Risk and Reliability of Offshore Structures
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Module- 02
Reliability Theory and Structural Reliability
Lecture – 05
Reliability Methods – I

Friends, let us continue with the 5th lecture on module 2, where we are going to open up on reliability methods.

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This lecture we will continue for further couple of lectures. Therefore, we say reliability methods 1. We already said in the last lecture, that the major part of performance assurance is covered at the design stage itself. So, the major part of performance assurance which is required from a given system, in terms of its functional requirement is generally done at the design stage itself. We all agree and understand that the one which is covered the design stage, is what we call as level one reliability.

However, in the design, there are varieties of uncertainties which is present. Let us see that, let us talk about uncertainties in design in general then, we will talk about

uncertainties in the design applicable to offshore structures in particular. So, this is what reference is from, it is a grandt 204 Haldar and Mahadevan 2000 and 1995 these researches very clearly say, the reliability analysis imply estimation of limit state probabilities. So, reliability analysis is actually focused to estimate, the limit state probabilities of a structure for it is under adverse combination of loads, for its intended period of use.

Therefore, safety is to actually quantify the satisfactory coverage of uncertainties in the design stage. Uncertainty in the design stage itself. So, that we can eliminate them, control them, minimize them, at the budding stage itself. Therefore, safety is related to an existing process which has direct consequences to failure.

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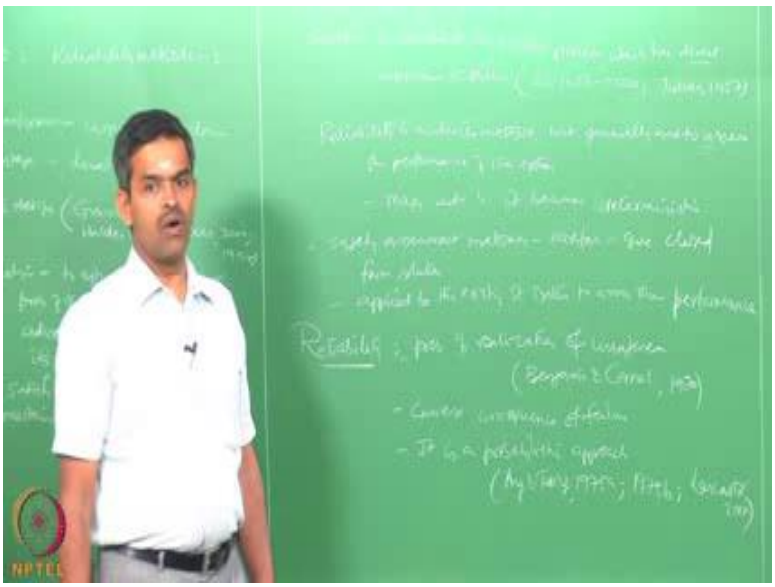

As clearly defined and stated in IS 1656, 2000, Julian 1957. So, we agree that in the design stage reliability can be addressed to take care of uncertainties present in the system, while it is in a design method, reliability can be seen indirect it is a design method, but used actually to assess the performance of a structure. That is very important though reliability is a design method; because you are using it at the design stage, but generally used to assess the performance of the structure I should say performance of the system for its functional use.

Now, by doing so or by limiting it only to assessment there is a great advantage. What is that advantage? The major advantage is it becomes deterministic. So, safety assessment methods give therefore, a close form solution. They can be applied to existing structural systems to assess their performance. They can be easily applied to the existing structural system to assess their performance. Now let us look at reliability now in comparison to safety, on the other hand we look at reliability, it is actually a probability of realization of unsafeness. That is what researchers defined the reliability very critically Benjamin and Cornell in 1970.

Reliability has converse consequence of failure, where as safety has direct implication of failure. It is a probabilistic approach, it can be also used as one of the design methods as clearly people said in the literature Ang and Tang 1975a, 1975b Lancaster 2000. However, accuracy of the results of the reliability approach, essentially depends on the data based on the results are arrived. Therefore, reliability methods have a probability of giving erroneous results, if the data is in accurate.

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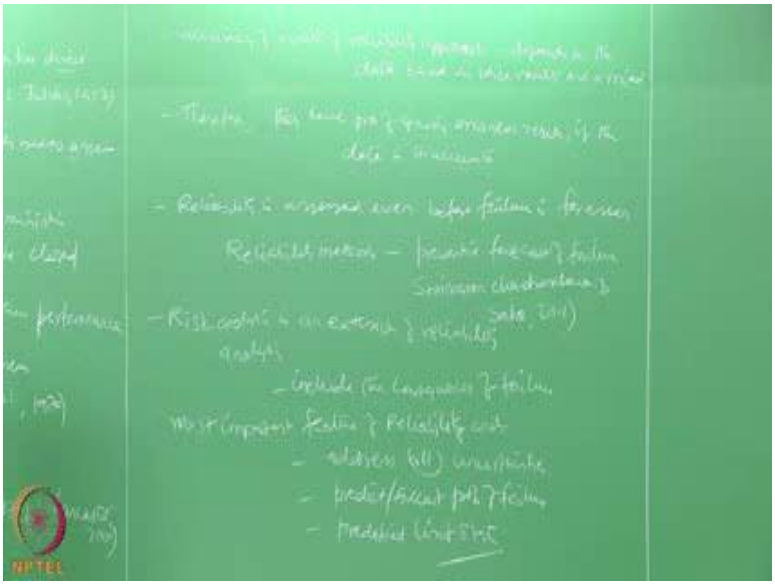

Therefore, to have a proper assessment or results of reliability methods or analysis your data should be dependable and reliable. Most importantly reliability is assessed even before the failure is forcing that is very, very important. Therefore, reliability methods

can be also called preventive forecast of failure, as said by Chandrasekaran and Saha 2011.

Now, let us extend the discussion from safety to reliability to risk. Risk analysis which actually an extension of reliability analysis, in this extension what we actually do you include the consequences of failure also, therefore; most important aspect of reliability analysis is to consider the uncertainties which make the structure vulnerable to failure for a predefined limit state. So, these are the keywords. So, the most important feature of reliability analysis should be address uncertainties I mean, In fact, all uncertainties predict forecast probability of failure, for your predefined limit state that is very, very important. Here a predefined what is that limit state function limit or state condition you are going to apply to assess the reliability these are the keywords meaning reliability approach or reliability analysis we will focus on.

Now, the question comes we are talking about probabilistic estimate of failure or converse of failure. So, whenever you have associated property of probability to a theory you always have approximation. Therefore, a reliability engineer or any scientist will have question in mind what would be the accuracy of this analysis?

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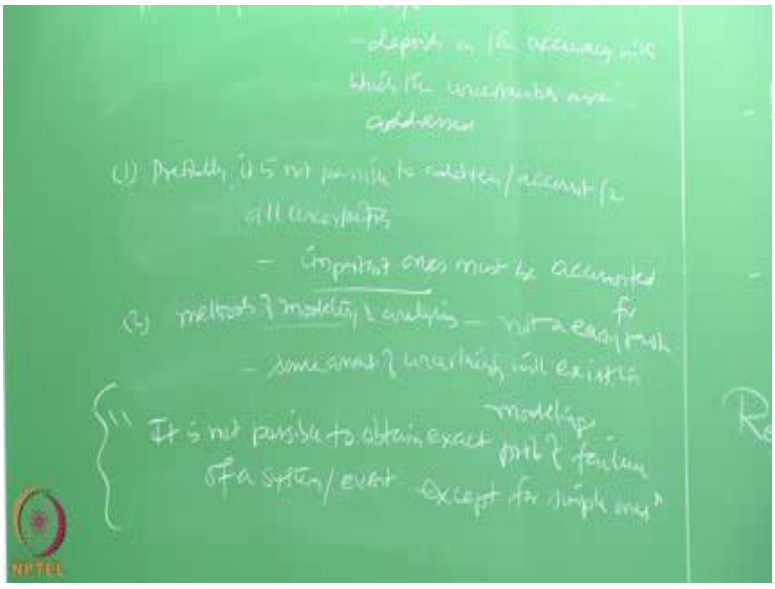

So, one can say accuracy of reliability analysis, actually depends on the accuracy with which the uncertainties are addressed. Let us try to apply this discussion more practically. So, one can say practically it is not possible to address or to account for all uncertainties. If you know them certainly, then the uncertainty will not exist. So, all of them cannot be addressed. But for sure important ones must be addressed at least; at least important ones must be accounted for the analysis. So, that is a first point. Then second point could be which is challenged the accuracy is one has to focus on the methods of modeling and analysis.

Because accuracy reliability analysis essentially depends on what method of modeling you are following and of course, this also not easy task. But this can be done anyway even in this case also you know that some amount of uncertainty will exist in model that anyway will be there.

So, one can make a statement it is not possible, to obtain exact probability of failure of structural system or any event except for simple ones you get. This statement is very much valid; we already said there are basic 2 types of uncertainties aleatory and epistemic. This can be further classified which are dominant in reliability analysis.

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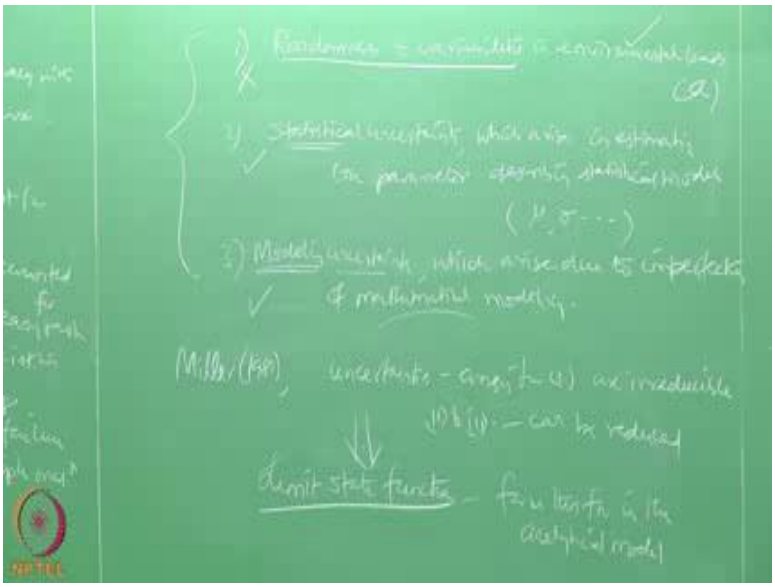

Uncertainties that are dominant in reliability analysis are 5, 1 randomness that is uncertainties which arise from randomness, and variabilities in environmental loads. Let us say q action, a second could be statistical uncertainty which arise due to estimation of parameters describing the statistical models the parameters describing the statistical models. What could be that parameter? It can be mu can be mean, standard deviation etcetera. Coefficient of kurtosis etcetera, the third could be modeling uncertainty which arise due to imperfection mathematical modeling. Because the physical phenomenon is very complex, it may not be possible to account for all those complexities while you convert them into a numerical model or analytical model.

So, there can be uncertainties arising from modeling statistical parameter estimates or inherently present randomness and variabilities in the loads. Now; one can easily see here the error in reliability estimates even in the design stage itself can occur from these three types of sources. Out of which depending upon the data or depending upon the assembled size to some extent this can be controlled, to some extent to some extent with detailed knowledge and mathematical modeling this can be addressed.

However, the presence of the randomness and variability in the loads cannot be addressed at all in full. Unfortunately if you look at the hierarchy or the order of influence in the accuracy of analysis with respect to these three uncertainty types this will be dominating compared to these two. Of course, the order will be first second and third. It means the contribution arising from model uncertainties in the overall error in the reliability analysis will be the least compared to that arise from randomness and variabilities in the loads. So, the one which we do not have control is unfortunately prompting up to the maximum contribution in the error of reliability analysis. Therefore, reliability analysis can never give you a very accurate statement. Therefore, we can say it is not actually possible to obtain exact probability of failure, of a system or event except that which are very very simple.

As said by miller 1981 as said by miller, the uncertainty is arising from irreducible and those arising from these 3. For example, I will call this as one the uncertainties arising from 1 or irreducible. Whereas, those arising from 2, 1, 3 can be reduced, now how to do this how to handle this it all depends upon how accurately you form the limit state

function how accurately you form this function in the analytical model. So, mathematically the whole complexity will amount to choosing forming proposing a limit state function, which will account for uncertainties or unknowingness in the whole analysis, the second of course, complexity will arise when we start integrating the probability density function within the domain of interest which is also complex, every now 2 approximations or 2 seriesness.

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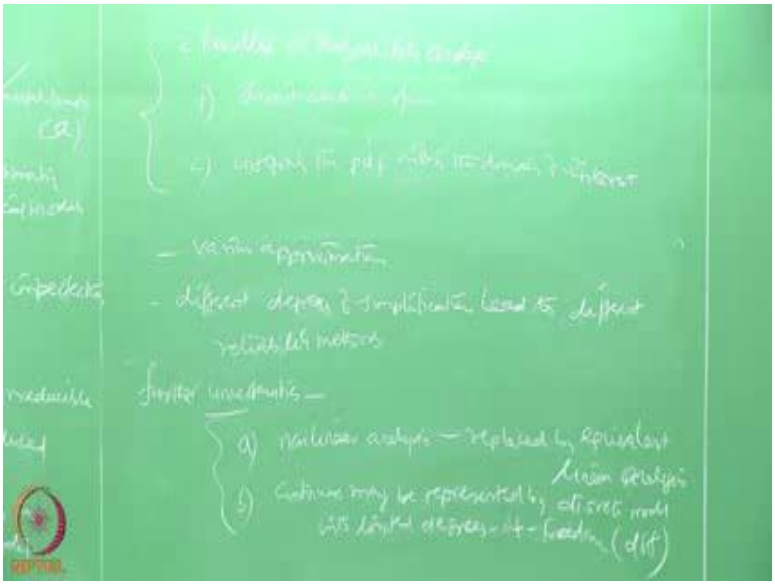

So, I could say 2 hurdles in relativity analysis, the first one arising from the limit state surface. How accurately I am going to mathematically model this? How I am going to form this function etcetara. The second is integrating the probability density function within the domain of interest. Therefore, these hurdles result in various approximations, which are called reliability methods. Earlier we saw reliability levels now we are going to see reliability methods. Therefore, different degree of simplifications are done, lead to different reliability methods.

Apart from these uncertainties, there are others for which simplifications of the problem is definitely required on the hand. Let us say what are they apart from these uncertainties we have further uncertainties, for which simplification of the problem on hand is mandatory. The foremost in the q is a non-linear analysis, is one domain which can result

in lot of uncertainties. So, this should be equivalent replaced by linear analysis, replace or replaced by equivalent linear analysis. So, there is an approximations here; however, we already know even when you do this accurately still the reliability analysis will leave only approximate solutions we already know that. Therefore, one can straightly compromise here in estimating the reliability results by using preliminary the equivalent linear analysis in place of detailed non-linear analysis.

The second could be continuum may be represented by discrete model, with limited degrees of freedom. So, collection of more data or sample helps in providing a better statistical parameter. So, the second part of this can be addressed by improving their in symbol size, but the problems related to the modeling in terms of non-linear, capturing the non-linearity in the material well as in the load behavior discretizing the model in terms of limited degrees of freedom where as in originality and reality the model is behaving as a continuum model etcetera. These are all other further factors which will lead to further complication or uncertainties in reliability analysis.

Therefore, to avoid these confusions one generally refines the reliability model further to account for these uncertainties also in the analysis. In addition to this you can also have more rigorous analysis with sophisticated models of structure to account for the non-linearities or uncertainties arising from these sources in detail. Therefore, one can make a statement here a unified approach, for treating statistical and model uncertainties in the reliability analysis, is it possible? So, the question comes in mind is do we have any approach which addresses both statistical and model uncertainties in the reliability analysis.

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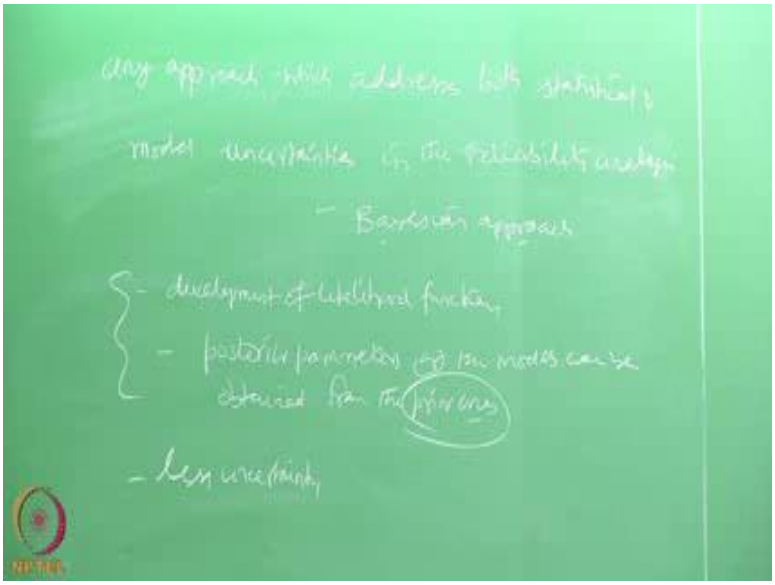

The answers is yes is what we call Bayesian approach. This is used to update the model parameters and develop what is called likelihood functions. We will talk about this later when you move on to the methods of reliability. So, it actually leads with development of likelihood functions with the help of these functions, the posterior parameters or the models can be obtained by from the prior ones like a follow up chain.

So, this method or this approach is considered to be having less uncertainty. The reason is very simple all the properties are derived from the information available in the system on the prior basis they have less uncertainty and they can use for development of more data and observations. We already said the reliability methods use probabilistic approach. So, different probabilistic models, which are commonly used in reliability analysis, could be the following.

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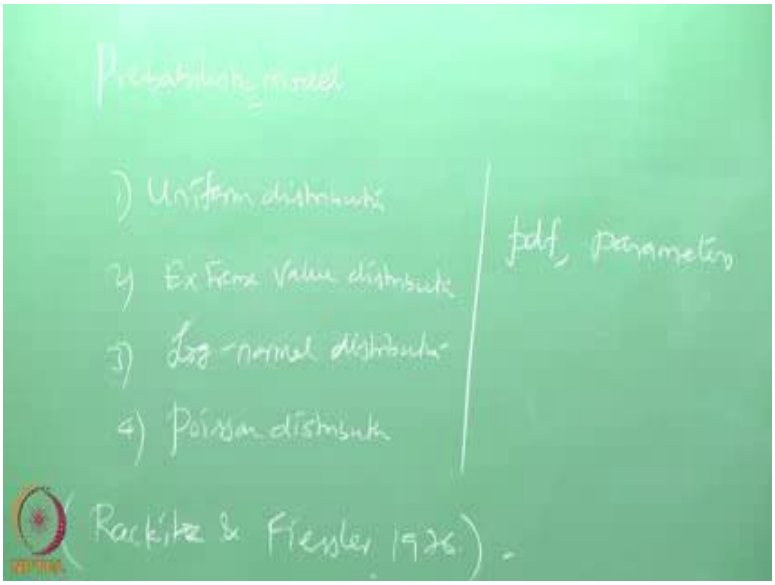

1: Uniform distribution, 2: Extreme value distribution, 3: Log normal distribution and 4: Poisson distribution. The probability density function of these distributions and the parameters associated with these functions are available in the standard literature for each type of distribution. I would request viewers and the listeners to kindly go through these distribution from any standard references available in the NPTEL website of this course try to understand and daily do some insight looking at the parameters associated with the PDF probability distribution function distribution function of these distributions and try to understand them with their limitations available in their application forms they are all useful to describe the distribution of different uncertain parameters which are actually handled in reliability analysis.

Now, therefore, friends' procedures for performing reliability analysis vary with the selection of the above models. What are probabilistic model you select or choose depending upon that performing reliability analysis will vary. When material and other uncertainties are introduced procedure for the analysis may further vary that is what the statements are as referred by Rackitz and Fiessler 1976, it is clearly said that as you keep on adding more and more details about the r and q that is the material resistances or structural resistance and the load effects q. The complexity in the analysis levels will be keep on increasing.

For example, a stochastic finite element analysis is used for random loading while material and other uncertainties may be included by simple procedures in a very appropriate or approximate manner. So, you look into very sophisticated models to account for simple inclusions in the reliability analysis. So, one has carefully choose the probabilistic model in such a manner that what uncertainty or what level of uncertainty you are going to address, because that will decide about the reliability methods or reliability analysis levels. In fact, various levels of approximation are often used to simplify the reliability analysis procedure, and make it consistent with the desired accuracy.

Now, let us see what are uncertainties related to the design stage in offshore structures.

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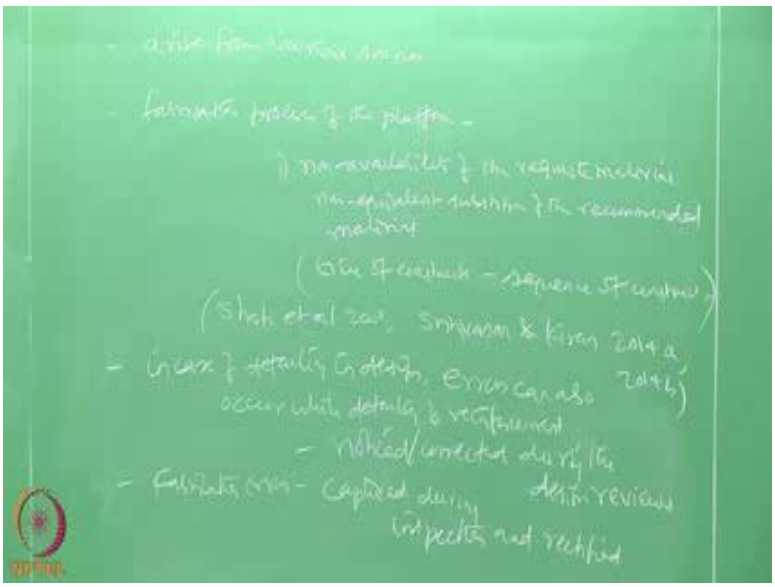

Uncertainties in system design of offshore structures to be very particular. Let us do let us try to find the results uncertainties arise from the various sources. If I look at the fabrication process of the platform, let us say fabrication process of the platform. If that is considered as a case of study uncertainties can arise from the following sources, non availability of the requisite material or non equivalent substitution of the recommended material.

Because it is a very common problem in case of fabrication offshore structures why because it is going to now govern the time of construction or the period of construction and of course, we also govern the sequence of construction that is very important since these 2 factors are very dominant in offshore structural design and the design stage itself or construction stage itself. Let us say, they will govern and they will also introduce uncertainties. So, if you attempt to substitute an equivalent material which will cause a minor uncertainty of course, this can be handled the design stage itself as said by Shate Etel 2005, Srinivasan and Kiran 2014 ab etcetera.

The next could be in case of detailing in design errors can also occur while detail of reinforcement etcetera. Of course, this can be noticed and corrected during the design reviews, because designs are reviewed thoroughly therefore, during the review meetings this can be corrected fabrication errors can also come up. They can be captured during inspection and can be rectified subsequently, but one can say these uncertainties are quite complex.

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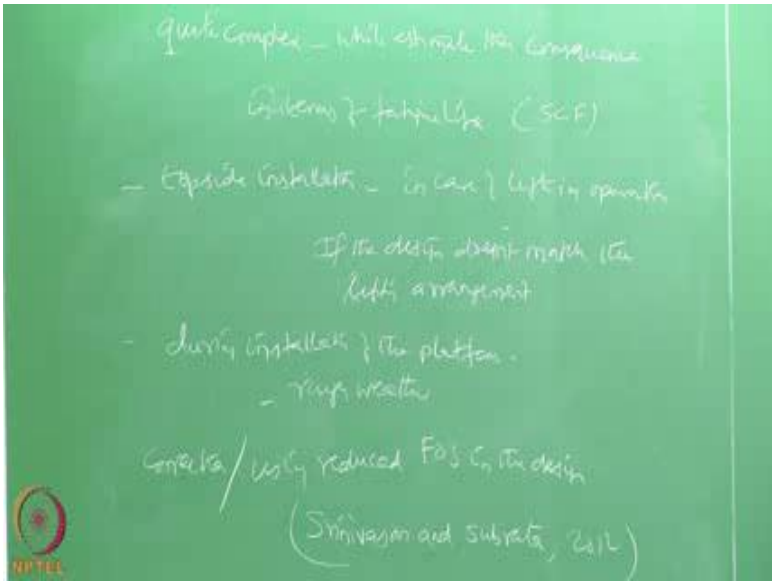

While you want to estimate their consequence in terms of fatigue life that is to estimate the fatigue analysis people use the stress concentration factor. The stress concentration factor depends on the errors arising from fabrication, improper replacement, detailing

etcetera. This is a are very interesting case study which is dealing with the stress concentration factor of k joints and t joints which I will discuss in detail when we talk about reliability applications of offshore structures. So, there you will clearly understand what are those anomalies, which can arise when you are estimating a stress concentration factor especially how loading systems which we did experimentally in our institute.

Therefore people use empirical rules for multiplane or joints which do not represent the true behavior. Because these empirical rules account for some uncertainties; however, they introduce some errors in the whole analysis because they do not represent the real behavior of the joint under real loading state. The next uncertainty can arise from topside installation topside installation, can have uncertainty while in case of lifting operation either design does not match the lifting arrangement, proposed by the lifting contractor or the constructor it may have lot of errors and uncertainties arising from during the construction and the lifting stage itself.

Inadequate detailing will lead to transfer lifting loads to cause imbalance in the structural design these aspects can be rigorously checked during the design review process of course, uncertainties may also arise during installation of the platform it may be due to rough weather which of course, increases the loads during installation that is one reason in particular there are more seriousness in case of commissioning large complain offshore platforms.

It is rather interesting to note that the dimensioned compartment scenario is study the design stage, which accounts for the uncertainty that arise during sinking of the jacket while launching. There are some methods by which these kinds of uncertainties are forcing and they are taken care of the design stage or at least in the review process. Therefore, friends uncertainties also arise during grouting of shear keys in particular in case of jacket structures alternatively such issues can be taken care of in the design by admitting a reduced factor of safety because remedial action may not be possible for any reason further in such mistakes.

The correction could arise from the correction could arise from using reduced factor of safety in the design, as suggested by Srinivasan and Subrata 2012. So, friends in this

lecture, we understood that reliability methods, uncertainties presents in the reliability methods decide what kind of analysis you are planning to do. Probability distribution models will decide. What is the extent of coverage of uncertainty in your analysis? Uncertainties arise from different stages, design stage construction, fabrication, erection transporting, welding, even grouting, etcetera. Can all the uncertainties arising from this stage can be taken care of what are approximation method which can account for these uncertainties.

For example, one such is reduced factor of safety in the design etcetera. So, people in the design stage have suggested various alternatives, one could be stress concentration factor to account for the fatigue analysis, other could be factor of safety in the design for different load combinations. Other could be a design check which accounts for the damaged compartment failure, in case of the sinking of the jacket while it is being transporting or launching or after launching it may happen. So, all these procedures address rigorously the probable failure which could happen, which could be forcing in the design stage or review stage itself.

So, reliability is done inherently in offshore structural design as a part of checking process itself in the preliminary stage of design itself. It means reliability or safety assessment in offshore structures is inherently in built in the design mechanism itself. So, that all such failures mostly arising from construction, fabrication, erection, etcetera. Are foreseen in advance and appropriate measures are taken care of or accounted for in the design by some appropriate rules and methods, as suggested by international codes and various researchers.

In the further lectures we will talk about different models of reliability, methods of reliability in detail.

Thank you very much.