Basic concepts and data updating, reliability aspects

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Backgrounds: EN 1990, ISO 2394, ISO 13822, JCSS, RILEM

When assessment of existing structures ?

- rehabilitation of an existing facility when new structural members are added to the existing load-carrying system;
- adequacy checking in order to establish whether the existing structure can resist loads associated with the anticipated change in use of the facility;
- repair of a structure deteriorated due to time dependent environmental effects, or which has suffered damage from accidental actions, for example, impact;
- doubts concerning actual reliability of the structure.

General aspects

Assessment is in many aspects different from designing a new structure - ISO 13822

The following aspects seem to be the most significant:

- effect of construction, alterations, misuse;
- past performance, damage, deterioration, maintenance;
- actual actions, geometry and material property;
- reliability differentiation (consequences, cost of safety measures, societal, political and culture aspects).

Two main principles

- Actual characteristics of structural material, action (permanent load), geometric data and structural behaviour should be considered.

- Currently valid codes should be considered (models for actions and resistances), codes valid in the period when the structure was designed should be used as guidance documents.

Main steps of assessment

Assessment is an iterative process consisting of:

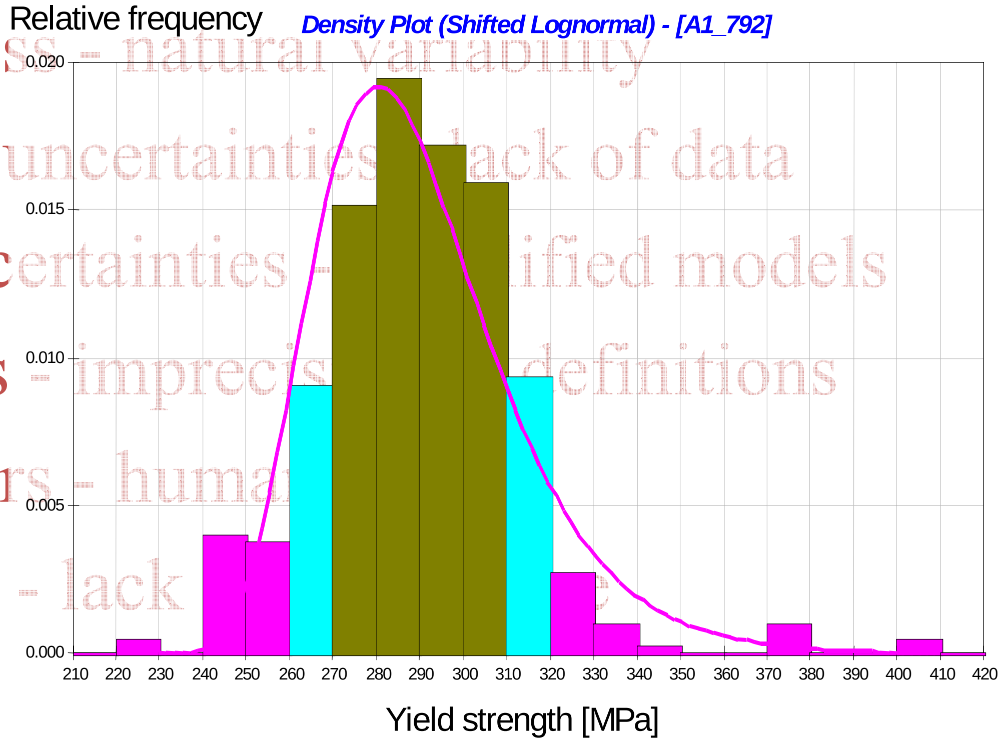
- specification of the assessment objectives;
- scenarios related to structural conditions and actions;
- preliminary assessment including recommendations;
- detailed assessment including reliability verification;
- report including proposal for intervention;
- repetition of the sequence if necessary.

Limit State Approach

- Limit states - states beyond which
  the structure no longer fulfils
  the relevant design criteria
- Ultimate limit states
  - loss of equilibrium of a structure as a rigid body
  - rupture, collapse, failure
  - fatigue failure
- Serviceability limit states
  - functional ability
  - users comfort
  - appearance

Uncertainties in assessment may be great

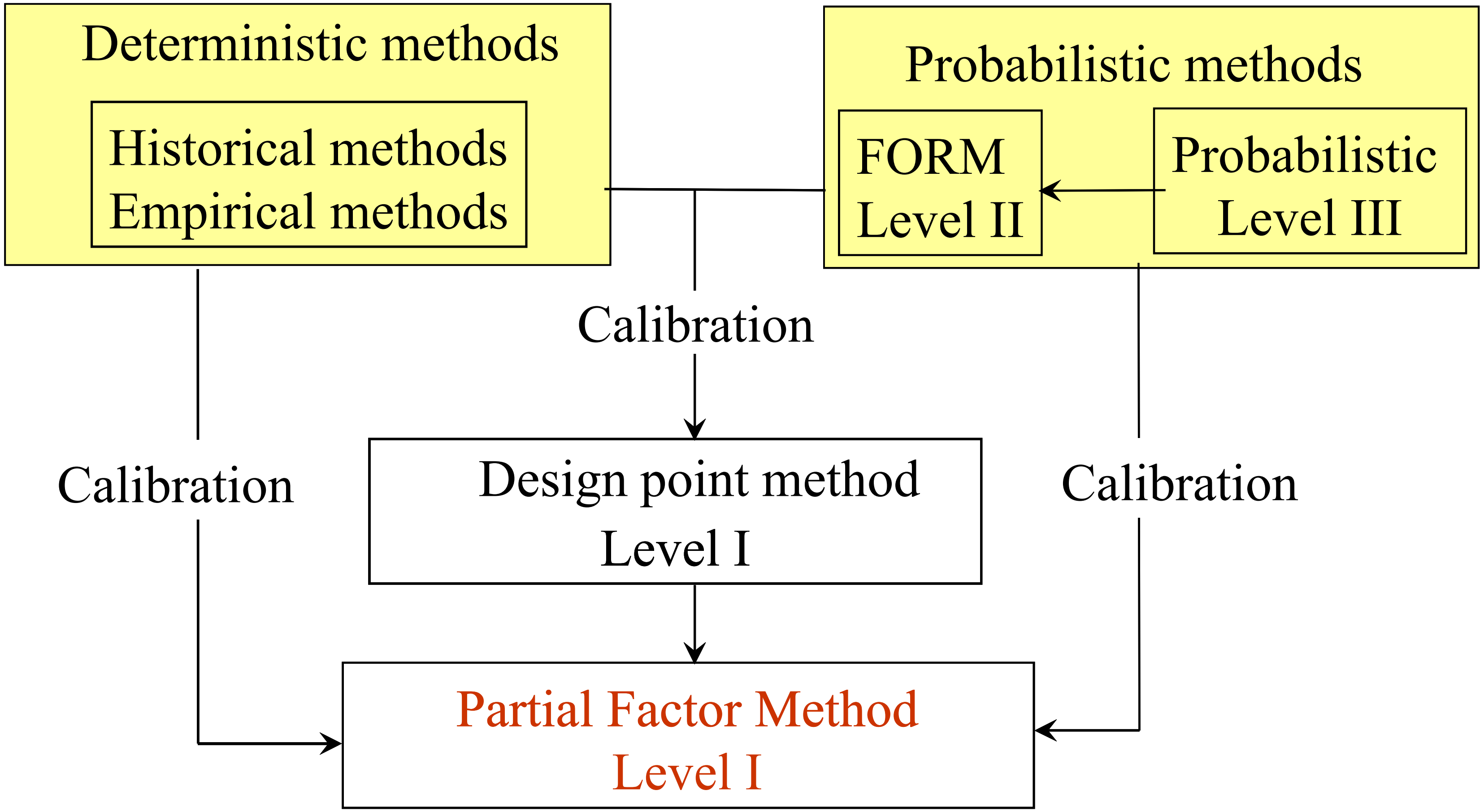
- Uncertainties (aleatoric and epistemic) Decription
  - randomness - natural variability
  - statistical uncertainties - lack of data
  - model uncertainties - ified models
  - vagueness - imprecis definitions
  - gross errors - huma
  - ignorance - lack



- Tools
  - theory of probability and statistics, fuzzy logic
  - reliability theory and risk engineering

Some uncertainties are difficult to quantify

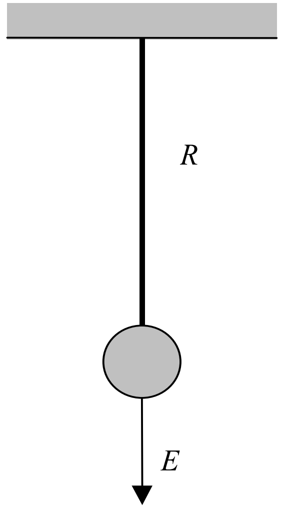
Reliability Methods



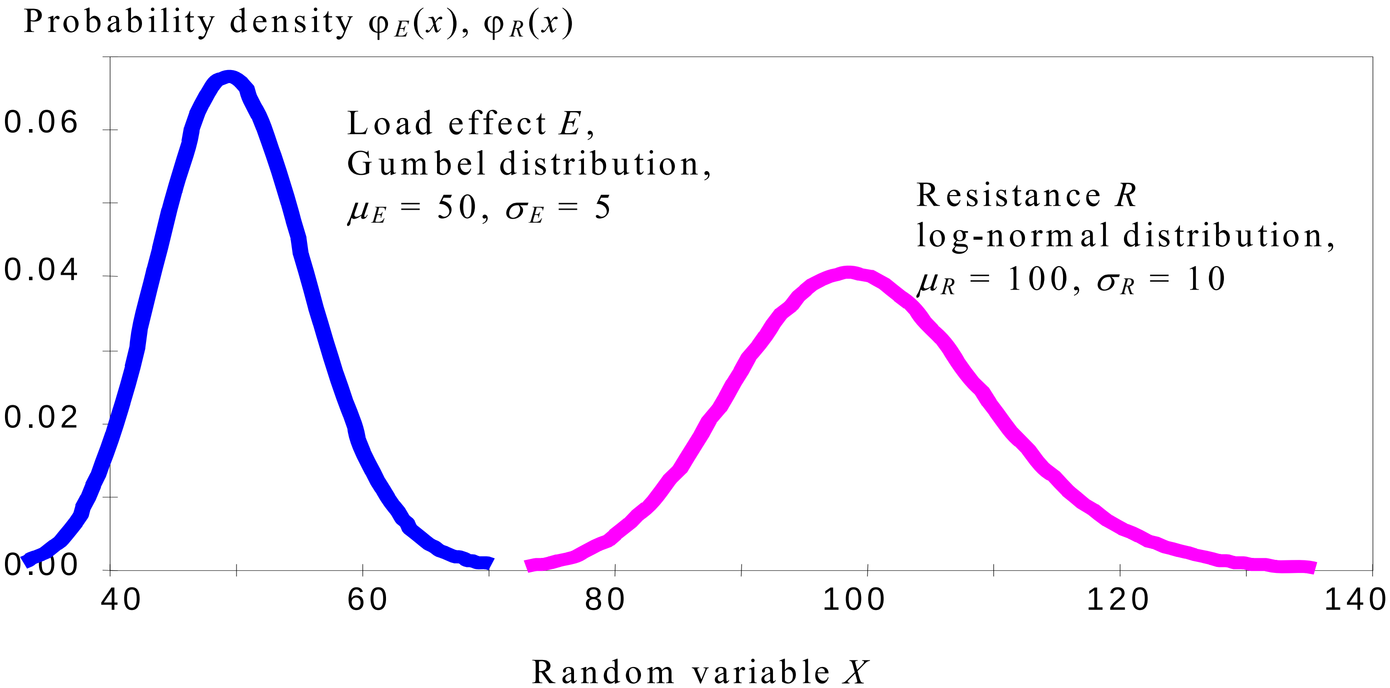
Reliability measures: failure probability p_f and reliability index β

p_f	10^{-1}	10^{-2}	10^{-3}	$\mathbf{10^{-4}}$	10^{-5}	10^{-6}	10^{-7}
β	1,3	2,3	3,1	**3,7**	4,2	4,7	5,2

Probabilistic models



		distribution	mean	sd
R	resistance	Lognormal	100	10
E	load effect	Gumbel	50	5



Fundamental case for normal distribution

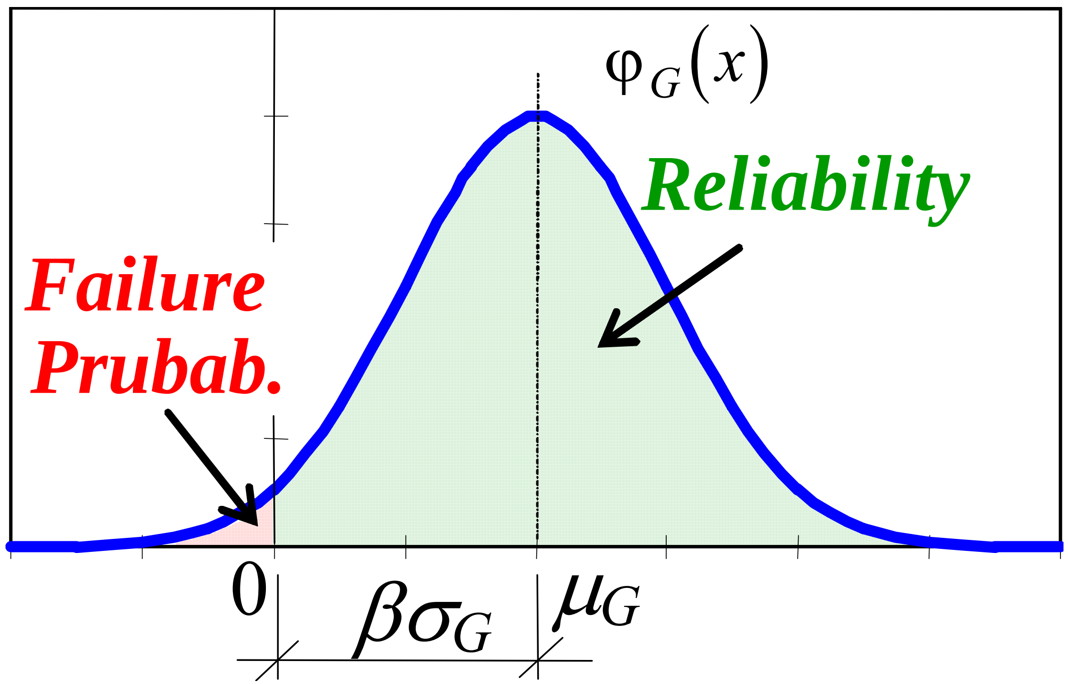
$$E \leq R$$

$G = R - E$ $\qquad \mu_G = \mu_R - \mu_E \,,\, \sigma_G^2 = \sigma_R^2 + \sigma_E^2$

Transformation of G to standardized variable $U=(G - \mu_G)/\sigma_G$

For $G = 0$ the standardized variable $u_0 = (0 - \mu_G)/\sigma_G$

Reliability index : $$\beta = -u_0 = \frac{\mu_G}{\sigma_G} = \frac{\mu_R - \mu_E}{(\sigma_R^2 + \sigma_E^2)^{1/2}}$$



Failure probability

$$p_f = \Phi(-\beta)$$

An example of the fundamental case

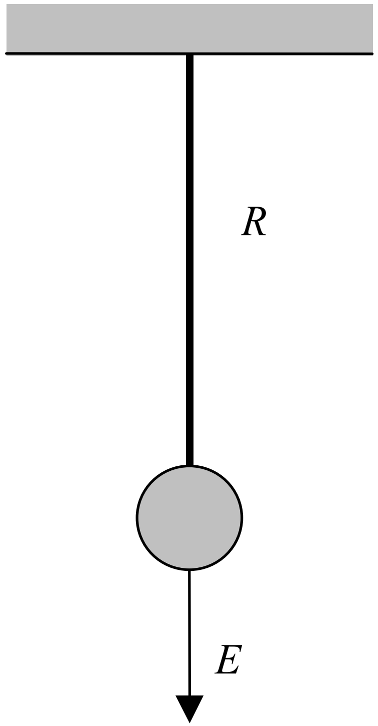
$$Z = R - E$$

$$\mu_Z = \mu_R - \mu_E = \qquad 100 - 50 = 50$$

$$\sigma_Z^2 = \sigma_R^2 + \sigma_E^2 = 14^2$$

$$\beta = \mu_Z / \sigma_Z = 3.54$$

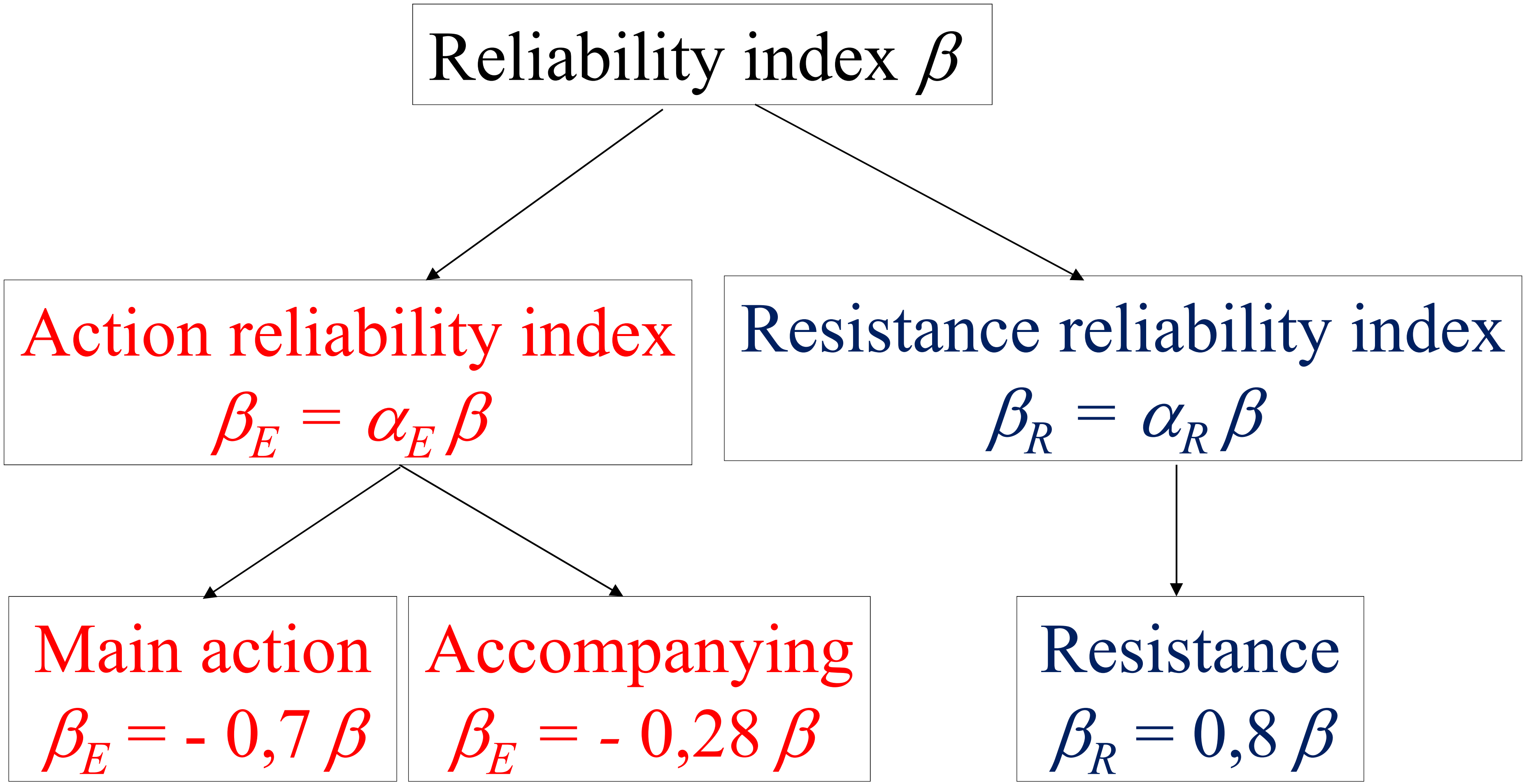
$$P_{\mathrm{f}} = \mathrm{P}(Z < 0) = \Phi_Z(0) = 0.0002$$



Indicative target reliabilities in ISO 13822

Limit states	Target reliability index, β	Reference period
Serviceability		
Reversible	0,0	Intended remaining working life
Irreversible	1,5	Intended remaining working life
Fatigue		
inspectable	2,3	Intended remaining working life
not inspectable	3,1	Intended remaining working life
Ultimate		
very low consequences of failure	2,3	L_S years*
low consequence of failure	3,1	L_S years*
medium consequence of failure	3,8	L_S years*
high consequence of failure	4,3	L_S years*
* L_S is a minimum standard period for safety (e.g. 50 years)		

Eurocode concepts of partial factors



Partial factor of a resistance variable R

$\gamma_R = R_k/R_d$ based on $\beta_R = 0,8 \times \beta$

Normal distribution

$$R_k = \mu_R - 1,645 \times \sigma_R = \mu_R(1 - 1,645 \times V_R)$$

$$R_d(\beta) = \mu_R - \alpha_R \times \beta \times \sigma_R = \mu_R - 0,8 \times \beta \times \sigma_R = \mu_R(1 - 0,8 \times \beta \times V_R)$$

$$\gamma_R(\beta) = (1 - 1,645 \times V_R) / (1 - 0,8 \times \beta \times V_R)$$

Lognormal distribution

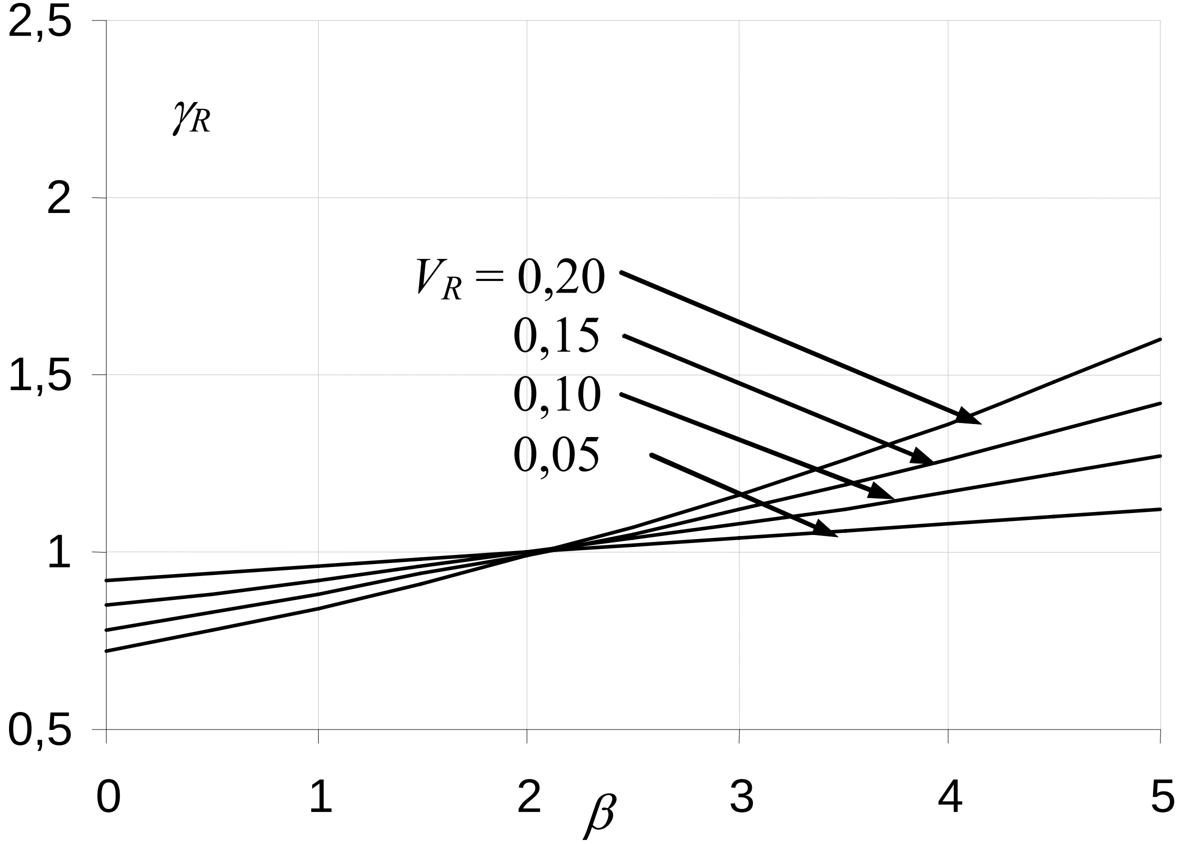
$$R_k = \mu_R \times \exp(-1,645 \times V_R)$$

$$R_d(\beta) = \mu_R \times \exp(-\alpha_R \times \beta \times V_R)$$

$$\gamma_R(\beta) = \exp(-1,645 \times V_R) / \exp(-\alpha_R \times \beta \times V_R)$$

Partial factor of a resistance *R*

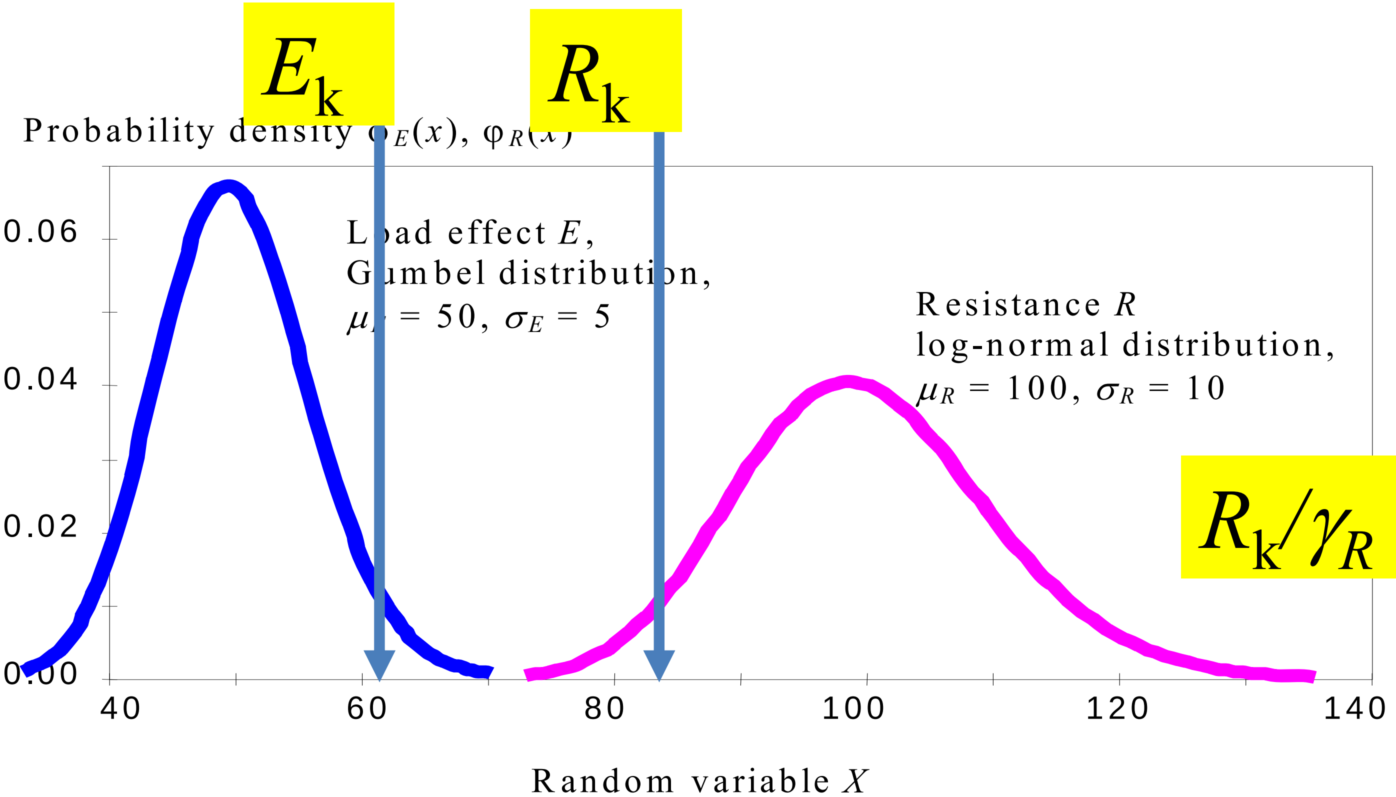
$$\gamma_R(\beta) = \exp(-1{,}645 \times V_R) / \exp(-\alpha_R \times \beta \times V_R)$$

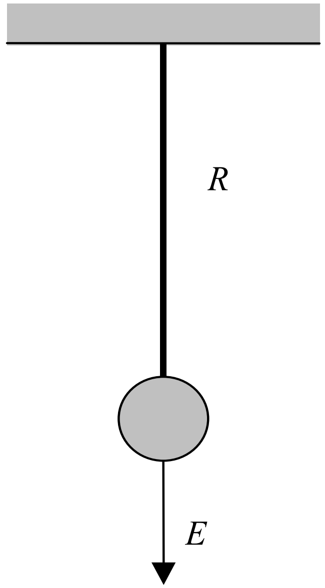


Variation of γ_R with β for lognormal distribution of *R*

An example of the partial factor approach

		distribution	mean	sd
R	resistance	Lognormal	100	10
E	load effect	Gumbel	50	5





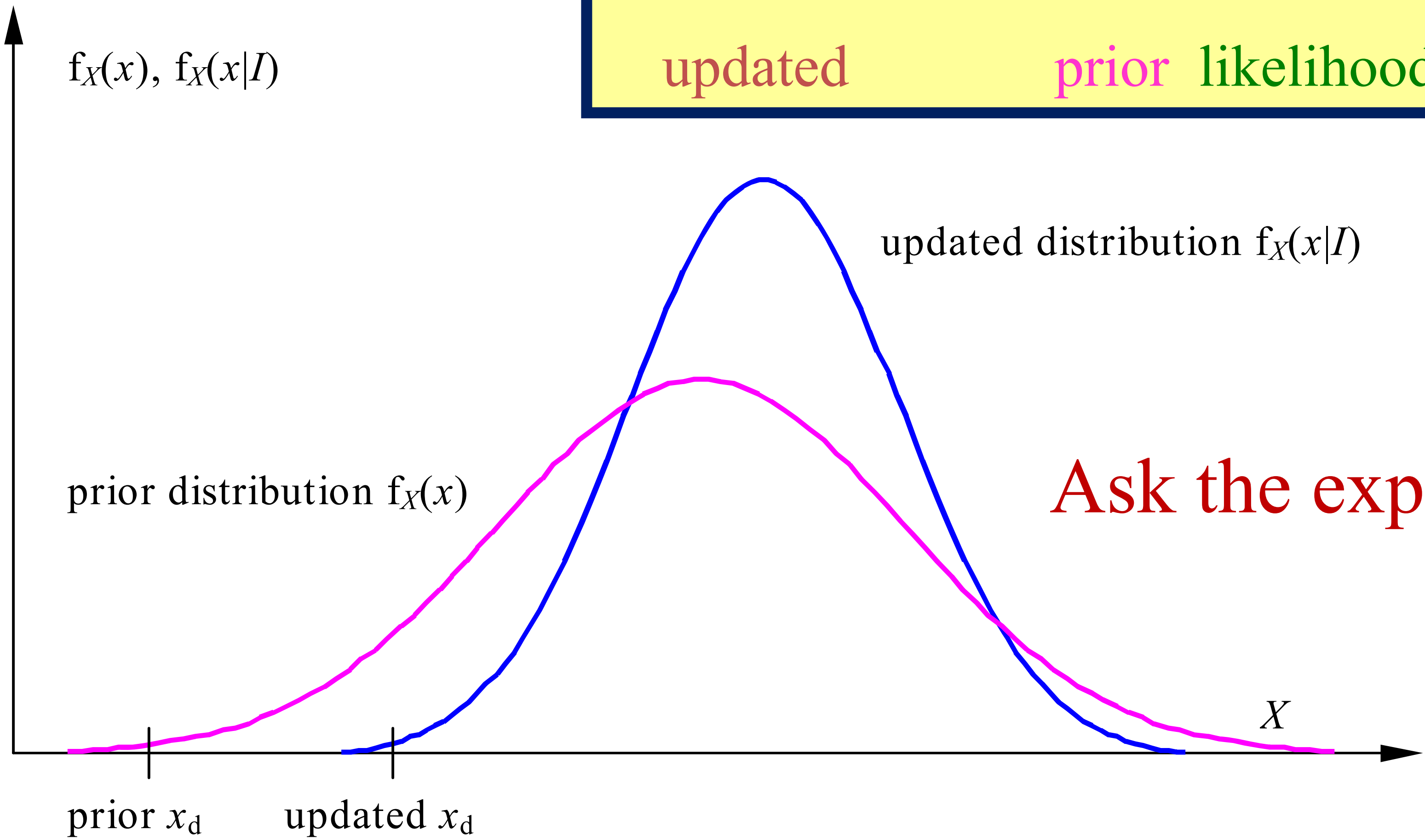
$$R_k/\gamma_R > E_k\,\gamma_E$$

Updating distributions

$$P(x|I) = P(x)\ P(I\ |\ x)\ /\ P(I)$$

$$f_X(x|I) = C\ \ f_X(x)\ P(\ I\ |\ x)$$

updated prior likelihood



Ask the experts!

Concluding remarks

1. **Actual characteristics** of structural materials, actions (permanent loads), and geometric data are decisive.
2. **Currently valid codes** should be applied for actions and resistances, previous codes may provide valuable information.
3. **Uncertainties** in assessment of existing structures may be greater than in design of new structures.
4. **Probability theory and statistics** are useful tools.
5. **Target reliability** may be decreased depending on failure consequences and optimization.
6. **Relevant partial factors** can be modified considering the specified reliability index.
7. **Updating** of reliability using newly obtained data (experimental and inspection results) is often useful.

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