JCSS

Action effects uncertainties

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Prague, 2024.05.22

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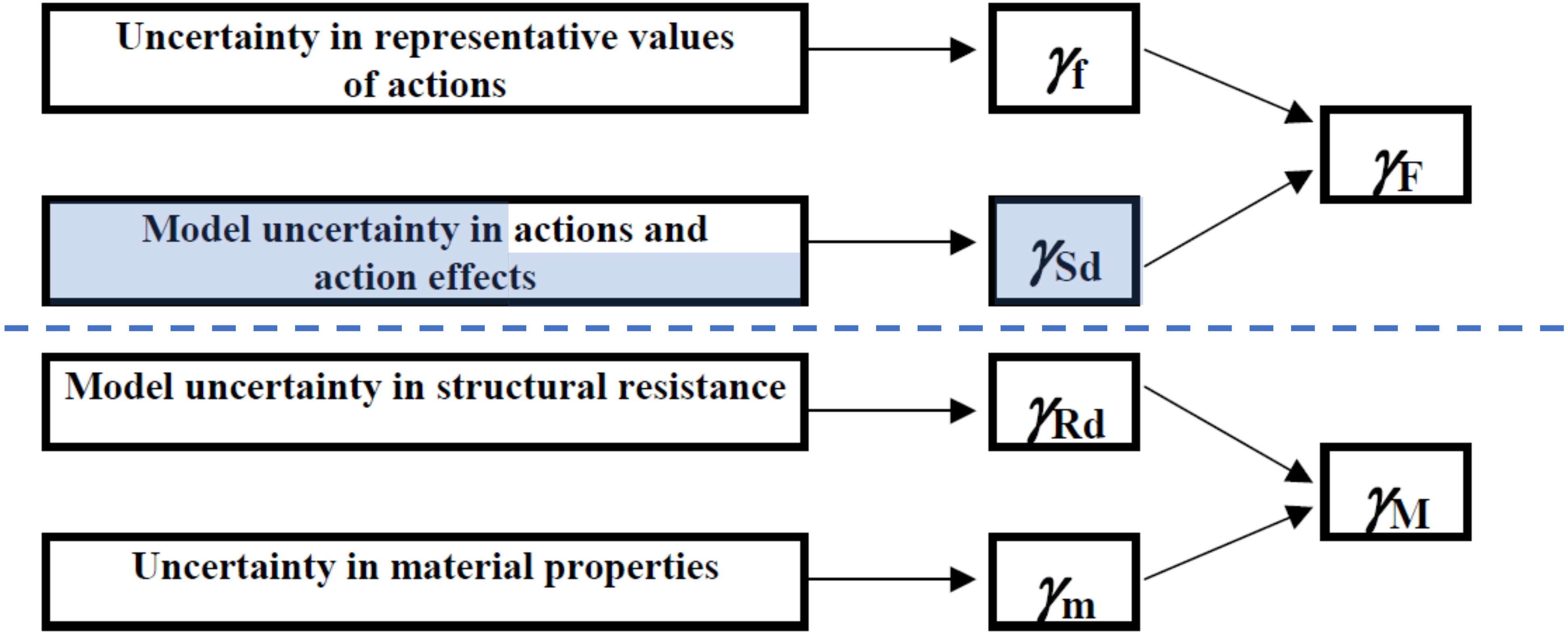
Introduction – Partial Safety Factor Format



Adapted from
EN 1990:2002

State of the art

- EN1990:2002 : $1.05 \le \gamma_{Sd} \le 1.15$
- γ_{Sd} defined in CEB rules (1964) and CEB/*fib* Model Codes (1976, 1990, 2010, 2020)
- Detailed information given in CEB Manual "Structural Safety" (1980)
- JCSS : *LN* distribution with mean 1.0 and CoV between 5 and 20%

Coefficient γ_{Sd} accounts for:

i. effect of differences between the actual structure and the idealized system assumed in the analysis (CoV = 8% for concrete structures and 5% for steel structures);
ii. approximations in the analysis (CoV = 5%);
iii. influence of imperfections during execution on the internal forces (5% for concrete structures and 2% for steel structures);
iv. the effect of neglected actions at ultimate limit state (as for instance imposed deformations, including thermal effects and shrinkage);
v. the inaccuracy in determining the influence of load combinations with the chosen safety format of partial safety factors

(for the uncertainties iv. and v., CoV = 8% for concrete structures and of CoV= 5% for steel structures)

See detailed review in Yu, Valeri et al. 2021

State of the art

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Open questions

γ_{Sd} depends on:

- Material?
- Statical system
- Calculation method?
- Modelling of the structure?
- Governing failure mode?
- Erection mode?

Introduction: model uncertainty in action effects

Statically determinate system

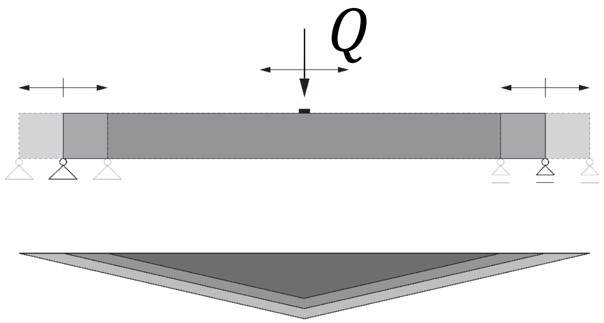
Museu Brasileiro da Escultura e da Ecologia, Sao Paulo, 1995, Arch. P. Mendez da Rocha

Statically indeterminate system

Pavilion for the Kingdom of Bahrain Expo 2020 Dubai, Arch. C. Kerez, Structural designer J. Schwartz

Introduction: model uncertainty in action effects

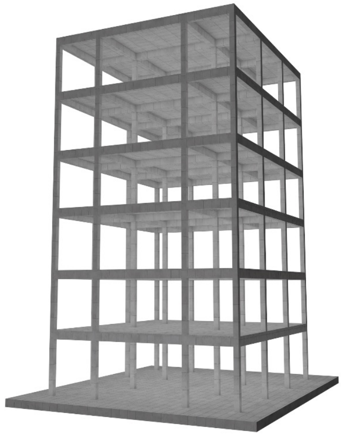
Statically determinate system



Uncertainties in action effects related to:

- Geometrical uncertainties (for instance span + position of load)

Statically indeterminate system



Uncertainties in action effects related to:

- Geometrical uncertainties
- Material uncertainties (in case of several material)
- Model uncertainties
  - Mechanical modelling uncertainties (for instance M-χ relationship, shear deformations accounted for or not, ..)
  - Modelling of the structure (software used + user)
  - Structural system changes during construction

Model uncertainty in action effects

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ARTICLE

fib WILEY

Model uncertainties in action effects and load bearing capacity calculation in statically indeterminate reinforced concrete structures

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Federal Roads Office, Switzerland

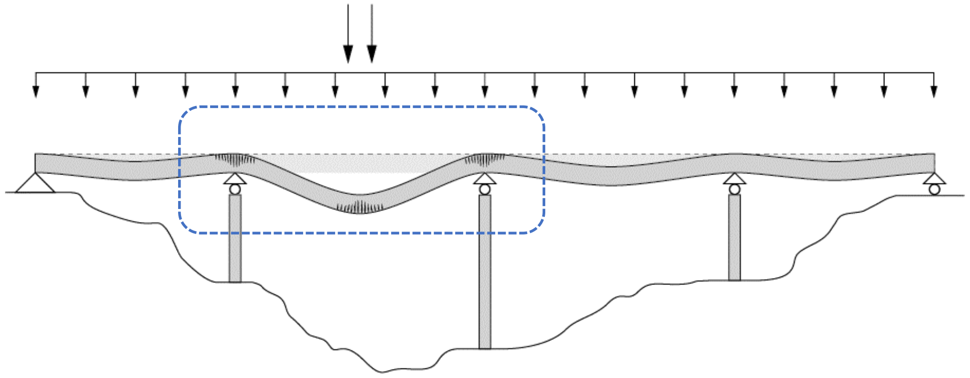
Abstract
For the dimensioning and assessment of structures, it is common practice to compare action effects with sectional resistances. Extensive studies have been performed to quantify the model uncertainty on the resistance side. However, for statically indeterminate systems, the model uncertainty in the calculation of action effects has not been properly investigated yet. The aim of this article is to contribute in quantifying the model uncertainty in action effects and load bearing capacity calculations for reinforced concrete structures, accounting for the type of mechanical model used and for various failure modes. To collect a sufficient amount of data and perform statistical analyses, the experimental response of statically indeterminate systems is obtained with a simple and effective technique which allows using experimental results available in literature. Finally, on the basis of a parametric analysis and case studies, practical implications are discussed and recommendations are given concerning the implementation in the partial safety factor format.

KEYWORDS
action effects, load bearing capacity, model uncertainty, nonlinear analysis, reinforced concrete, statically indeterminate systems, structural reliability

Structural Concrete, 2024

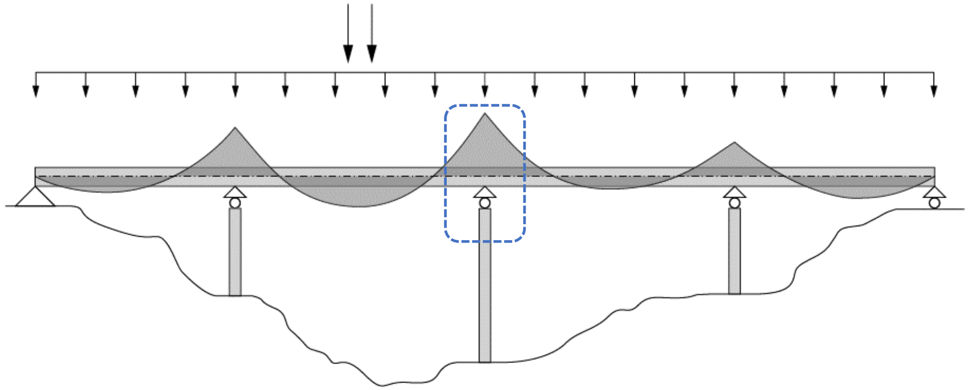
Definitions

Global verification method (θ_G)
Load carrying capacity R



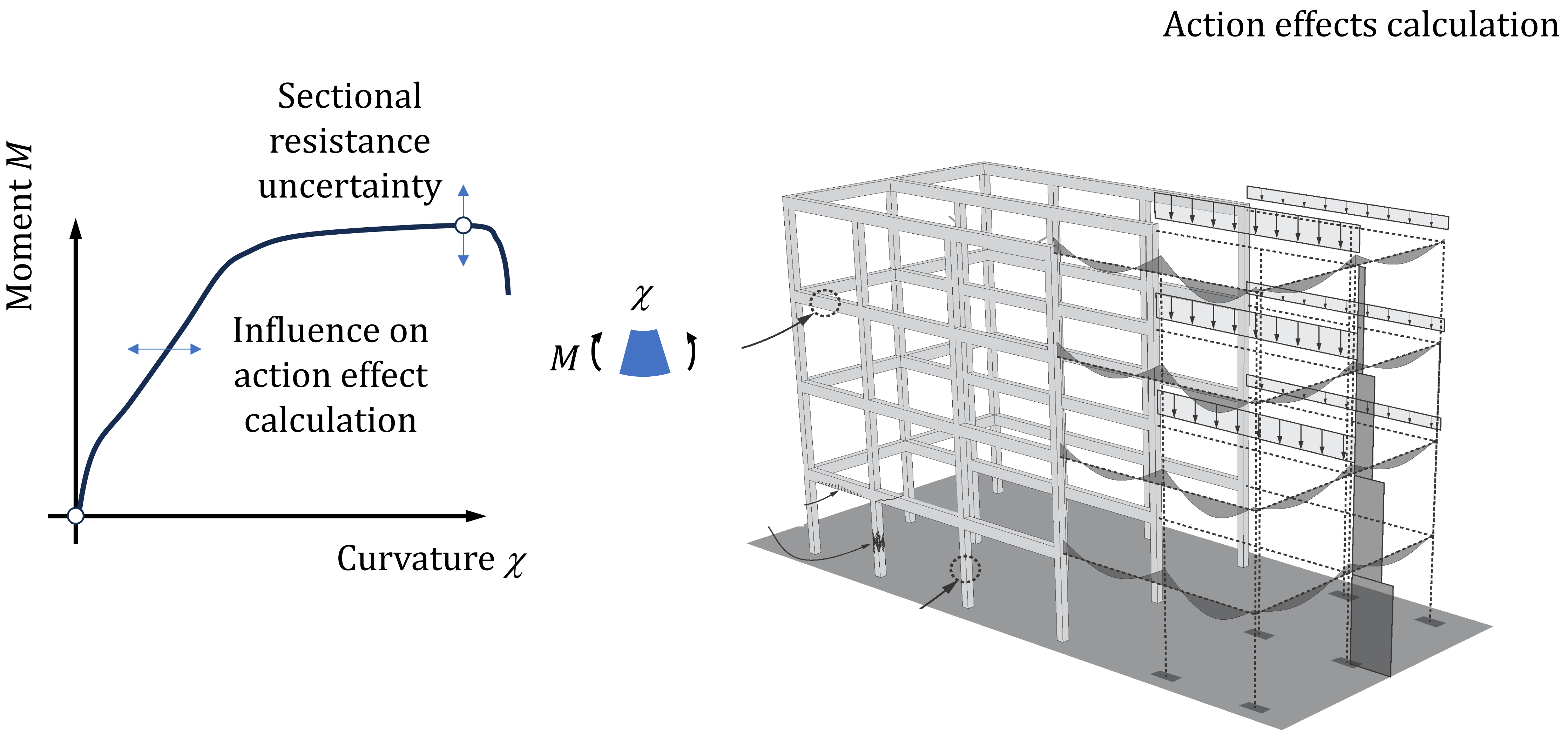
$Q_E \leq Q_R$ Global $\theta_G = \frac{R_{sys,exp}}{R_{sys,mod}}$

Local verification method (θ_E)
Internal force E



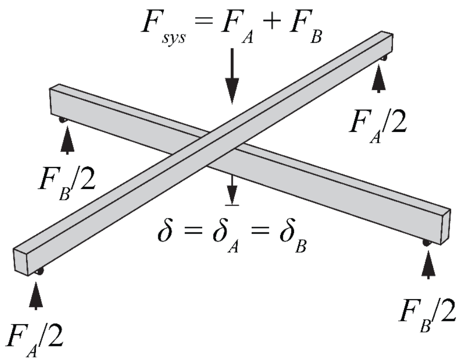
$E_D \leq R_D$ Local $\theta_{E,n} = \frac{E_{n,sys,exp}}{E_{n,sys,mod}}$

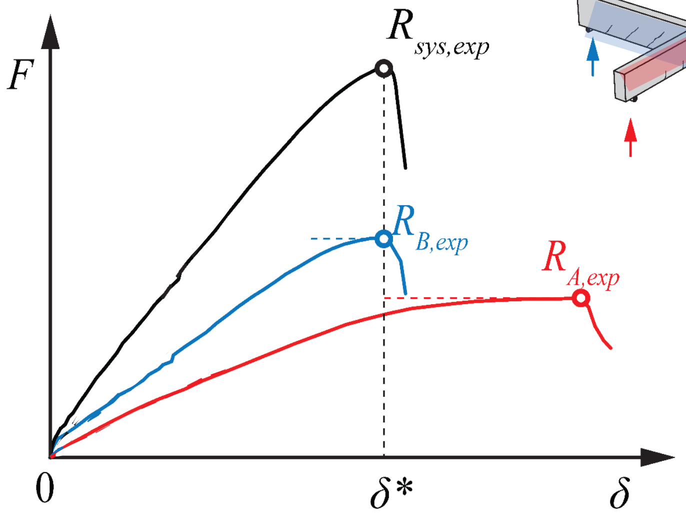
Model uncertainty in internal forces and load carrying capacity

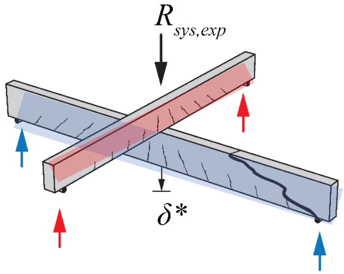


Quantification of the model uncertainty

- Model uncertainty typically quantified by comparing the so-called reality with the calculated value
- Measured internal forces or load-carrying capacities of actual structures relatively scarce ⇒ laboratory tests considered instead of actual structures
- For statically indeterminate system, laboratory tests also are relatively scarce
- ⇒ synthetized tests produced from assembled system using tested simply supported beams

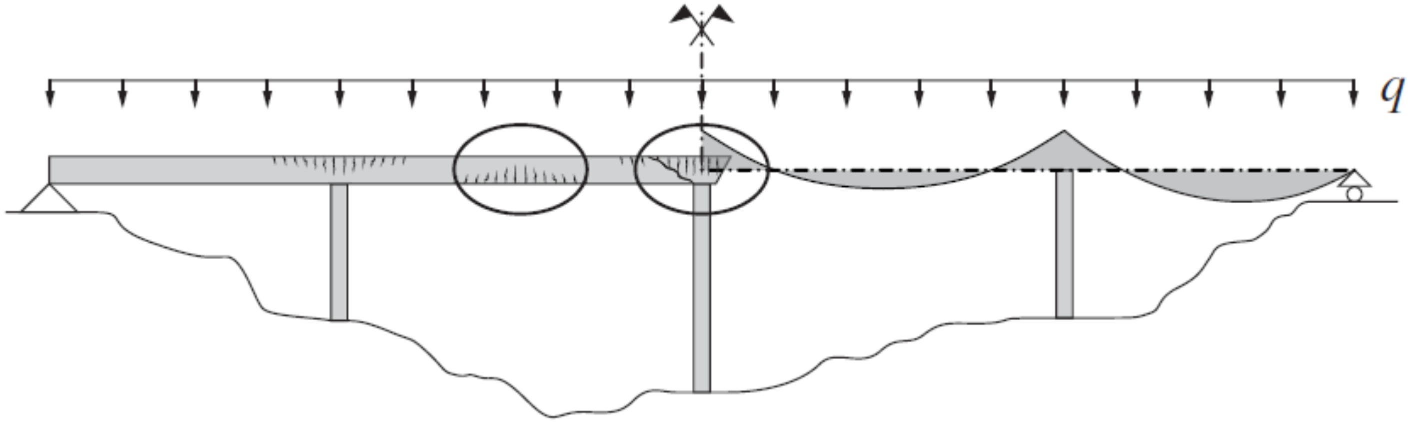


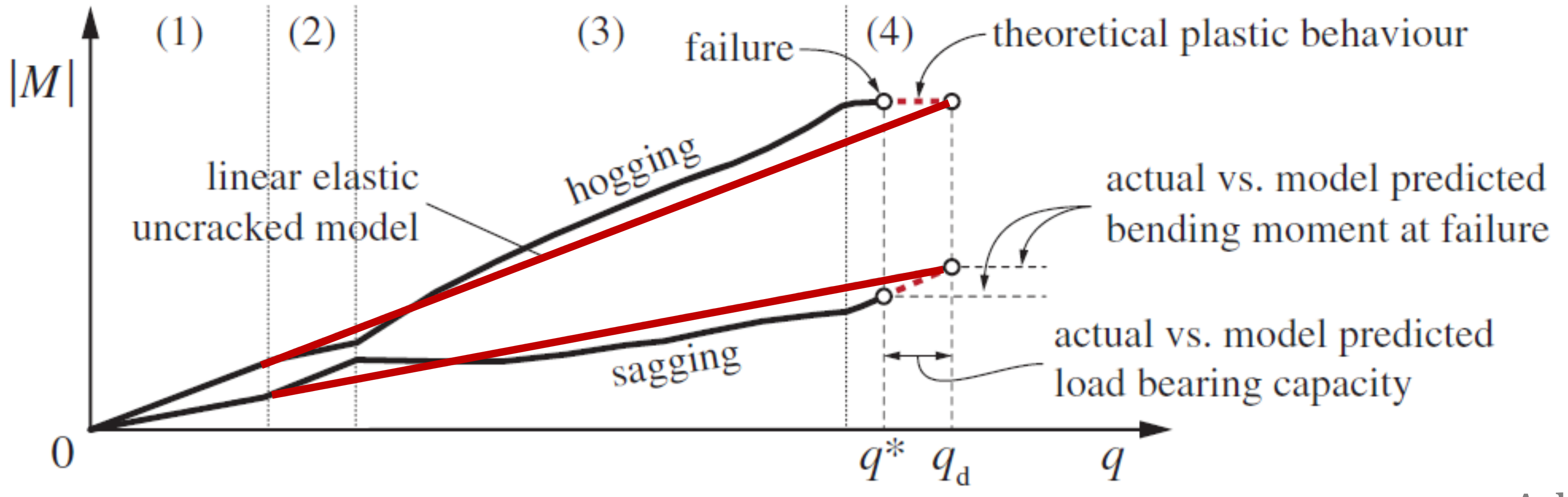


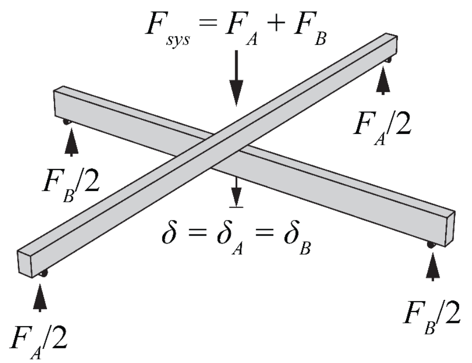


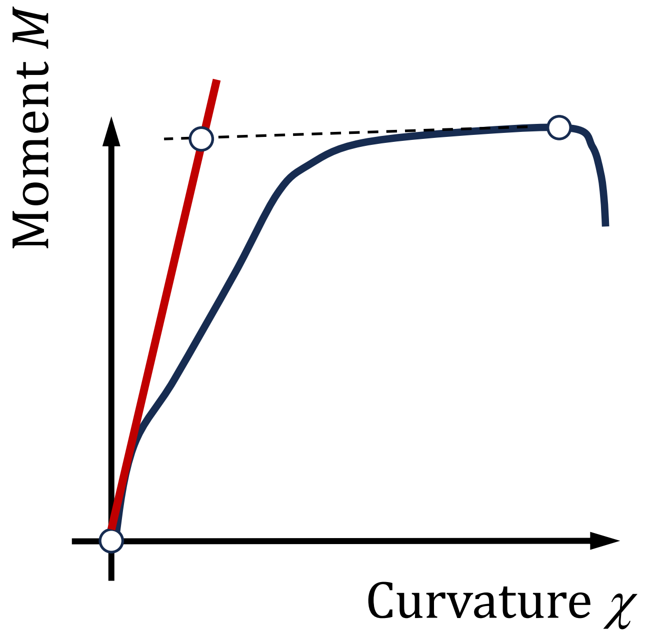
$$\binom{93}{2} = \frac{93!}{2!\cdot(93-2)!} = 4278$$

Representativeness of investigated system





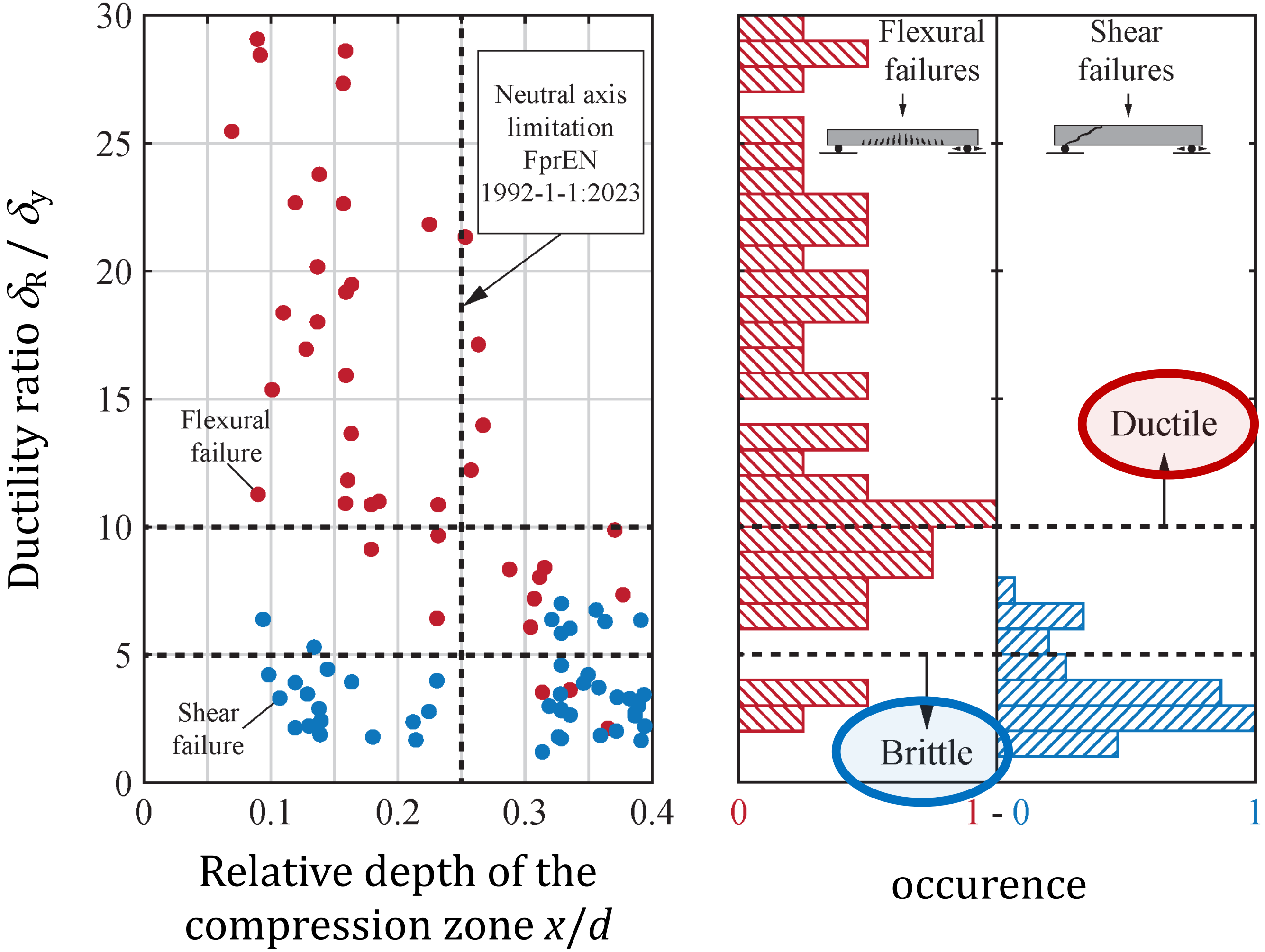




Adapted from Muttoni 1990

Considered tests

Failure classification



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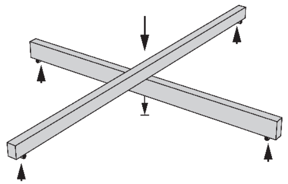
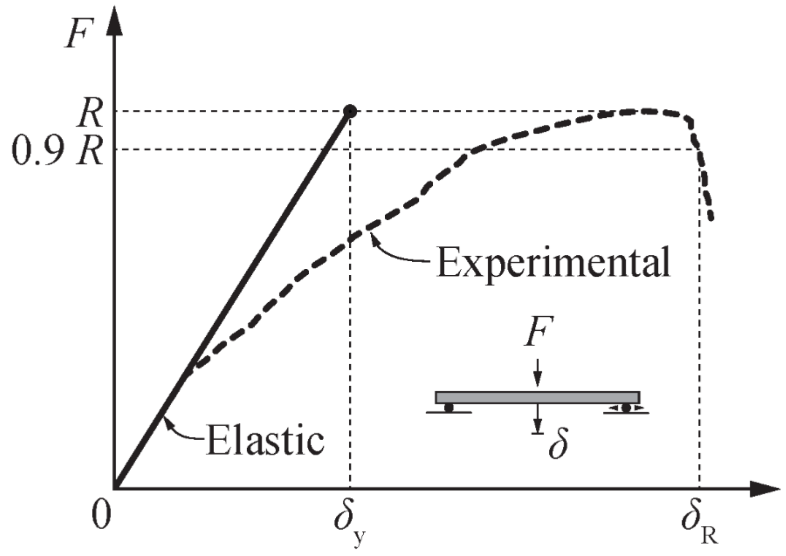
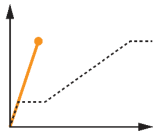
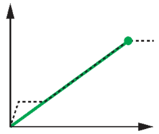
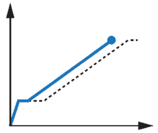
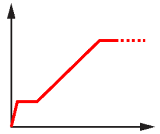
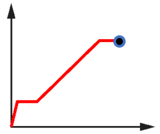
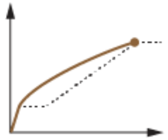
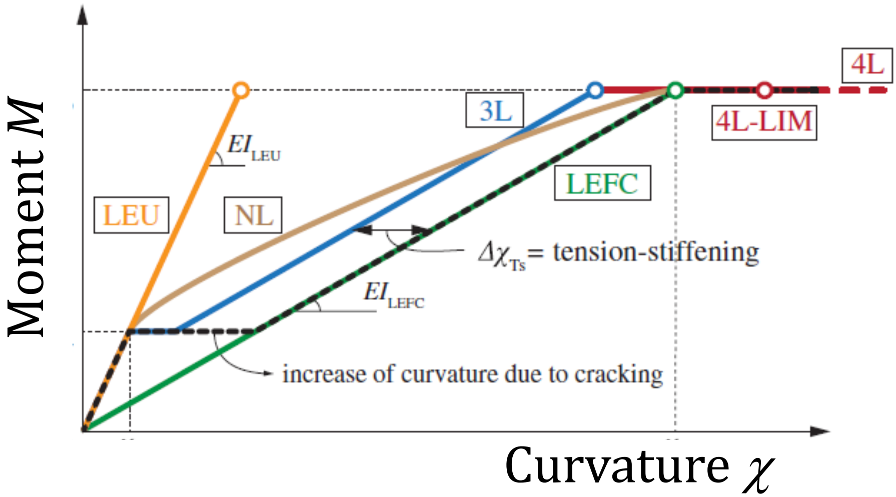
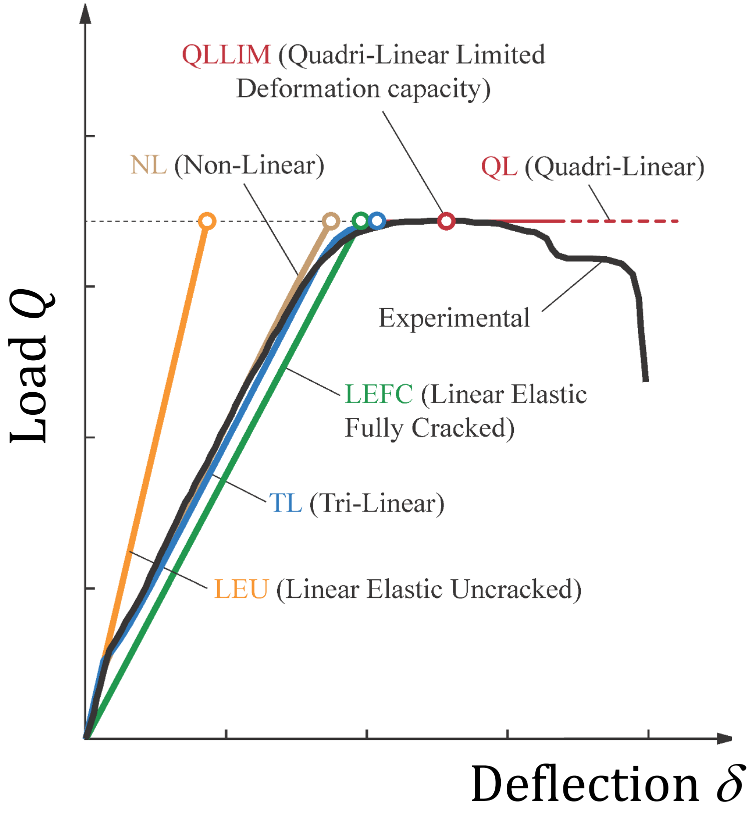




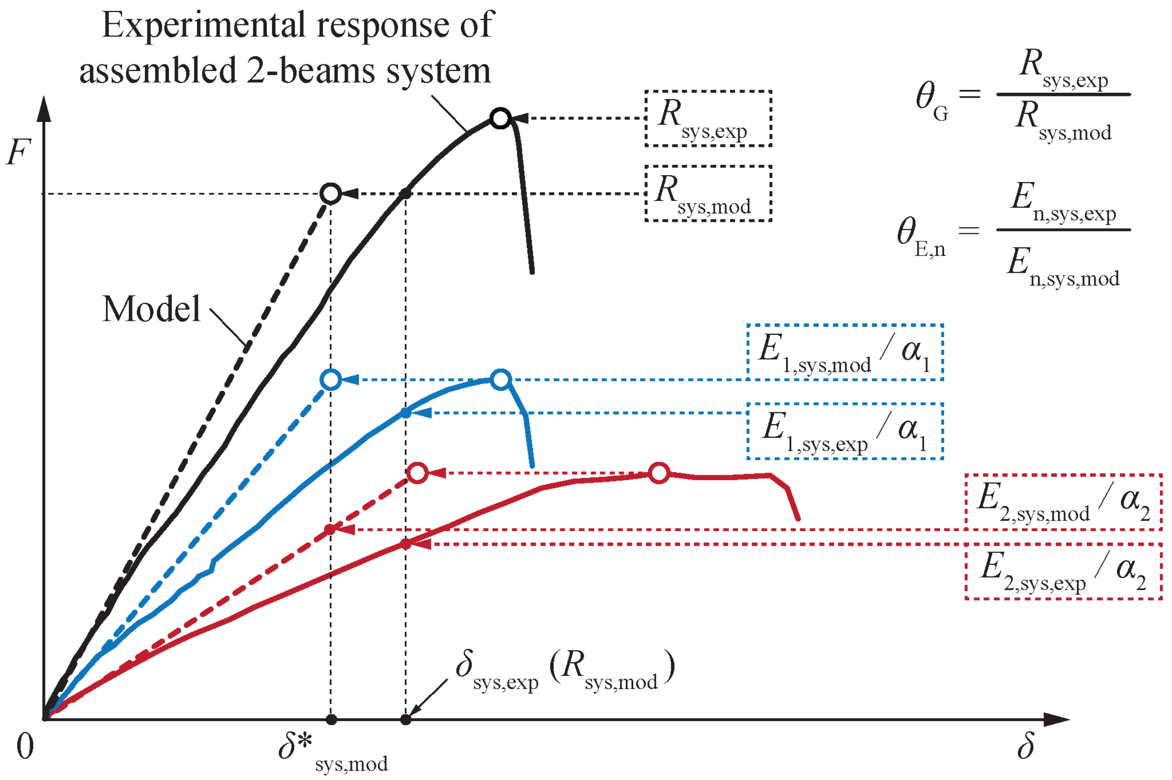
Considered mechanical models

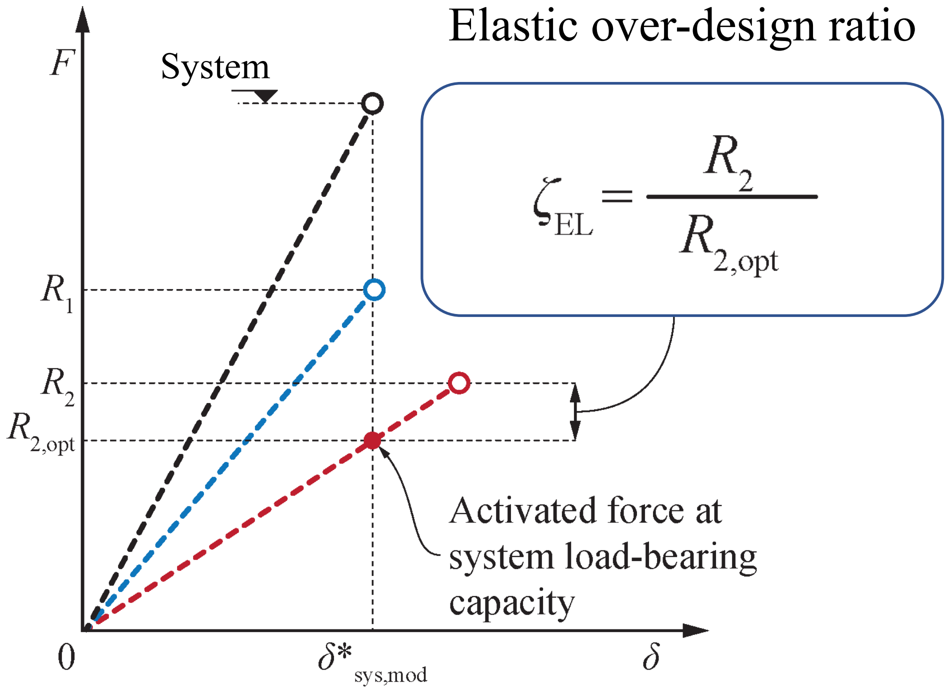
Name	M-χ	Shear	Tension stiffening	Section Stiffness
Linear Elastic Uncracked		No	-	Uncracked
Linear Elastic Fully Cracked		No	-	Cracked
Tri Linear		Yes	Yes	Uncracked – Cracked
Quadri Linear		Yes	Yes	Uncracked – Cracked – Plastic
Quadri Linear Limited		Yes	Yes	Uncracked – Cracked – Plastic Limited
Non Linear		No	No	Variable



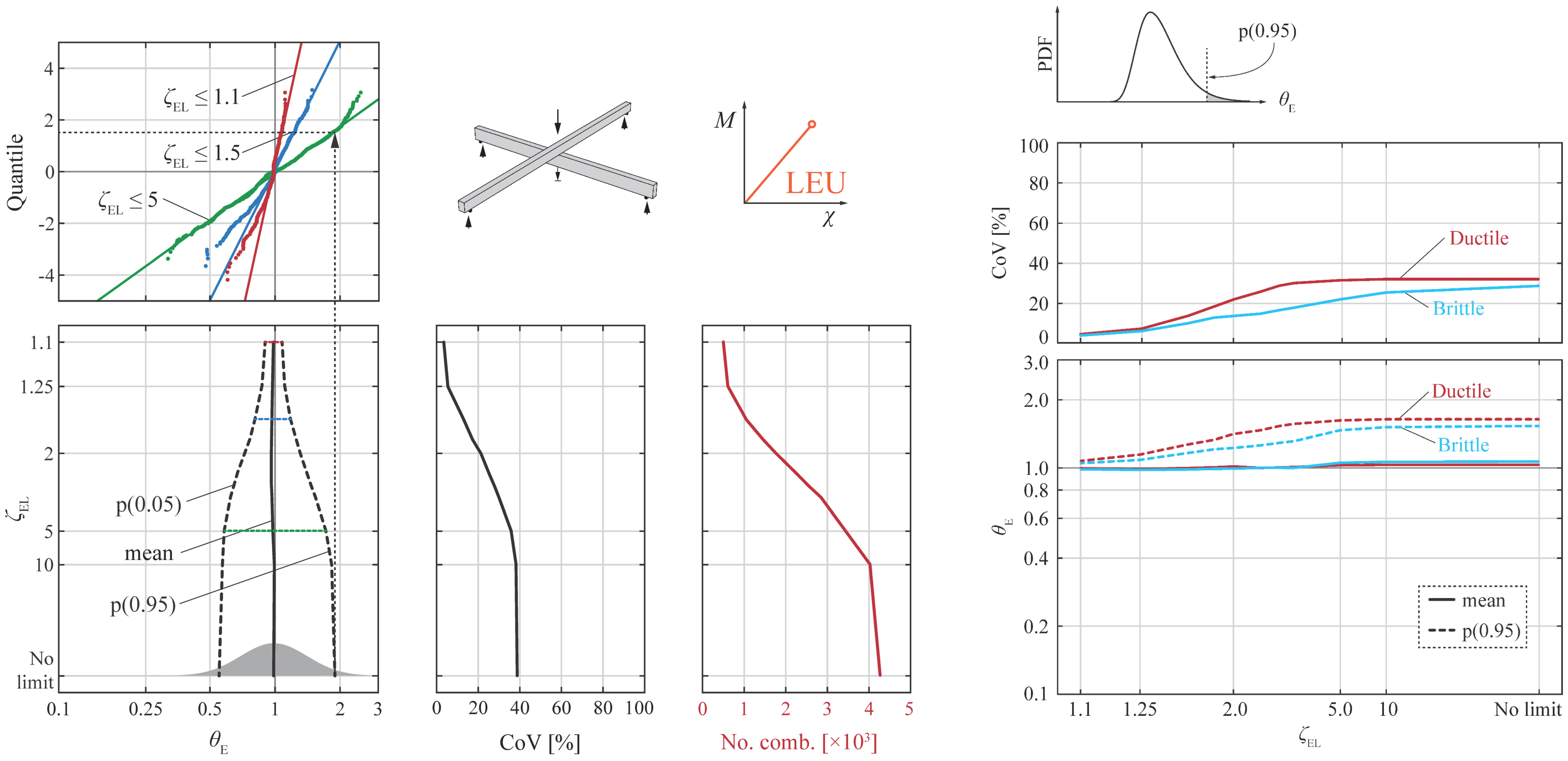


Example of linear elastic uncracked calculation

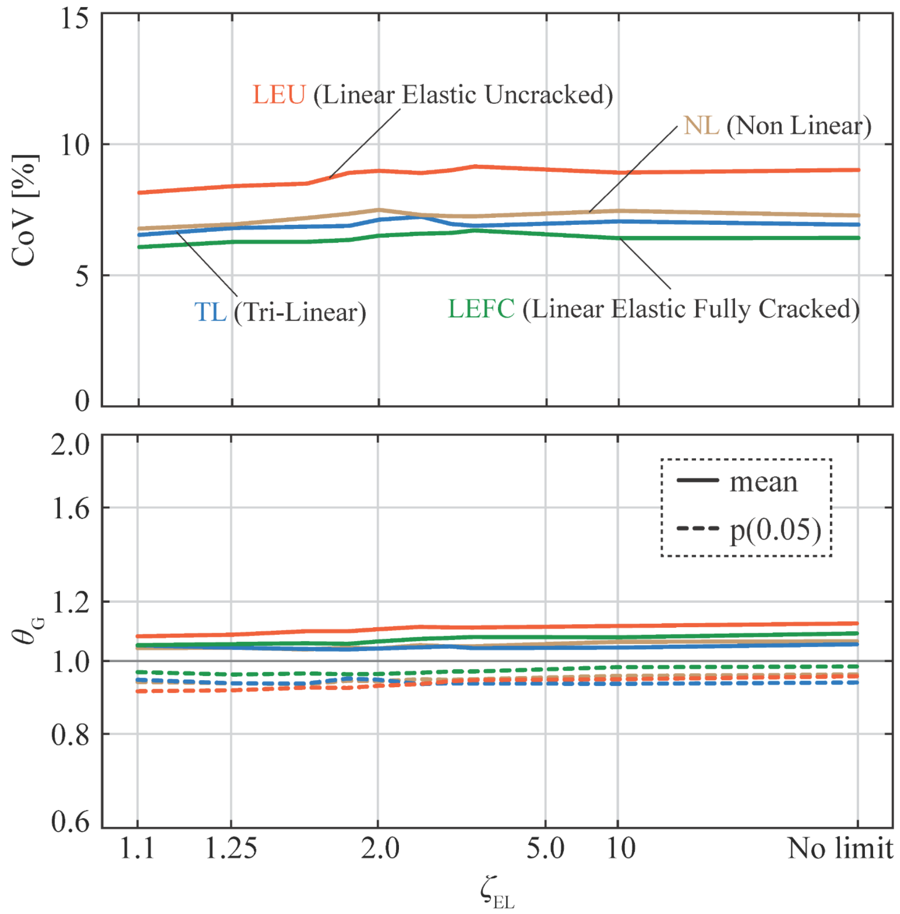




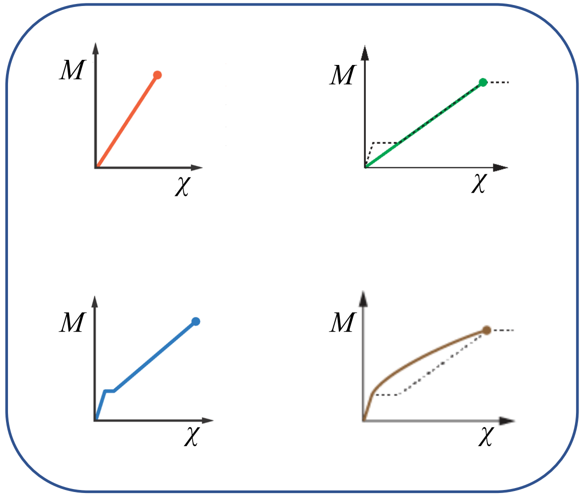
Action effects θ_E (linear elastic uncracked)

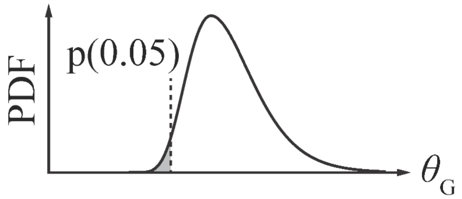


Load bearing capacity θ_G

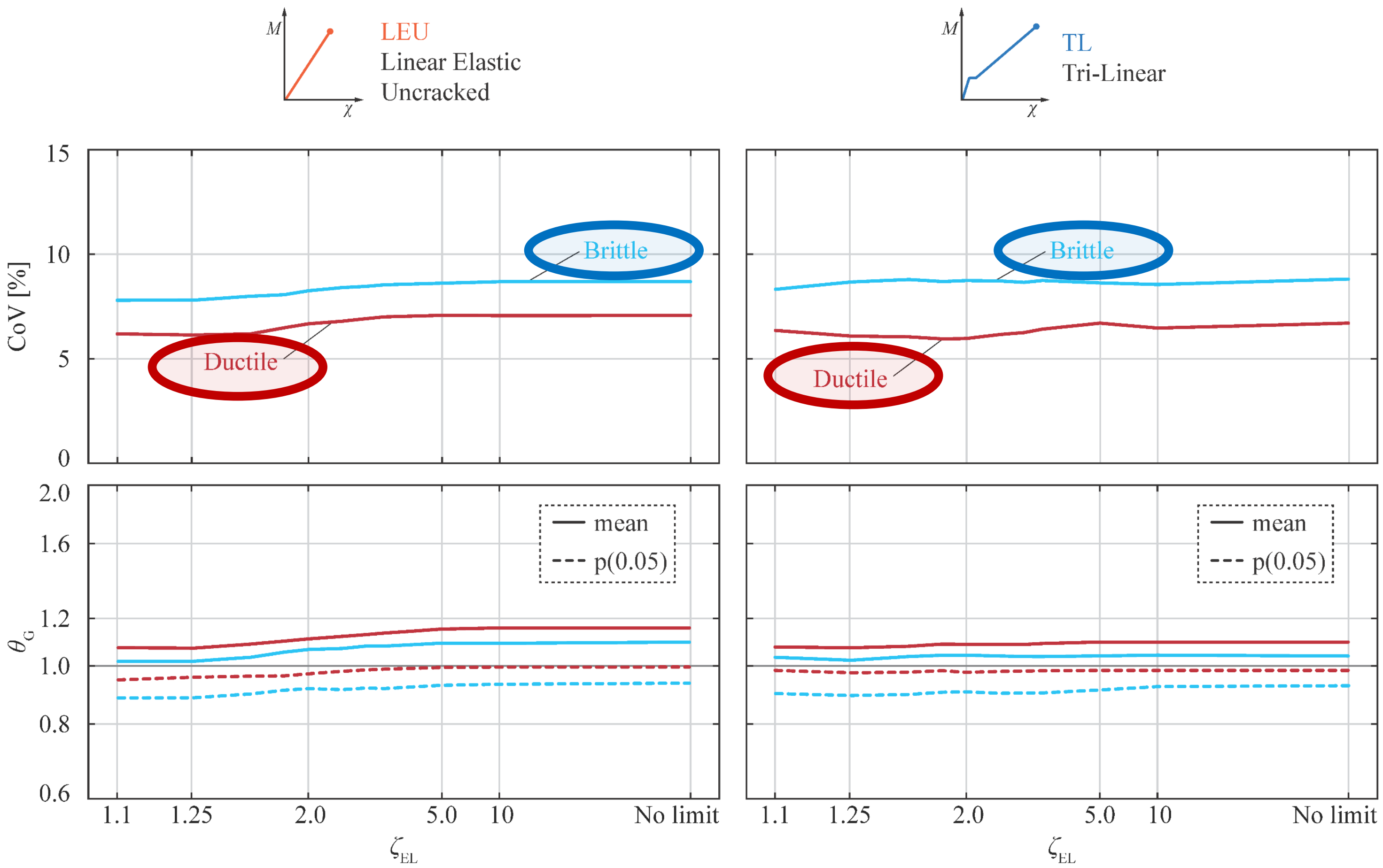


Moment-curvature





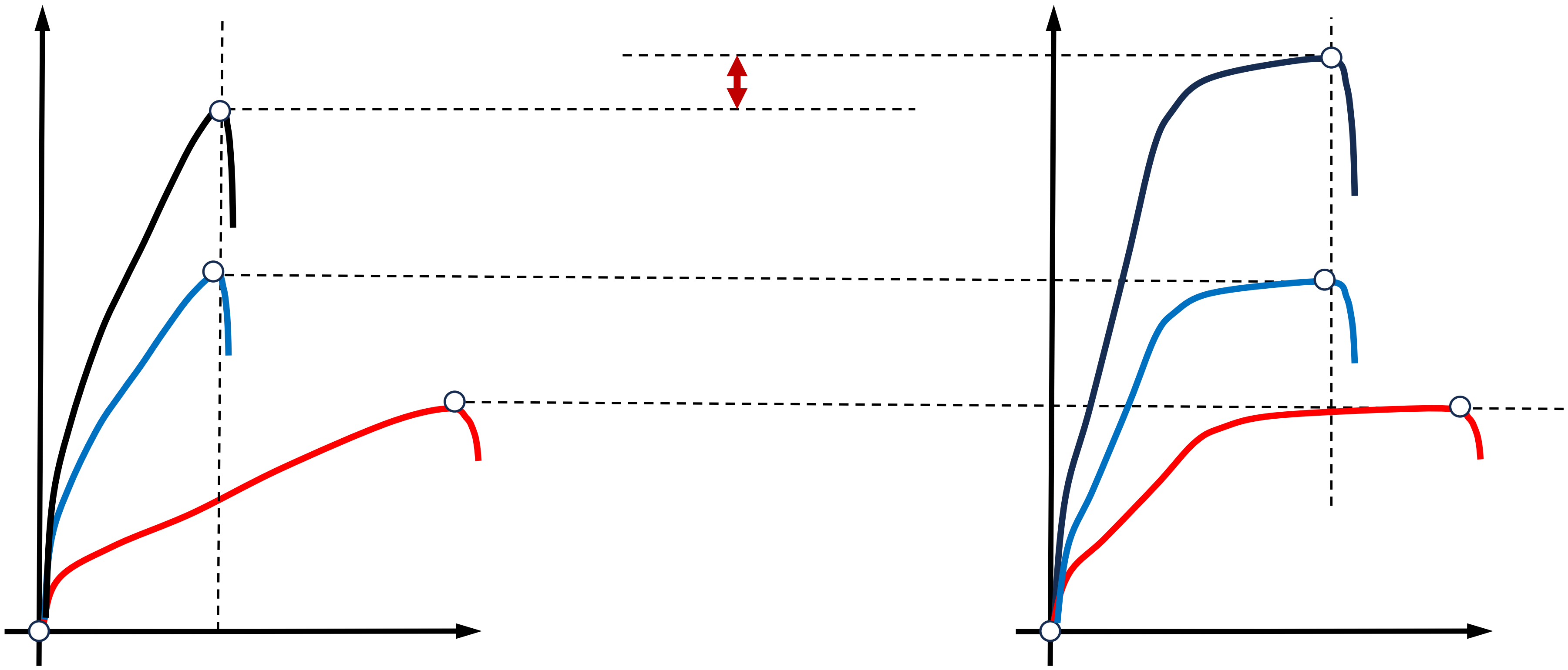
Load bearing capacity θ_G

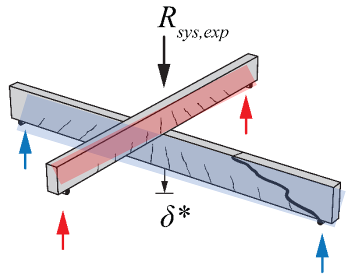


Influence of deformation capacity (“ductility”)

“Brittle” behaviour

“Ductile” behaviour



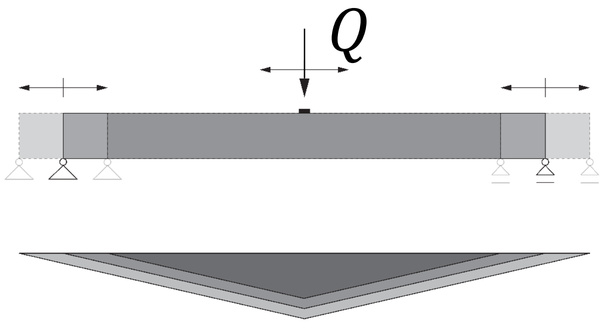


Proposal (for next *fib* MC or other standard?)

Since the model uncertainty of the internal force calculation mainly depends on the deformation capacity of the material and the failure mode, why not to move γ_{Sd} to the resistance side as a function of the material (γ_C and γ_S , for instance as a function of the ductility steel class) and the failure mode (γ_V in MC2020)?

Other uncertainties

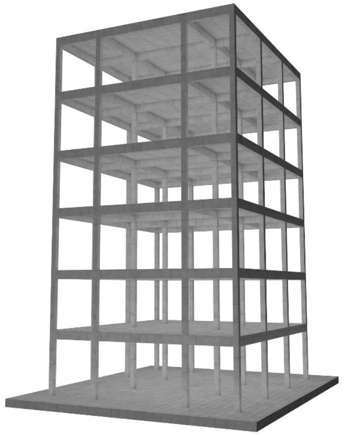
Statically determinate system



Uncertainties in action effects related to:

- Geometrical uncertainties (for instance span + position of load)

Statically indeterminate system



Uncertainties in action effects related to:

- Geometrical uncertainties
- Material uncertainties (in case of several material)
- Mechanical modelling uncertainties (for instance M-χ relationship, shear deformations accounted for or not, ..)
- Modelling of the structure (software used + user)
- Structural system changes during construction

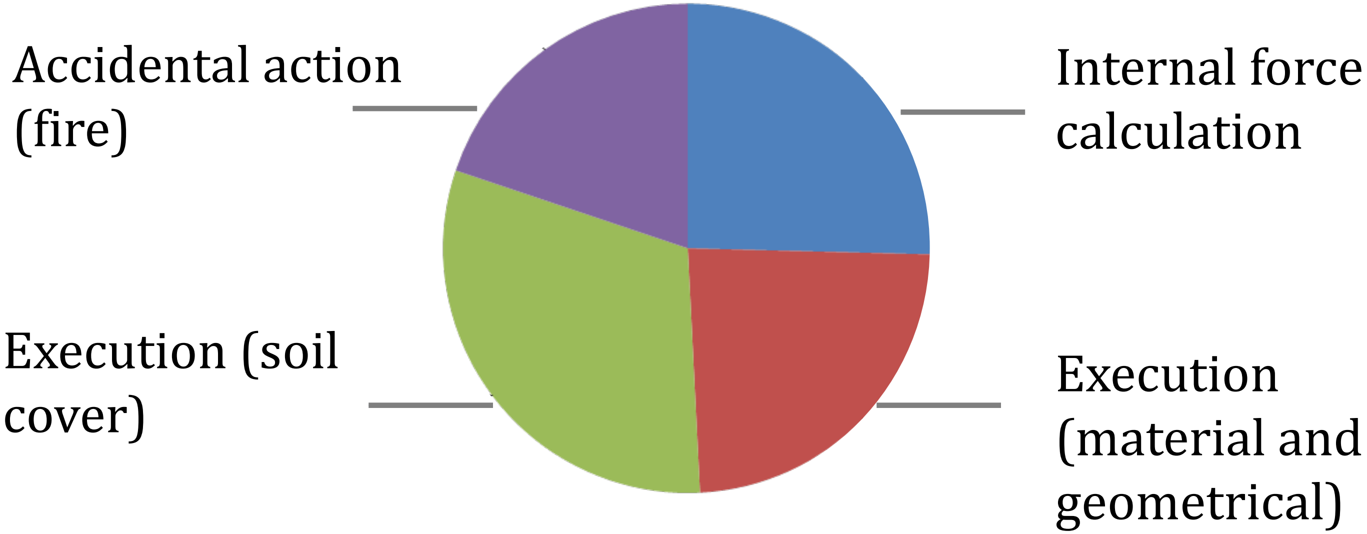
Relevance of model "uncertainties" related to the calculation of internal forces

Analysis of failures and accidents shows that

- The influence of analysis and design "errors" cannot be neglected
- We often describe them as "human errors", but what is the limit between "human error" and "a not completely suitable modelling" or "an unsuitable approximation" ? Is such a Manichean distinction, in case of modelling, even possible?

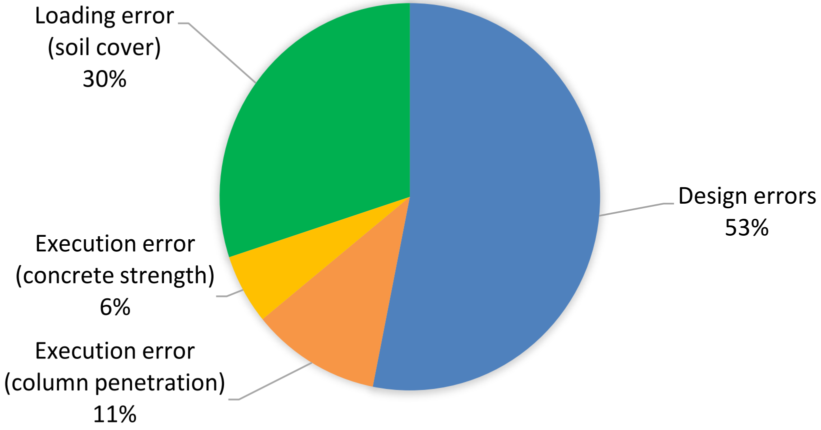
Relevance of model uncertainties/errors related to the calculation of internal forces

Collapse of a car parking slab at Gretzenbach, Switzerland, 2004

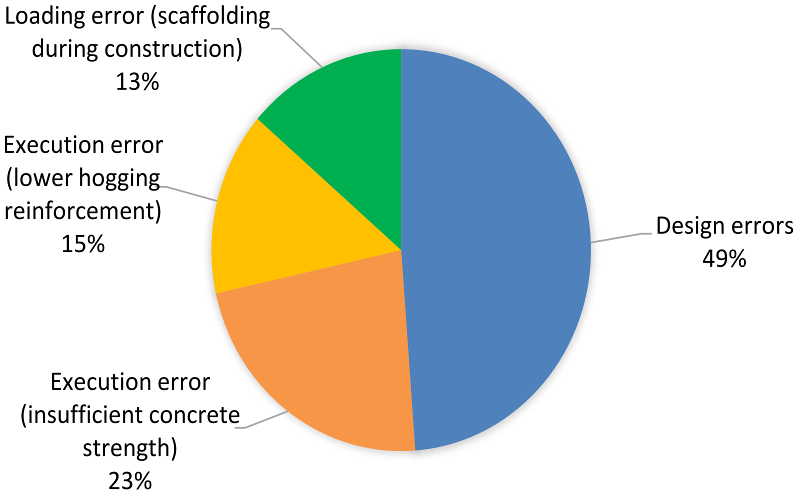


Relevance of model uncertainties/errors related to the calculation of internal forces

Collapse of a car parking slab at Bluche (VS), Switzerland, 1981



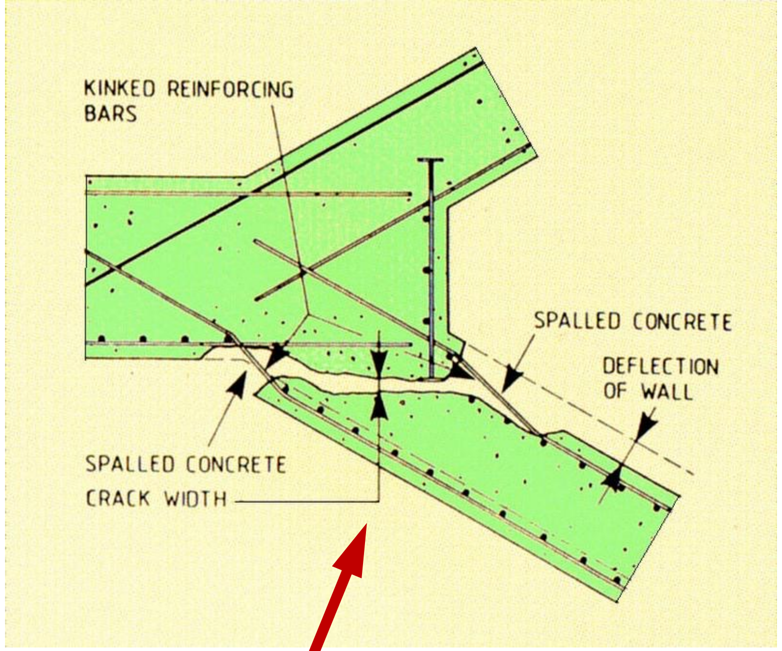
Collapse of a building at Cagliari, Italy, 2004

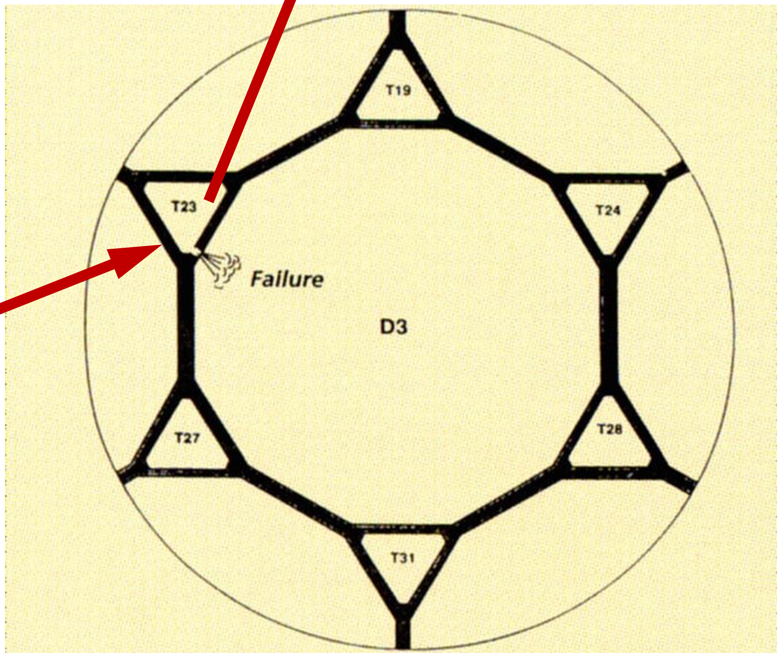


Relevance of model uncertainties/errors related to the calculation of internal forces

Accident of the oil platform Sleipner A in the North Sea, 1991

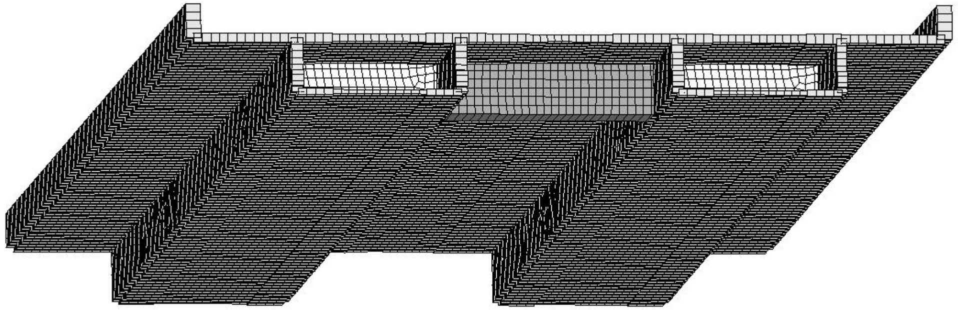
- Finite element modelling producing results that were difficult to interpret,
- Unclear combination of load cases
- Critical construction details not properly represented and designed
- Effect of water pressure in cracks neglected



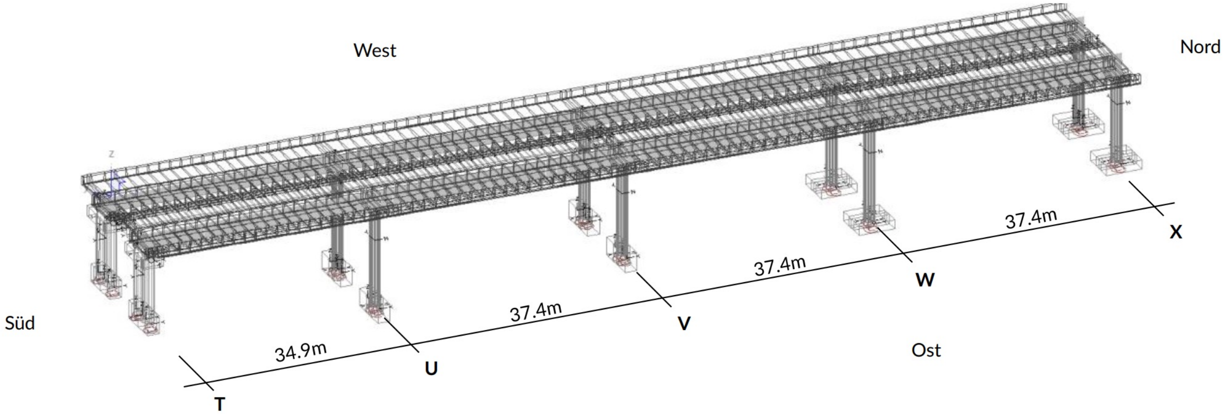


Uncertainties in modelling the structure

Linear elastic shell elements

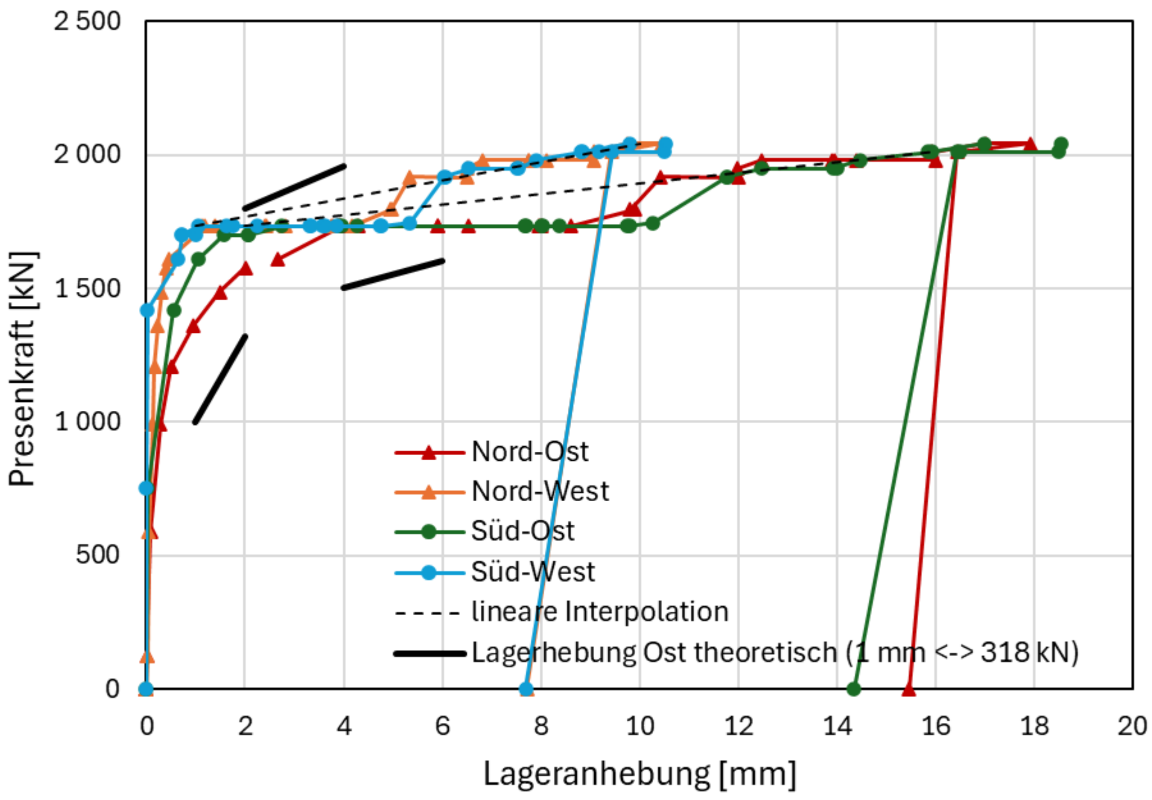


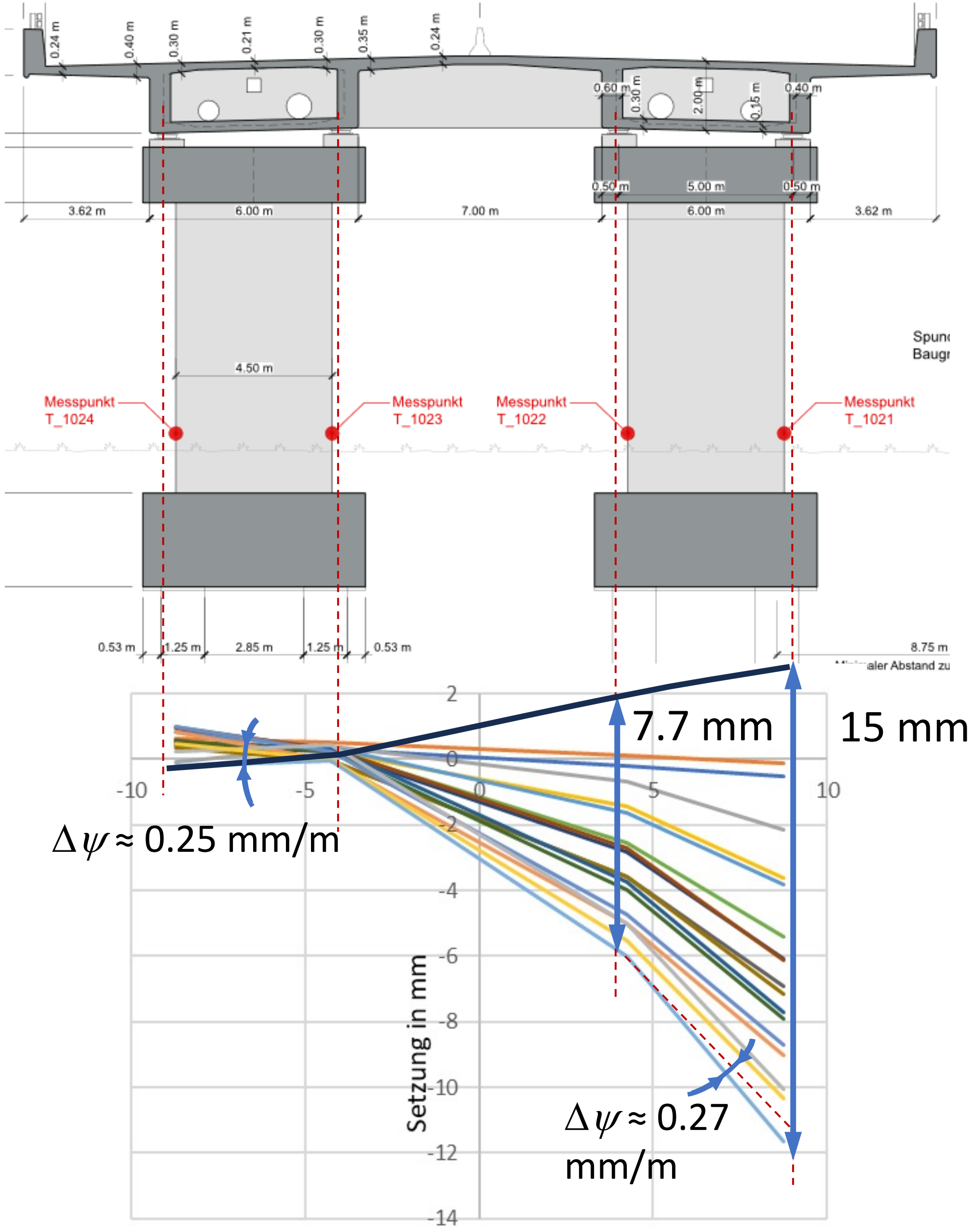
Linear elastic beam elements



Uncertainties in modelling the structure

Bridge lifting, Weyermannshausviadukt, Berne, Switzerland, 2024.05.07





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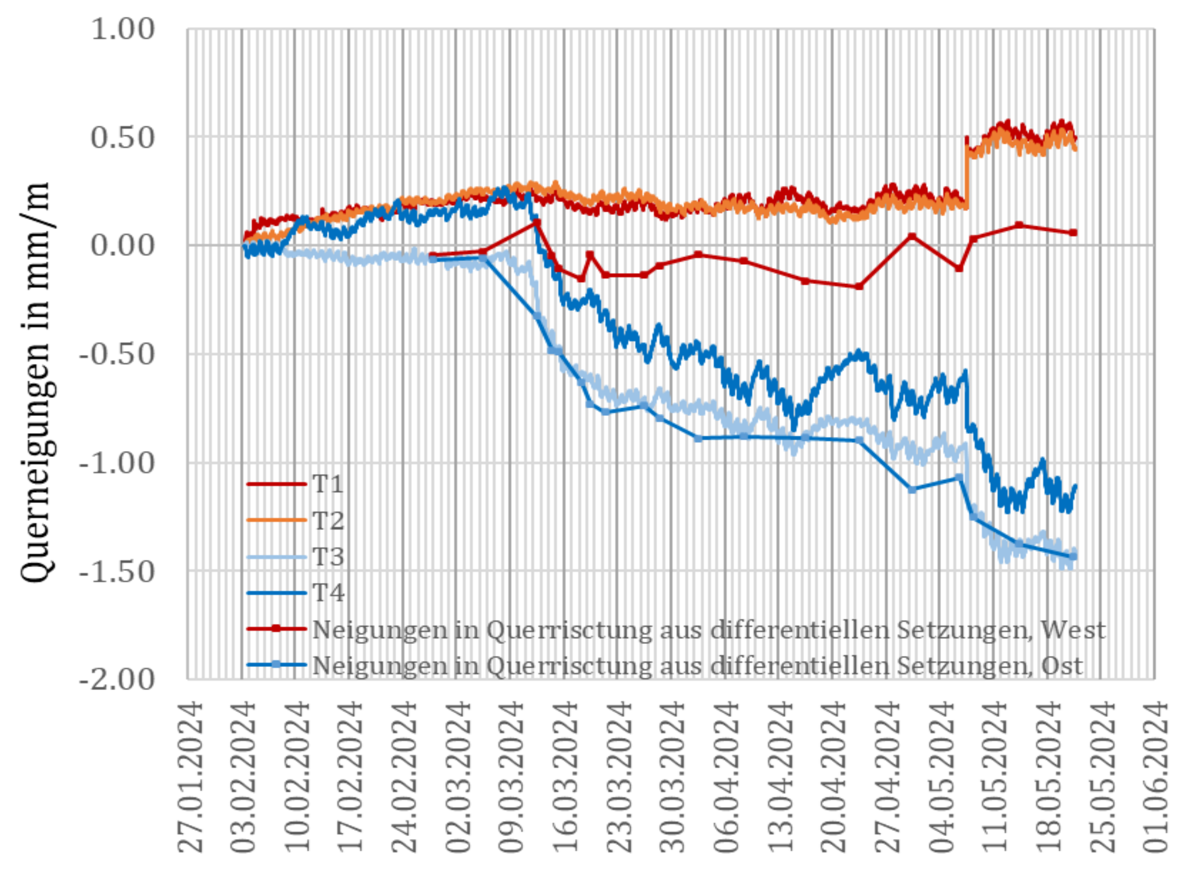
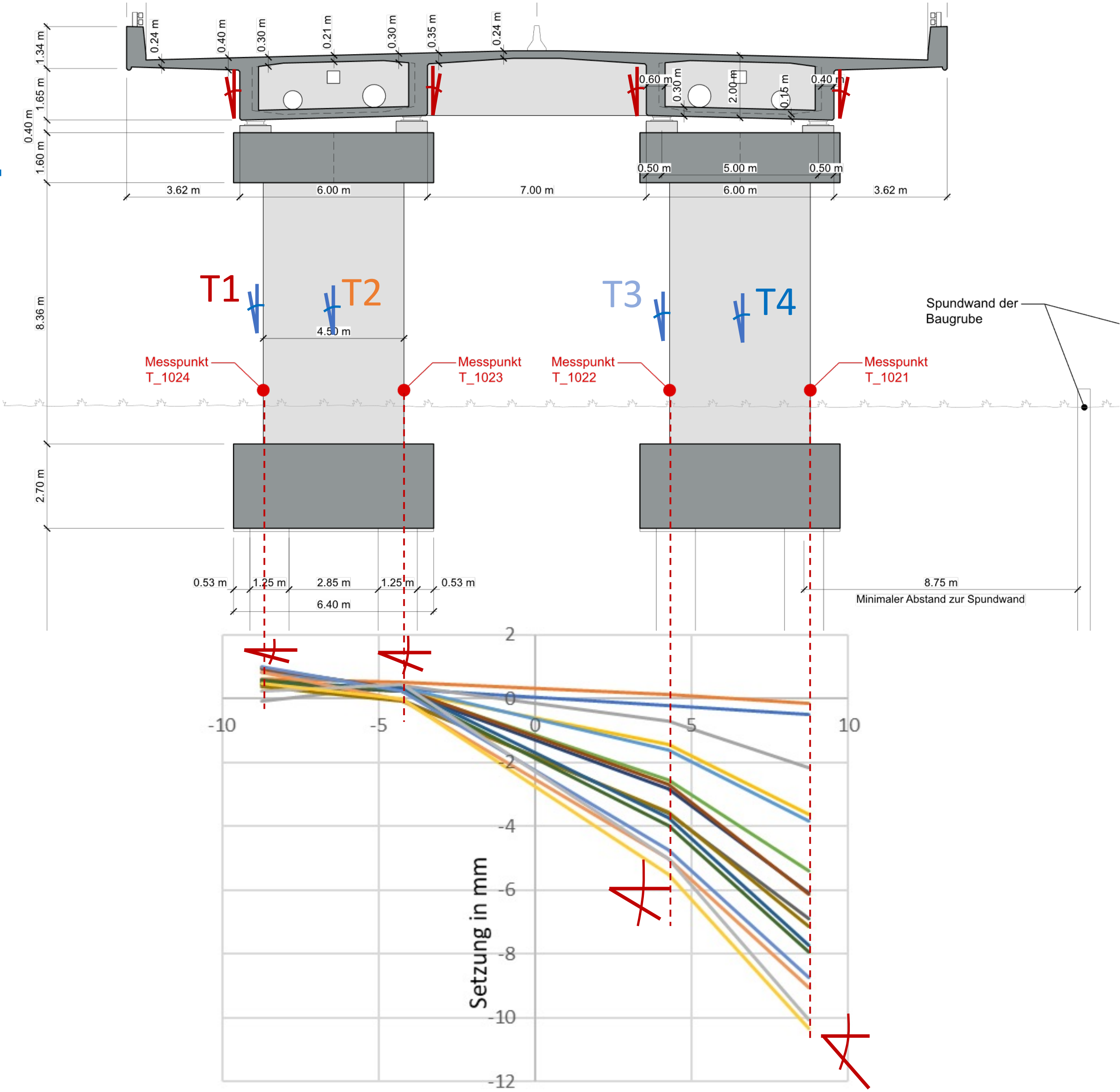
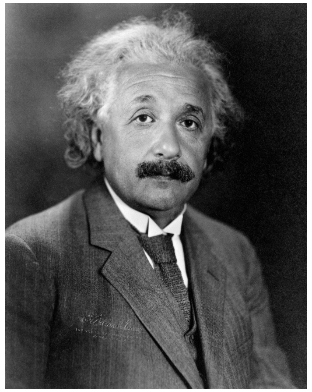
More and more monitoring results are available => this allows improving the reliability of modelling



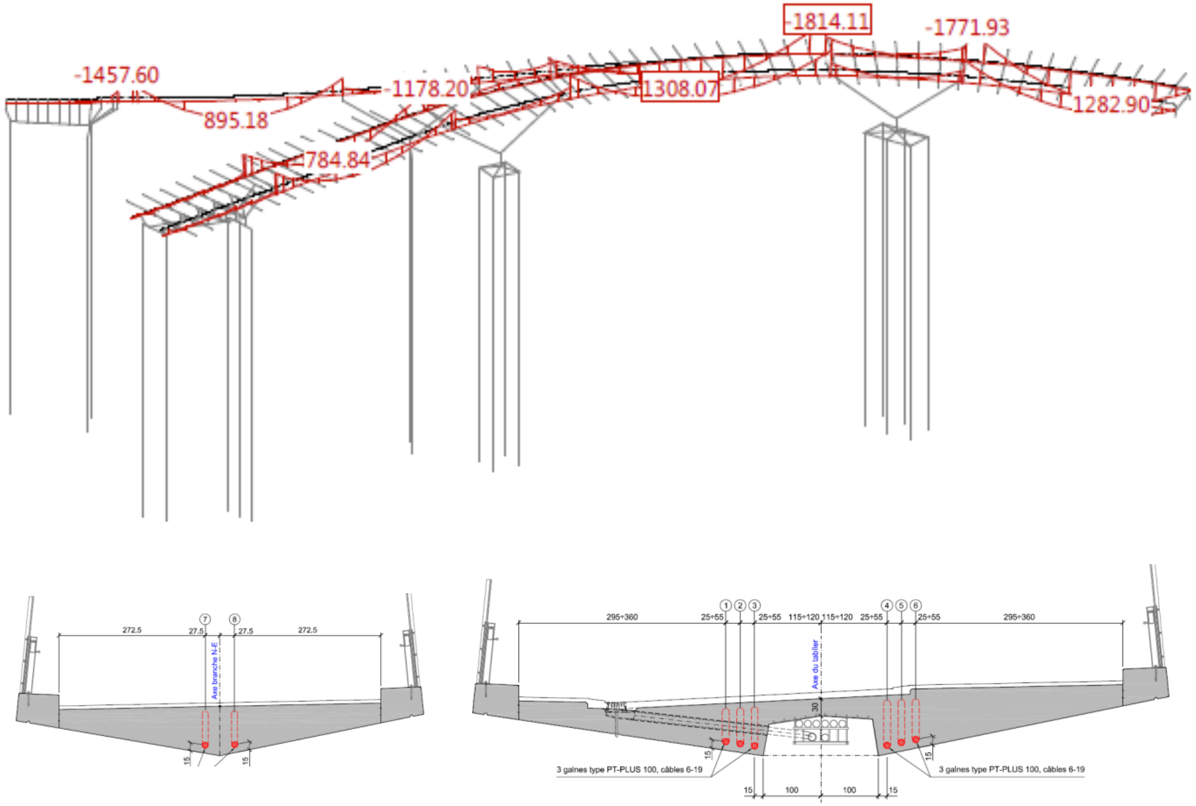


Some final personal considerations



In calculating and dimensioning **new structures**,

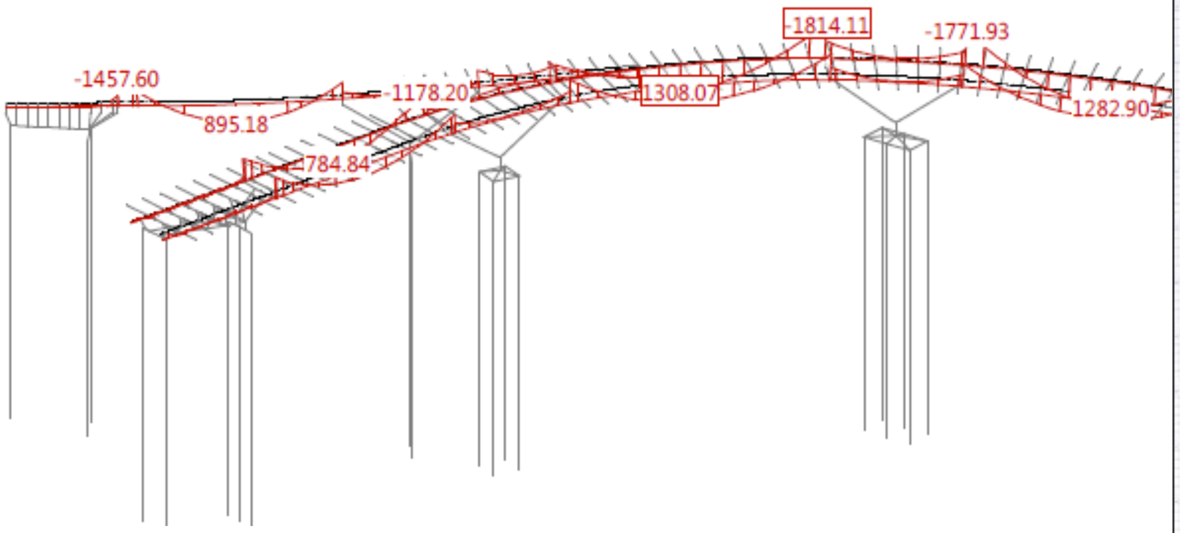
- the modelling of the structure should be “as simple as possible, but not too simple”

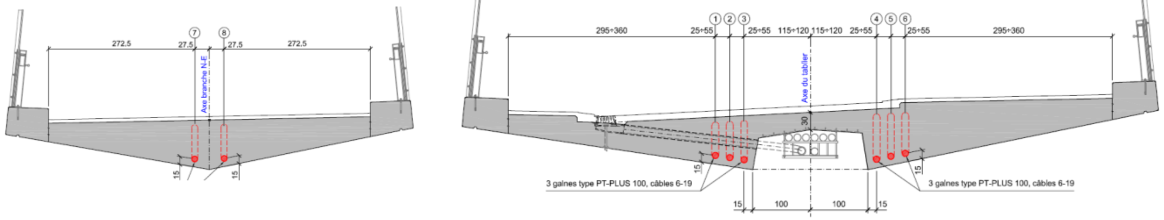


Some final personal considerations

In calculating and dimensioning **new structures**,

- the modelling of the structure should be "as simple as possible, but not too simple"
- FE calculations should always be compared to simple hand calculations





Some final personal considerations

In calculating and dimensioning **new structures**,

- the modelling of the structure should be "as simple as possible, but not too simple"
- FE calculations should always be compared to simple hand calculations
- The structure should be designed to be less sensitive to uncertainties (for instance, increasing the deformation capacity and the robustness)

  => this also allows to simplify the calculations (imposed deformations have a minor influence) and to design a structure in a more sustainable manner (saving materials)

Some final personal considerations

In assessing **existing structures**,

- Refined models are not always necessary: they give the illusion to provide more "exact" results, but an increased complexity is often associated to additional uncertainties!