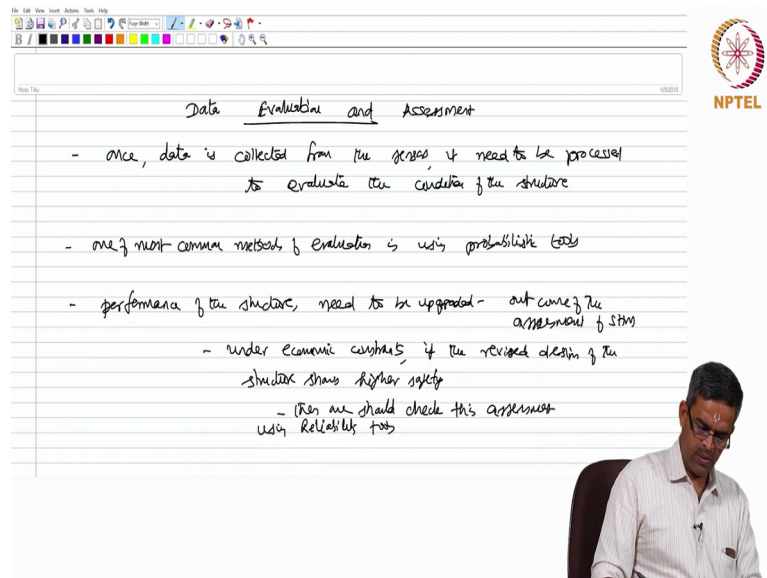


Structural Health Monitoring (SHM)
Prof. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Lecture – 20
Part – 2: Data Evaluation and Assessment

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Data Evaluation and Assessment

- once, data is collected from the sensors, it needs to be processed to evaluate the condition of the structure
- one of the most common methods of evaluation is using probabilistic tools
- performance of the structure, needs to be upgraded - outcome of the assessment of SHM
 - under economic constraints, if the revised design of the structure shows higher safety
 - then one should check this assessment using reliability tools

Having said this let us talk about the importance of Data evaluation and Assessment. Friends, once data is collected from the sensors this data need to be processed to evaluate the condition of the structure. One of the most common methods of evaluation is using probabilistic tools.

So, let us say the performance of the structure need to be upgraded which is one of the important outcome of assessment of the structure under health monitoring. So, later let us say under the economic conditions and economic constraints if the revised design of the structure shows higher safety then one should check this assessment using reliability tools.

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Reliability-based classification is also important in such cases

✓ S. Chandrasekaran. Risk & Reliability of offshore structures, NPTEL, IIT Madras

S. Chandrasekaran. 2016. Risk & Reliability of offshore structures, CRC press, USA

So, reliability based calculation and classification is also important in such cases. So, for your extra knowledge and reading there is a course in NPTEL risk and reliability of offshore structures which is done by me and NPTEL at IIT, Madras this can be useful additional reading for people to know more about reliability based calculations for estimating the risk on a given structure.

One can also refer to my textbook risk and reliability of offshore structures under CRC press. So, just for the interest of viewers let us cover some fundamental on this now.

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For satisfactory performance of the structure, following conditions should be satisfied:

$$R \geq S \quad \checkmark$$

where R : resistance of the structure
 S : load effect on the structure

To obtain load effect on the structure, distribution of loads, intensity

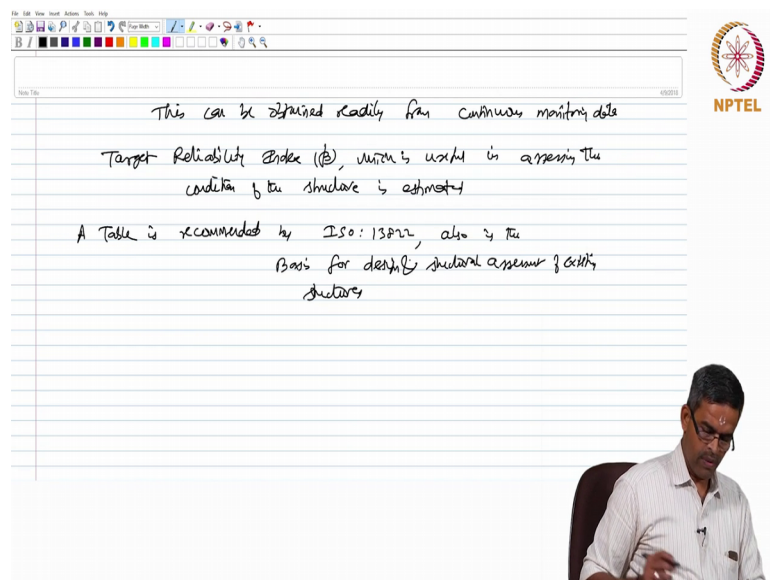
- location
- intensity
- time/space dependence
- direction etc

Variables that time dependent need to be known

We do agree as the reliability that for a satisfactory performance of the structure following condition must be satisfied R should exceed S , where R is the resistance of the structure and S is the load effect on the structure.

Now, to obtain the load effect on the structure distribution of loads in terms of its location, intensity, time and space dependence, direction etcetera which are all variations that are time dependent need to be modeled I should say it need to be known to estimate this relationship.

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The image shows a digital whiteboard interface with a toolbar at the top. The whiteboard contains the following handwritten text:

- This can be obtained readily from continuous monitoring data
- Target Reliability Index (β), which is useful in assessing the condition of the structure is estimated
- A Table is recommended by ISO: 13822, also is the basis for design of structural assessment of existing structures

In the bottom right corner, there is a small inset video of a man with glasses, wearing a light-colored shirt, sitting in a chair and speaking. The NPTEL logo is visible in the top right corner of the whiteboard area.

Now, the best solution is this variation can be obtained readily from a continuous monitoring data based on that target reliability index beta which is useful in assessing the condition of the structure is estimated.

So, a table is being recommended by ISO 13822 which also is the basis for design of structures or design of structural assessment of existing structures design and structural assessment. Let us see what is this table?

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Limit state	β	Reference period
a) serviceability		
i) reversible	0	} to calculate remaining service life
ii) irreversible	1.5	
b) fatigue		
i) can be inspected	2.3	} - remaining service life limit
ii) cannot be inspected	3.1	
c) ultimate		
i) very low consequence of failure	2.3	} To design for service life limit (about 50y)
ii) low consequence of failure	3.2	
iii) medium consequence of failure	3.8	
iv) high consequence of failure	4.3	

It is varying for different limit states. So, let us say a column like limit state target reliability index and what is the reference period? As recommended by ISO 13822. There are three states of limit states as we indicate here; serviceability fatigue limit state and ultimate limit state.

Under serviceability if I have reversible or irreversible the reliability index is 0 and 1.5 which is useful to calculate the remaining service life of the structure. For fatigue reliability the condition saw if the structure can be inspected or it cannot be inspected the structure can be inspected then target reliability index is 2.3 if not is 3.1 which will also help you to calculate the remaining service life of the structure.

For ultimate limit state there are four categories; very low consequence of failure, low consequence of failure, medium consequence of failure and high consequence of failure. So, it is classified based on the consequence of failure and the reliability indexes are 2.3, 3.2, 3.8 and 4.3. They are actually used to design for service life of the structure, usually the service life design is about 50 years.

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relationship b/w (β) & P_f .

$$\beta = \Phi^{-1}(P_f)$$

P_f	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
β	1.3	2.3	3.1	3.7	4.2	4.7	5.2

safety class

			1	2	3		
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In general P_f is given by: $P_f = P(R - S \leq 0)$
where (R, S) are stochastic variables

The slide also features a software toolbar at the top, an NPTEL logo in the top right, and a photograph of a man in a white shirt in the bottom right corner.

Now, let us see the relationship between the target reliability index beta and the probability of failure. Beta is actually given by the phi function inverse of probability of failure, where the table says probability of failure and beta are connected by a simple figure for different values of failure 10 power minus 2, minus 3, 4, 5, 6 and 7; 1.3, 2.3, 3.1, 3.7, 4.2, 4.7 and 5.2.

However, friends, interestingly there is a safety class which is also introduced depending upon the reliability index. So, this safety factor or safety class is 1 and 2 and 3. So, in general if I know the probability of failure I can find the index or if I know the reliability index. I can always check what is my probability of failure of a given system which, tells me the assessment of the structure, which is actually accumulated and collected from the continuous monitoring data.

So, in general probability of failure is given by the following expression which is probability of R minus S exceeds 0, where R and S stochastic variables.

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But, as the structures with same classification are designed for equal load with different material,
design codes recommend partial coeffs

Design value (f_d) will be based on
partial factor for material
partial factor for load effects
model uncertainty
& load estimate error

But, as the structures within same classifications are designed for equal loads with different material there are need to be a modification to the estimate of probability of failure as we discussed in the previous slide.

So, therefore, design codes recommend partial coefficients. The design value which is f_d will be based on the partial factor for material, partial factor for load effects to cover the modeling uncertainties and error in load estimates.

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$$f_d = \frac{f_k}{\gamma_m \gamma_l} \cdot \frac{1}{\gamma}$$

f_k = stress capacity, which is reduced by the factor (γ_m) ($1/\gamma_m$)
 γ_m = load capacity factor
 γ = model uncertainty,
gives account for scaling up the test results & full scale structures.

So, f_d is given by f_k by γ_m and γ_n , k by η ; where f_k is the stress capacity which is actually reduced by the factors γ_m and γ_n ; k refers to load capacity failure, sorry load capacity factor and η refers to the value accounting for model uncertainties and effect accounting for scaling up the lab scale results to full-scale structure.

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The slide is titled "Summary" and contains the following bullet points:

- local & global monitoring
- static & dynamic monitoring
- different sensors, different phenomena
states of H/M
- Data assessment & evaluation
- Reliability tool to assess condition of the structure
- P_f - linked to β - partial factor is given.

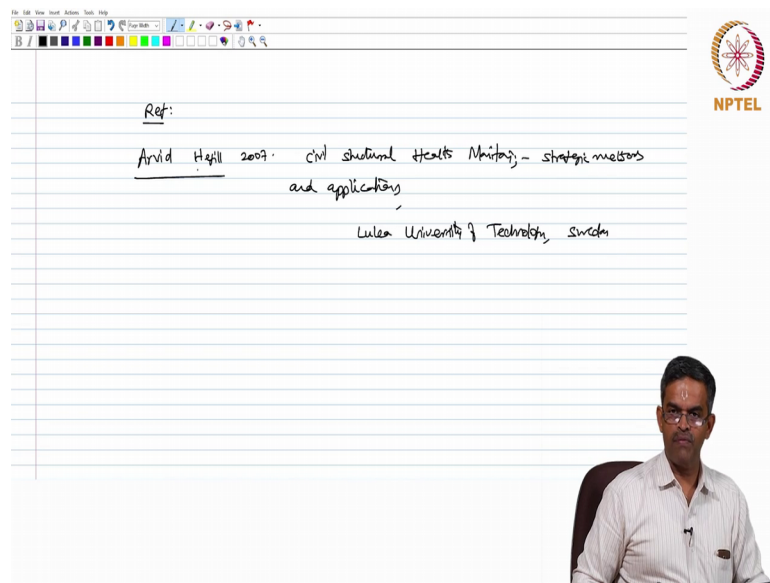
The slide also features the NPTEL logo in the top right corner and a small inset video of a man in a white shirt speaking in the bottom right corner.

So, friends, in this lecture we learnt about local and global monitoring. We understood what conditions static and dynamic monitoring are carried out. We also learned use of different sensors for different monitoring phenomena and different states of health monitoring like local, continuous, periodic and triggered monitoring.

We also learned the importance of data assessment and evaluation. We learnt the use of reliability as a tool to assess condition of the structure whose data is actually supplied from the continuous monitoring system and we also learned how the probability of failure is linked to the reliability index and why we use partial factors in design.

We will continue with the discussion in the next lecture and explain different methods of monitoring further in detail where we talk about damage identification and how to actually plan for a structural health monitoring scheme.

(Refer Slide Time: 17:18)



Ref:

Arvid Hejill 2009. Civil structural Health Monitoring - strategic methods and applications,
Lulea University of Technology, Sweden

So, that is a good reference which you should read to learn more about this the good reference is Arvid Hejill, 2009, Civil Structural Health Monitoring - strategic methods and applications, Lulea University of Technology, Sweden. We give credits to this author for highlighting important methods of health monitoring in civil infrastructure.

Thank you very much.