Advanced Design of Steel Structures
Dr. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Lecture - 57
Ice spectrum

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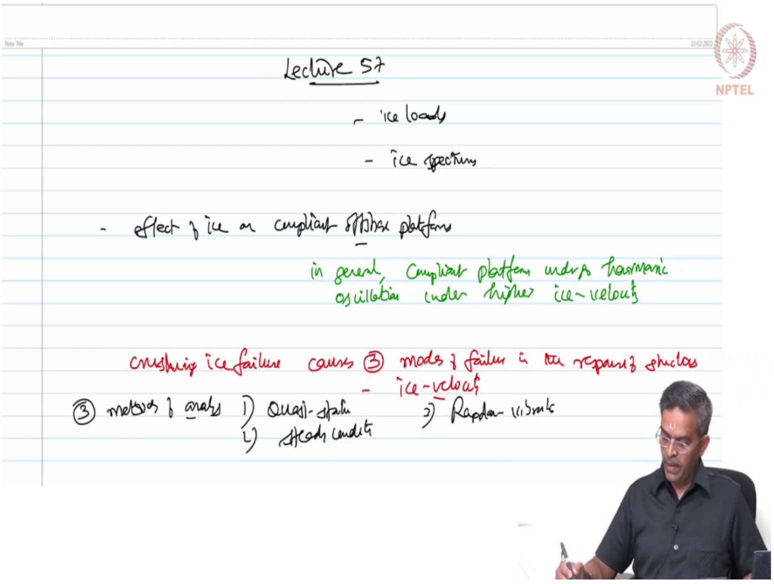

Friends, welcome to lecture-57, in which we are going to learn more about the Ice Loads and Ice Spectrum. In the last lecture, we understood that crushing ice failure is considered to be the worst scenario as this induces the maximize ice force on the member. Let us say, what would be the effect of ice on complaint platforms. In general, complaint platforms undergo harmonic oscillation under higher ice-velocity. Under the crushing ice failure 3 distinct ice 4 modes occur in the response.

The main factor which governs this failure mode is ice-velocity. So, the response of the structures and ice loads especially under crushing ice failure, can be done by 3 methods. One, you can take this process of quasi-static process. You can also handle this as a steady condition of loading. Further, you can also handle this as a phenomena of random vibration.

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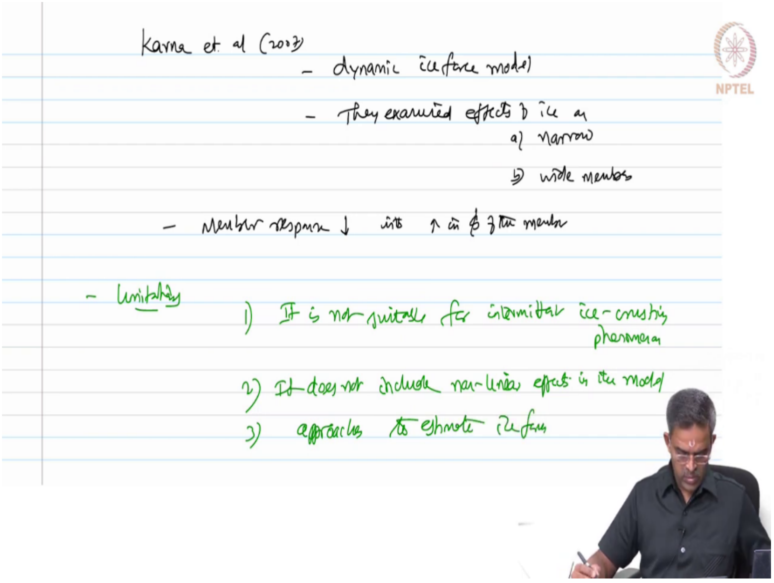

So, Karna et al, 2007 expressed the dynamic ice forced model. They studied the ice force effects are narrow and wide members. And they said that member response decreases with increase in diameter of the member. The study conducted by them postulated certain limitations of the study. One, the study is not suitable for intermittent ice-crushing program. Two, it does not include non-linear effects in the development. It also governs the approaches to estimate ice force.

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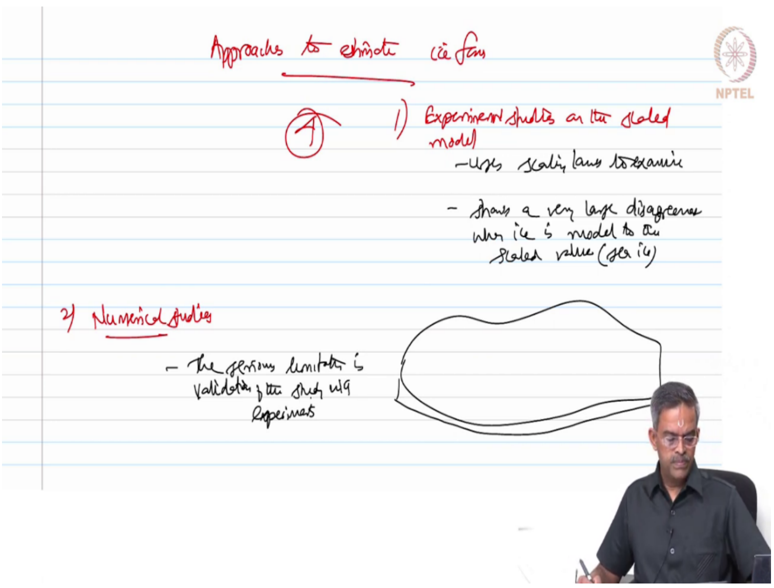

Let us quickly see what are various approaches to estimate ice forces. There are essentially 4 approaches. One is experimental studies on the scaled model. Now, this method uses scaling laws to examine. This method shows a very large disagreement when ice is modeled through the scaled value that is especially in case of CS because you know the large area, but a very minimum thickness. So, the scaling law actually affects the correlation between the excellent studies and the ideal behavior in the numerical model.

The second approach is using numerical studies. Numerical studies have a very serious limitation in terms of validation of results with respect to experiment. The serious limitation is validation of the study with experiments which is quietly big challenge in the present scenario of research.

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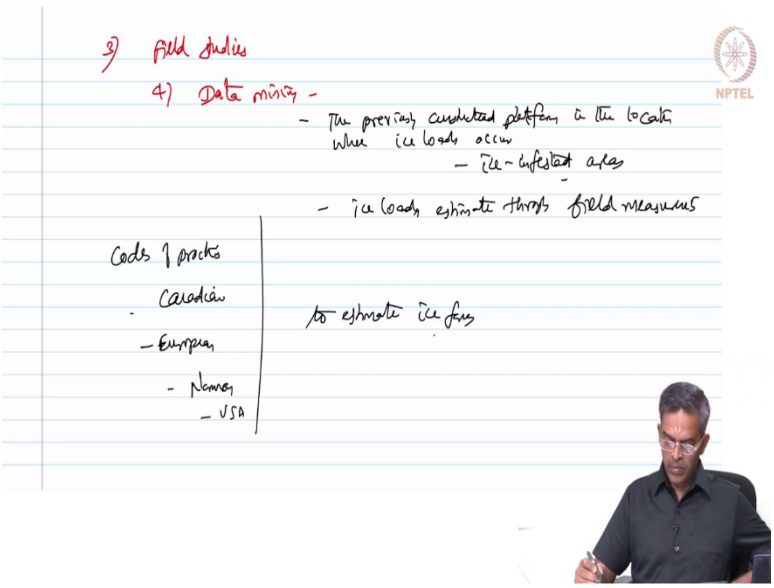

The third approach what generally people follow is field studies. And the fourth one is addressed as data mining. In sense, one can examine the previously constructed platforms in the locations where ice loads are occurring. They are called ice-infested areas.

The second approach could be estimate ice loads through field measures. Nor through the lab scale, nor through the full numerical scale, but establish these measurements through free observations. There are many codes of practice available to estimate ice loads like Canadian code, European, Norway, and USA. There are many international codes which help you to estimate ice forces.

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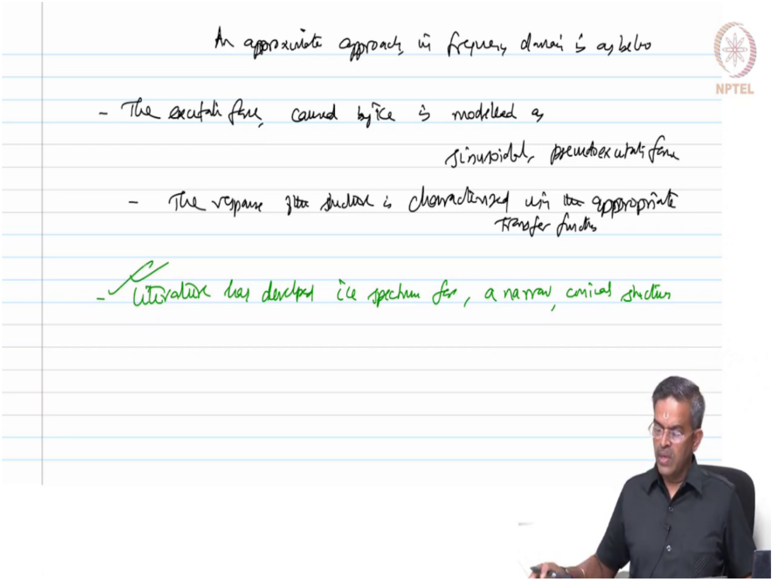

Out of all of them, an approximate approach which is quite simple in frequency domain is as below. The excitation force, caused by ice is modeled as sinusoidal, pseudo-excitation force. Subsequently, the response of the structure is characterized using the appropriate transfer function.

Friends, literature has developed an ice spectrum for, a narrow, conical structure. In the absence of extensive field studies and experimental studies, one can use this ice spectrum to compute the loads on narrow conical structure.

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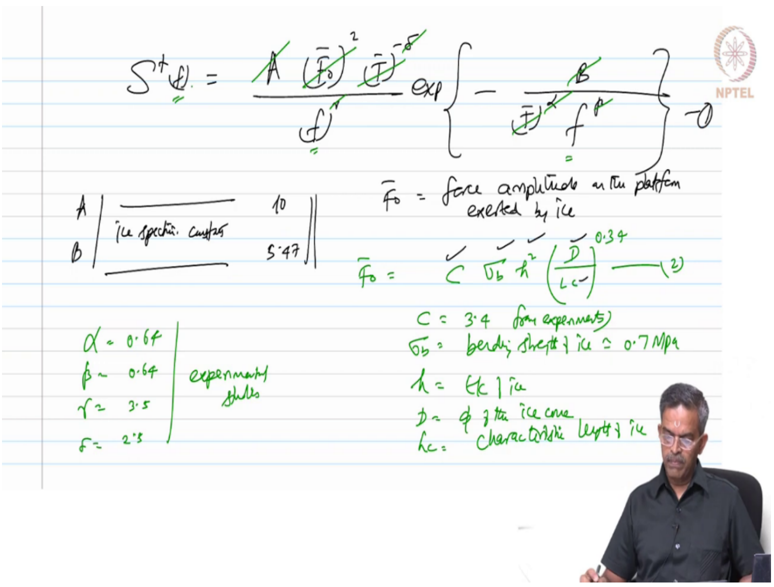

The ice spectrum S of f, one sided power specialist function is given by following equation 1.

$$S^{+}(f) = \frac{A\overline{F}_0^2\overline{T}^{(-\delta)}}{f^{\gamma}} \exp\left[-\frac{B}{\overline{T}^{(\alpha)}f^{\beta}}\right]$$

Let us see what are the factors which govern this equation. Let us say A and B are called ice spectrum constants, A is 10 and B is 5.47 obtained from the experimental studies.

So, A and B are known. A is known, B is known. F bar naught is the force amplitude on the platform exerted by ice. So, F_0 is also now known. F_0 is given by an additional equation which is

$$\overline{F}_0 = C\sigma_{\mathrm{f}}h^2\left(\frac{D}{L_{\mathrm{c}}}\right)^{0.34}$$

We call this equation number 2.

So, in this equation C is derived from experiments as 3.4. C is derived. $\sigma_{b\ or\ f}$ is called bending strength of ice which is approximately equal to 0.7 megapascal. So, σ_b is known. h is the thickness of ice, so h is known. D, the diameter of the ice core, so D is known. L_c is called characteristic length of ice which is further given by

$$L_{\mathrm{c}} = \left[\frac{Eh^3}{12g\rho_{\mathrm{w}}}\right]^{0.25}$$

Call the equation number 3.

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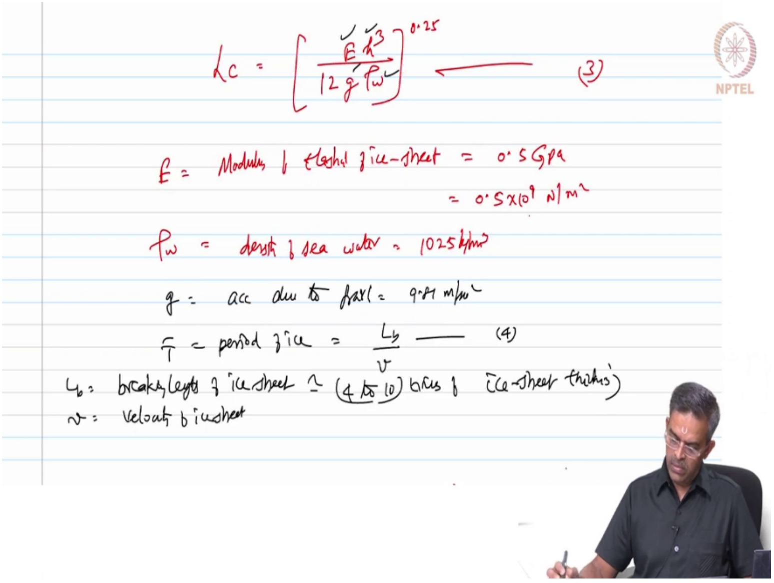

So, friends, in this equation E is modulus of elasticity of ice or ice-sheet to be very specific. Usually, taken as 0.5 Gpa, which comes to 0.5 into 10 power 9 newton per mm square; it is a newton per meter square. Of course, ρ_w in this equation, E is known, h is of course, thickness of ice, ρ_w is density of sea water which is 1025 kg per cubic meters.

So, in this equation, we carefully look at of course, g is acceleration due to gravity which is 9.81 meter per second square. So, we know g. So, we know L_c. If you go back and check we know L_c. So, equation 2 all values are described.

Let us go back to equation 1, we still have something called T bar. That is not explain. Something called T bar, so let us do that. T bar is called period of ice which is given by

$$\overline{T} = \frac{L_b}{v}$$

Where L_b is a breaking length of ice-sheet and v is the velocity of ice-sheet.

Usually, the breaking length is approximately 4 to 10 times of ice-sheet thickness. Usually, that is the usual practice. So, let us go back to this equation and see, I know now T bar, we would like to know the values of alpha, beta, del, and gamma. So, let us see. Alpha is 0.64, beta is also 0.64, gamma is 3.5 and del is 2.5 based on experiments. So, del, gamma, alpha, beta are known. So, it is the frequency f, is a variable to be plotted. Let us quickly use the MATLAB program, to plot the spectrum.

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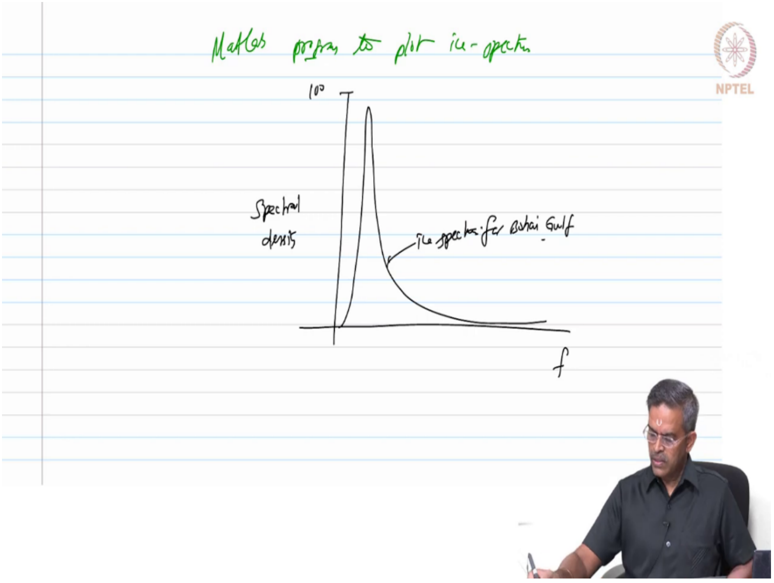

Equations are already given to you. Now, I will use the MATLAB program to plot the spectrum.

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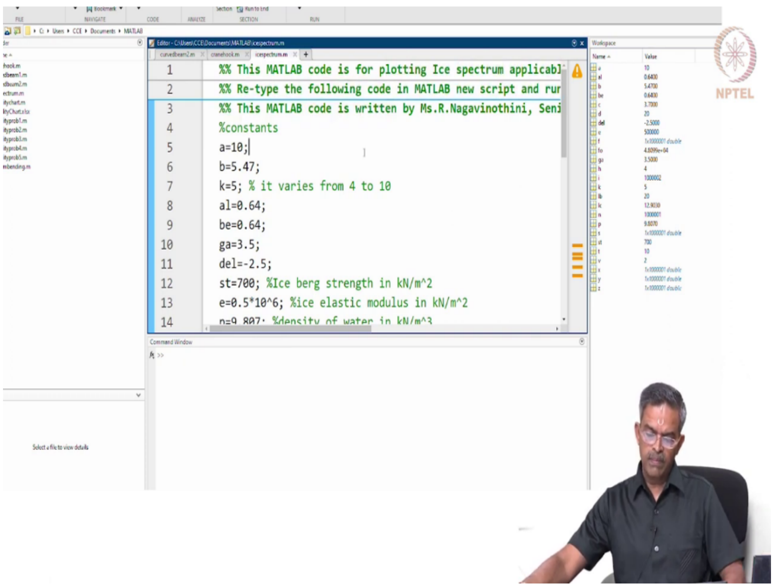

So, this is a program being used for plotting ice spectrum.

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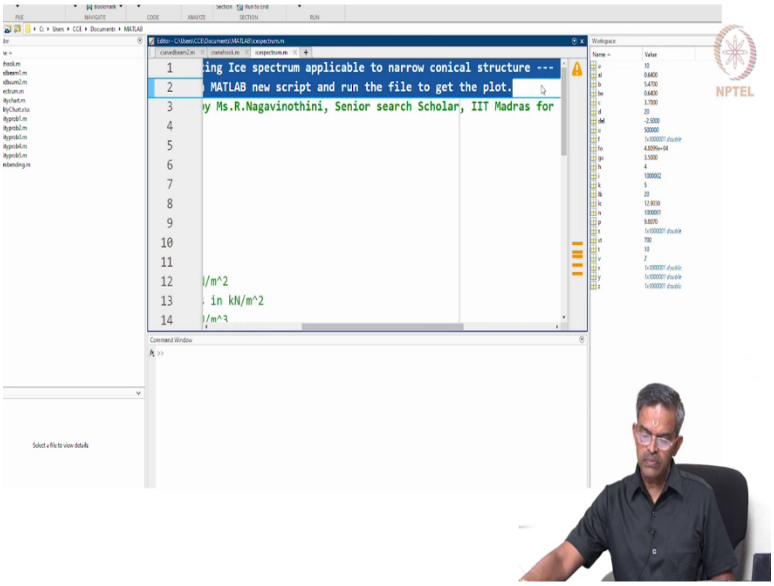

This was a joint effort made by research scholar working under me.

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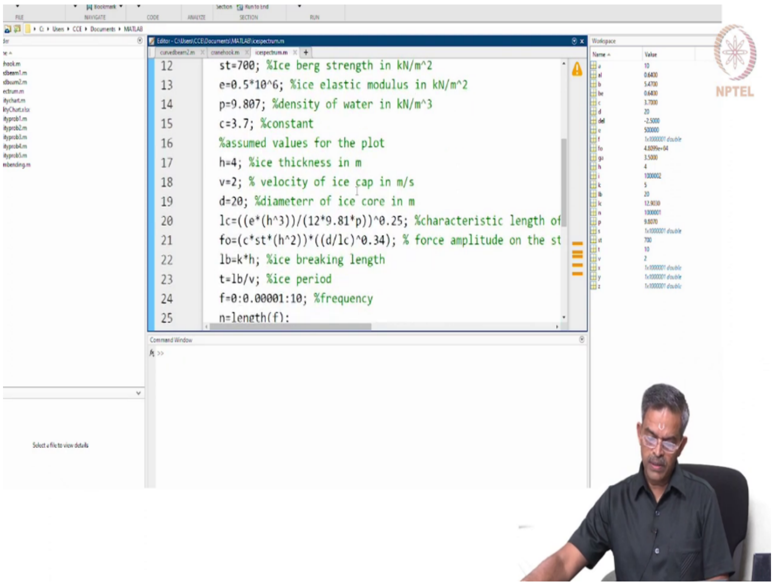

That is a program which is being written available in the textbook.

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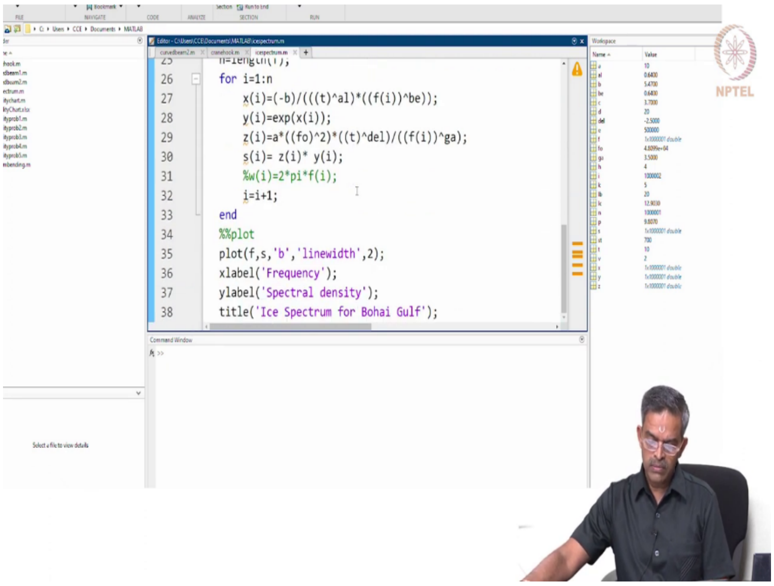

You can download and run the program in MATLAB.

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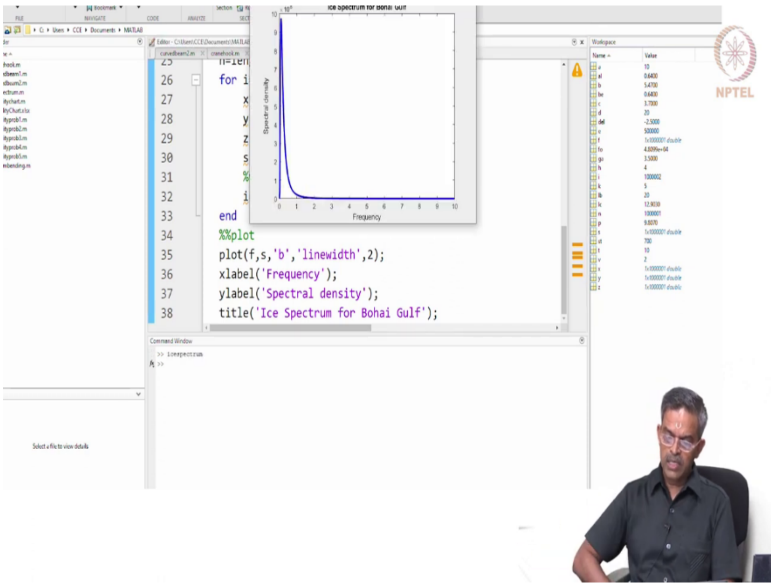

Let us run the program and see how typically an ice spectrum looks like. Ice spectrum looks like I will see on the screen which is having a very sharp peak at a very low frequency and then it dies down instantaneously. So, it is a narrow band spectrum which is meant only for the Bohai Gulf which is a typical input used for calculating ice loads on offshore platforms in arctic region.

So, the typical ice spectrum. So, this is my f, this is my spectral density which goes as high as 100, is an ice spectrum for Bohai Gulf.

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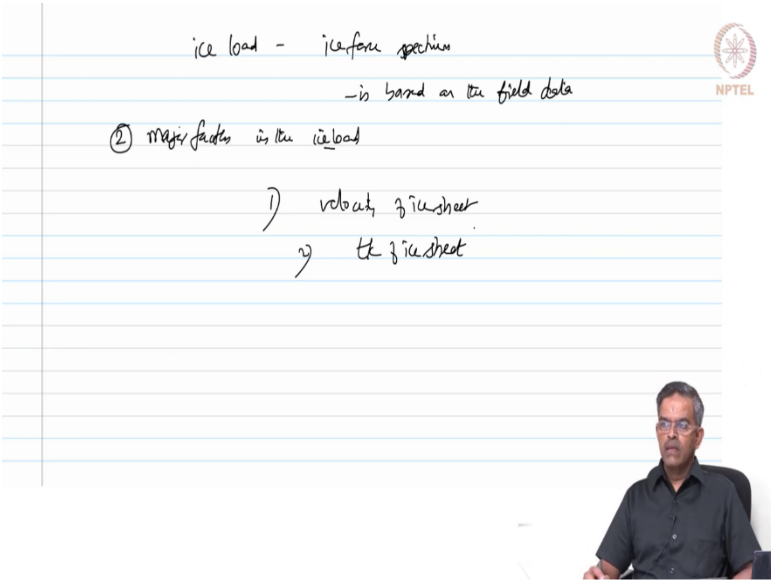

The ice low which is calculated from the ice force spectrum is based on the field data. There are 2 major factors in the ice load. The first factor is the ice-velocity. The second factor is the thickness of the ice-sheet. Let us quickly see the probability density function of ice-velocity and ice-thickness.

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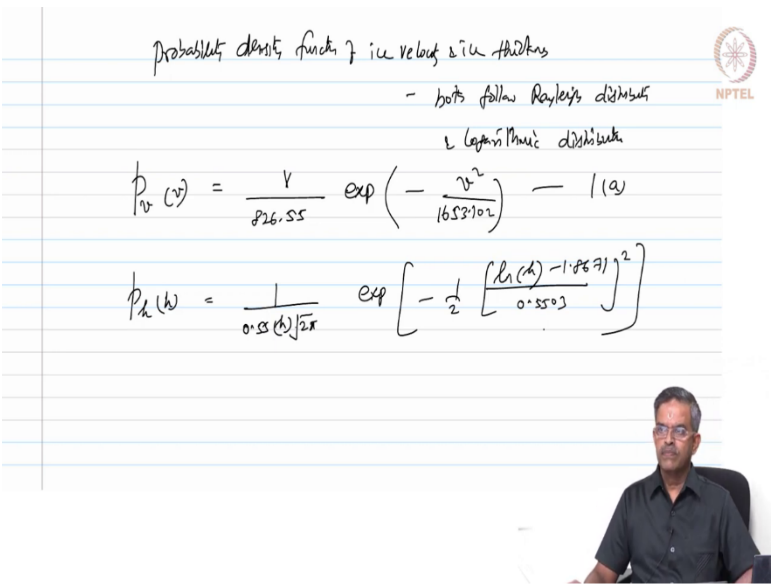

It is assumed that both follow Rayleigh distribution and logarithmic distribution. Probability function of velocity v is given by

$$P_v(v) = \frac{v}{826.55} exp\left(- \frac{v^2}{1653.102}\right)$$

equation 1 a. Probability density function of thickness h is given by

$$P_h(h) = \frac{1}{0.55h\sqrt{2\pi}} exp\left[- \frac{1}{2}\left[\frac{ln(h) - 1.8671}{0.5503}\right]^2\right]$$

Let me put the square carefully here. So, one is a logarithmic distribution, other one is a Rayleigh distribution.

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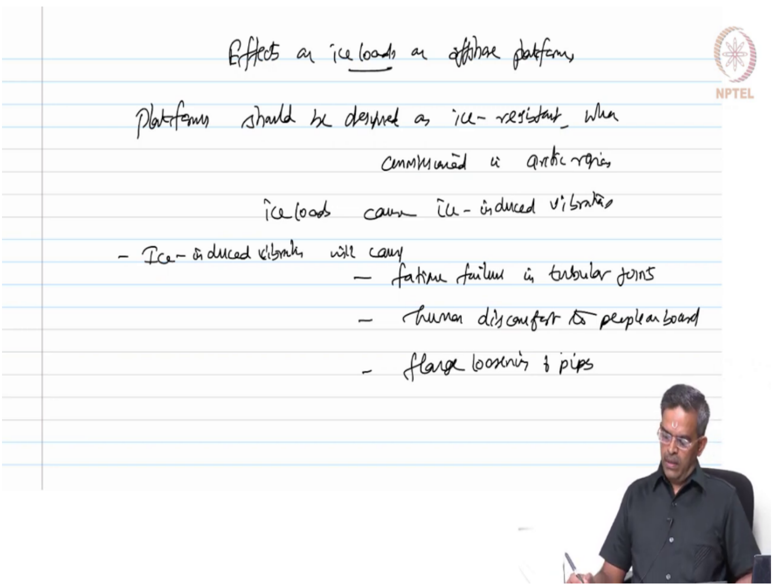

Let us now quickly see what are the effects of ice load on offshore platforms. Platforms are generally designed to be ice resistant when they are commissioned in arctic region, when commissioned in arctic region. Ice loads are generally caused or ice loads induced, ice-induced vibrations.

Further, ice-induced vibrations will cause fatigue in tubular joints. It also causes lot of human discomfort to people on board. It also causes flange loosening of pipes. The effect of ice force on an offshore platform is generally measured from deck acceleration.

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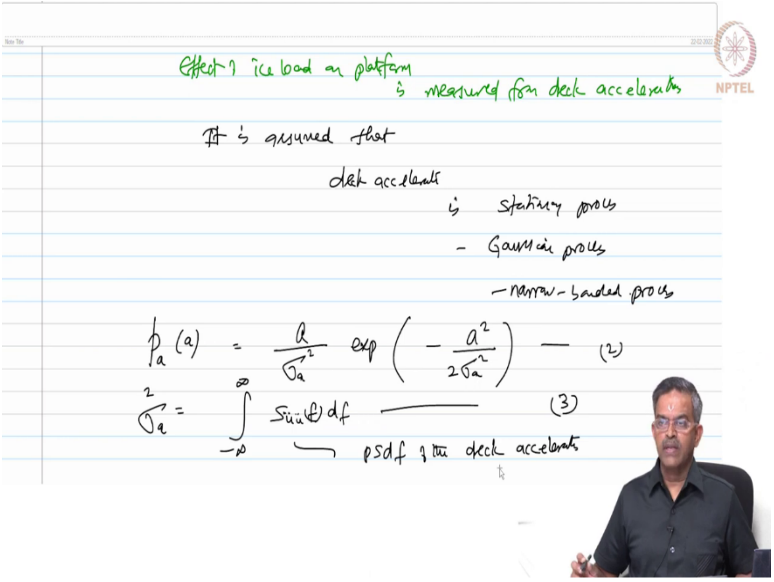

So, while doing this analysis, it is assumed that the deck acceleration is a stationary process. It can be also taken as a Gaussian process, and it is a narrow banded process. Rayleigh distribution is used to determine the acceleration response of the deck.

Now, the probability condition of the acceleration is given by

$$P_a(a)=\frac{a}{\sigma_a^2}exp\left(-\frac{a^2}{2\sigma_a^2}\right)$$

equation 2. Where, σ_a^2 is given by the integral S u double dot spar distribution of df. $S\ddot{u}\ddot{u}$ is called as the power spectral density function of the deck acceleration which is developed due to ice loads on offshore platforms.

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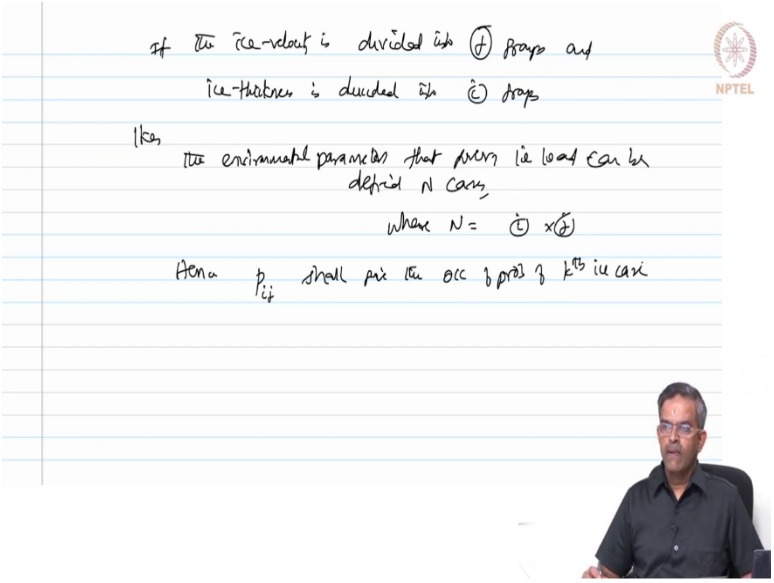

If one knows the power spectral density function of the deck acceleration, then if the ice-velocity is divided into j groups and ice-thickness is divided into i groups. Then, the environmental parameters that govern the ice load can be defined by N cases, where N will be i cross j cases. So, hence, p_{ij} shall give the occurrence of probability of kth ice case, in working on the ice load.

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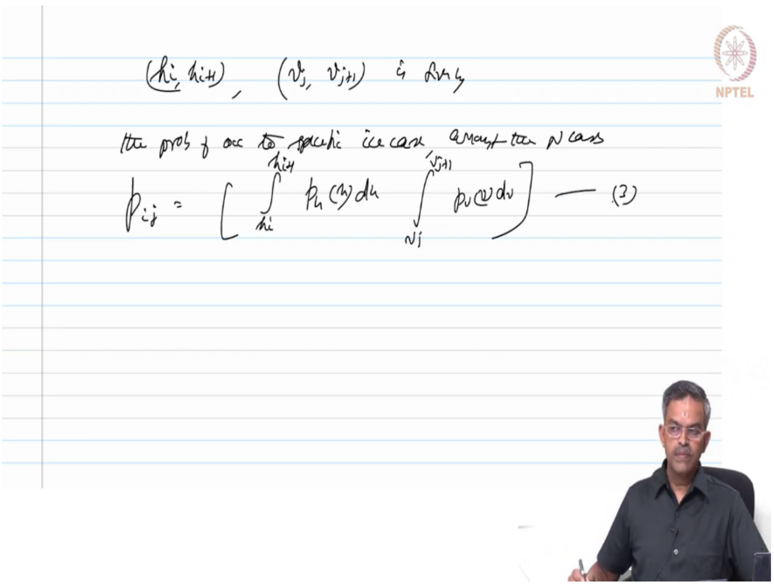

So, therefore, h_i, h_{i+1}, v_j, v_{j+1} is given by the probability of occurrence of specific ice case amongst the N cases. So, p_{ij} specific case, if you want to look at, it will be integral h_i to h_{i+1}, p_h (h) dh into integral v_j to v_{j+1}, p_v (v)dv equation 3.

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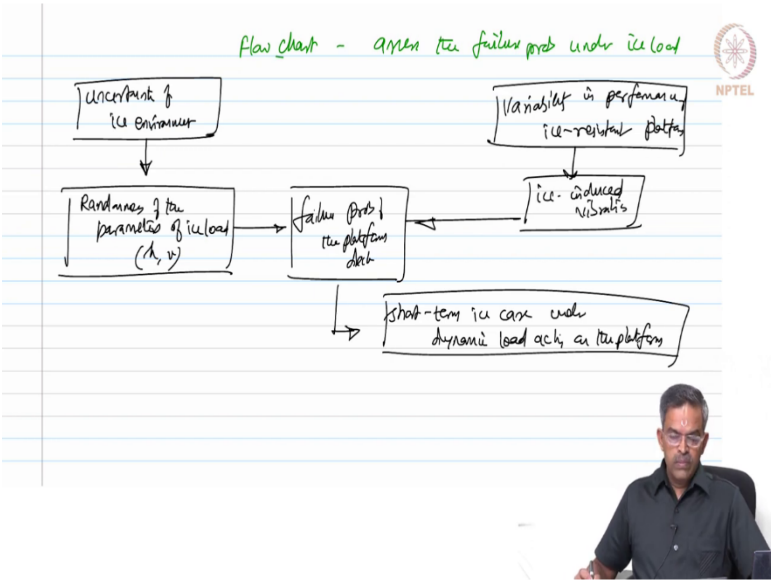

So, we can also explain this using a flowchart. So, let us discuss a flowchart being used to assess the failure probability under ice loads. So, starting with the first factor which deals with uncertainty of ice environment based on the uncertainty conditions and models one can select the randomness of the parameters of ice load.

What parameters are we looking at? If you remember, thickness and velocity we are looking only at these 2 parameters. So, once we know these, they can we can then choose the failure probability of the platform deck.

On the other hand, if we have variability in the performance of ice resistant design, most ice resistance platform, based on the variability we can try to compute ice-induced vibration characteristics. From the ice-induced vibration characteristics, one can also assess the failure probability. Once the failure probability is assessed, then one can look at short-term ice case under dynamic loads acting on the platform.

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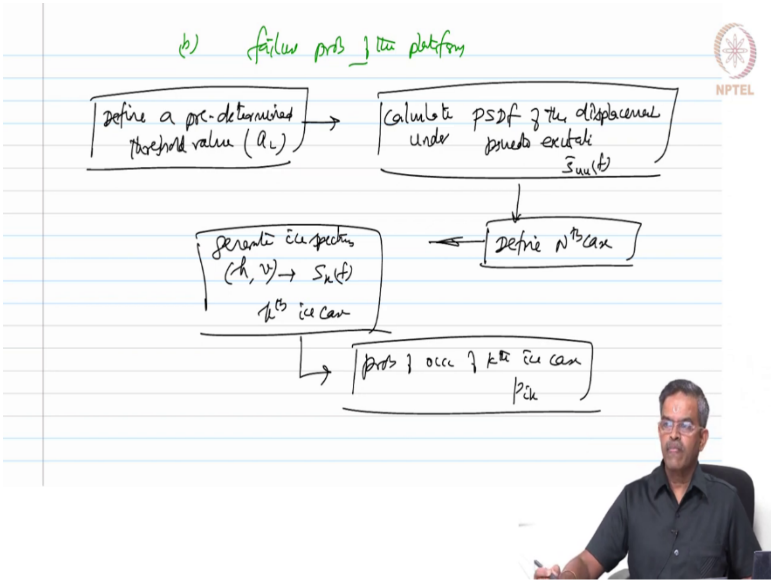

One can also assess, the failure probability of the platform itself directly. So, first we have to define a predetermined threshold value. Let us call this value as a L. Once this value is defined, then one can calculate power spectral density function of the displacement under pseudo-excitation which is S_{uu}(f). Then, one can define a specific case of ice. Let us call this Nth case.

For the Nth case one can generate the ice spectrum that is for specific velocity and specific thickness, for a specific velocity and thickness. You can generate a spectrum which is $S_k(f)$. This is for the k^{th} ice case. Once this is generated, from this one can estimate the probability of occurrence of k^{th} ice case which is called as p_{ik}.

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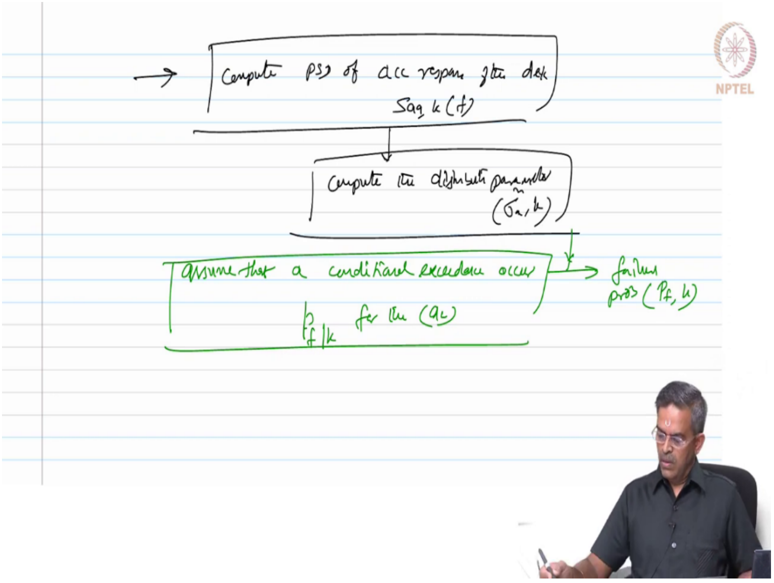

Once this is assessed, then one can compute the power spectral density function of acceleration response of the deck which we call as S_{aa}, k(f). Having computed this one can further also compute the distribution parameter which is σ_a^2 and k. We need to assume that a conditional exceedance occurs, the conditional exceedance of probability of failure given k^{th} case for the predetermined cases. So, under this assumption one can now compute failure probability which is at p f , k.

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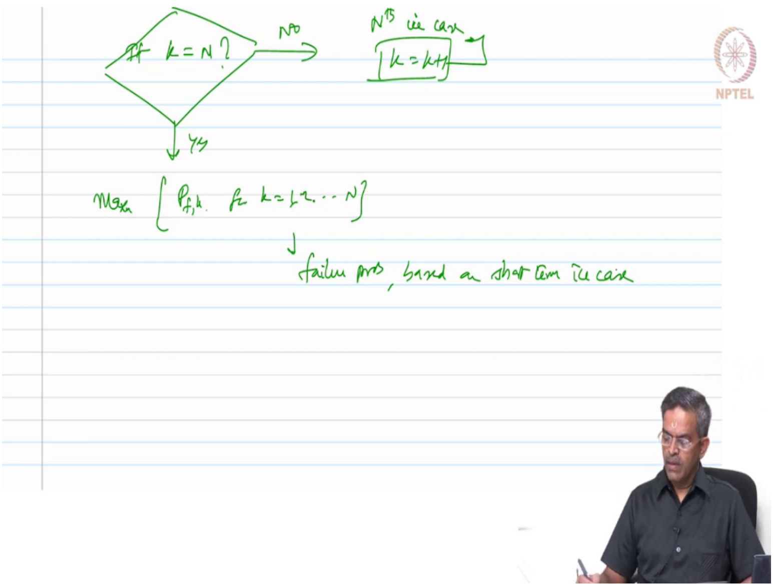

Further, if k is equal to N, then what happens?. If k is equal to N, if it is not equal then look for the Nth ice case and say k is k plus 1 and run the program. If it is yes, then find the maximum of p of k for k equals 1, 2, till N, to obtain the failure probability based on short-term ice case. Friends, ice load can be estimated by 2 methods.

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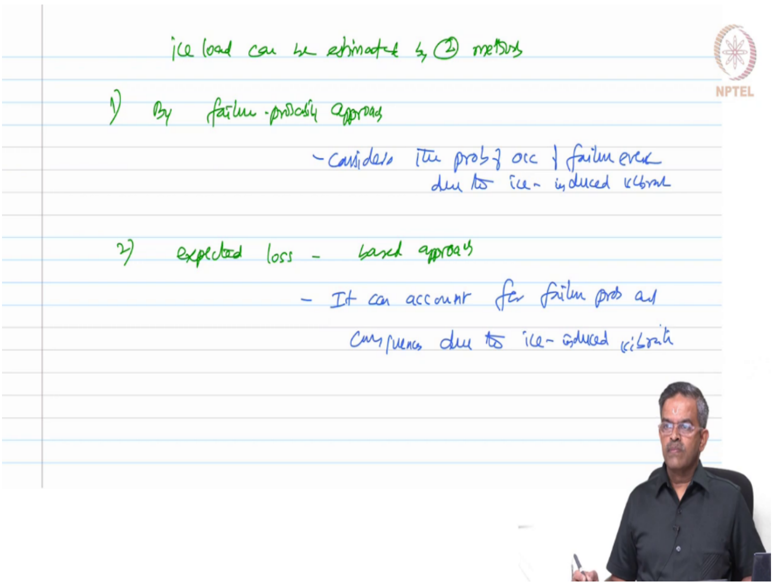

One, by failure probability approach which we just now discussed the flow chart. This approach considers the probability of occurrence of failure event due to ice-induced vibration. The second one is based on the expected loss. In this method, all this method can account for failure probability and consequences due to ice-induced vibration.

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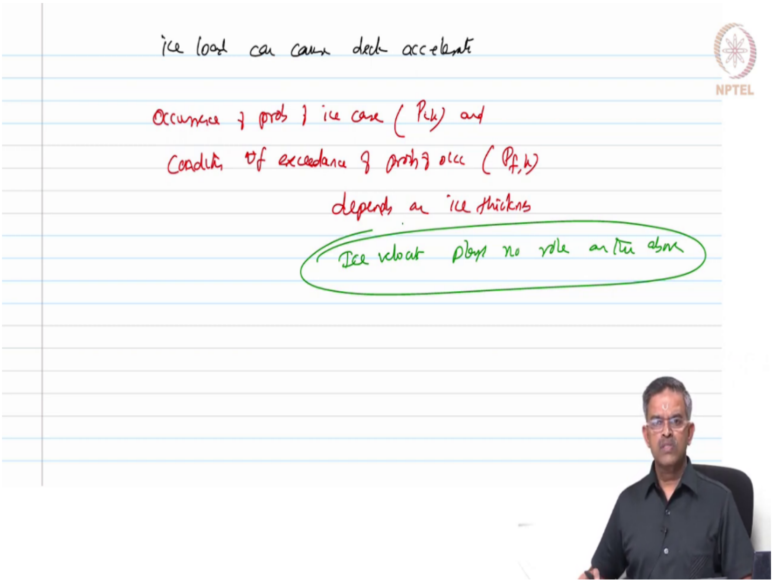

We all know that ice loads can cause deck acceleration. It is accepted as a scenario of severe consequence of the ice load. So, the occurrence of probability of ice case is P_{ik} and condition of exceedance of this depends on ice-thickness.

So, very importantly, the occurrence of probability of ice case which is P_{ik} and the condition of exceedance of probability of occurrence which is P f, k both depends on ice-thickness. Ice-velocity plays no role on the other. That is a very important factor which you must realize. When ice acts on the breaking ice cones, broken ice pieces are cleared up. Ice force is periodic in nature which results in ice-induced vibration.

So, friends we know that estimation of ice force has a basic assumption on a narrow conical structure. An ice is formed by breaking of ice. Ice force a random process which is controlled by 2 parameters, thick classifies and velocity of motion of ice break.

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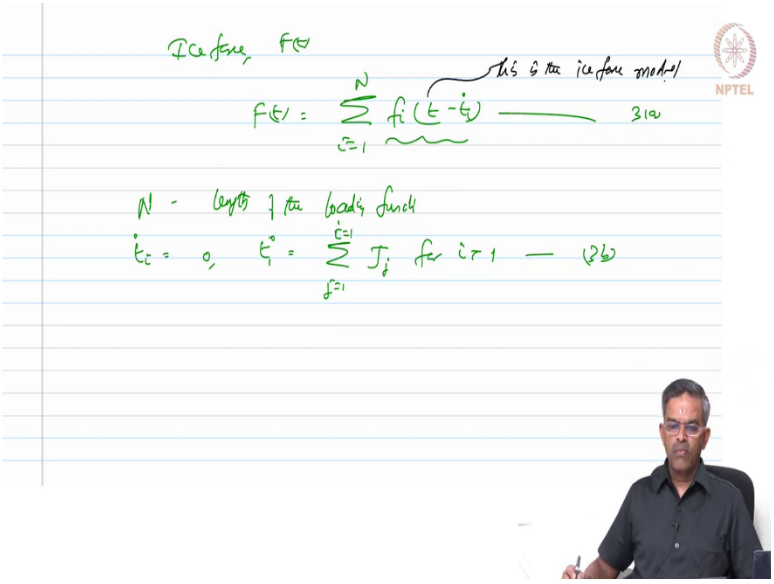

$$F(t) = \sum_{i=1}^{N} f_i (t - \dot{t}_i)$$

So, the ice force, F of t can be given by summation of i equals 1 to N, f_i (t-$\dot{t}_i$). Equation, will call this 3 a. Where in this above equation N is the length of the loading function and $\dot{t}_i$ is 0, whereas, t 1 0 is summation of j equals 1 to i equals 1, J j for i greater than 1; 3 b. The function f_it minus i, this function is ice force model for any chosen event of ice failure. How do you define this?

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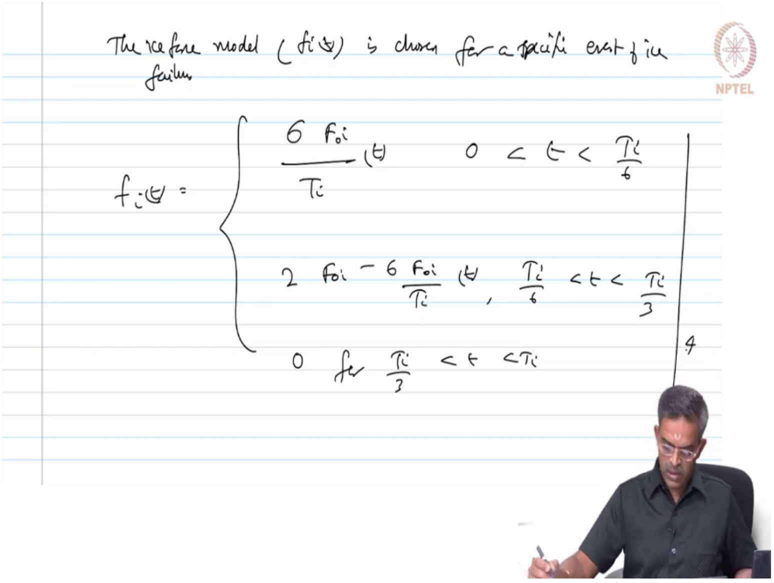

The ice force model which is f_i(t) is chosen for a specific event of ice failure. So, f_i(t) is given by 6 F_{oi} of t by T_i, if 0 less than t less than T_i by 6. It is equal to 2 times F_{oi} minus 6 times F_{oi}(t) by T_i. Now, not into t, F_{oi} into t is also into t for T_i by 6 less than t, T_i by 3. Otherwise, it is 0 for T_i by 3, t, T_i. We call this equation as 4.

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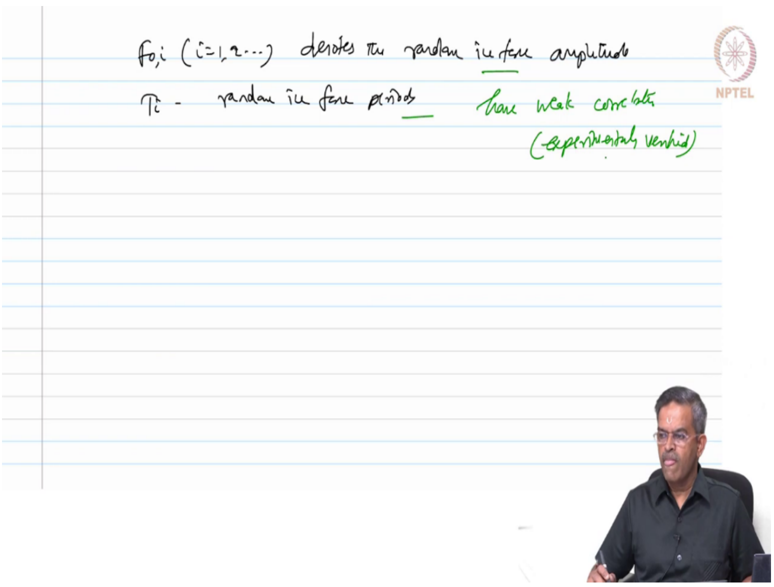

So, F_{oi} for i equals 1, 2 etcetera denotes the random ice force amplitude. T_i denotes the random ice force periods. Ice force amplitude, ice force periods are weak correlation. These 2 parameters have a very weak correlation which are experimentally verified. So, they can be considered as an independent parameter in the model.

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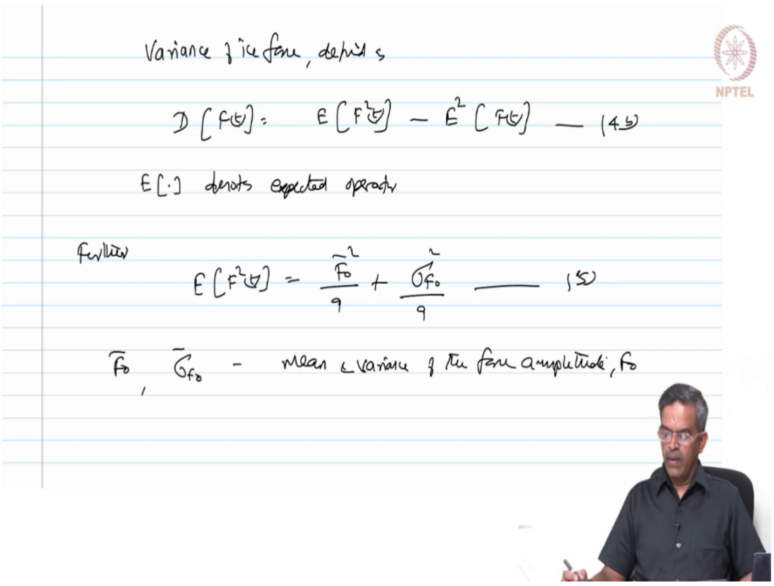

So, variance of ice force is defined as expected value of

$$D[F(t)] = E\left[F^2(t)\right] - E^2[F(t)]$$

Equation 4 b. Where, E denotes expected operator. Further,

$$E\left[F^2(t)\right] = \frac{\overline{F_0^2}}{9} + \frac{\sigma_{Fo}^2}{9}$$

$\overline{F_0}$ and σ_{Fo}^2 are mean and variance of the force amplitude F naught.

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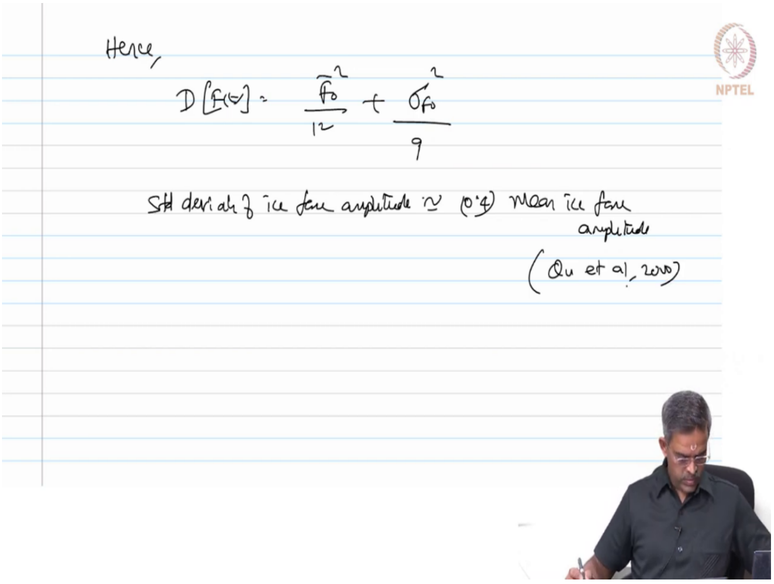

$$D[F(t)] = \frac{\overline{F_0^2}}{12} + \frac{\sigma_{Fo}^2}{9}$$

That is the standard deviation of ice force amplitude is about 0.4 of the mean ice force amplitude, is approximately 0.4 times of mean ice force amplitude. That is a correlation computed by Qu et al, in the year 2000.

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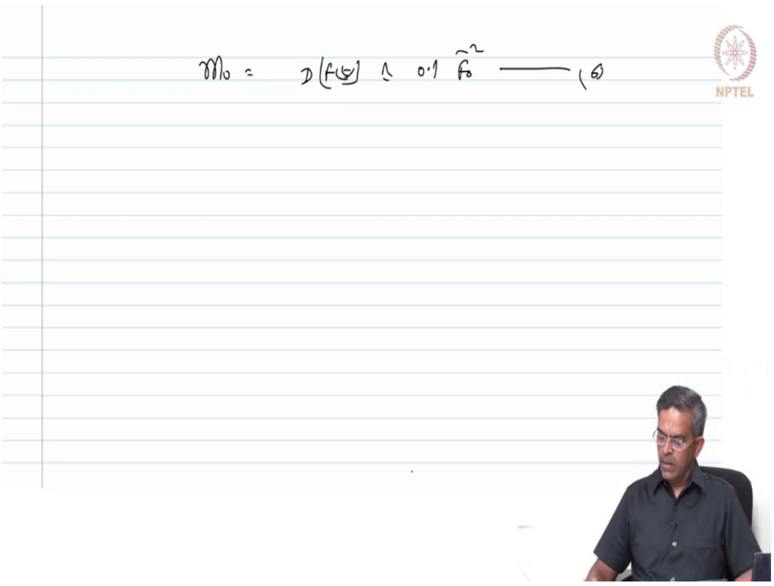

$$m_0 = D[F(t)] \cong 0.1\,\overline{F_0^2}$$

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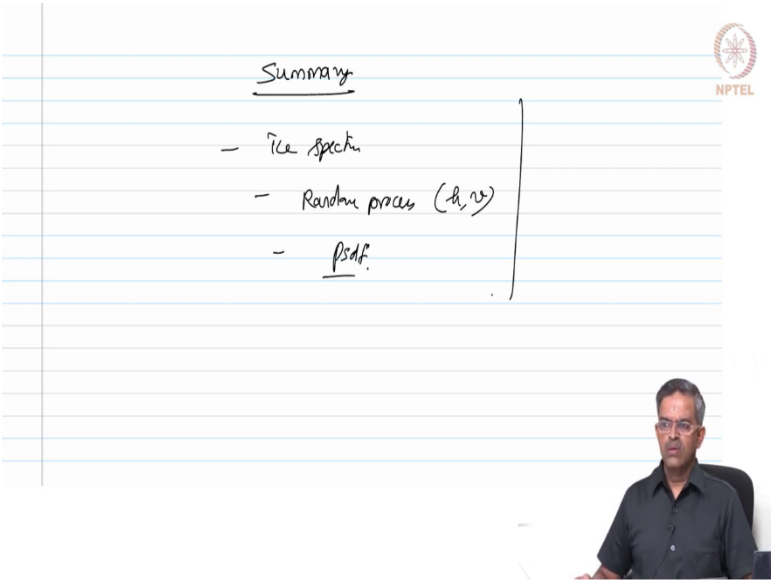

So, friends, in this lecture, we learnt how to compute ice spectrum, how to handle ice as a random process which is controlled by the thickness and velocity of ice movement. We have also learnt how to compute the spectrum with ice load by characterizing this as a power spectral density function.

So, kindly go through these lectures again. And try to understand the parameters involved in ice load generation, which will be helpful for learning ice load as a process, which excites force or load on an offshore platform constructed in arctic region.

Thank you very much. And have a good day.