Risk and Reliability of Offshore Structures
Prof. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module-02
Reliability theory and Structural Reliability
Lecture-23
Mechanical models in Reliability analysis

Friends, welcome to the 23rd lecture on module 2, wherein we are going to now discuss mechanical models.

(Refer Slide Time: 00:19)

In reliability analysis is a twenty third lecture in module 2, where you are focusing on structural reliability and in the online course on Risk and Reliability of offshore structures.

In the last lecture, we already said or showed you the approximate representation of physical reality. We said that the mechanical model should be able to as close as possible represent the physical behavior of the real model. So, if there are any differences or disagreements between the behavioral phenomenon compared to the physical model, which is represented or seen or visualized in a mechanical model they should be minimum as far as possible because the errors in reliability essentially arise from the experimental methods, which can be a source of important error when you talk about mechanical models.

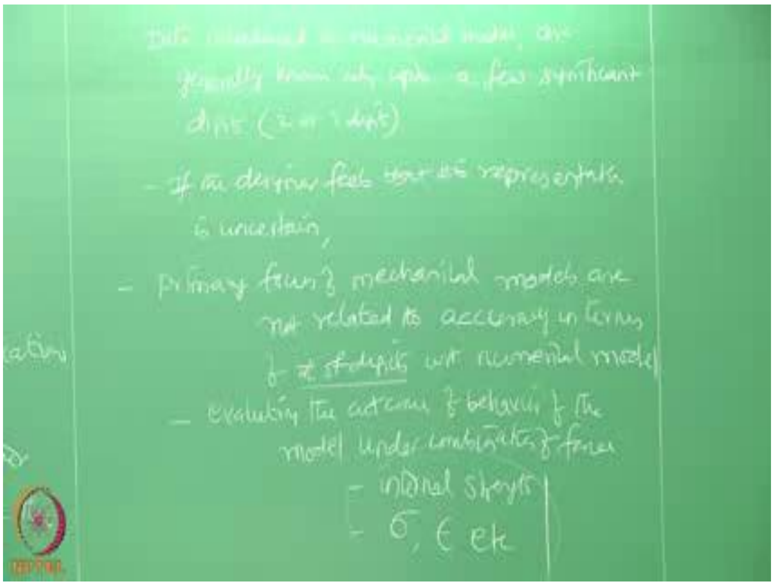
Therefore, models should be evaluated for their closeness in response behavior to physical phenomenon. Mathematical models on the other hand should explain and represent the physics as close as possible. Alternatively, we look at numerical modeling they should control the accuracy of the results, so that if there is any deviation between the physics and that of the represented value that should be the least as far as possible.

(Refer Slide Time: 03:23)

Hence, before we do a reliability analysis based on data which are derived experimentally or from a mechanical model, it is necessary to validate the mechanical model. Now, if we are talking about a numerical model for validation, let us say one can validate this using equivalent numerical solution in terms of improving the density of finite element mesh, one can also conduct convergence tests as accurate as possible. So, that one can qualify or validate the mechanical model with a numerical approach.

Of course, these comparisons should be a measure of the bias of the model and they should be indicated the deviations on the random variable as far as possible. So, the focus is to check or assess the deviations on the random variables that is very important of course, when we validate a mechanical model with a closeness of its behavior to that of the physics model, then the next stage should be to check whether uncertainties in the data influence the variable of the model or not. So, one has got to assess this check at the second stage. Interestingly, friends the data introduce a numerical model are known only on few significant digit values.

(Refer Slide Time: 06:20)



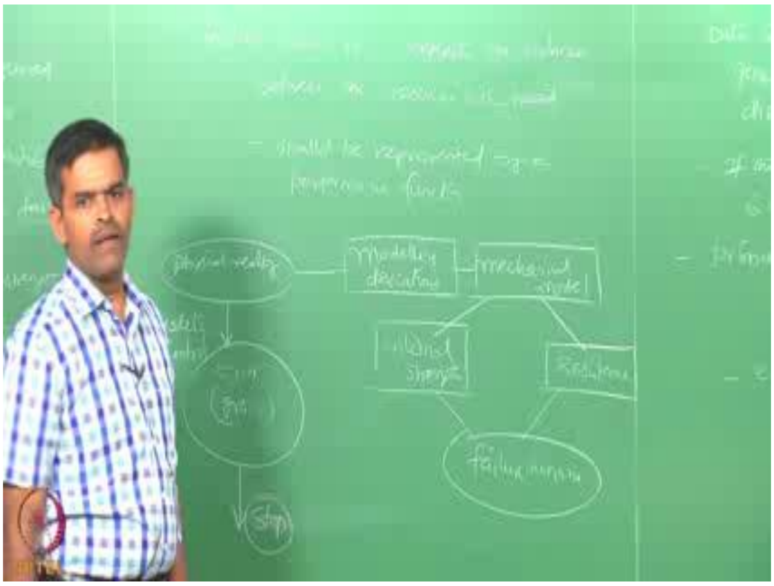
The data introduced in numerical model are generally known only up to a few significant digits usually 2 or 3 digits. If the designer feels they are uncertain, if the designer feels that this representation is uncertain, then one should initiate this correction in the coding itself. So, therefore, essentially the primary focus of mechanical models is not related to the accuracy in terms of number of digits with respect to numerical model then what is the focus? They are generally focused on evaluating the outcome of behavior of the model under combination of forces that is internal strength, stresses, strain etcetera.

So, one should focus on the physical values and compare them with that of numerical model. For validation, one should not rather focus on the number of digits of accuracy in terms of comparison that is very important. To compare this, to understand the behavior of the mechanical model in terms of internal strength the most important data required could be the material property and the resistance characteristics of the element.

(Refer Slide Time: 09:09)

Now, interestingly if you look at the theoretical analysis, generally this is based on failure scenario. It combines the internal strength and their resistance which essentially are functions of the variables for reliability analysis. Therefore, failure scenario which is an important aspect of any theoretical analysis reflects the balance between the resource and the need and it is always expressed by what is called a performance function.

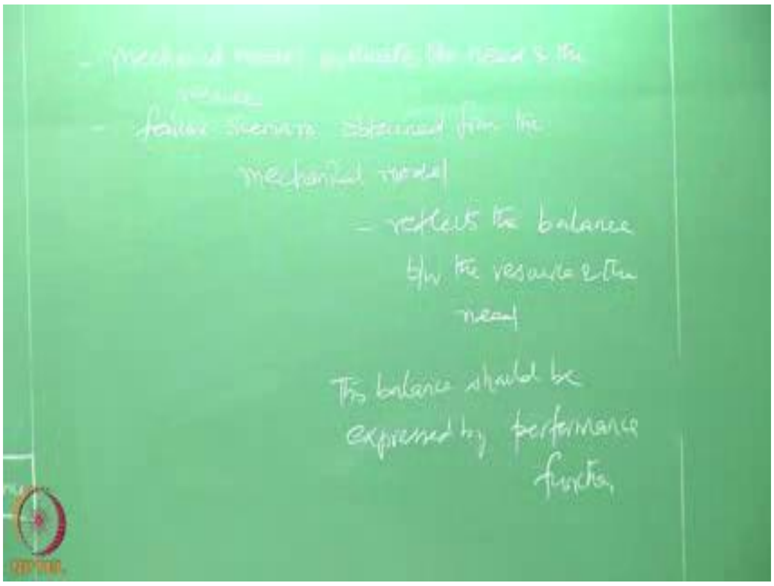
(Refer Slide Time: 11:03)



So, failure scenario always reflects the balance between the resource and the need. This should be represented ideally by a performance function. Let us look at various failure scenarios in mechanics and let us see how the failure scenario can affect, interestingly their results of reliability. Let us say, I have a physical reality, a physical reality is assets to get a quality control on that and checked for error which are gross in nature, check for error if the errors are phenomenally high. Then the physical reality which is not properly performing in the quality control should be actually stopped, one cannot go ahead with this kind of model.

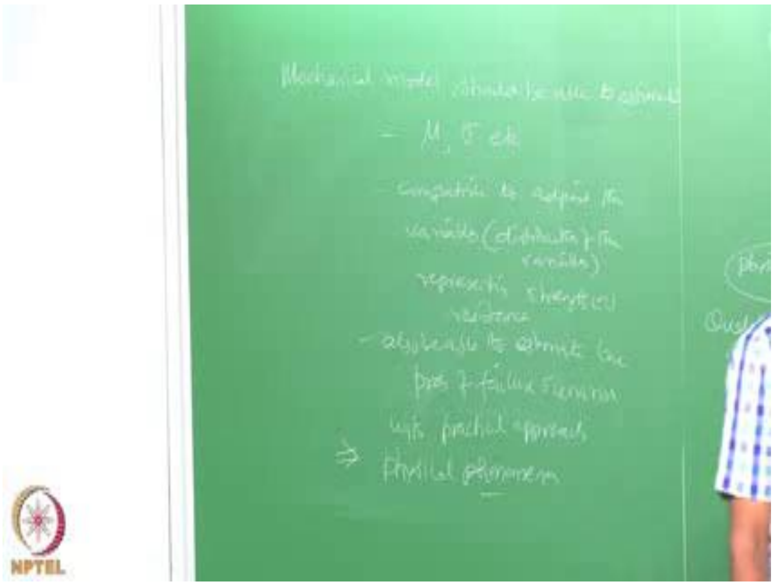
So, the physical reality should be converted to mechanical modeling that is our idea to mechanical modeling while doing. So, we do certain deviations in the model because one cannot ideally prepare exactly the physical reality into a mechanical model. Now, the mechanical model will help us to understand the internal strength. It also helps us to understand the resistance both of them together will lead to me what is call failure scenario. Now, interestingly mechanical model actually evaluates the need and the resource.

(Refer Slide Time: 14:11)



The failure scenario obtained from the mechanical model reflects the balance between the resource and the need. So, this balance should be expressed by appropriate performance function, which will be minimized for deviations because we know the mechanical model had deviations with respect to the physical model. So, the performance function should indicate and minimize this deviation such a manner that whatever results we get from the mechanical model, which are the failure scenario should truly depict the failure scenario of the physical model. So, mechanical model should be able to estimate the statistical parameter like mean, standard deviation etcetera.

(Refer Slide Time: 16:05)

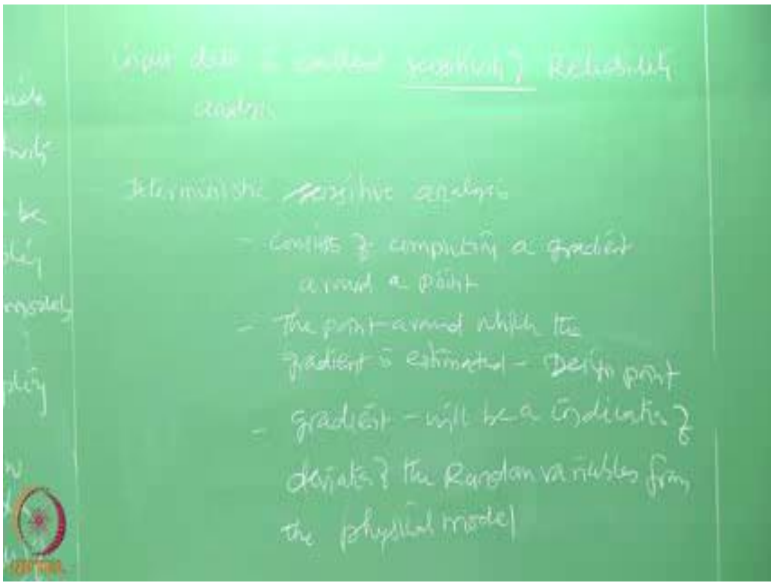


It should also have a compatibility to adjust a distribution of internal strength or resistance, if required. So, it should be compatible to adjust the variables or rather distribution of the variables representing strength or resistance. It should also be able to estimate, also be able to estimate the probability of failure scenarios with practical approach. On other hand mechanical model should depict as close as possible the physical phenomenon, but in most of the cases the failure scenarios identified or derived from the mechanical model does not really predict or explicitly show the physical phenomenon. There are some constrains in mechanical modeling which I will discuss.

(Refer Slide Time: 18:20)

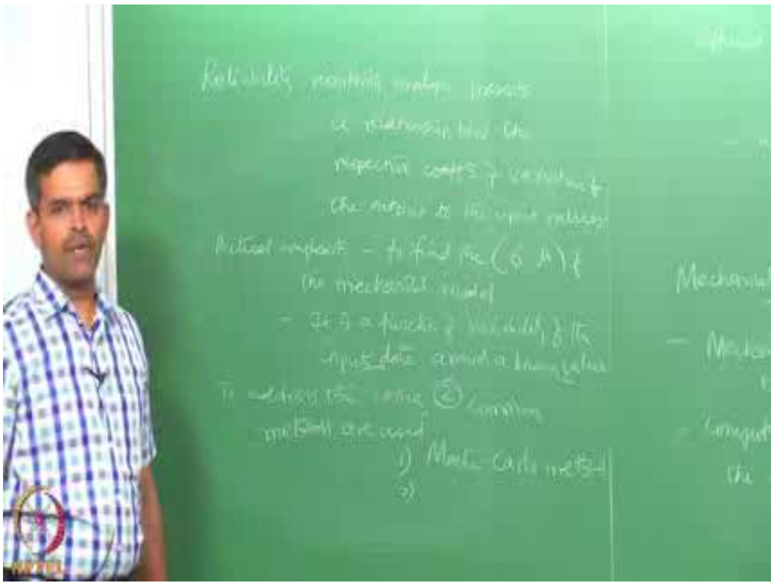
Therefore an efficient reliability analysis should provide decent reliability sensitivity. This can be achieved by applying a coupling between the mechanical and stochastic models. So, you have good reliability, sensitivity can be achieved by adopting a coupling between the mechanical and stochastic models. Now, let us talk about the coupling between the mechanical model and reliability. We all now agree and understand that mechanical model ensures transition between the input data and the output variables; mechanical model ensures transition between the input data and output variables. Therefore, computation of statistical parameters like mean and standard deviation of the output variables with respect to that of the input data is actually called sensitivity of reliability analysis.

(Refer Slide Time: 21:14)



So, sensitivity index of reliability analysis is actually a measure to check the computation of statistical output with respect to that of the input available, or given to the mechanical model, one can do what is call deterministic sensitivity analysis. It consists of computing a gradient around a point, the point around which the gradient is estimated is called the design point and gradient will be an indication of deviations of random variables from the physical model. Therefore, friends' reliability sensitivity analysis presents a relationship between the respective coefficients of variation.

(Refer Slide Time: 23:19)

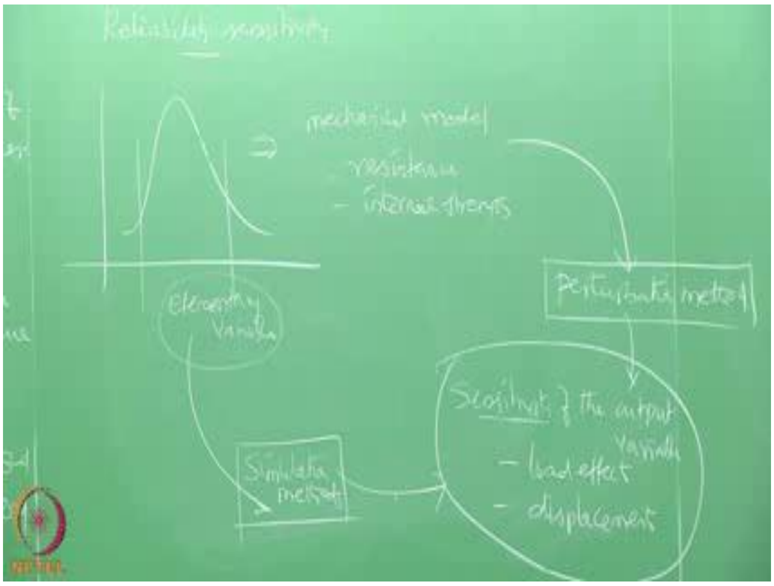


Variations of the output to the input values, the actual complexity of the reliability analysis is to really find out the statistical parameters with a response of the mechanical model. So, the actual complexity is to find the statistical parameters of the mechanical model. If I am able to locate that and then plot or estimate the sensitivity of the analysis and minimize it as far as possible, or plot deviation to know how much the variation then that can show me the success rate of the reliability index computed from the mechanical model.

Now, interestingly estimate of standard statistical parameters of the mechanical model is a function of variability of the input data around a known value because you know the input data should have, let say, the permissible stress value at 250 mega pascal, but the rate of what you are feeding in depends upon the mechanical model estimated from the experiments which does not give you exactly this value of 250. You always try to find out the difference and deviation of the data obtained, which is going to be fed as an input data around a known value, which is showing a deviation from the input data, what are giving for the mechanical model.

Now, to address this issue, two common methods are used in an analysis; one is what is called Monte Carlo method, the other is what is called perturbation method.

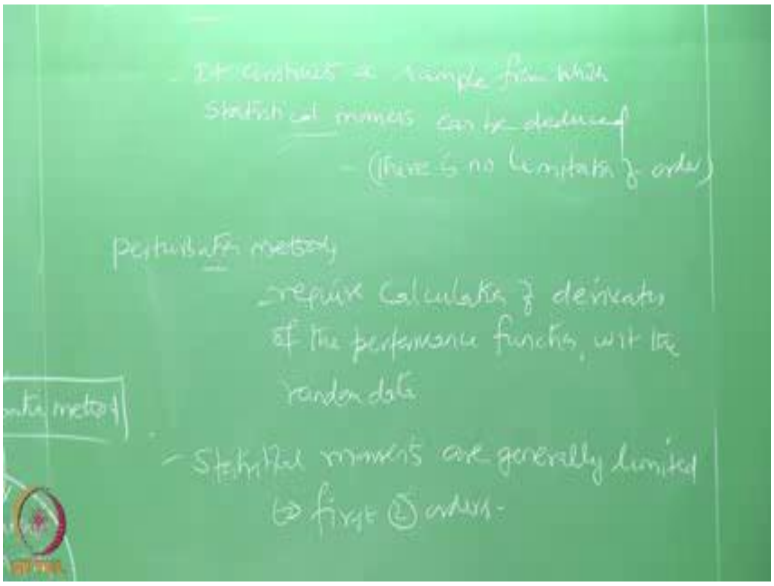
(Refer Slide Time: 26:58)



Of course Monte Carlo method proceeds by simulations, let us talk about the influence of reliability, sensitivity. Let us say, this is an elementary variable, one of the elementary variables whose probability distribution function is known to me which has got the values taken only between the min and maximum values whereas, a tail end values are not considered for the analysis. So, the mechanical model looks for the resistance and internal strength offered by the material as an elementary variable, one can use alternatively a perturbation method or simulation methods to ultimately get the sensitivity of the output variables in terms of the load effects and the displacements.

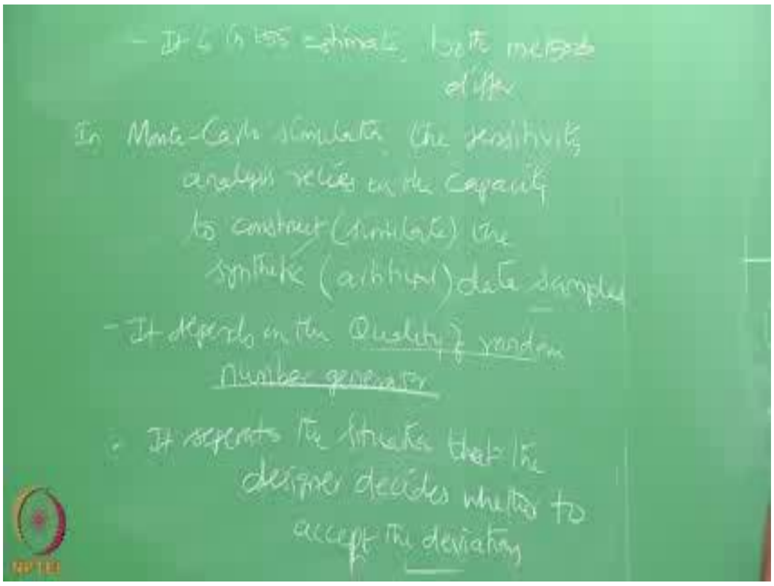
So, this layout clearly shows the importance of the function used to represent elementary variable in the mechanical model, and the influence of that function or in general the performance function which is being used to estimate the load effects or displacements which will give me the sensitivity index of the whole reliability. So, sensitivity of the output variable will indicate, essentially the deviation between the original properties represents a physical phenomenon of the elementary variable and that property used in an analysis either by perturbation methods or by simulation methods.

(Refer Slide Time: 30:10)



If you look at the simulation methods say, for example, Monte Carlo simulation method it construct the sample from which the statistical moments can be deduced. Interestingly, there is no limitation of order that is an advantage here whereas, perturbation methods require calculation of derivatives of the performance function with respect to the random data even though we talk about the estimate of statistical moments the statistical moments are generally limited to first two orders. We all said that in both the methods one should be able to estimate the deviation with respect to the most probable failure point.

(Refer Slide Time: 32:31)

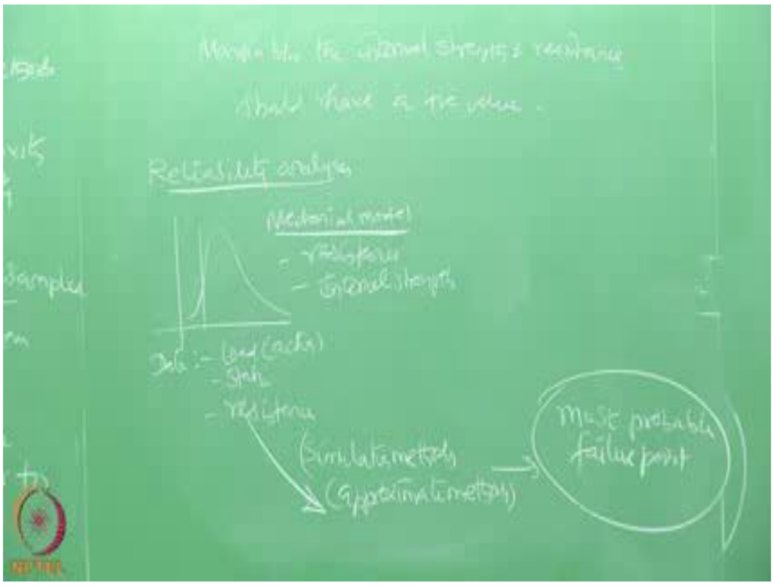


So, the most probable failure point is crucial in estimating the reliability analysis. So, it is in this estimate both methods defer. It is not that the problem formulation, it is on identifying or expressing the deviation with respect to the identified probable failure point. So, the perturbation method and simulation method deviate significantly at this stage in identifying the deviation of the performance function with respect to the critical point which we call in analysis as design point.

In Monte Carlo simulation, the sensitivity analysis released on the capacity to construct the synthetic data samples or I should say, simulate the synthetic data, artificial data samples because here the data samples are simulated they are not actually obtained from the real studies. Therefore, it depends on the quality of the random number generator which is used to generate or to create or simulate the synthetic data. It is a separate situation that the designer decides whether to accept or unaccepted the deviations.

So, the accuracy of controlling the deviations or accepting the deviations depends upon essentially the quality of the random number generator because the simulator or the simulation process essentially generates a synthetic data, which should be as close as possible to the real physical data of the random variable. While doing such simulations, it is always possible to construct two independent numerical models; one for the internal strength other for evaluation resistance.

(Refer Slide Time: 36:41)



So, there is a possibility that you can construct two independent models; one for internal strength other for calculating resistance. In such cases, the difference between internal strength and resistance is a margin which is the random variable. So, in statistical context objective reliability analysis is therefore, to evaluate the probability that this margin should have a positive value. So, the margin between the internal strength and resistors should have a positive value in statistical context. So, let us apply this concept in reliability analysis and see what happens.

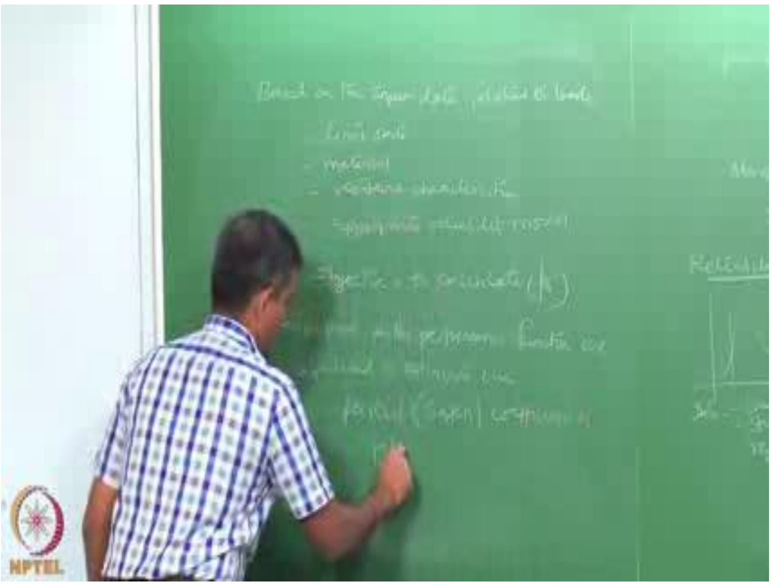
Let say, as usual I have a material strength which in elementary variable whose distribution is known to me. So, this can be a data for the analysis which can be loaded or let say, action which can be static more or less which can also show me the material resistance capacity. The mechanical model which is used for the reliability analysis should indicate the resistance and internal strength. If I use simulation methods which can be Monte Carlo that is simulation methods through which I will generate synthetic data for the random variable in terms of lower defects static and resistance of the material which we call as approximate models. Then it can lead to the most probable failure point, which is called as a design point which is very important in reliability analysis.

(Refer Slide Time: 40:11)

Therefore, friends the calculation of probability of failure which is very important in reliability analysis is generally done around the critical point which is called as a design point. So, in general if you see reliability analysis which is done using simulation methods results in searching this point that is why, if you understand the distance of the design point from the origin of a performance function should be as minimum as possible.

We call that as reliability index, for example, if a variable is non-linear or let us say linear the distance of the design value for the design point from the origin which is minimum is what we call the reliability index which we discussed in the earlier module lectures. So, in reliability analysis the sensitivity or accuracy of the analysis essentially depends on or focused on how accurately the design point is chosen, which will give me the least possible deviation between the physical representation of the material or resistance with that of the simulated variables which is indicating the strength or resistance using simulation methods.

(Refer Slide Time: 42:13)



Therefore, based on input data related to loads, limit state material resistance characteristics and appropriate reliability model because reliability model can have 4 levels of reliability. So, appropriate reliability model choice will all lead to the objectivity of the analysis, which in sense to calculate the reliability index beta which is graphically the minimum distance from the origin of the performance function at a point which is called the design point.

Therefore, this distance should be minimum distance, if the function is non-linear one has to estimate these points and these indices in many ways by iterative scheme, and minimize this difference in such a manner that will get an objective point along the failure domain of the performance function where the distance of that point from the origin should be the minimum. So, one can minimize this said because more or less an optimization problem.

It is also important to note that the probable failure points also called as design points will affect the sensitivity of the reliability analysis. Therefore, this is important that these design points are also used to evaluate partial safety coefficients in reliability analysis. So, one can say that design points on the performance function are also used to estimate the partial safety coefficients in reliability analysis therefore, one can infer that.

(Refer Slide Time: 45:19)

The numerical procedure of the reliability model excites internal strength and resistance. So, one need to apply the engineering judgment so as to compare the results obtain from the reliability analysis Monte Carlo simulation procedures or any other approximate methods a sum of these excitation strategies which are commonly used for reliability analysis

So, friends in this lecture we compared the mechanical model with that of the physical model, and tried to understand the parameters that influence the accuracy or inaccuracy of the mechanical models. If the random variables representing the load effects or internal strength of the material are simulated using numerical procedure to obtain the failure of the performance function which is nothing, but the reliability analysis in that case, the whole problem amounts to identifying or locating the design point of the performance function.

The design point is that point which indicates me the minimum distance from that of the origin or the performance function. Graphically, if there are many number of design points for a non-linear performance function one can always land up and estimating what we call not the correct reliability or safety coefficient, but partial safety coefficients it is because of this problem that exactly the reliability index cannot be obtained for a non-linear performance function, people always use these safety coefficients as partial safety coefficients.

So, friends I hope you understand the coupling between the mechanical model and the reliability analysis. In the next lecture, we will try to show you how the mechanical model can impose complexities in estimating the true behavior of a given system

Thank you very much