that earthquake forces, the way in which they act or I should say trigger the response; that is earthquake forces will become predominant, when the structure is bottom supported.

Wind force becomes predominant when the structure is flexible or compliant. So, there are two effects of these forces on the behavior; one is by the way they are handled in the analysis, one is deterministic, other is probabilistic. The other is depending upon the support given to the structural system, is flexible other is fixed. The moment you say probabilistic, then wind becomes a random process, it is very difficult to as it is model it in an analysis, because compare to earthquake modeling, this becomes more complicated. So, how people have intelligently used this mechanism, to make it simple, that is what we are not focusing. Now, the drag forces on members will be caused due to wind, will be caused due to waves. Inertia forces will be also caused due to waves. Inertia forces will also arise from earthquakes, what it means is that, earthquake does not produce drag force. So, what does it means?

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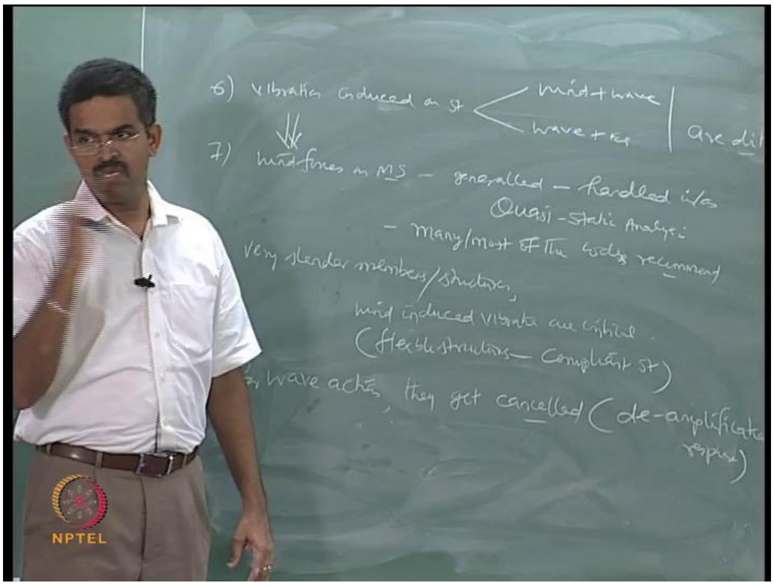

This statement implies a very important confirmation to me that vibrations induced on structures, because of wind plus wave, wave plus earthquake are different.

Now, from this level onwards, there has been very serious idealization done by the literature.People said wind forces on marine structures are generally modeled, or considered, or handled in or as quasi static analysis. That is what many and I should say most of the codes do. Additionally, when you got very slender members, or send structures as a whole, wind induced vibrations are critical. This is also true for flexible structures; in my case I will call this as compliant structures. Now, if I handle this in same manner for wave action, this is what the wind action. Talk about wave action, there is a possibility that they may get cancelled, how. Look at the morijan equation; look at the relative velocity term, the structure velocity is phenomenally high, in comparison to the wave velocity, or wave water particle kinematics. Then, the net velocity to which a structure will respond to, will become lower.

So, there is a cancellation effect, but that does not happen in wind. That is what we call as de amplification of response. This can take place in flexible structures, in case of wave action. Whereas in wind action, when the structure becomes flexible, the wind induced vibration become more critical, is that clear, so it is very dangerous. Or you must look at that with more care compare to that of wave action.That is what we are trying to say with point number eight. There are some of the important critical factors which you must remember, before start estimating the wind forces on marine structures. Very simple it is got two components mean and gust component, we have looked upon them independently in the previous discussions. Wind is a low frequency phenomena, wave is not a low frequency phenomena. The fluctuating component of wind force, is handled in the analysis on the design, using a probabilistic technique, where as unlike in earthquake forces we do deterministic methods.

So, the behavior of marine structures under these kinds of forces; that is wave, wind, and earthquake, they are different in many forms, many manner.One, the way which they handled the analysis, two depending upon what force will trigger what kind of structure is also important. So, with this context, look at this point, if you have very slender structure or slender member in a structure. We all understand what is slender member; the length of the structure is very long compare to the cross sectional dimension; therefore, the radius of gyrationbecomes very small, in that specific axis of bending.Therefore, the structure will start, inducing vibration on its way on, even under small magnitude of forces of lateral action.That is what we call as slender members, or you have got slender structure, in that case considering wind it is very critical, because it can induce vibration, it is called wind induced vibration.

Whereas, for waves are concerned, they have an action of, they have category of capacity of even de amplifying, they get cancelled, so they behave differently; that is what we put here. And interestingly, wind and wave both can cause drag forces, where as earthquake cannot. Wave and earthquake can cause inertia forces, wind cannot. So, let us categorize understand, before we estimate this. Now the question is how this fluctuating component, which is probabilistic, modeled, is handled along with the gust, with the mean wind component in the force; that is what we are looking at now. So, I need a function, which can transform the fluctuating component to a static component, to make it easy to handle in my analysis; that job is done, using aero dynamic admittance function.

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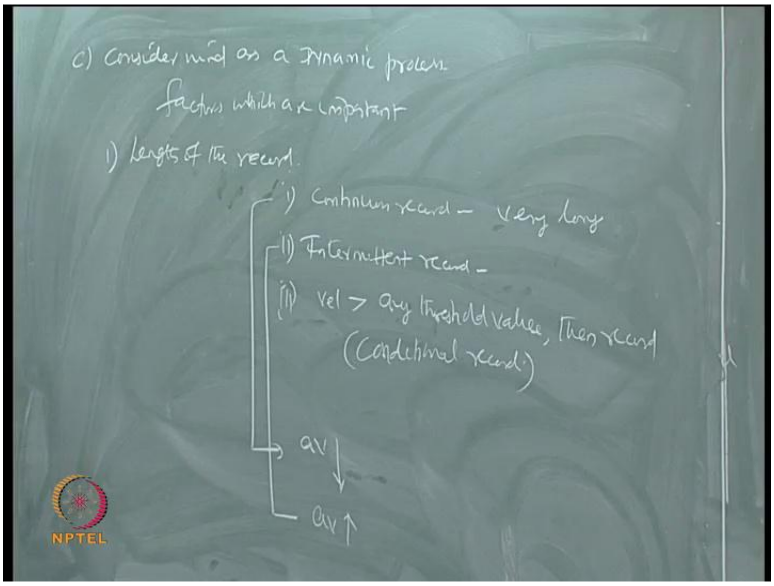

c) Consider wind as a Dynamic process
factors which are important
i) Length of the record.
i) Continuous record – very long
ii) Intermittent record –
iii) vel > any threshold value, then record
(Conditional record)
av ↓
av ↑

Now, let us say, I want to consider wind as a dynamic process. If you want to construct wind as a dynamic process, then what are those factors, which are important to qualify wind is a dynamic process; one, length of the record, how long is your record. There are many ways of observing wind forces, or wind pressure on anybody. One, you can have a continuous recording, so the record length can be very long; for example, let us say, throughout the year, throughout the day, you got many number of records, so the record length can be very long. The second process can be, you can record intermittently; that is every one hour interval you record, let say 8, 9, 10 am 11, 12, like every one hour interval you record; that is called intermittent record. The third can be, you keep on monitoring the wind velocity, if the value exceeds any threshold value, then record is called conditional record.

So, keep on monitoring it, if the value exceeds any threshold value, may be 30 miles per hour 100 miles per hour, the threshold value is fixed by the code. If a velocity during the day, during the year, during the month, if it exceeds one mark is given, so keep on; that is what condition. Now very easy, if you got a long record, the average will be very low, is it not, the denominator is higher. If you got an intermittent record, the average will be high. So, depending upon the process of the length of the record, you will land up in a variation. You can say my wind velocity is higher; one can say wind velocity is lower, depending upon by what method you have recorded; that is what we call as length of record. All these are dynamic in nature, because all this are varying with time.

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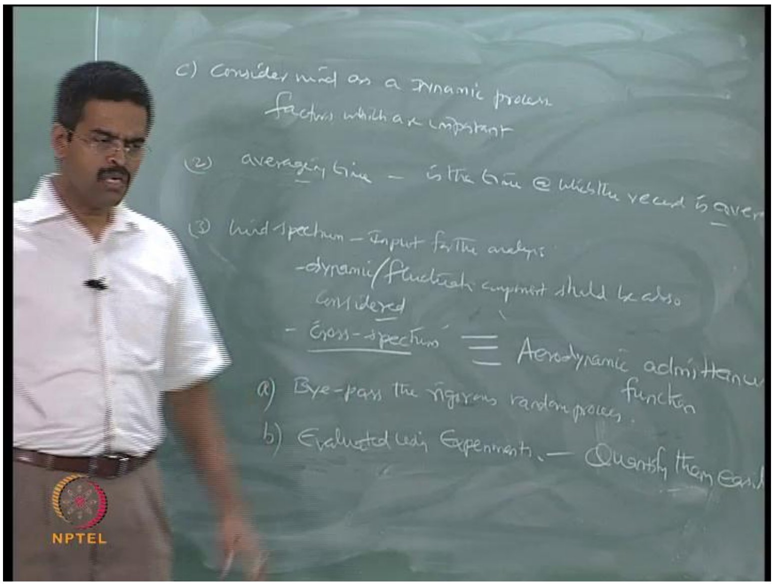

Now, the second aspect is, averaging time; it is actually the time, at which the record is averaged. Then thirdly, the wind spectrum becomes an input for the analysis, so the dynamic component, or the fluctuating component, should be also considered. Strictly speaking, in probabilistic modeling, this kind of component can be considered, using what we call the cross spectrum. Equivalently, this can be considered by deploying a new function called, aero dynamic admittance function. Now, the fundamental question comes before we understand what is this function, the fundamental question comes, what would be the advantage of using an aero dynamic admittance function, in place of a cross spectrum, or in place of a fluctuating component? There are two advantages in this; a, the foremost advantage is, you can bypass the rigorous random process.

Two, the aero dynamic admittance function can be evaluated, using experiments; that is very important; that is can always quantify them easily. So, if you are able to quantify them easily, why we should go for complicated phenomena. So, the aero dynamic admittance function, is actually substituted for the fluctuating component, because of two reasons; that I can easily by pass a rigorous random process, involved. Secondly, this function can be evaluated actually, using experimental quantify; that is wind tunnel testing we can do this, and find out the aero dynamic admittance function, for different bodies, or different shape, different height, different special distances I can do this, I can find out these functions, easily on any surface of a body. Therefore, now we are inclined understand how this function looks like, how this is plotted, how this is being used.

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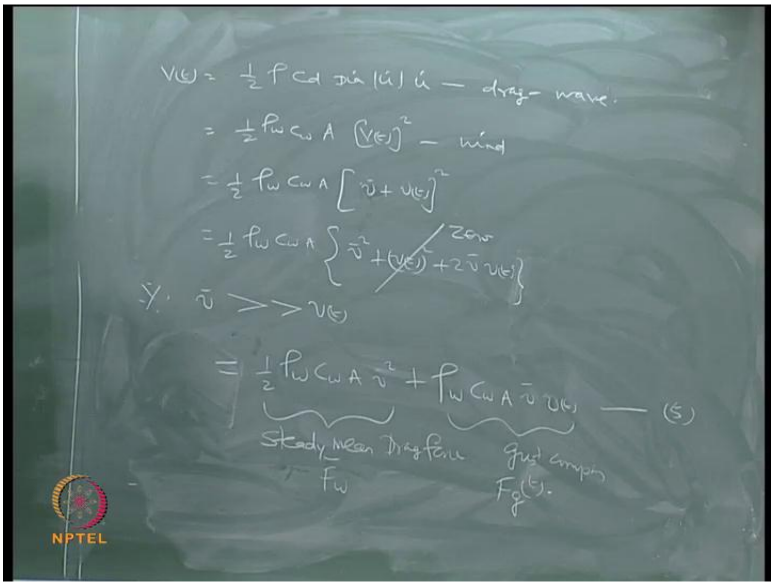

$$V(t) = \frac{1}{2} \rho C_d \, \mathrm{Dia} \, |\dot{u}| \, \dot{u} \text{ — drag- wave.}$$

$$= \frac{1}{2} \rho_w C_w A \, [V(t)]^2 \text{ — wind}$$

$$= \frac{1}{2} \rho_w C_w A \left[\bar{v} + v(t) \right]^2$$

$$= \frac{1}{2} \rho_w C_w A \left\{ \bar{v}^2 + \overset{\text{zero}}{\cancel{(v(t))^2}} + 2 \bar{v} \, v(t) \right\}$$

$$\because \; \bar{v} >> v(t)$$

$$= \underbrace{\frac{1}{2} \rho_w C_w A \bar{v}^2}_{\substack{\text{Steady mean Drag force} \\ \bar{F}_w}} + \underbrace{\rho_w C_w A \bar{v} \, v(t)}_{\substack{\text{Gust compon} \\ F_g(t).}} \text{ — (5)}$$

Let us see, v of t is equal to half rho c d Dia u dot and u dot. This is for the drag force as for wave is concerned, half rho w c w projected area, I should say v t square this is for the wind is concerned, is it not. I, expand this half rho c w a v plus v of t the whole square. So, the mean velocity, mean wind and the gust wind, so half rho c w a v square v of t square plus 2 v bar v t. It is very important to note that, v bar mean wind velocity, is much higher than the gust component. In that situation, this square can be made to zero, we can neglect this. So, I can rewrite this equation, which is force due to wind, I will do this later. Now, can be written as, half rho c w a v bar square plus rho w c w a v bar v, so I call this as steady mean drag force, which is indicated by f w, the bar above indicates means it is a mean value, other is the gust component, which I call f g; of course, the function of t, I will call this equation number five.

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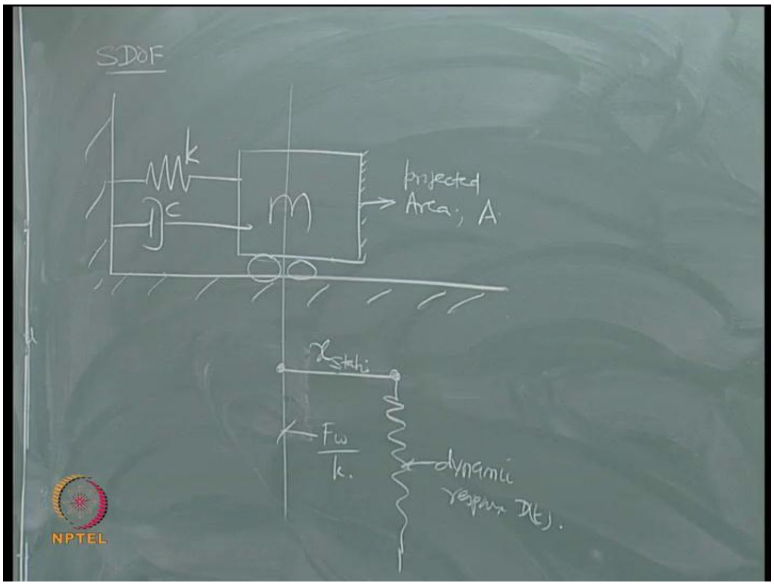

So, let us say, I have a single degree freedom system model, when the mod and this model has, the projected area A, and its projected area as A. Now, the response, the response will have a static component, then will have a dynamic component, which will vary within this. Static component can be easily indicated by f w by k, where f w is a static mean drag force here, which we call as static displacement, x static, static displacement plus the vibrating component, which is called the dynamic response. I call this as d of t; one is the static value, other is the fluctuating component, or the dynamic component, which is d of t.

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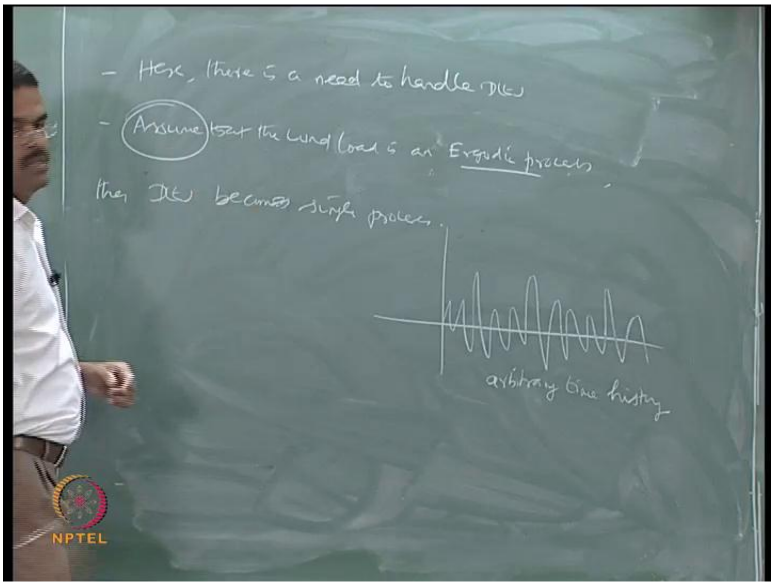

- Here, there is a need to handle D(t)
- Assume that the wind load is an Ergodic process,

then D(t) becomes single process.

Now, here, there is a need to handle d of t, here there is no problem for the static component, worried about the dynamic component. Now, how this is handled, assume that the wind force is, or wind load is an ergodic process. We already saw in the last lecture, what you mean by ergodic process. Ergodic process is that single sample, form the ensemble of different dynasties, which is got the mean value, as equivalent to the classic value of whole ensemble. It represents the ensemble in a indirect form. If this is agreed upon, then d of t becomes a single signal, some process single, which is an arbitrary time history. Once we agree that is approximation is valid, why this is valid, because we are assuming, the wind load as an ergodic process. Once we agree this process as ergodic with this approximation.

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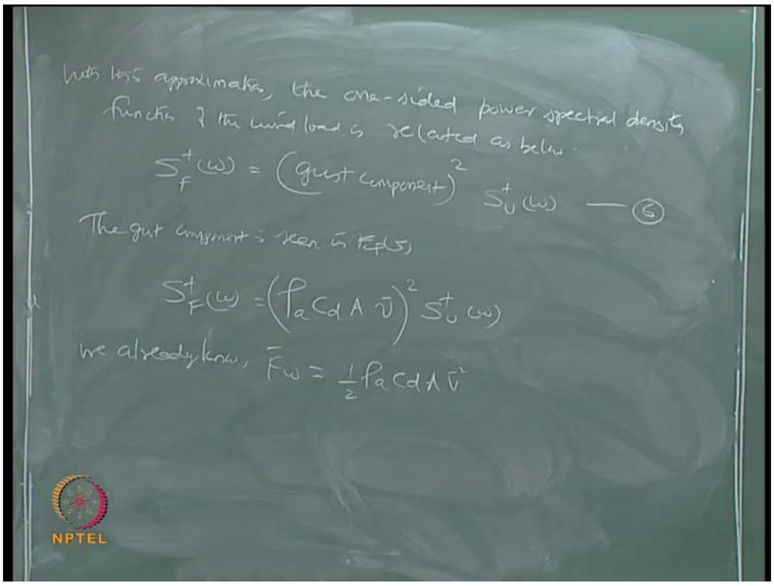

With this approximation, the one-sided power spectral density function of the wind load is related as below.

$$S_F^+(\omega) = (\text{gust component})^2 \; S_U^+(\omega) \quad \text{— ⑥}$$

The gust component is seen in Eq(5),

$$S_F^+(\omega) = (\rho_a C_d A \bar{v})^2 \, S_U^+(\omega)$$

We already know, $\bar{F}_w = \frac{1}{2}\rho_a C_d A \bar{v}^2$

Now, one sided power spectral density function, of the wind load, is related as below. The wind force is related to, the gust component square of the wind velocity, or the velocity. This is true, when the process is idealized as an ergodic process. We call this equation number six. Already we need equation five to turn back, we have this gust component ready there is called f g, what is that component. The gust component is already seen in equation five; that tells me, that can be related now to rho c d a v bar square, because multiplied with v t is what we have in the f g value square, where that of the wind velocity spectrum. Now interestingly, in the same equation five, v bar can be also obtained separately, where as f w component is there, substitute back for v bar separately, because we already know that f w, or f bar w, is half rho v bar square, is it not? So, what I wanted to do, is I pickup v bar square from this equation, substitute back here, and get my equation modified.

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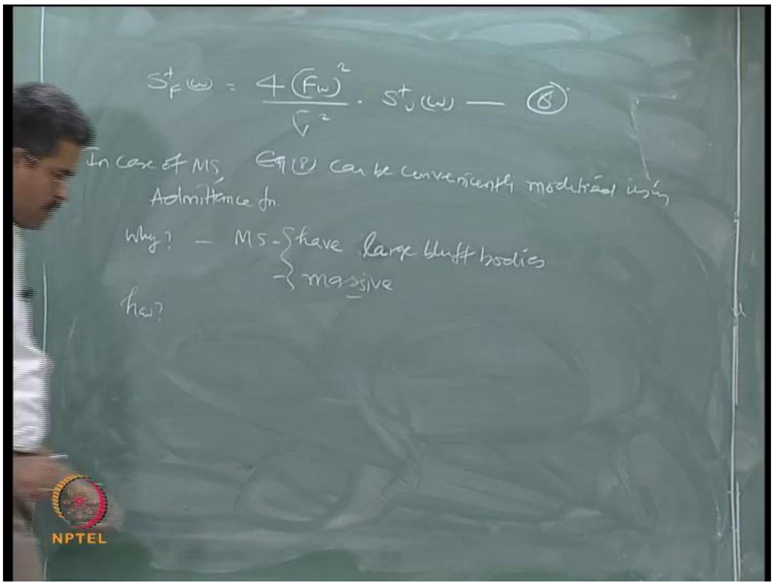

$$S^+_F(\omega) = \frac{4(F_w)^2}{\bar{V}^2} \cdot S^+_v(\omega) \text{ — } ⑧$$

In case of MS, Eq ⑧ can be conveniently modified using Admittance fn.

Why? — MS – have large bluff bodies
– massive

how?

If we do that, my force will become 4 f bar square by v bar square, of is that, I call this equation number, this is seven, equation number eight. Now, in case of marine structures, equation eight can be conveniently modified, using aero dynamic admittance function, we will see how it is modified. First, let us see why it is possible, it is possible, because marine structures have large bluff bodies, and they are massive. Because of these two characteristics, can always replace or handle this equation eight, using an admittance function. Now will see how, why I using, how I will see now. I will remove this.

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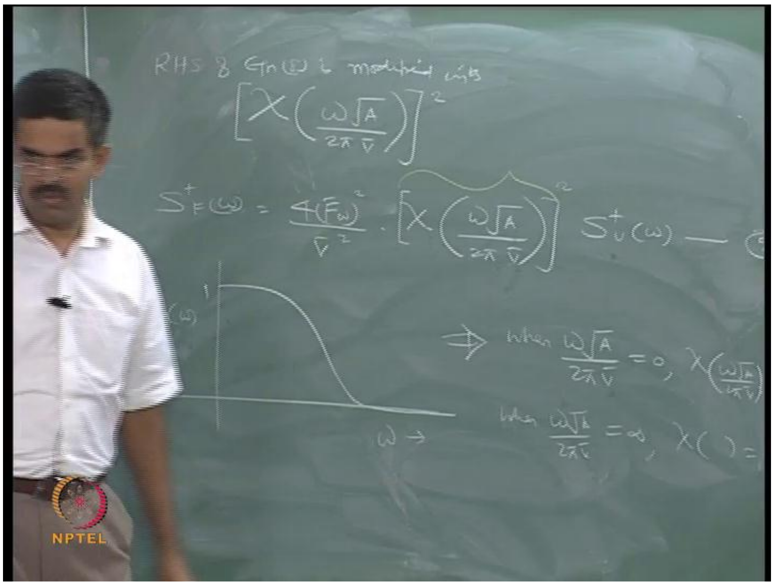

Now, the right hand side of equation eight is modified with a new function, which I call chi function of square. Now, my force spectrum will become 4; equation number nine. Let us quickly see the characteristic of this function, I try to plot this function as a variable with A, because in this case, projected area, wind velocity, or the mean velocity are all fixed values. The only variation is omega, let us see how, the admittance function varies with omega, try to plot that. This is omega, this is chi of omega, and this value is one. So, this figure implies that, when omega root a by 2 pie v bar is 0, when it is 0 A cannot be 0, because area is got projected area it cannot be zero, wind velocity can never be zero, so the only possibility is omega is zero.

In that case, my chi of omega root a by 2 pie v bar becomes unity. When omega root a by 2 pie v bar becomes infinity, thus very large, then my chi value becomes zero; that is what informs on this figure. That is a behavior of the aero dynamic admittance function, as a function of frequency. Remember, fluctuating means what, frequency dependent; that is what fluctuating is,is it not? I am handling that here actually, I am taking care of that fluctuating component, with a function which takes care of this of course, with this idealization. I can multiply this function directly, in the spectrum to give me force output, if I know the velocity spectrum.

So, the fluctuating component which the function of frequency, which is probabilistic modeling element, is transform to a methodology like this, which is comfortable to handle in this case; this is what we call as aero dynamic admittance function. Now, how literature qualify this function, how this function can be evaluated. Experimentally, you can evaluate this, conducting by conducting experiments in wind tunnels, you can evaluate this; how? You have to evaluate this, if you have a bluff body, work out the projected area, work out the velocity mean wind velocity attacking the bluff body, for every frequency keep on plotting this, you will be able to get chi value, but analytically also literature suggested that chi value can be handled using equation given by Davenport.

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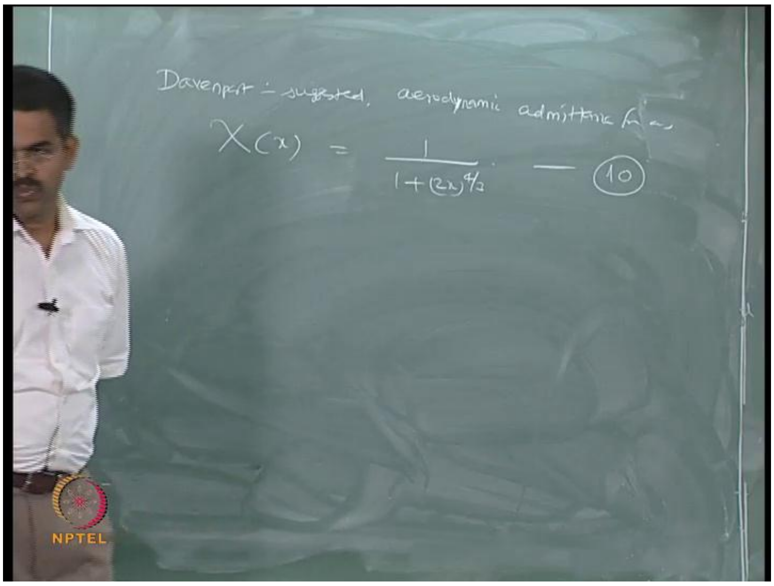

Davenport - suggested, aerodynamic admittance fn ~

$$\chi(x) = \frac{1}{1+(2x)^{4/3}} \quad \text{— } \textcircled{10}$$

Davenport suggested, the aero dynamic admittance function as, any value or any variable f x can be said as 1 by 1 plus 2 x to the power 4 by 3; that is given by davenport. Where as in my case, x will be omega root A 2 by v 1, I can plot this. I call this equation number ten. So, we have understood now in this lecture, how to handle wind forces, on marine structures, be it flexible, be it fixed, or be it rigid, be it compliant. And wind has got two components; one is basic wind speed, or average, or mean wind speed, other is the gust component, fluctuating component. We have understood, how to handle both of them, using the power law, and the fluctuating component, using the admittance function like this. So, one can easily able find out what would be the forces spectrum, on a given member of a marine structure, if I know the velocity spectrum, using the aero dynamic admittance function.

This can be generally evaluated using experiments, but analytically also we can evaluate; this by suggested davenport. These are all suitable and closely applicable only for marine structures. Why it so,because they are all average the work out, at one minute average speed, for 125 miles per hour, for hundred year time period, as suggested by the U S Weather Academy, that so we have handled, we have learnt how to handle the aero dynamic loads on marine structures, how to handle the aero dynamic load on the marine structures, how are they different, why are they different, where are they different, how are they handled. Now, we will in the next lecture, will talk about ice loads and earthquake loads, and will summarize all the four components of loads. There are other loads also, but these are major components acting on the marine structures. Once we understand them, we start designing, and understanding ultimate load design methodology for marine structures, once we understand that, we will move on to plastic design of marine structures; is that clear?