NPTEL course offered by IIT Madras

Risk and Reliability of Offshore structures

Tutorial 1: Introduction to Reliability

Answer all questions **Total marks: 25**

1. Identify two major challenges that are faced by designers of offshore platforms in the recent past

Offshore structures are designed to remain more flexible to alleviate environemntal loads, effectively. FORM-dominant design are becoming more popular and replaces the concept of strength-based deisgn.

They need to remain robust and safe at all levels of operations.

Use of new and innovative materials for topside construciton demand detailed understanding of mechancial properties of materials under various stages of functioning.

2. What uncertainties make the analysis and design of offshore structures complex?

Randomness in environmental loads increases uncertainties during various stages namely: planning, analysis, design and construction/erection stages of offshore structures. Levels of complexities increase mainly due to i) error in accurately estimating the environmental loads anticipated on the offshore platform during its service life; and ii) complexities that arise from construction process and techniques used in offshore construction projects.

3. What are the major advantages that Reliability methods possess?

Reliability methods have many advantages namely: i) offering a realistic possession of uncertainties; ii) offering methods to evaluate safety factors, which are otherwise chosen arbitrary; iii) offering decision-making support for more economic and better-balanced design; iv) enabling to analyse different modes of failure and measure the reliability provided by application of code regulations; v) allowing an optimal use of materials amongst various components of the structure; and vi) enabling to expand the knowledge of uncertainties in the response of structures. In general, reliability methods project the overall process of analysis, design and construction of offshore structures as a probable solution and not exact ones. Hence, the decisions, supported by experience are always questioned for a better alternative.

4. List serious limitations possessed by Reliability methods

There exist a few limitations namely: i) probabilities (to a major extent) and statistics (to a lesser extent) are more a part of mathematician's knowledge who can doubt rather than that of the engineer, who must have certainties; and ii) explicitly underscoring the acceptance of a risk, which is only an implicit. Even it shall be justified by using safety coefficients, but it steel needs an engineering-based judgement to support the decision process. While uncertainties are expressed in probabilistic terms for their better representation, failure is also then expressed in terms of probability. This also confirms the fact that there is some degree-of-uncertainty in assessing the failure of any structure. In general, failure is assessed by inability of the structure to perform its intended function adequately on demand for a specified period; it is very important to note that the assurance is true only under *specific conditions*. Conversely, reliability is expressed in terms of success of a system to sustain the demand expected from it. Reliability is also expressed in terms of probability indicating the following vital parameters namely: i) quality of performance; ii) over an expected period; and iii) to perform under *specific conditions*. This is the genesis of reliability, being implied as the probability of success to perform the intended function. Reliability implies estimate of limit state probabilities of a structure under critical demand. Safety is generally used to indicate reliability, which is more a traditional concept.

5. Define Risk and Reliability

Reliability is defined as probability that a facility will perform its intended function for a specific period, under defined conditions. It is expressed as converse of failure (as R = 1-Pf), where Pf is the probability of failure. Risk is defined as a measure of magnitude of a hazard. Two constituents of risk are probability of failure (P_f) and frequency of failure (h_f) of a damaging event, E.

6. Explain risk assessment

Risk assessment deals with two fundamental questions namely: i) what could happen in what way and how often?; ii) what may be allowed to happen, how often and where?. Answering the above two questions will lead to Risk assessment. For an offshore structural engineer, if the assessment turns out to be negative, further questions need to be answered is what suitable measures are needed to provide the required safety? Then he has to ensure that appropriate measures are put in place to guarantee proper functioning. Reliability is focused on those problem areas that are not realized by the society directly but those challenge safety indirectly. It is interesting to know that risk assessment from failure analyses of structures does not generate discussions but only lead to rules and recommendations. However, reliability opens into an engineering questionnaire that shall lead to a better understanding of (probability of) failure

7. What are different types of uncertainties? Explain them in detail

There are different types of uncertainties namely: i) those arise from the parameters; ii) variables that are vital input for analysis and design; iii) those arise from mathematical modelling; iv) those arise from the mathematic algorithms being used in the analysis and design; v) those arise during experimental investigations that are carried out to calibrate the response parameters of the chosen structural geometry; and vi) those arise from interpolating the response parameters of a prototype from that of the experimental or numerical simulations.

Parameter uncertainties arise from the input to mathematical model for analysis and design. They remain uncertain as their exact values due to many reasons namely: i) they are unknown to experimentalists; ii) they cannot be controlled during the experimental investigations; and iii) their values cannot be exactly inferred by any statistical methods. A few examples are damping estimates in offshore structures, compatibility behaviour at connections (joints), coupling effect of different degrees-of-freedom in their real extent, effect of P-M interaction of universal joints (see, for example, offshore triceratops) etc. Parametric variability arises from the input variables of the physical or numeric model. For example, limitations in the number of finite element mesh, cross-sectional dimensions of ball joints in hinged connections, tether tension variations that arise from the seismic activities at the seabed etc. may not be exactly modelled as designed, which would cause variability in its performance.

Structural uncertainties arise from the inaccuracy of mathematical model that shall simulate the real time behaviour of offshore structures under installed conditions. It is a known fact that numerical models approximate reality and cannot be modelled accurately. For example, it is difficult to model the behaviour of pinned connections, as required in Articulated Towers under the combined action of axial load and moment. In addition, damping that arise from the geometric interferences of members in the top side that can cause serious variations in wind load estimates are difficult to model. In such cases, even if there are no unknown parameters in the model, a discrepancy is still expected between the model and the true physics.

Algorithmic uncertainties arise from the approximations per implementation of the analytical models. As the solution of equation of motion of offshore structures is generally iterative, numerical methods are used to solve the system of equations; most models are too complicated to solve exactly. For example the finite element method or finite difference method may be used to approximate the solution of a partial differential equation, which, however, introduces numerical errors. Numerical integration methods inherently deal with the infinite sum truncation that is necessary approximations in the scheme of numerical implementation.

Experimental uncertainties arise from the variability of experimental measurements. Experimental investigations, which are inevitable part of the analysis of offshore structures, are generally circumscribed by serious limitations that arise from electronic sensors.

Experimental uncertainties are inevitable and can be easily realized by repeating a set of measurements for many times using exactly the same settings for all inputs/variables. Interpolation uncertainties arise from the lack of available data collected from computer model simulations and/or experimental measurements. For other input settings that don't have simulation data or experimental measurements, one must interpolate or extrapolate in order to predict the corresponding responses.

The problem is more serious if the physical model of the structure does not represent the appropriate mass of the proto type for simulating the real dynamic behaviour.

8. List the rules of probability, which are useful for reliability analysis

The following important rules of probability that are frequently employed in reliability studies are derived from the understanding of plausible reasoning:

Rule 1:

Let E be the event to occur. P[E] is a simple number to express the confidence in the occurrence of that event. Thus P[E] is the probability that translates mathematically and consistently the confidence in occurrence of event E. This is called subjective probability

Rule 2:

Let E be the event of interest.

$P[E] \neq P[E|H]$

This statement implies that probability of event E is now different from that of the earlier ones. Hence, with the known hypothesis (H), knowledge status changes the probability of the event, E but always conditional to the given hypothesis.

Rule 3:

In estimating P[E], there can be other alternatives. All the alternatives put together is called as *space of events, S*. P[S] = 1; this is a union of all possible alternative events. Hence, following statement is valid:

S= U{EUCUSUF} and P[S] = 1

Rule 4:

If we now group the alternative events as “either E can occur or everything else can occur”, then the following statement holds good:

P [EUA] = P[E] + P[A]

The above statement valid under the condition that A and E are mutually exclusive. If they are not mutually exclusive, then following statement is valid:

P [EUA] ≠ P [E] + P [A]

Rule 5:

For a given event E, we assign either of the following:

P[E] = 0 when for sure, event E will not occur

P[E] = 1 when for sure, E will occur

$P[E] \epsilon [0.1]$ implies that E can happen, probably.

Rule 6:

$P(E|C) = \frac{P[E \cap C]}{P[C]}$

Rule 7:

$P[E \cap C] = P[E|C].P[C] = P[C|E].P[E]$

Rule 8:

$P[E \cup C] = P[E] + P[C] - P[E \cap C]$

Rule 9:

For $P[E|C]$ is known and $P[E|\bar{A}]$ is also known, P[E] is given by the following relationship:

$P[E] = P[E|C].P[C] + P[E|\bar{C}].P[\bar{C}]$

This is called T*otal Probability Theorem*.

Rule 10:

Given event E, what is the probability that this event is occurring due to the occurrence of a specific event I? This is a reverse problem and can be estimated using Baye's Theorem, as given below:

$$P[I|E] = \frac{P[E \cap I]}{P[E]}$$

$$= \frac{P[E|I].P[I]}{P[E]} = \frac{P[E|I].P[I]}{P[E|I].P[I] + P[E|\bar{I}].P[\bar{I}]}$$

9. Explain how plausible reasoning is useful in Reliability analysis

Rules of thinking are generally termed as plausible reasoning. Probability theories are complex in nature and one finds it difficult to learn as it tries to model everything that a human brain shall think. However, system for probability, based on plausible reasoning looks like abstract in the beginning but everything becomes derivable, leaving no chance for confusion.

10. How safety, reliability and Risk are different?

Reliability is defined as probability that a facility will perform its intended function for a specific period, under defined conditions. It is expressed as converse of failure. Risk is defined as a measure of magnitude of a hazard. Two constituents of risk are probability of failure (Pf) and frequency of failure (hf) of a damaging event, E. Reliability is focused on those problem areas that are not realized by the society directly but those challenge safety indirectly. It is interesting to know that risk assessment from failure analyses of structures does not generate discussions but only lead to rules and recommendations. However, reliability opens into an engineering questionnaire that shall lead to a better understanding of (probability of) failure. Reliability implies estimate of limit state probabilities of a structure under critical demand. Safety is generally used to indicate reliability, which is more a traditional concept.