INFRASTAR
Training school®

Innovation and Networking for Fatigue and Reliability Analysis of Structures – Training for Assessment of Risk

Design and assessment criteria for safety and cost efficiency

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Norwegian University of Science and Technology

2nd Infrastar Training School, online, 27-30 October 2020

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Coordinated by Université Gustave Eiffel

The build environment

- As the main contributor to our societal development,
- And, as a major consumer of natural resources,
- Needs proper strategies for decision support for further development and maintenance !!
- Objective: sustainable development.

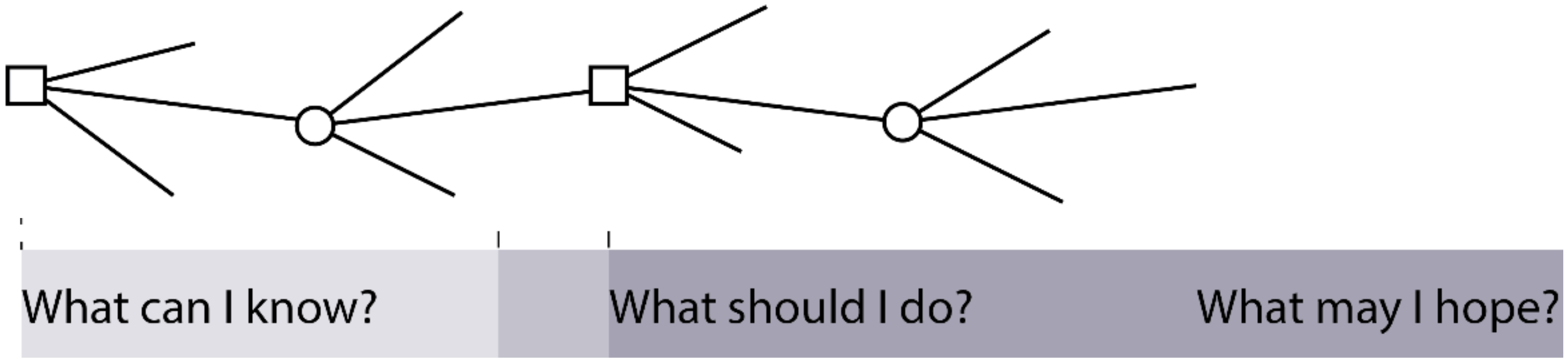
The build environment

Strategy

- Decisions are made
- It is not how we can identify the right decision, but how we identify the “best” decision
- Reasonable to assess the effect of different decision alternatives on “our” utility

Formal Decision Theory

Experiment	Sample	Actions	State	Utility
$e \in E$	$z \in Z$	$a \in A$	$\theta \in \Theta$	$u(.)$



- ➢ Reasonable strategy
- ➢ Challenging to apply
- ➢ Simplifications necessary

System definition

- ➢ Reduction and simplification
- ➢ Decision alternatives ←→ utility

Experiment	Sample	Actions	State	Utility
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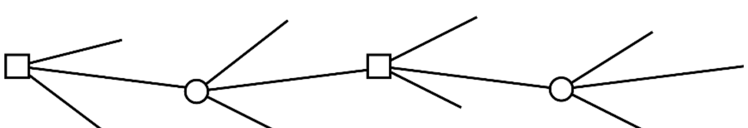
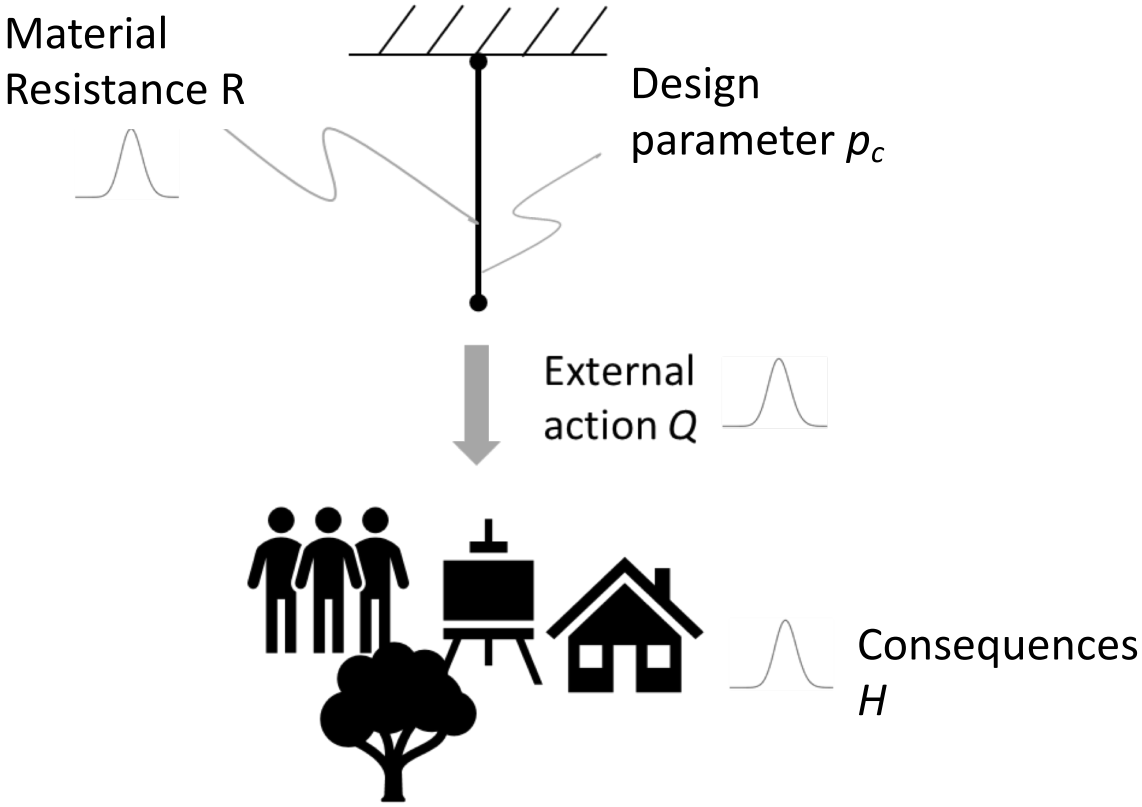
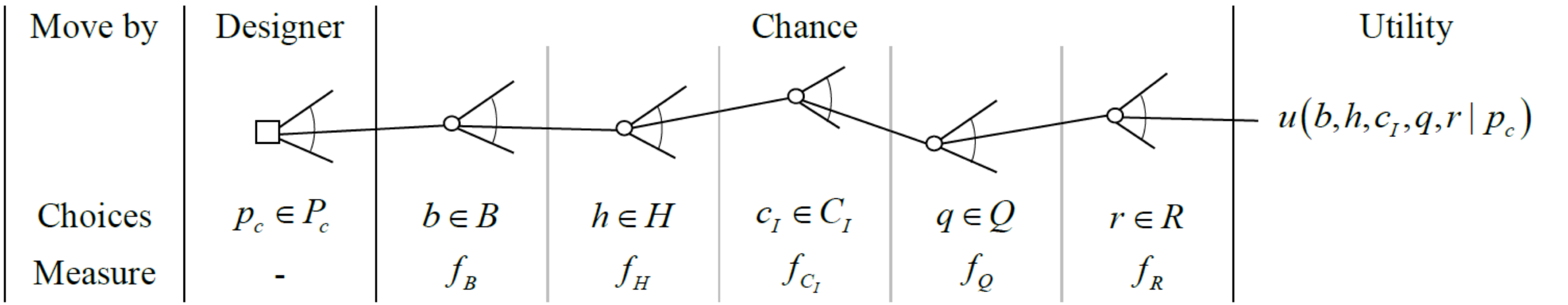


Structural design decision problem

➢ Objective: minimum use of resources over time



Structural design decision

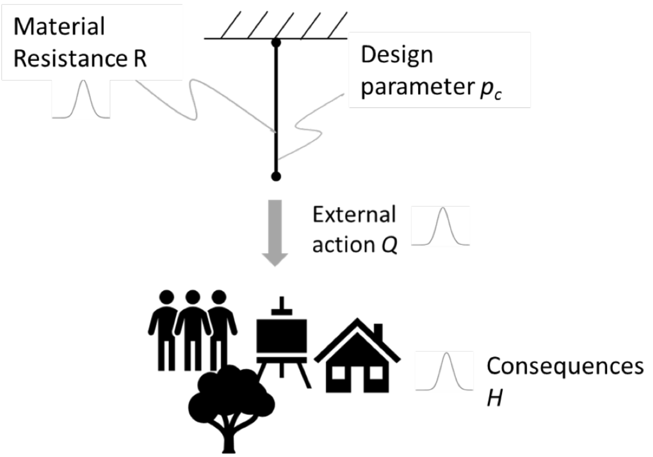


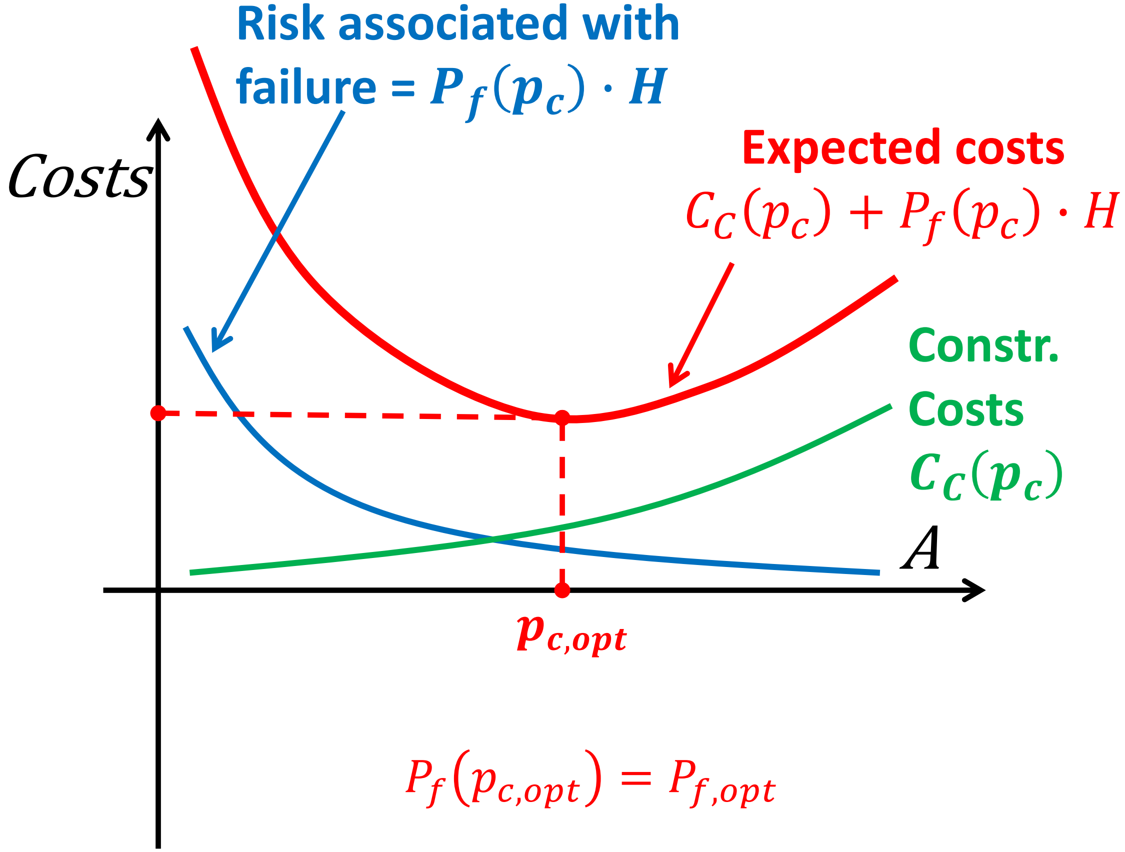
$$\boldsymbol{p}_{\boldsymbol{c},\boldsymbol{opt}} = \underset{\boldsymbol{p}_{\boldsymbol{c}}}{\operatorname{argmin}}\{E_{\boldsymbol{\Theta}}[u(\boldsymbol{\theta},\boldsymbol{p}_{\boldsymbol{c}})]\} = \underset{\boldsymbol{p}_{\boldsymbol{c}}}{\operatorname{argmin}}\{E_{\boldsymbol{\Theta}}[C_{tot}(\boldsymbol{\theta},\boldsymbol{p}_{\boldsymbol{c}})]\}$$

$$E_{\boldsymbol{\Theta}}[C_{tot}(\boldsymbol{\theta},\boldsymbol{p}_{\boldsymbol{c}})] = (E[C_0] + E[C_1]p_C) - E[H]P_f(\boldsymbol{p}_{\boldsymbol{c}})$$

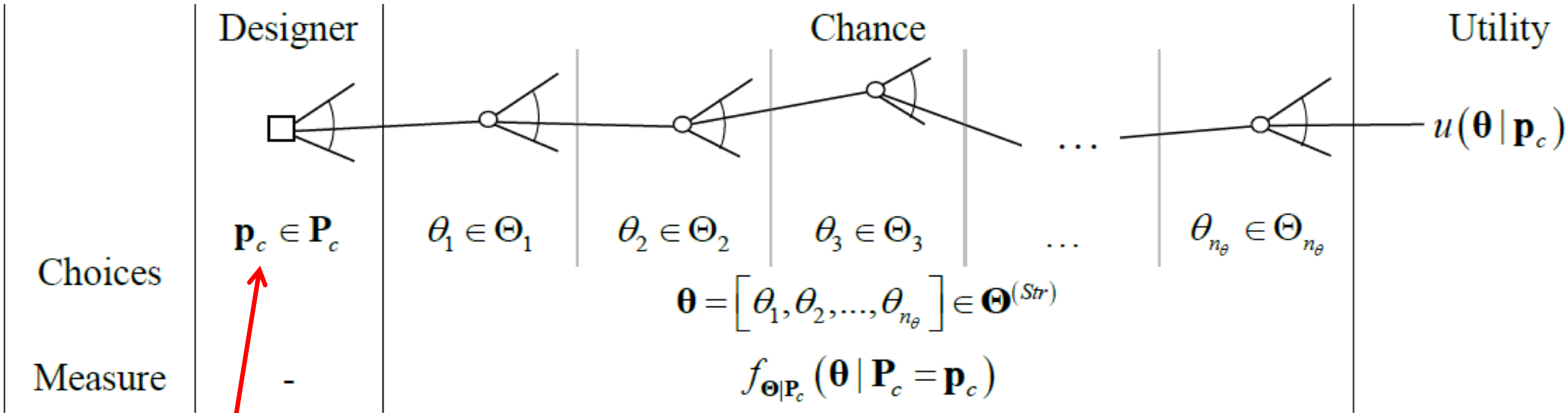
$$P_f(\boldsymbol{p}_{\boldsymbol{c}}) = \int_{p_C r<q} f_{R,Q}(r,q)dr\,dq$$

Risk informed decision





Generalization of the risk informed design problem



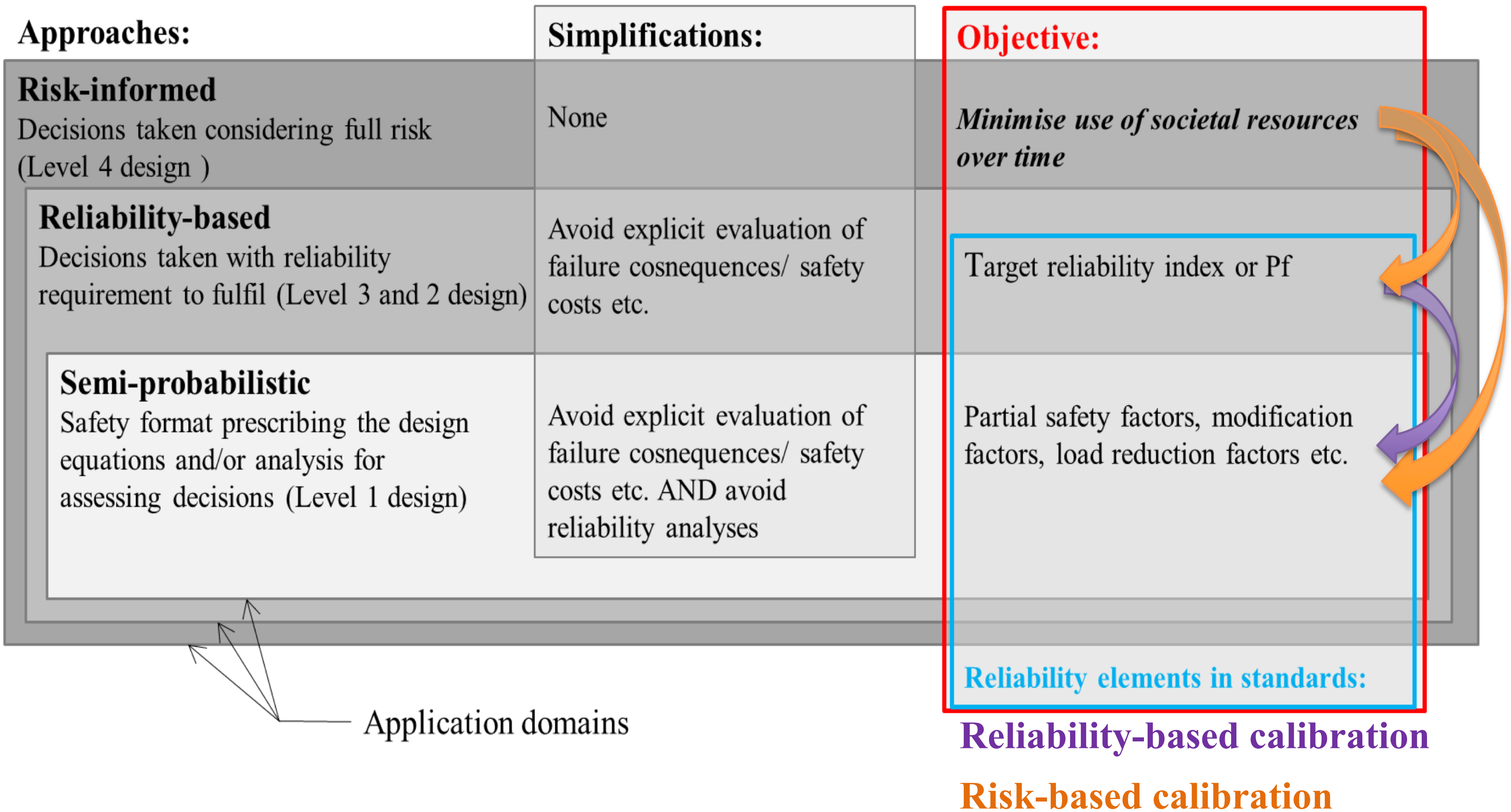
Decision variable

"State of the world" Variables
Not known with certainty by the decision maker

Level of detail sensibly chosen!

$$\boldsymbol{p}_{c,opt} = \underset{\boldsymbol{p}_c}{\operatorname{argmin}}\{E_{\boldsymbol{\Theta}}[u(\boldsymbol{\theta}|\boldsymbol{p}_c)]\}$$

Simplified design methods



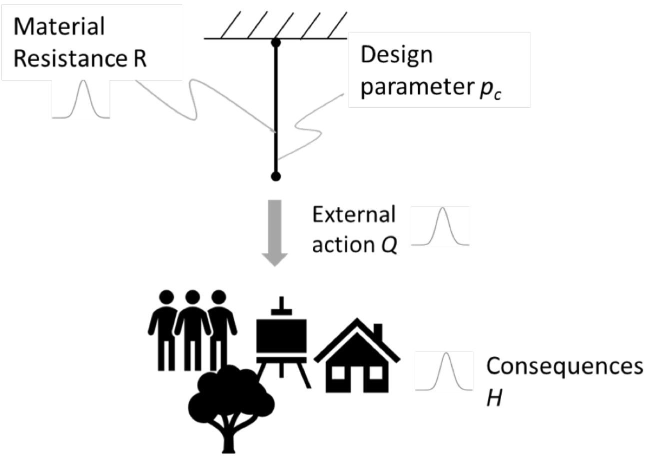
Simplified design and assessment of decision approaches [ISO 2394]

- **Level 4: Risk-informed**

  - **Levels 3 (and 2): Reliability-based**

Simplification

Reliability based design (Level 3 and 2)



Design:

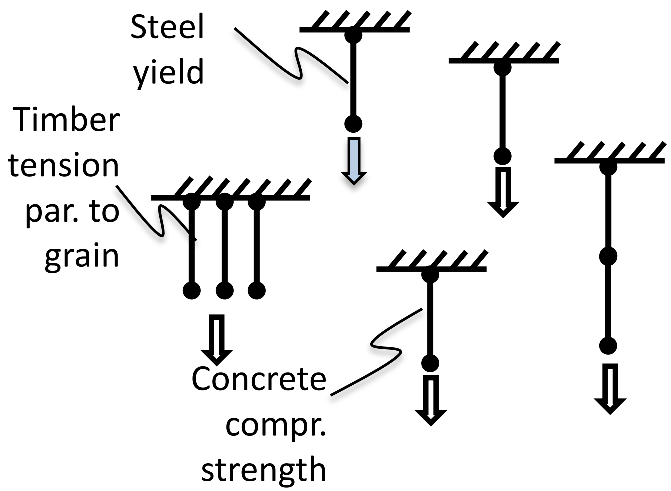
$$p_c\colon\ P_f(p_c) = P_{f,target}$$

Level 3 ≡ Level 4 ⇔ $P_{f,target} \equiv P_{f,opt}$

Code calibration, why?

- Simplification:
    1. No explicit evaluation of costs, consequences, etc

→ **simplify calculations**



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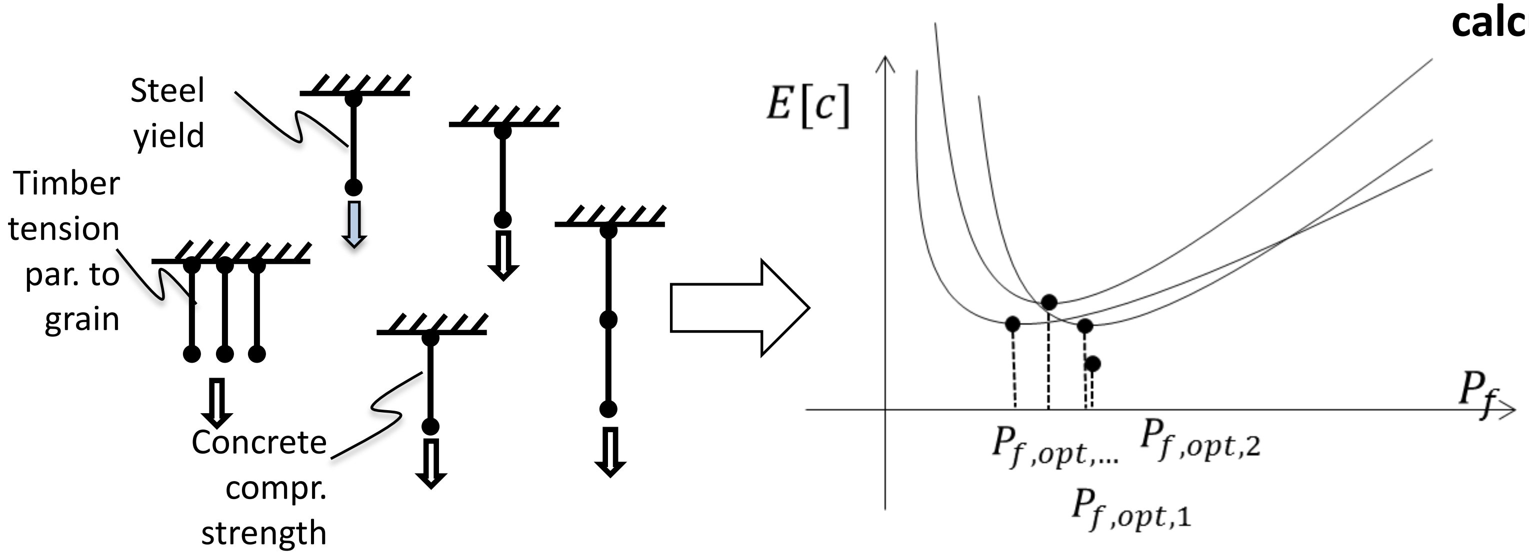

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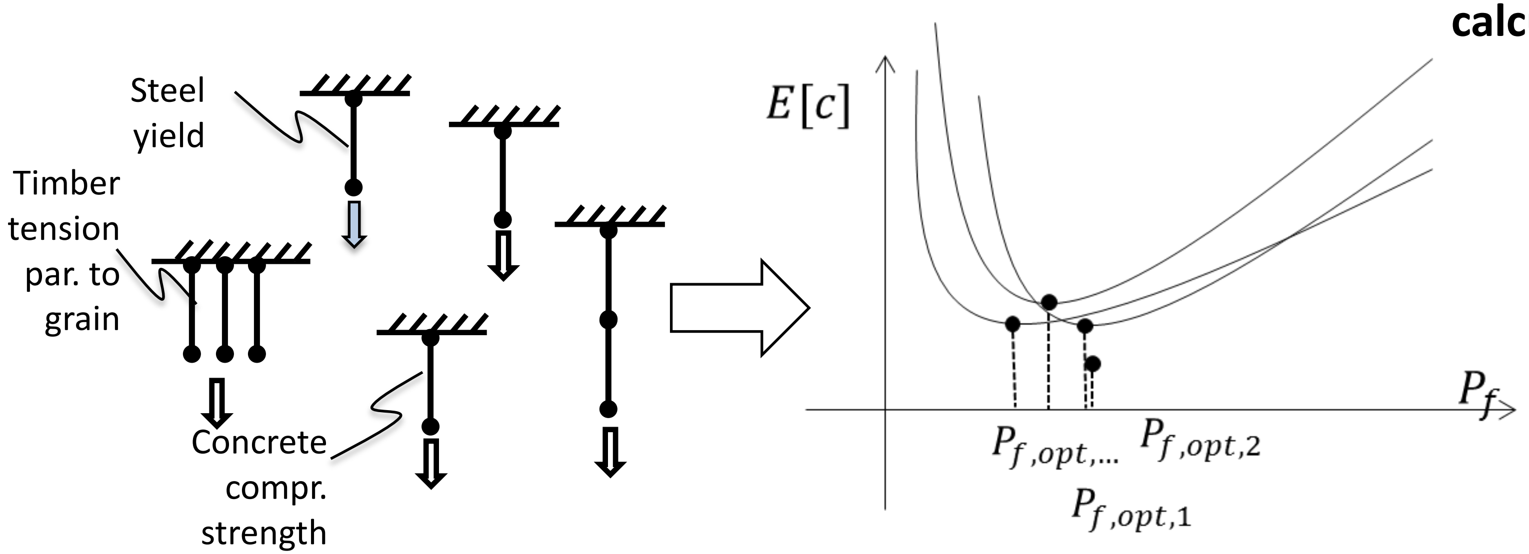
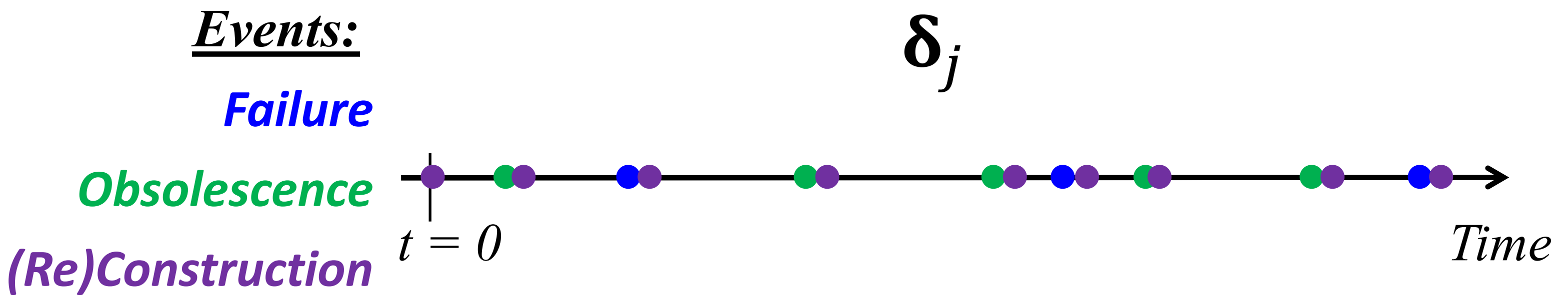


  2. One $P_{f,target}$ for a class of structures → **simplify standards and calculations**

CALIBRATION: what $P_{f,target}$ is optimal for the class?

Code calibration as a decision problem under risk

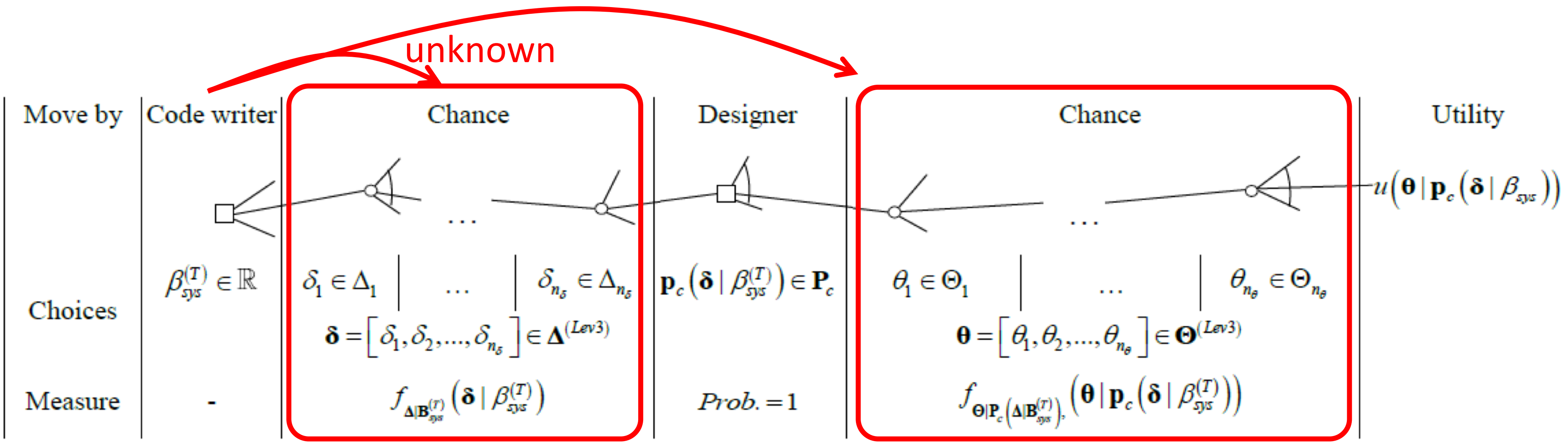
- Decision variable: $\boldsymbol{\beta_{target}}$ for Level 3 and 2 design
    - each structure in the class defined by $\boldsymbol{\delta}$
    - present and future structures



- Decision maker: **society** (codes guard the interest of society)
- Level of detail in system representation consistent with the generalisation over classes

Optimisation of β_t for Level 3 codes

- Game between *Code writer* and *Chance*
  1. *Code writer* selects a β_t
  2. *Chance* chooses a possible structure to be designed $\boldsymbol{\delta} \in \boldsymbol{\Delta}^{(Lev3)}$
  3. Designer finds dimensions $\mathbf{p}_c$ giving $\beta \equiv \beta_t$
  4. *Chance* chooses a state of the nature $\boldsymbol{\theta} \in \boldsymbol{\Theta}^{(Lev3)}$



e.g. limit state, variables

e.g. realisation of variables

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Optimisation of $\beta_{sys,t}$ for Level 3 codes

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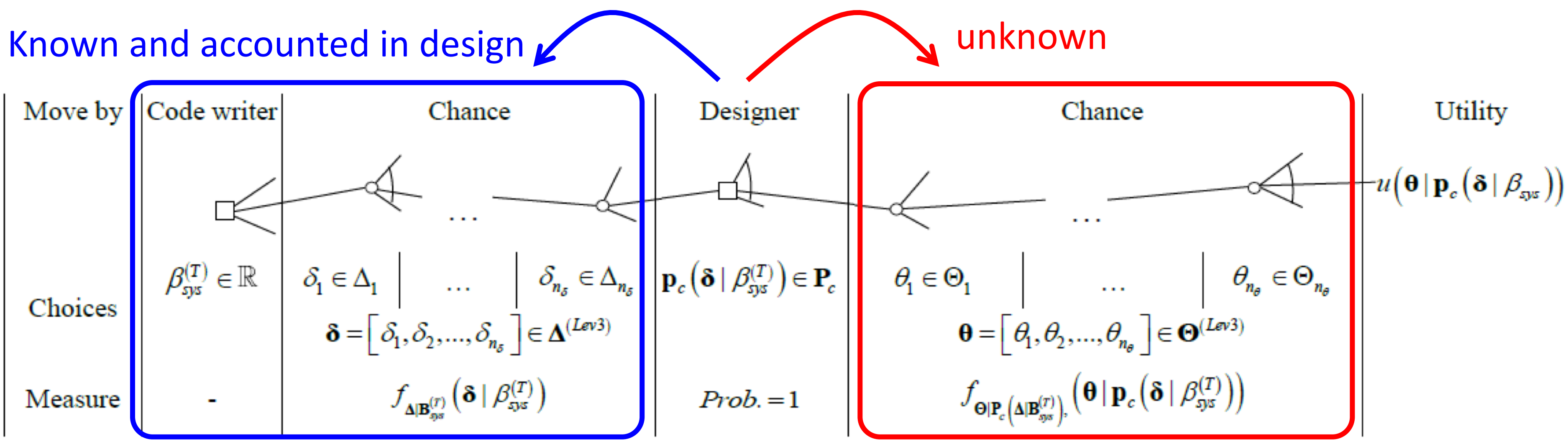

e.g. limit state, variables

e.g. realisation of variables

Current target reliability values in JCSS PMC and ISO 2394

- Based on monetary optimization

		Failure consequences		
		Minor	Moderate	Large
Relative cost of safety	Large	$3.1\ (P_f \approx 10^{-3})$	$3.3\ (P_f \approx 5 \cdot 10^{-4})$	$3.7\ (P_f \approx 10^{-4})$
	Normal	$3.7\ (P_f \approx 10^{-4})$	$4.2\ (P_f \approx 10^{-5})$	$4.4\ (P_f \approx 5 \cdot 10^{-6})$
	Small	$4.2\ (P_f \approx 10^{-5})$	$4.4\ (P_f \approx 5 \cdot 10^{-6})$	$4.7\ (P_f \approx 10^{-6})$

- Objective function:

$$E[PV(C_{tot}(p))] = \boxed{C_0 + C_I p} + [C_0 + C_I p + A_d]\frac{\omega}{i^{(1a)}} + [C_0 + C_I p + H]\frac{\lambda P_f(p)}{i^{(1a)}}$$

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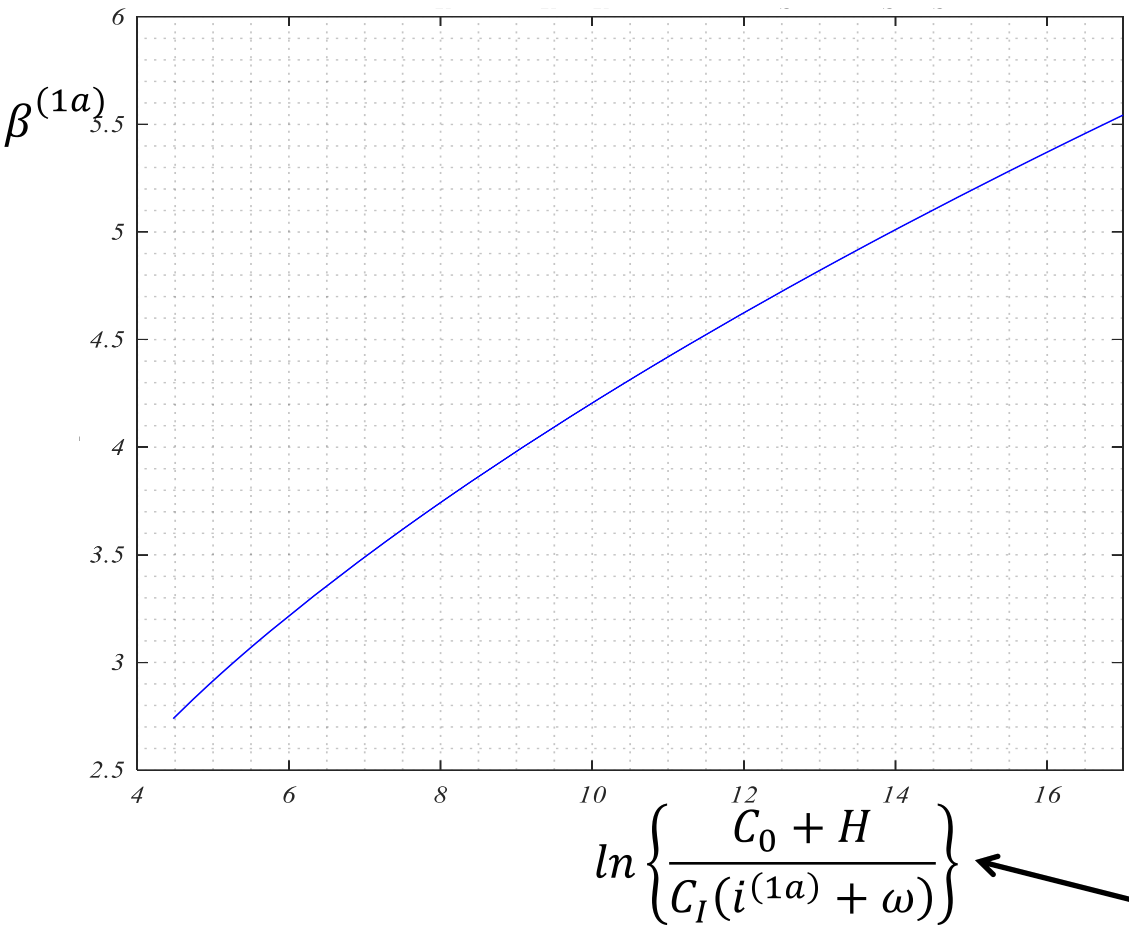
Failure domain: $g(p, r, s) = pr - s < 0$

Plot representing target reliabilities



Line satisfying the condition at optimum

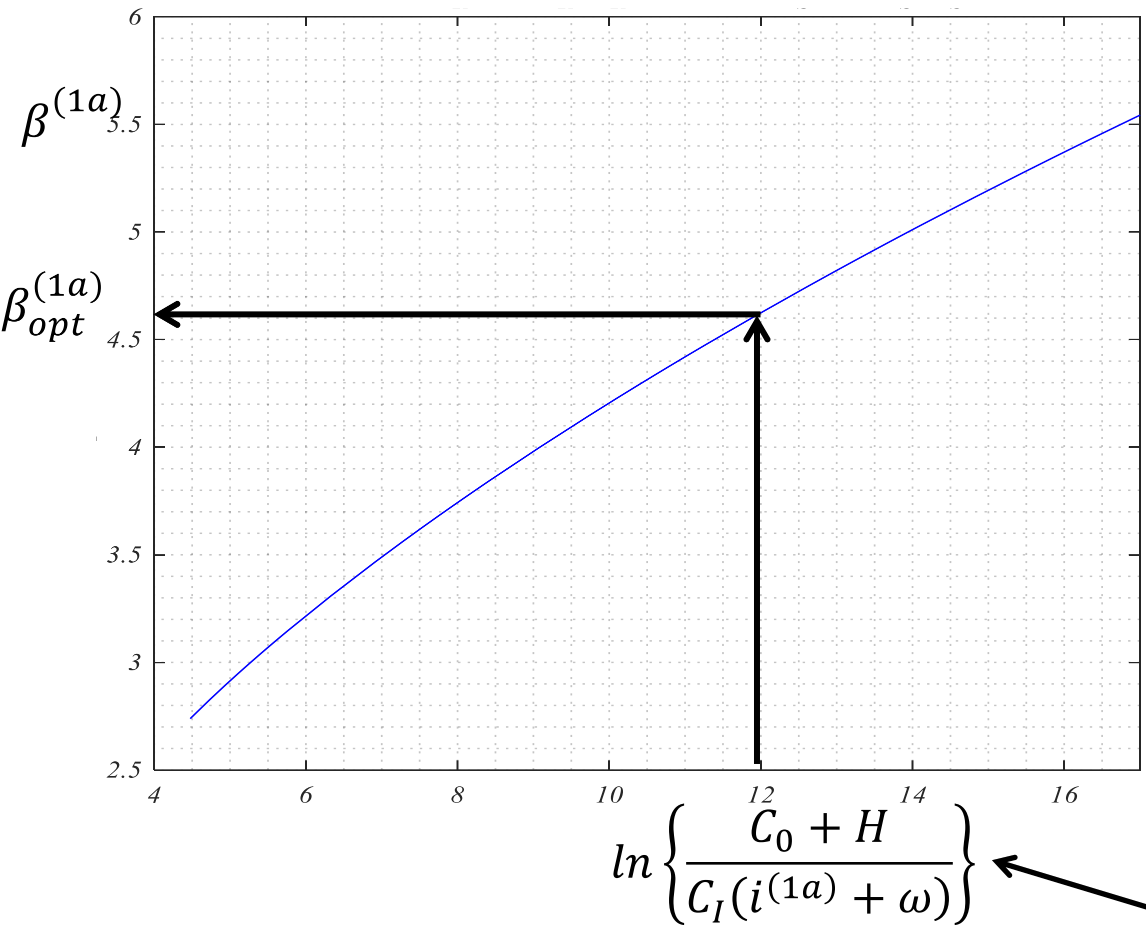
$$\frac{C_0 + C_I p_{opt} + H}{C_I \cdot (i^{(1a)} + \omega)} \approx \frac{1}{-\left.\frac{dP_f^{(1a)}(p)}{dp}\right|_{p=p_{opt}}}$$

for:

$COV_R = 0.15$ and $COV_S = 0.30$

Safety costs;
Failure costs;
Interest rate i;
Obsolescence rate ω.

Plot representing target reliabilities



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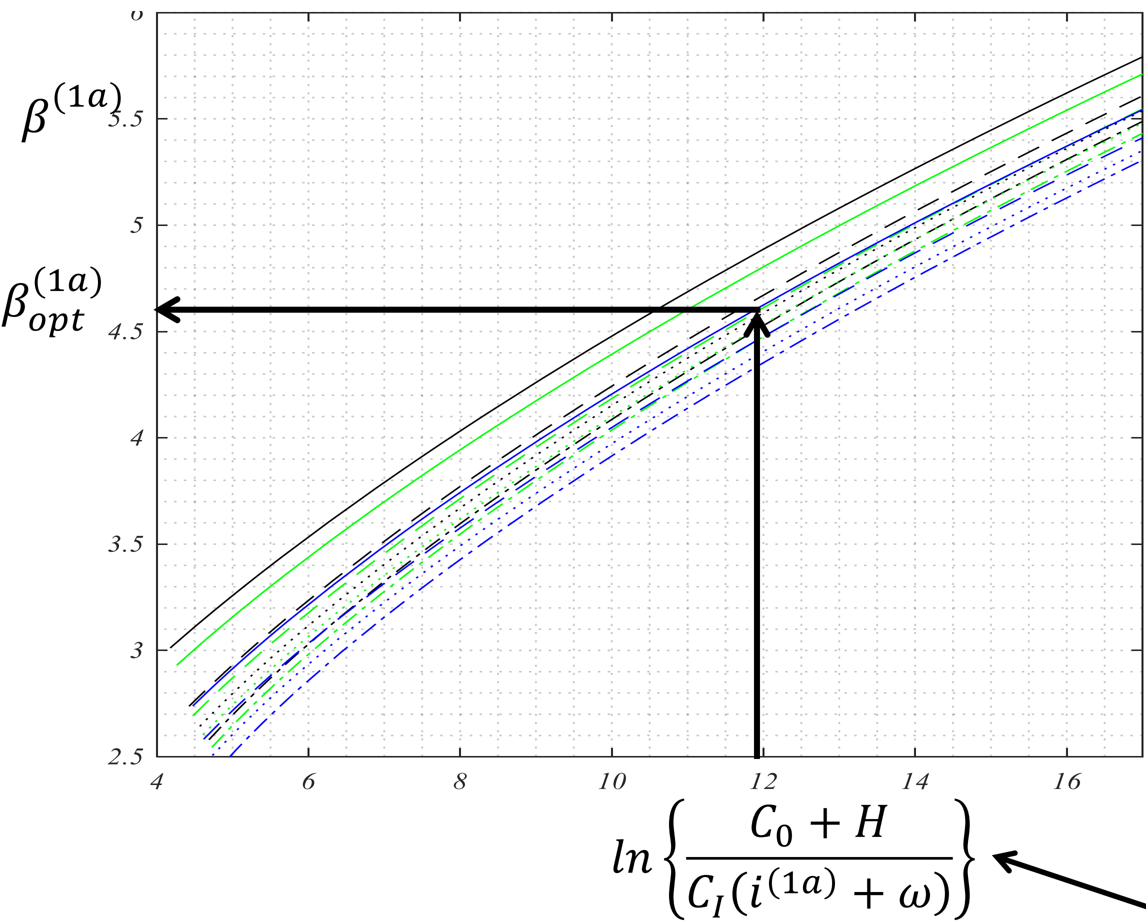

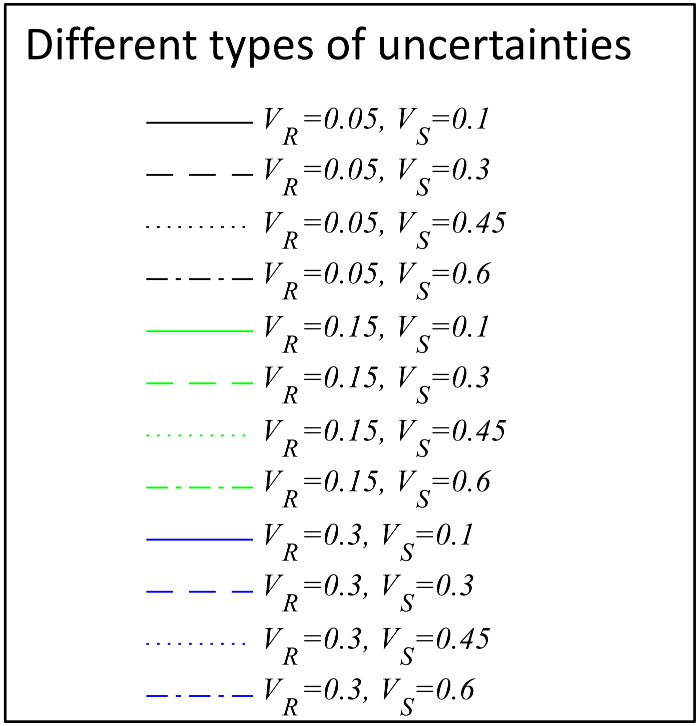

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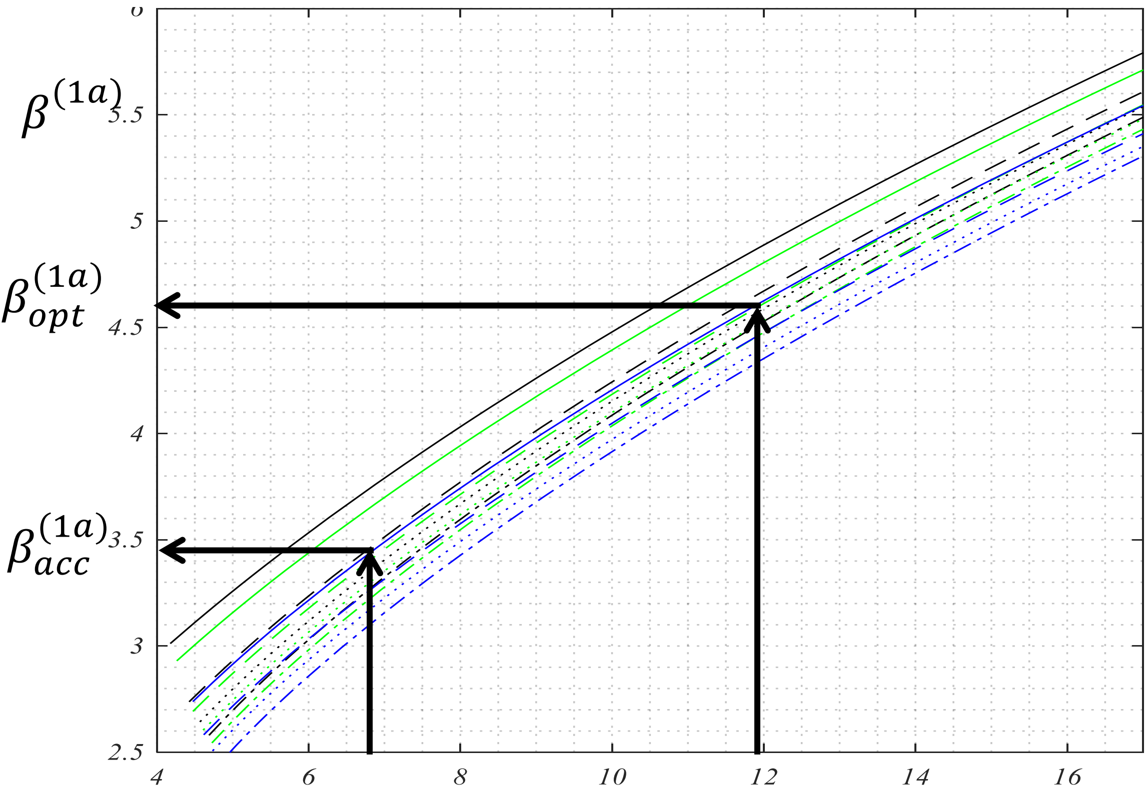


Different types of uncertainties

$$ln\left\{\frac{SWTP \cdot N_F}{C_I\left(i_S^{(1a)} + \omega\right)}\right\}$$

$$ln\left\{\frac{C_0 + H}{C_I(i^{(1a)} + \omega)}\right\}$$

Safety costs;
Failure costs;
Interest rate i;
Obsolescence rate ω.

Marginal Lifesaving Cost Principle with Life Quality Index

Remarks

- Determination of target reliabilities for reliability based design is a calibration problem
- Generalisation and classification requires "low" level of detail of system representation
- Risk criteria can be in-cooperated

- Risk based design in open to any/(the appropriate) level of detail.

Simplified design and assessment of decision approaches [ISO 2394]

- **Level 4: Risk-informed**

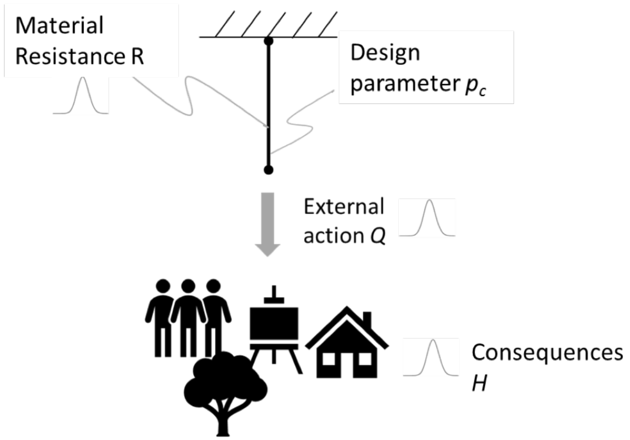
Simplification

  - **Levels 3 (and 2): Reliability-based**

Simplification

    - **Level 1: Semi-probabilistic**

Semi-probabilistic approach (Level 1)



Partial Safety Factors
(reliability elements)

Design:

$$p_c : p_c \geq \frac{\gamma_M}{f_k} \cdot \gamma_Q \cdot q_k$$

Level 1 ≡ Level 4 $\Leftrightarrow \gamma_M, \gamma_Q\text{:}\ \boldsymbol{P_f}\left(p_c = \frac{\gamma_M}{f_k} \cdot \gamma_Q \cdot q_k\right) \equiv \boldsymbol{P_{f,opt}}$

Code calibration, why?

- Simplification:
  1. No explicit evaluation costs, consequences, etc.
  2. No reliability analyses

→ **simplify calculations**

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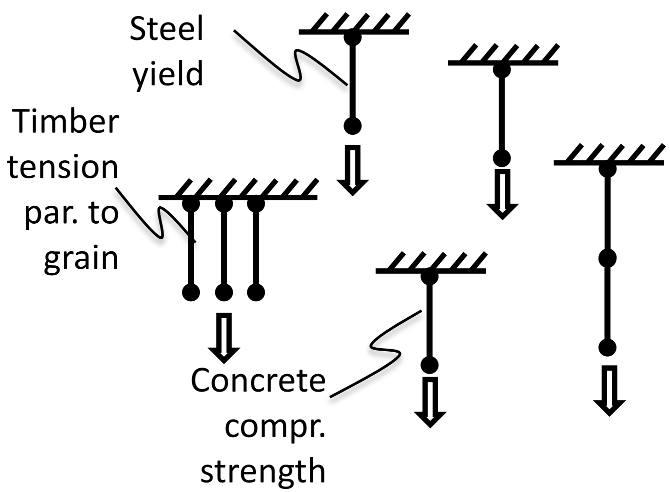

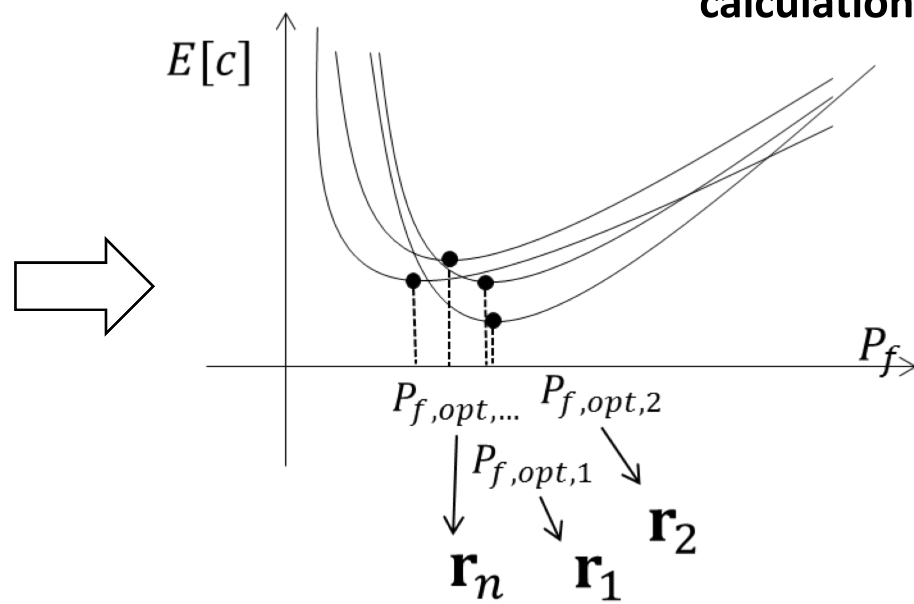

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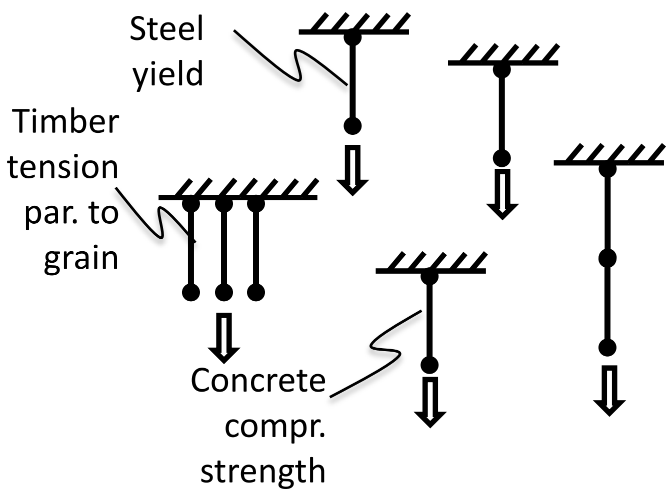

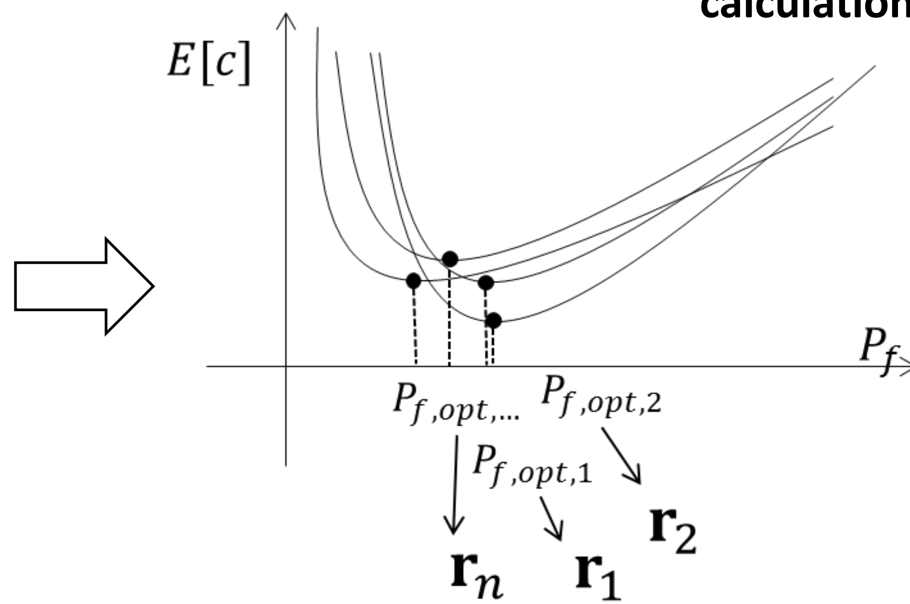

3. One $\mathbf{r} = [\gamma, \psi_0, k_{mod}]$ for a class of structures

→ **simplify standards and calculations**

CALIBRATION: what r is optimal for the class?

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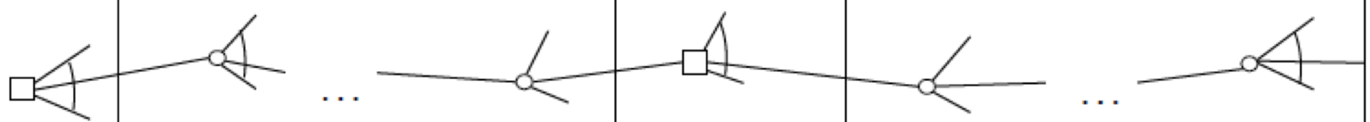
Decision problem

- Decision variable: $\mathbf{r}_{el}$ for Level 1 design for a class of structures
  - Partial safety factors
  - Modification factors
  - Load combination factors

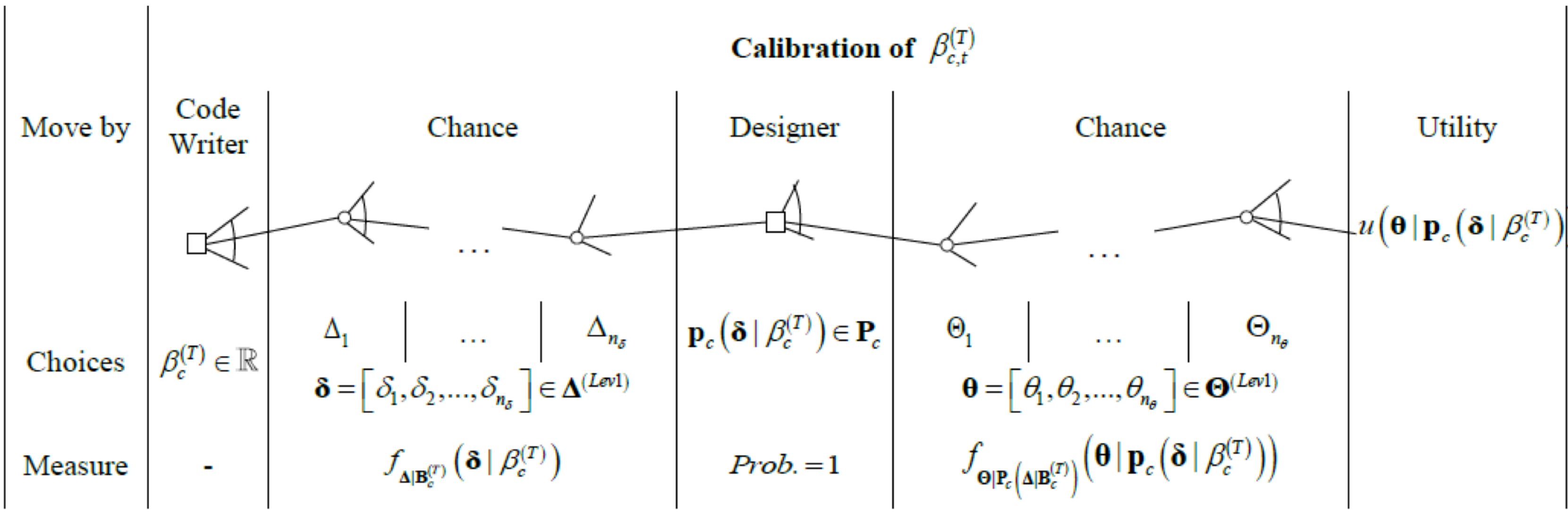


Move by	Code Writer	Chance	Designer	Chance	Utility
					$u(\boldsymbol{\theta} \mid \mathbf{p}_c(\boldsymbol{\delta} \mid \mathbf{r}_{el}))$
Choices	$\mathbf{r}_{el} \in \mathbb{R}^n$	Δ_1 | $\dots$ | Δ_{n_δ} $\boldsymbol{\delta} = [\delta_1, \delta_2, \dots, \delta_{n_\delta}] \in \boldsymbol{\Delta}^{(Lev1)}$	$\mathbf{p}_c(\boldsymbol{\delta} \mid \mathbf{r}_{el}) \in \mathbf{P}_c$	Θ_1 | $\dots$ | Θ_{n_θ} $\boldsymbol{\theta} = [\theta_1, \theta_2, \dots, \theta_{n_\theta}] \in \boldsymbol{\Theta}^{(Lev1)}$	
Measure	-	$f_{\Delta \mid \mathbf{R}_{el}}(\boldsymbol{\delta} \mid \mathbf{r}_{el})$	$Prob. = 1$	$f_{\Theta \mid \mathbf{P}_c(\Delta \mid \mathbf{R}_{el})}(\boldsymbol{\theta} \mid \mathbf{p}_c(\boldsymbol{\delta} \mid \mathbf{r}_{el}))$	

e.g. type of structure

Simplified decision problem

1. **Optimise $\boldsymbol{\beta}_{c,target}$**
   - Decision variables: $\boldsymbol{\beta}_{c,target}$ for Level 1 design for a class of structures



2. **Reliability-based calibration**
   - $\mathbf{r}_{el,opt}$: $\boldsymbol{\beta}_c(\mathbf{r}_{el})$ as close as possible to $\boldsymbol{\beta}_{c,target} = \boldsymbol{\beta}_{c,opt}$

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Code Calibration Overview