

Structural Reliability
Prof. Baidurya Bhattacharya
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture –07
Introduction (Part - 07)

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Structural Reliability
Introduction

Managing uncertainties


- Manifestation of uncertainties
 - At design stage
 - At construction stage
 - In service
- In Nature
 - Loads (winds, waves, earthquakes etc.)
 - Aging effects
- In People's behavior
 - Changed usage (live loads etc.)
 - Negligence
 - Intentional harm
- In System properties
 - Material
 - geometric
- Models and computations
 - Idealization
 - Ignorance

"The laws of structural design must be considered a combination of functional and statistical relationships – functional so far as the laws of the theory of structures are concerned and statistical to the extent that real physical properties appear as parameters of the functional relations. There are cases in which apparently functional relations are intrinsically statistic."

"[The safety margin] must provide for (1) the imperfection of human observations and actions (uncertainty); (2) the imperfections of intellectual concepts devised to reproduce physical phenomena (ignorance)"

"With increasing perfection of design methods ... "ignorance" can be largely eliminated; but ... "uncertainty" ... can never be removed. Hence the safety factor is a measure of uncertainty rather than of ignorance."

-Alfred M. Freudenthal, "The safety of structures," 1947



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Now in the context of structural systems what are these uncertainties that we must be aware of and where are they? You will find them in all stages the design stage the construction stage and throughout the structure service life. You will find them in nature natural hazards and processes that cause aging we find them in the behavior of people who use them and are supposed to take care of them in the strength properties of the system in models through which we analyze the structural systems and the computations that we perform in order to get the answers.

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Managing uncertainties

- Acknowledging and identifying the presence of uncertainties
- Estimation and modelling of uncertainties
- Analyses involving randomnesses
- Decision-making



So, once we acknowledge and identify the presence of these uncertainties how do we handle them and provide the best engineering solutions. The first important step is to estimate and model these uncertainties appropriately through the using theory of probability through random variables, stochastic processes, random fields as appropriate. Analyze the structure by including all relevant randomness's and then take the best decisions.

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Managing uncertainties

In 1849 the Royal Commission appointed to investigate the use of iron in railway bridges asked of the prominent engineers of the time:

"What multiple of the greatest load do you consider the breaking weight of the girder ought to be?"

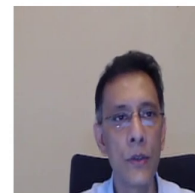
The answers ... ranged from 3 to 7.

And when asked, **"With what multiple of the greatest load do you prove a girder?"**

the panel responded with factors ranging from 1 to 3.

The commission concluded that an appropriate factor of safety for railway bridges would be 6.

- From To Engineer is Human by Henry Petrosky, Vintage Books, 1992 (bold fonts by BB).



Now this thinking is not new as early as the middle of the 19th century engineers were trying a systematic method to find factors of safety and counter these uncertainties.

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Example - factor of safety : For mild steel in US:

| Year | Yield strength (MPa) | Factor of safety | Allowable stress (MPa) |
|------|----------------------|------------------|------------------------|
| 1890 | 197 | 2 | 97 |
| 1918 | 190 | 1.72 | 110 |
| 1923 | 228 | 1.83 | 124 |
| 1936 | 228 | 1.65 | 138 |
| 1963 | 250 | 1.67 | 152 |

Taken from "Design codes" by T. Galambos in Engineering Safety, Ed. Blockley, 1992

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This table which shows the evolution of factor of safety for mild steel in the US in the starting from the late 19th century to the middle of the 20th century it also reflects the same thought process to be able to ensure against all that might go wrong but not waste resources in the process. And the sudden and temporary decrease in the fact of safety during the middle of the world war one is a testament to that thinking.

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Partial Safety Factors in Design - example

AISC LRFD

$$\phi R > 1.2D + 1.6L$$

$\phi = 0.85$ for compression

BS 5950

$$\phi R > 1.4D + 1.6L$$

$\phi = 1.0$ for compression


AASHTO LRFD

$$\phi R > 1.25D + 1.5D_d + 1.7(1+I)L$$

$$\phi = \begin{cases} 0.95 & \text{steel girders in moment and shear} \\ 1.00 & \text{PCC girders in moment} \\ 0.90 & \text{RCC T-beams in moment} \\ 0.85 & \text{PCC and RCC in shear} \end{cases}$$

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More recently we see that the dawn of partial factors of safety not just one safety factor but more

than one to account for multiple sources of uncertainty the AISC LRFD the load and resistance factor design the old British standard the ASHTO LRFD.

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Partial Safety Factors in Design - example

EN1990:2002

Design value of action effects:

$$E_d = \sum_{j \geq 1} \gamma_{G,j} G_{k,j} \oplus \gamma_p P \oplus \gamma_{Q,1} \psi_{0,j} Q_{k,1} \oplus \sum_{i \geq 2} \gamma_{Q,i} \psi_{0,i} Q_{k,i}$$


Design resistance:

$$R_d = \frac{1}{\gamma_{R_d}} R \left\{ \eta_1 \frac{X_{k,1}}{\gamma_{m,1}}, \eta_2 \frac{X_{k,2}}{\gamma_{m,2}}, \dots, a_d \right\}$$

Verification:

$$E_d \leq R_d$$

G_k = characteristic permanent actions
 Q_i = characteristic variable actions
 $\gamma_p, \gamma_G, \gamma_Q$ = partial load factors
 a_j = design geometric quantities
 X_k = characteristic material properties
 γ_m = material partial factors
 η = adjustment factors
 $\oplus \Sigma$ = nonlinear combinations



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And more recently the EURO codes that we use today.