Advanced Marine Structures

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Lecture - 4
Reliability Framework in Marine Structures

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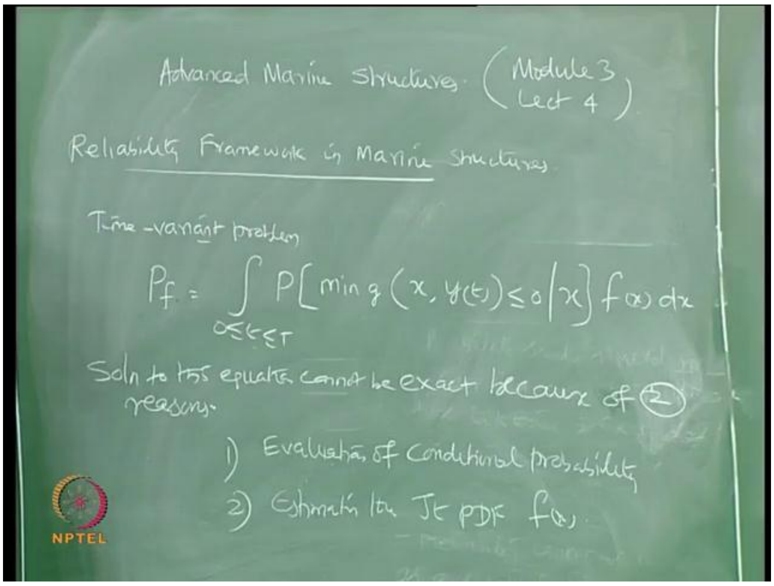

So, in the last lecture we discussed formation of a reliability problem, we said the time variant problem can be expressed by this equation where the probability of failure is given by this equation, where it is a conditional probability because with the given condition of the variables, within a given condition of t lying within the service life of the structure capital T, what is the probability of failure? So, solution to this equation cannot be exact, you cannot find an exact solution for this equation, because of two reasons. The foremost reason is evaluation of conditional probability itself is a problem, itself is a complex task, the second difficulty is are estimating the joint probability density function f of x.

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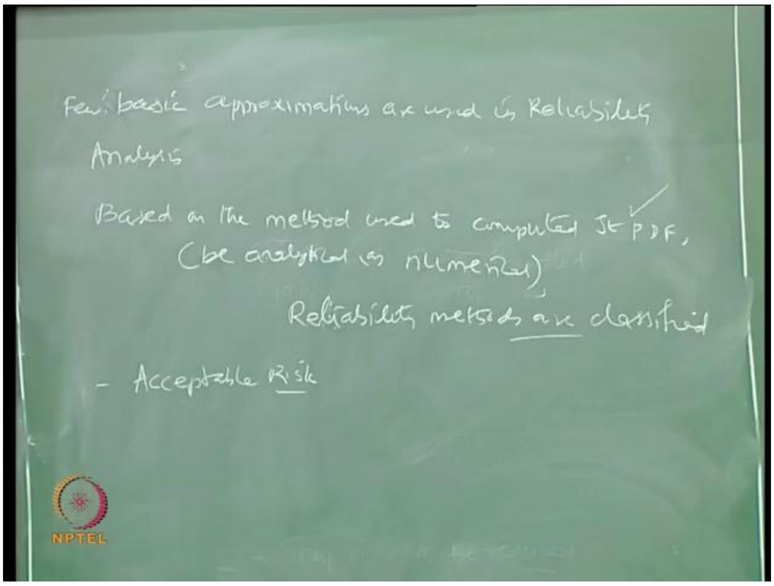

Therefore, few basic approximations are used in reliability analysis, depending upon how accurately are we able to compute the joint probability density function. And how closely you can evaluate the condition probability, the accuracy solution equation 1 or equation 7 in the last lecture, can be closed to accuracy. So, based on the method used to compute the joint probability density function, the method is analytical or numerical reliability methods are classified. They are classified further based on the analytical, numerical method employed by the person to compute the joint probability density function, you classify the relative methods as well.

Before we look into the methods in detail, there are many functions available to estimate the joint probability density function for random variables. Many methods are available in the literature. Before we look into them in detail, let us see what do we understand by something called acceptable risk? We already said that risk and reliability are associated reliability discusses the effect or the limit of failure it is actually, one minus probability of failure, where as risk takes it one step forward to. Also, address if the failure occurs, what would be the consequence of the failure in the society on the financial damage on the human loss of life etcetera?

The moment I say reliability cannot be 100 percent in any engineering design, I mean there is nothing like 0 probability failure of any system because of uncertainties present in the load effect as well as material characteristics. We just now saw one classical example is dynamic models of elasticity, one classical example therefore; there is nothing like 100 percent safe or 0 percent failure of any given structural system. Therefore, reliability is not 100 percent or one it can be any number varying from 0 from 0.1 to 0.99. Therefore, for every number of reliability associated, there will be always parallelly a number of risks associated. Then one must understand now, what do we call by acceptable risk?

On the other hand indirectly, there is something called acceptable failure in the design. You accept a failure because you know it cannot be 100 percent safe, failure will be there, but to what level you will accept this failure? So, instead of saying acceptable failure because that looks very irrational statement, people say acceptable risk. Let us look into that, what do we mean by acceptable risk?

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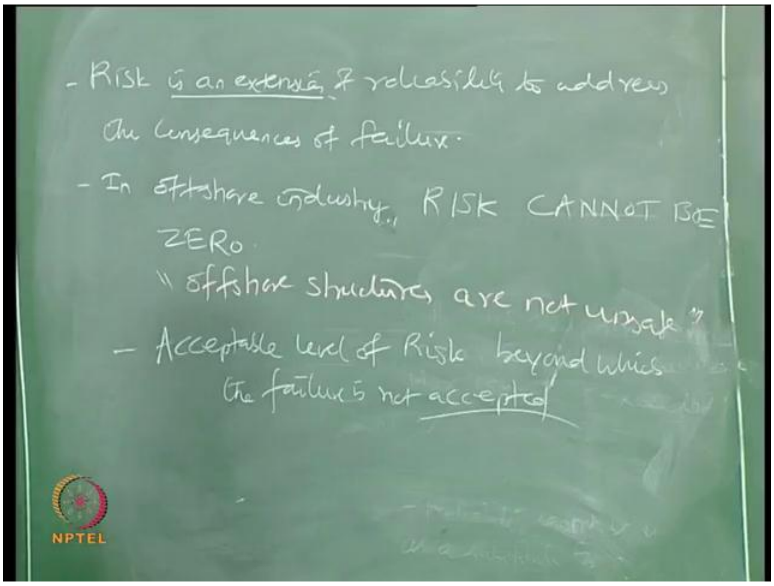

As we know risk is an extension of reliability to address the consequences of failure also, is it not? So, it is an extension, as we all understand in particular in offshore industry risk cannot be 0. In offshore industry risk cannot be 0, there will be some risk associated with offshore industry because of high level of uncertainties different groups of uncertainties and kinds which we saw in the last lectures, but this also makes a very important statement that offshore structures are not unsafe. Please understand this, the moment I say the risk cannot be 0, it does not mean that offshore structures are not unsafe.

They are safe even though the risk cannot be 0, it means there is an acceptable level of risk beyond which the failure is not acceptable, is it clear? Beyond which it is not accepted. The moment I say, I should declare an acceptable level of risk in a system, who will give me this system or who will give me this level of risk? So, you and me cannot sit and frame this level of acceptance because if you and me sit and frame the third person, will say I do not agree to it. So, it should be done in consultation with the people looking into the past systems.

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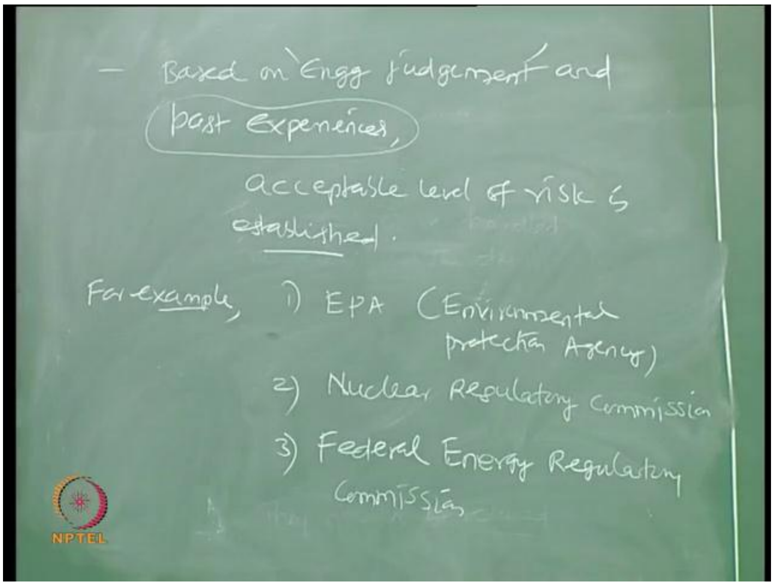

So, based on engineering judgment and past experience, acceptable level of risk is established. They are already available in the literature, where are they available who makes them. For example, it is generally prepared and then made established by international regulatory agencies. Let us see, couple of them now for our understanding, where are they available? Who are these agencies EPA, environmental protection agency, nuclear regulatory commission, federal energy regulatory commission. These are few international authorities, who formulate the acceptable level of risk for marine structural systems, based on the past experiences of different modes of failure encountered by the structures and also based on the engineering judgment as applied to the methodology of analysis and design, based on which these structures are constructed.

Now, as we understand, now that reliability framework in marine structure needs to be formulated, it can be a time variant problem. It can be a time invariant problem.

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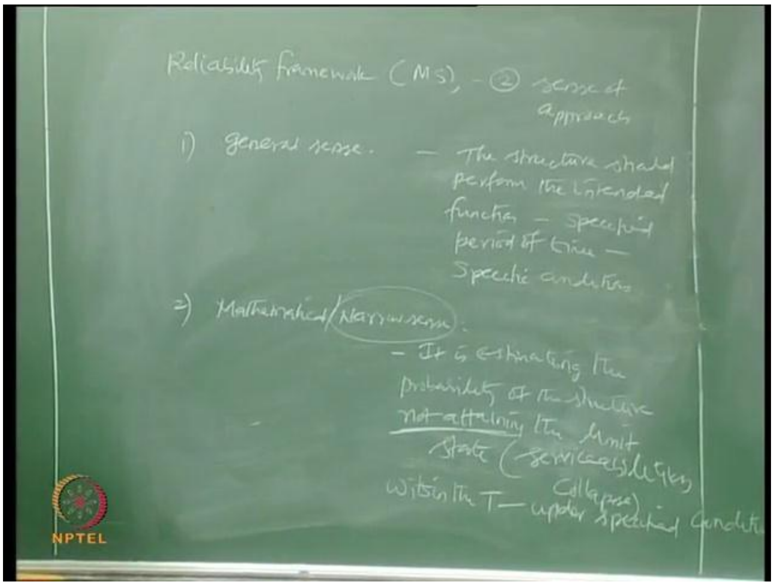

But it has got two sense of approach, reliability framework as applied to marine structure specifically has got two sense of approach. Let us try to understand this, these are the basics, the first is the general sense which means that the structure should perform the intended function within specified period of time under specific conditions. That is a general sense there is a narrow sense to it, which we call a mathematical sense or I should say a narrow sense to the reliability framework as applied to marine structures, what is that? It says that it is estimate of, the probability of the structure, not attaining the limit state. It can be either limit state of serviceability or collapse within the period t of the structure under specified conditions.

So, that is a very interesting statement in narrow sense, it says that try to estimate the probability that the structure will not attain the limit state, though the structure is designed to attain a limit, state very important plastic analysis and design is a methodology, where the structure should reach the limit state, what we call as a collapse load. So, here reliability is what is that probability the structure will not attain the state. So, if a designer is perfect, if a plastic analysis based on upper bound or lower bound is accurate, considering all possible mechanisms considering the real analytical method by which you worked out the collapse load correctly, then the probability of the structure attained the limit state is 100 percent.

So, reliability framework is only guessing that probability of how much extent it will reach? The limit state not exceeding. Exceeding means failure it is attaining the limit state that is the framework of the problem. So reliability framework overall is encompassed in estimating the probability of failure. As we discussed in the last lecture, the focus is to estimate the probability of failure.

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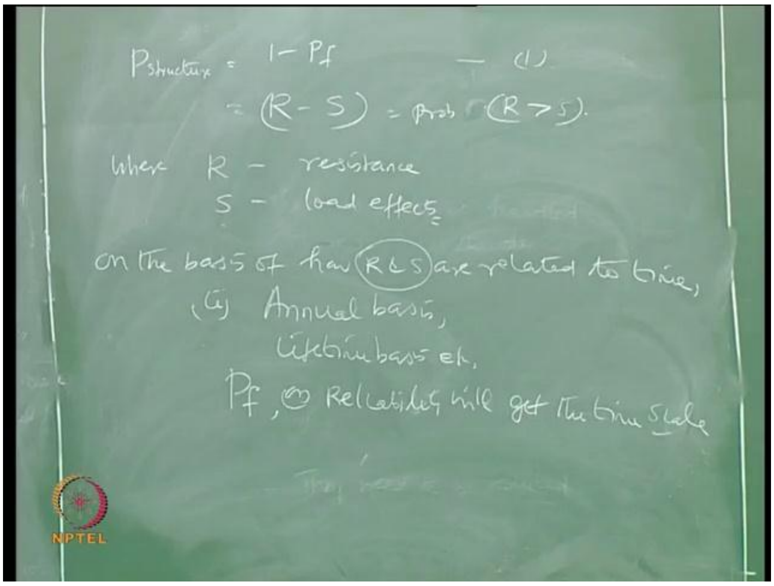

So, the probability of structure can be one minus probability of failure, which can be expressed as R minus S, where I call this equation number 1 for this lecture. R is indicating the resistance of the structure and s indicates the load effects, that is why this s is here load effects or I should say probability of R greater than s that is reliability. Now, interestingly on the basis of how R and S are related to time, that is are you looking the resistance and load effects on annual basis or on lifetime basis etc. Probability of failure or reliability will get the time scale; a time scale of the reliability study depends on the time scale of how you are establishing the R and S values?

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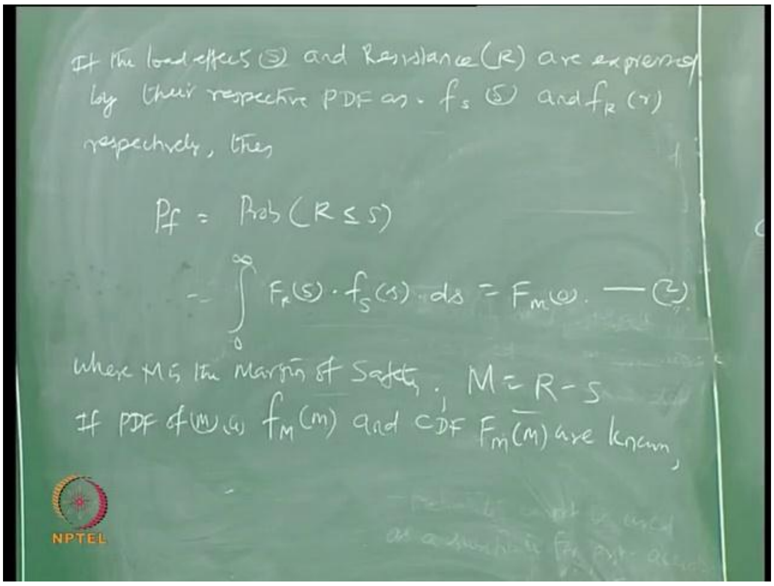

If the load effect S and resistant R are expressed by their respective probability density functions as f of s of s and F of R of R respectively. Then probability of failure can be probability of R less than S. I am talking about failure, there it is one minus failure which is integral 0 to infinity F R of s into f s of s d s, which gives me F m as 0, where m is what we call margin of safety, where M is given by R minus s. If the probability density function of m that is f of M of m and C D F cumulative density function f of m of M are known. Then probability of failure can be computed analytically are of course, numerically. Let us look some analytical expressions of estimating the probability of failure.

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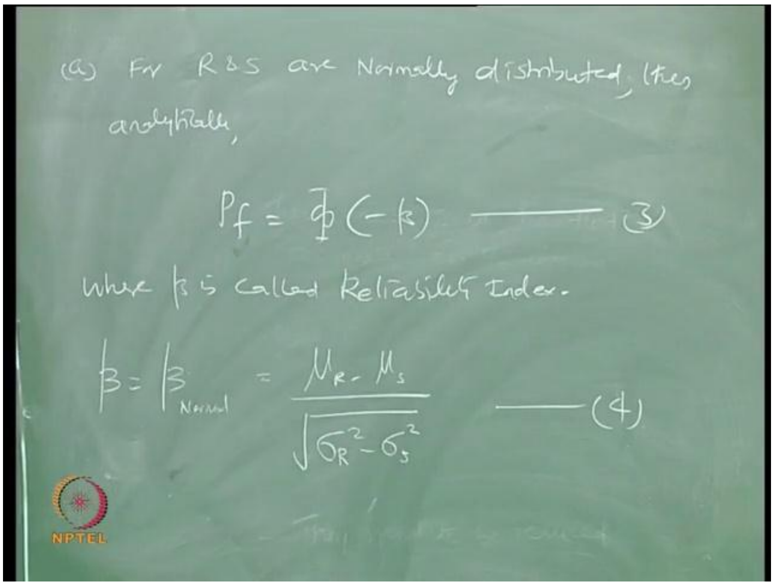

If R and s are normally distributed, R is resistance of the material, which is a statistical property it varies s is the load effects, load can be caused from different variables. v 1 x , x 2 x 3 etc. It is again a statistical parameter both of them, let us assume they are normally distributed. If they are normally distributed then analytically probability of failure can be given as a function of minus beta, where beta is called reliability index. So, I should say beta for normal distribution is given by mu R minus mu s by root of sigma R square minus sigma s square, equation number 4, where for R and s normally distributed, I already know the mean and standard deviation of these two.

You can find out beta once, I know reliability index. I can find out probability of failure using a simple table though the table is available in our standard text books of reliability of statistics. I will just give some values of this table for our interest, okay?

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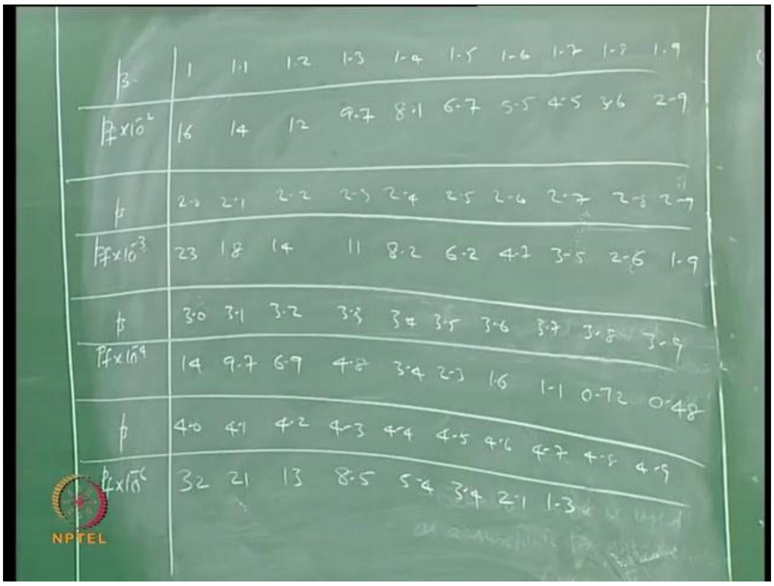

Beta and probability of failure in terms of 10 power minus 2 beta probability of failure in terms of 10 power minus 3 ,probability of failure 10 power minus 4, probability of failure 10 power minus 6. I am just grouping them, this is available in almost all the statistical tables, it is very bad to reproduce them on the black board here, but still I want to give you for completion, otherwise you will never refer back to any books and find out these value. Let me give these values here, for our better understanding because it is very simple to know beta. I can find probability of failure using this table directly, let us know this where it is, very bad and I am writing the table on the black board, but considering that you are so intelligent and you will have so hardworking to refer the table back in the literature. Let us do it here no problem

So, this is the table, which is almost available in all text books of statistics, but still for completion sake, I want the viewers to look into this table and understand. I will just quickly read this table, how to use it.

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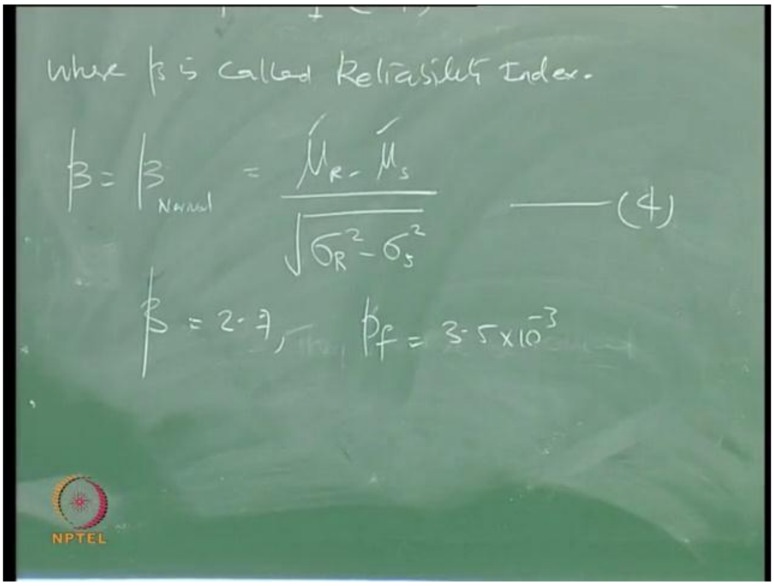

For example, if I get the beta value from this expression for in, I know mu R and mu s in sigma R and sigma s as, let us say the beta value comes to around 2.7 is indicates me that my probability of failure is above 3.5 10 power minus 3. It means the probability of failure comes to 3.5 10 power minus 3. So, if we take the values, so low is 1 by 3.5 10 power 3, that is the value. So, low so that is the amount of 1, in that value or 1 in x, which fails in the given system. So, reliability indices can be directly read for different levels of failure and this can be computed if the variables R and s are normally distributed.

So, which is standard case if they are log normally distributed. So, you must appreciate now, that the whole problem lies in finding out, how the join probability distribution function of the variables are distributed, that is a complexity if you know that, then you can find reliability study much easier.

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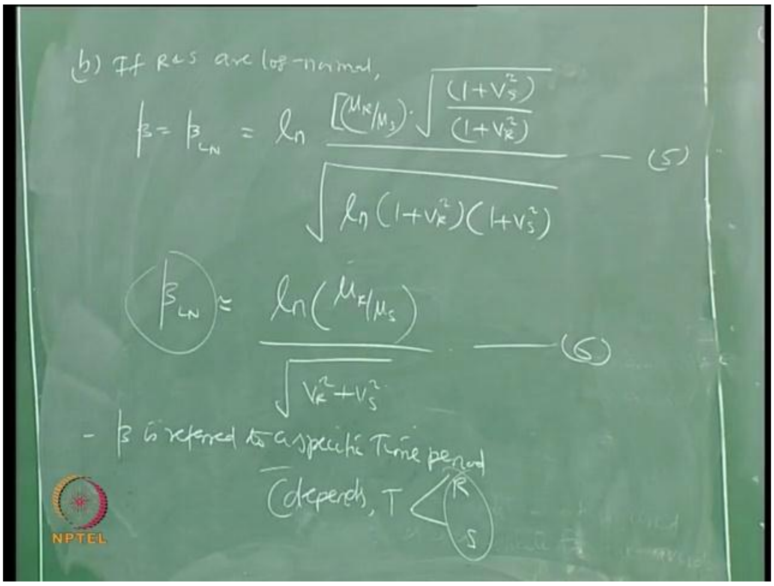

If they are log normal is one kind of distribution then beta is given as l n of that is natural algorithm mu R by mu s. Equation number 5, beta l n can also be approximately given a l n of mu R by mu s, by root of variance squares. So, if you know the variance squares of resistance and the load is effects and their mean value can also find beta l n to ones, you know beta l n using a standard distribution table as I showed you in the last. Few minutes back, can find out the probability of failure and probability of reliability, will be 1 minus probability of failure. You can easily find out the reliability for a given study if R and s are normally distributed, log normal distributed. Most importantly, in the both these equations are set of equations, beta is referred to a specific time period.

That is very, very important, this is an important statement. Beta is not an infinite value, it is extended only for specific time period. You may ask me a question, what is the time period associated with the reliability index? This depends on, what is the time period? You are associating your R and s, if it is annual, if it is service life etc depending upon what is the association of the resistance and the load effects? What is the period accordingly, that would be the time scale of a reliability index? Very important statement, it is not an infinite number, it cannot be computed and remain standard throughout the life of the structure.

What is that period of R and s? Which is substituted in this expression based on, what period of these you are calculated this? That is the associated period of beta also, they are they are not time invariant. There is a time factor available in this, but it is not based on any out crossing, that time is implicitly implemented in the analysis saying that on what time you are computing R and s? So, we will discuss about the ultimate limit state and reliability that is we have already seen. Ultimate limit state in the module 1, we will also apply reliability on to ultimate limit state and see how I can use and let us try to find out implicitly? What is the parameter, which governs ultimate limit state in the permeable of reliability?

There are two aspects here, one is R resistance of the material or strength of the material or characteristic associated with the material, which has uncertainties, for example dynamic models of velocities, one amongst them. There are many, the other parameter of the variable is my s, which is the load effects load combination load variations randomness in nature, mathematically modeling the randomness in your analysis. There are many uncertainties, in that also amongst these two set of uncertainties one is R and one is s. If you apply them on to me, ultimate limit state which is governing the reliability, which is important on the other hand. That is what we will see in the next lecture.

So, what is the ultimate limit state and the reliability application on to the ultimate limit state implicitly? We will see in the next lecture, then based on this how do we classify different levels of reliability level, 1, 2, 3 and 4. How are they classified and what is the equation available for different levels? Very briefly, we will look into them and we will close the lectures on module 3, do you have any questions now, in this? So, reliability problem or probability of failure is as simple as that for a given set of variables. You must know essentially mean and standard deviation and variance, what we call as first order, second moment method.

We will talk about that later FOSA methods. If you know them, you can easily find the beta from the expression given if they are normally distributed, assumed to be normally distributed. If they are logged normal, then I have an equation here. So, from these two set of equations, I can easily find out what is my probability of failure? Once I know that, I can always find the converse of this. It is 1 minus probability of failure, which will give me reliability, is that clear? So, this is as simple as that. So, how uncertainties are addressed in this? Why probability of failure in a time variant problem cannot be 100 percent accurate solution to this equation cannot be exact because estimating joint probability density function of a variable itself is a problem, which we saw and discuss in this lecture.

And this lecture we have understood, how to estimate quickly for certain examples, where by first or second moment method that is mu R and sigma R are available to me quickly using a standard table of statics. Can I find out probability of failure, we saw this in this lecture in the next lecture. We will extend this concept to understand, how reliability and ultimate limit state can be coupled? And from the base of reliability, which is the maximum parameter governing the ultimate limit state is it R or is it s? And why? we will talk about that, in next lecture.

Thank you.