Risk and Safety

in

Civil, Surveying and Environmental

Engineering

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Contents of Presentation

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- Structural reliability and safety formats
- Code calibration as a decision problem
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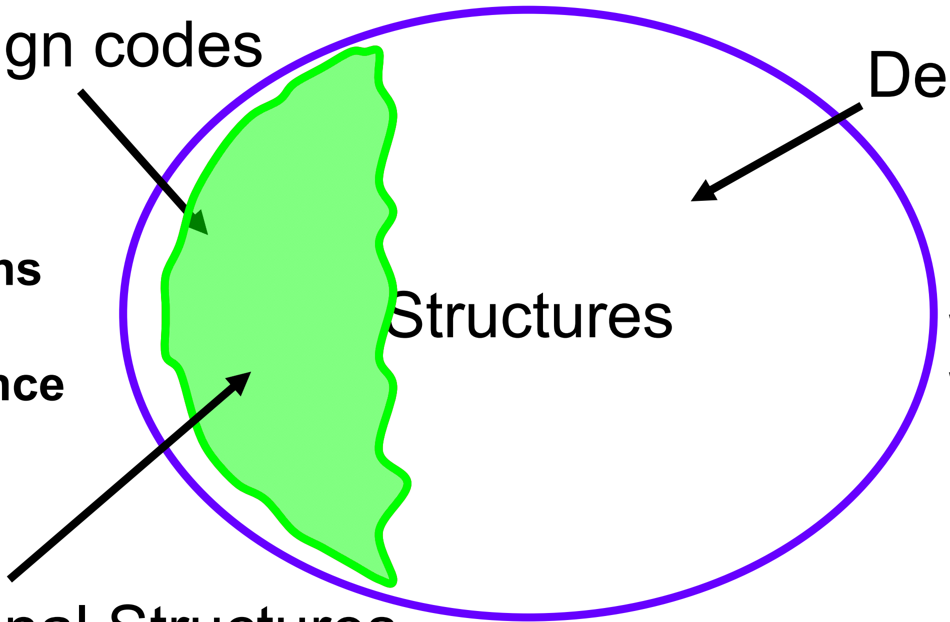
- The JCSS approach to code calibration
- The software CodeCal – for calibration of design codes

Codes and design of structures

- “Normal structures” are designed according to structural design codes

New purposes
Unusual designs
New materials
New maintenance



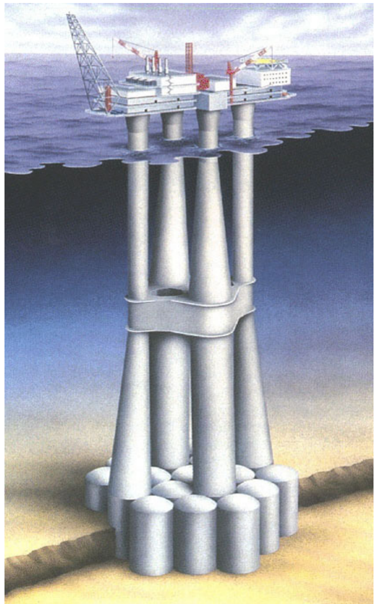
Normal purposes
Common design
Well known materials
Well tested maintenance

Codes and design of structures

- Exceptional structures are often associated with structures of

"Extreme Dimensions"

Great Belt Bridge under Construction

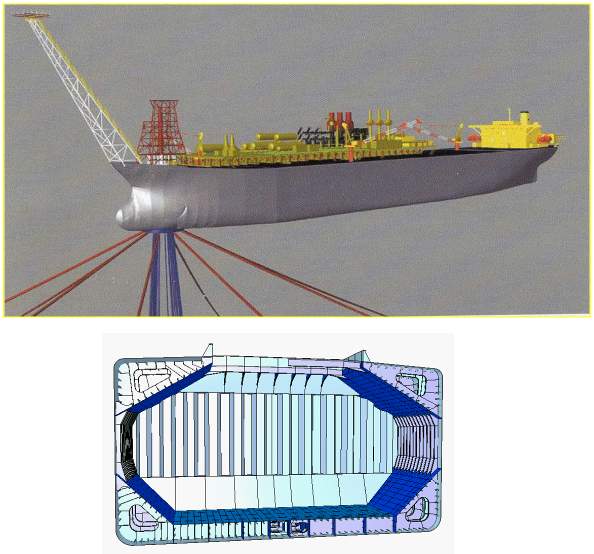


Concept drawing of the Troll platform

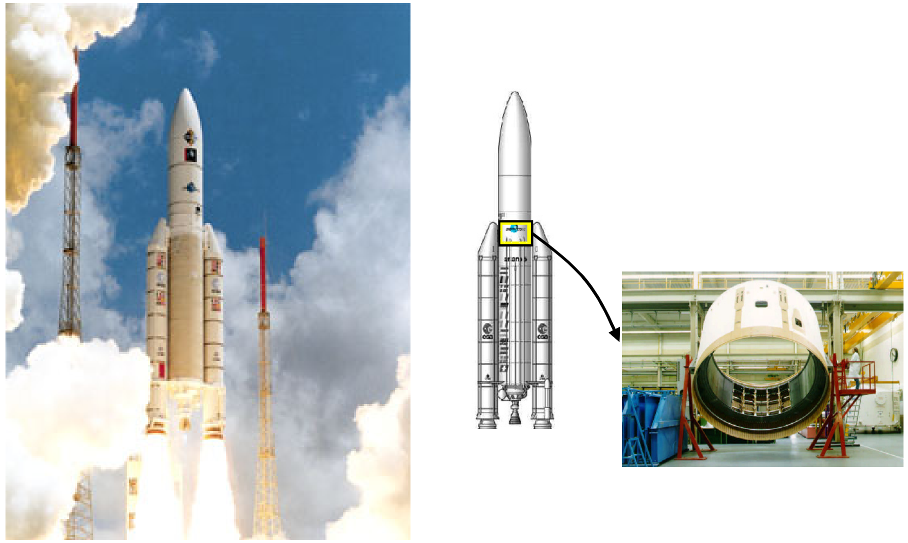
Codes and design of structures

- or associated with structures fulfilling

“New and Innovative Purposes”



Concept drawing of Floating Production, Storage and Offloading unit



Illustrations of the ARIANE 5 rocket

Structural reliability and safety formats

Structural performance is subject to uncertainty due to:

- Natural variability in material properties and loads or load effects
- Statistical uncertainties due to lack of or insufficient data
- Model uncertainties due to idealisations and lack of understanding in the physical modelling of the structural performance

Structural reliability and safety formats

- Structural performance may be treated in probabilistic terms by means of limit state functions

  i.e. defining the events of special concern (large consequences) – failure events such as

  - Collapse
  - Inserviceability
  - Deterioration

  } Failure Events

  as functions of the most important uncertainties – the basic random variables

$$F = \{ g(\mathbf{x}) \leq 0 \}$$

Failure Events

Limit state functions

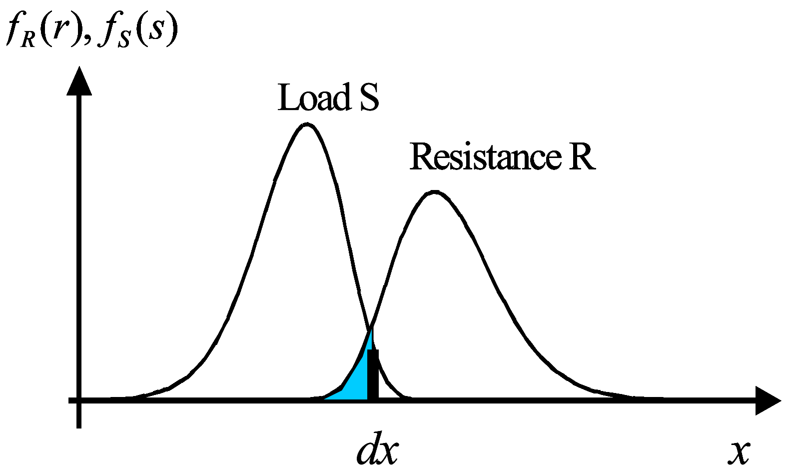
Outcome of basic random variables

Structural reliability and safety formats

- The fundamental case

$$P_F = P(R \le S) = P(R - S \le 0) =$$

$$\int_{-\infty}^{\infty} F_R(x) f_S(x) dx$$



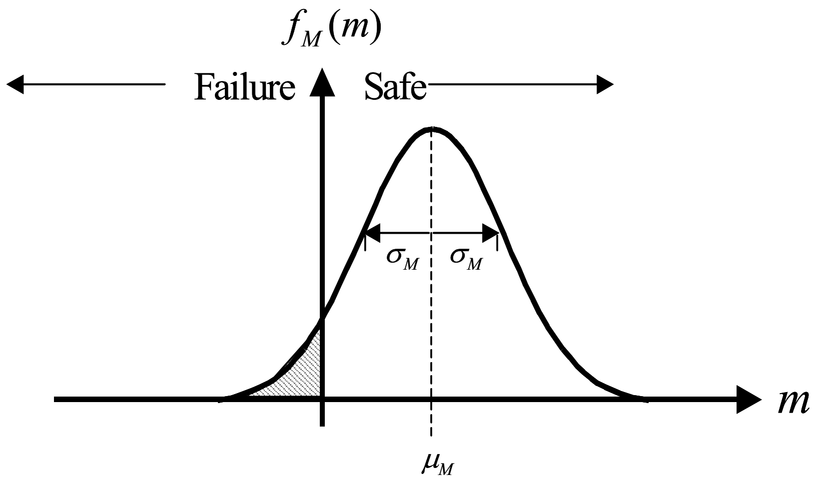
- Normal distributed safety margin

$$P_F = P(R - S \le 0) = P(M \le 0)$$

$$\mu_M = \mu_R - \mu_S$$

$$\sigma_M = \sqrt{\sigma_R^2 + \sigma_S^2} \qquad \mu_M / \sigma_M = \beta$$

$$P_F = \Phi\left(\frac{0 - \mu_M}{\sigma_M}\right) = \Phi(-\beta)$$



Structural reliability and safety formats

- The probability of failure in regard to:

  - Ultimate collapse

  - Loss of serviceability

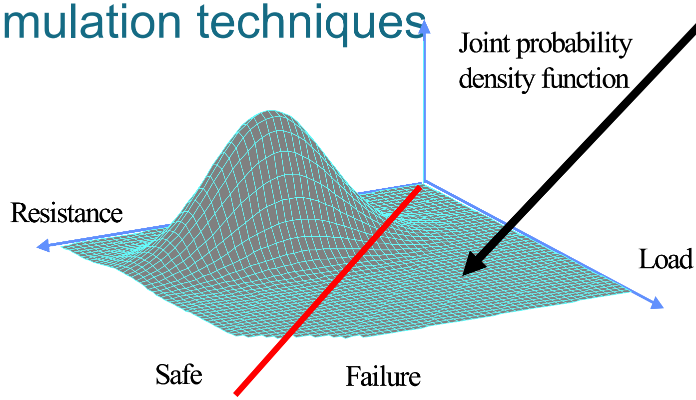
  - Excessive deterioration

  may then be assessed by evaluation of probability integrals using e.g. FORM/SORM or simulation techniques

$$P_f = \int_{g(\mathbf{x})\leq 0} f_{\mathbf{X}}(\mathbf{x})d\mathbf{x}$$

Failure event

Joint density function for the basic random variables



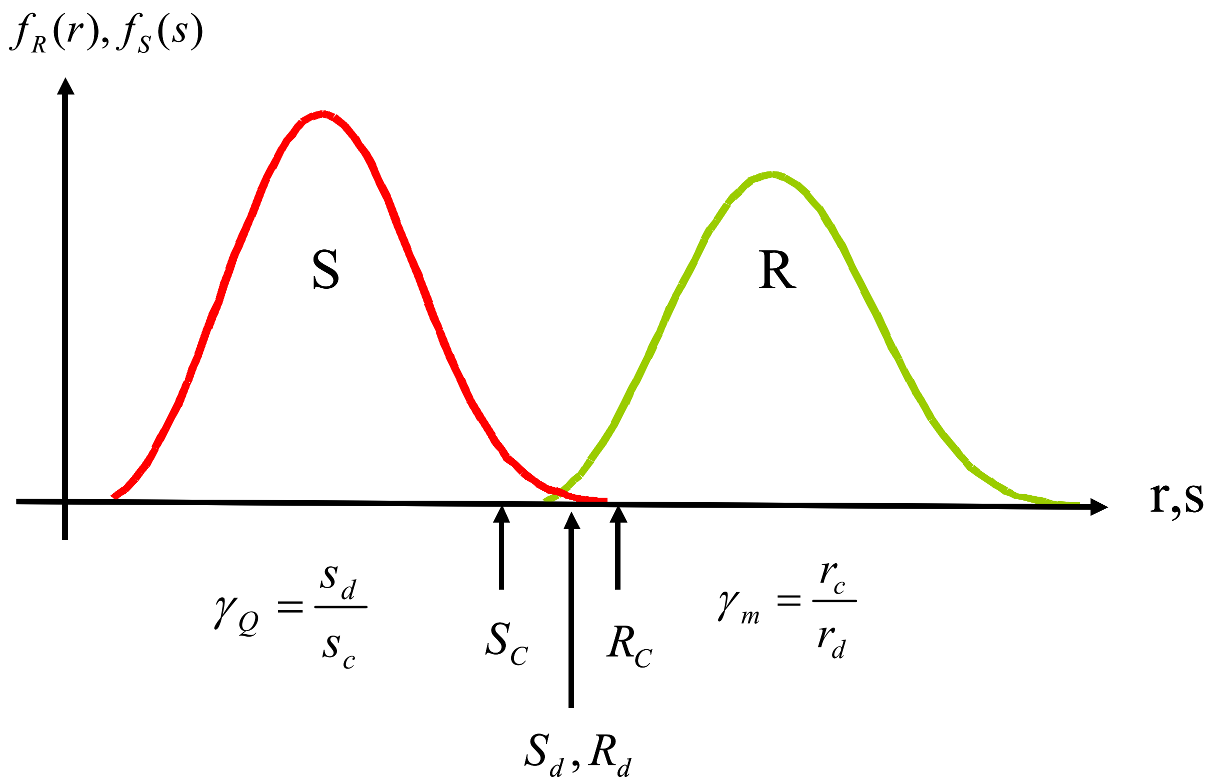
Structural reliability and safety formats

- The Load and Resistance Factor Design safety format is built up by the following components

Design situations	Ultimate, serviceability, accidental
Design equations	$g = \mathbf{z}R_c / \gamma_m - \left(\gamma_{G_a} G_c + \gamma_Q Q_C\right) = 0$
Design variables	$\mathbf{z}$
Characteristic values	$G_C \quad Q_C$
Partial safety factors	$\gamma_m \quad \gamma_G \quad \gamma_Q$
Design values	$\gamma_m = \frac{x_c}{x_d} \qquad \gamma_Q = \frac{x_d}{x_c}$

Structural reliability and safety formats

- The results of a FORM/SORM reliability analysis can be related to the parameters of a LRFD safety format



Code calibration as a decision problem

- The code calibration problem can be seen as a decision problem with the objective to maximize the life-cycle benefit obtained from the structures by "calibrating" (adjusting) the partial safety factors

$$\max_{\gamma} \quad W(\gamma) = \sum_{j=1}^{L} w_j \left[B_j - C_{Ij}(\gamma) - C_{Rj}(\gamma) - C_{Fj} P_{Fj}(\gamma) \right]$$

$$s.t. \quad \gamma_i^l \leq \gamma_i \leq \gamma_i^u \quad ,i = 1,\ldots,m$$

- The "optimal" design is determined from the design equations

$$\min_{\gamma} \quad C_{Ij}(\mathbf{z})$$

$$s.t. \quad G_j\left(\mathbf{x}_c, \mathbf{p}_j, \mathbf{z}, \gamma\right) \geq 0$$

$$\mathrm{z}_i^l \leq z_i \leq z_i^u \quad ,i = 1,\ldots,N$$

$$G_j(\mathbf{x}_c, \mathbf{p}_j, \mathbf{z}, \gamma) \geq 0$$

Target reliabilities for the design of structures

- **Target reliabilities for Ultimate Limit State verification**

Relative cost of safety measure	Minor consequences of failure	Moderate consequences of failure	Large consequences of failure
High	β=3.1 ($P_F \approx 10^{-3}$)	β=3.3 ($P_F \approx 5\ 10^{-4}$)	β=3.7 ($P_F \approx 10^{-4}$)
Normal	β=3.7 ($P_F \approx 10^{-4}$)	β=4.2 ($P_F \approx 10^{-5}$)	β=4.4 ($P_F \approx 5\ 10^{-5}$)
Low	β=4.2 ($P_F \approx 10^{-5}$)	β=4.4 ($P_F \approx 10^{-5}$)	β=4.7 ($P_F \approx 10^{-6}$)

- **Target reliabilities for Serviceability Limit State Verification**

Relative cost of safety measure	Target index (irreversible SLS)
High	β=1.3 ($P_F \approx 10^{-1}$)
Normal	β=1.7 ($P_F \approx 5\ 10^{-2}$)
Low	β=2.3 ($P_F \approx 10^{-2}$)

The JCSS approach to code calibration

- A seven step approach

1. Definition of the scope of the code
   - Class of structures and type of failure modes

2. Definition of the code objective
   - Achieve target reliability/probability

3. Definition of code format
   - how many partial safety factors and load combination factors to be used
   - should load partial safety factors be material independent
   - should material partial safety factors be load type independent
   - how to use the partial safety factors in the design equations
   - rules for load combinations

The JCSS approach to code calibration

- A seven step approach

4. Identification of typical failure modes and of stochastic model
   - relevant failure modes are identified and formulated as limit state functions/design equations
   - appropriate probabilistic models are formulated for uncertain variables

5. Definition of a measure of closeness
   - the objective function for the calibration procedure is formulated e.g.

$$\min_{\gamma} W(\gamma) = \sum_{j=1}^{L} w_j \left(\beta_j(\gamma) - \beta_t\right)^2 \qquad \min_{\gamma} W'(\gamma) = \sum_{j=1}^{L} w_j \left(P_{Fj}(\gamma) - P_F^t\right)^2$$

The JCSS approach to code calibration

- A seven step approach

6. Determination of the optimal partial safety factors for the chosen code format

$$
\begin{aligned}
\min \quad & C(\mathbf{z}) \\
s.t. \quad & c_i(\mathbf{x}_c, \mathbf{p}_j, \mathbf{z}, \gamma) = 0 \quad, i = 1,\dots,m_e \\
& c_i(\mathbf{x}_c, \mathbf{p}_j, \mathbf{z}, \gamma) \geq 0 \quad, i = m_e + 1,\dots,m \\
& \mathrm{z}_\mathrm{i}^\mathrm{l} \leq \mathrm{z}_\mathrm{i} \leq \mathrm{z}_\mathrm{i}^\mathrm{u} \quad, i = 1,\dots,N
\end{aligned}
$$

7. Verification
   - incorporating experience of previous codes and practical aspects

The code calibration software CodeCal

- CodeCal