IABSE

Commission 1
Performance and Requirements

TG1.4 Probabilistic
Non-linear Finite Element Modelling

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IABSE Commission 1

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Studies slender columns

Interfaces between old and new | materials and components

SED Probabilistic Finite Element Analyses

Characterization of Digital Twins

Strategies for service life extension of engineering details

Design vs. test standards

Commission 1

- TG1.1 Improving Seismic Resilience of Reinforced Concrete Structures
  Chair: Andreas Lampropoulos, UK

- TG1.2 Structures Design of Bridges against Fire Hazards
  Chair: Ignacio Paya-Zaforteza, Spain

- TG1.3 Calibration of Partial Safety Factors for the Assessment of Existing Bridges
  Chair: Alan O'Connor, Ireland

- TG1.4 Probabilistic Non-linear Finite Element Modelling – Reliability and Safety Formats
  Chair: Alfred Strauss, Austria

- TG1.5 Performance-Based Design Founded on Lessons from Bridge Failures
  Chair: Andrei Sizikov, UK/Russia

Commission 1

- TG1.6 Benefits for Practical Application of Risk and Reliability Considerations in Structural Engineering
  Chair: Jochen Köhler, Norway
- TG1.7 Sustainability-driven Bridge Engineering for Early Design Phases
  Chair: Rasmus Rempling, Sweden
- TG1.8 Design Requirements for Infrastructure Resilience
  Chair: Nisrine Makhoul, France
- TG1.9 Training and dissemination
  Chair: Maria Pina Limongelli, Italy
- TG1.10 Utilization of traffic data in research, design, and assessment of bridges
  Chair: Alan O'Connor, Ireland
- TG1.11 Design & Construction Techniques of Well (Caisson) Foundations
  Chair: Alok Bhowmick, India
- TG1.12 Liason with JCSS
  Chair: Niels Peter Høj, Switzerland

TG1.4 Probabilistic NFEA

Chair Alfred Strauss, Austria
Vice Chair Ana Mandić Ivanković, Croatia

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	Jose Matos, Portugal	André Orcesi, France	João André, Portugal
	Roman Wan-Wendner, Austria	Neryvaldo Galvao, Portugal	Pierre Marchand, France
	Mohammad El Hajj Diab, France	Dominik Skokandić, Croatia	Mladen Srbić, Croatia
	Venkatchalam Karthik, India		

Scope & Limitation

- TG1.4 focuses on systems, continuum mechanics, engineering structures, static and dynamic aspects, time-dependent aspects, linear and nonlinear material and system aspects, finite element methods (FEM), discrete element methods (DEM) and associated methods, partial safety factor and reliability index/probabilistic based safety formats.

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TG1.4 Probabilistic NFEA

Mission Statement/Objectives

In this period of TG1.4, the basic reliability concepts of probabilistic non-linear finite element modelling of performance-based assessment with a focus on service life assessment in conjunction with reliability and safety concepts are addressed. The proposed methodology is verified using case studies from the design of structural components and the importance of quality assurance in the service life assessment of civil engineering structures is demonstrated. We have also confirmed that reliability and quality assurance criteria are closely related. Therefore, a methodology for quality-based service life assessment is presented and elaborated on the basis of case studies.

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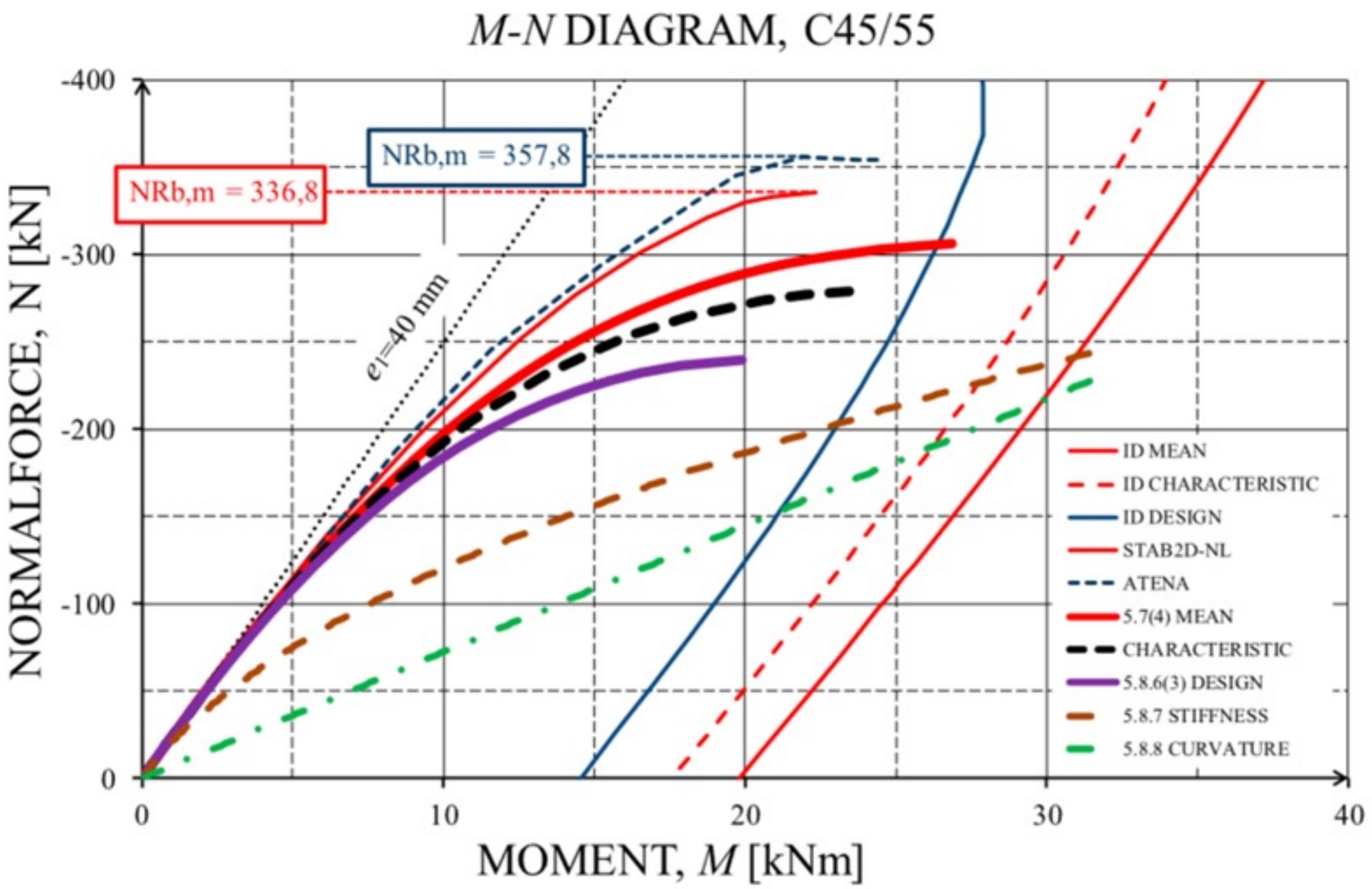
Prob. NLFEA

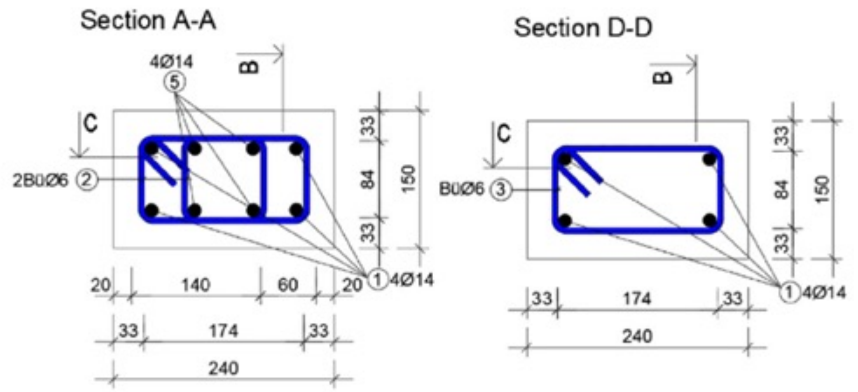
Reliability deficit with standard-compliant slender columns



"Probabilistic and Semi-Probabilistic Analysis of Slender Columns Frequently Used in Structural Engineering"

Authors: Alfred Strauss, Ana Mandic Ivankovic, Benjamin Täubling, Michael Hauser, Dominik Skokandic, Jose Matos, Neryvaldo Galvao, Vladimir Benko, Jakub Dobry, Roman Wan-Wendner, Kresimir Nincevic, Andre Orcesi.

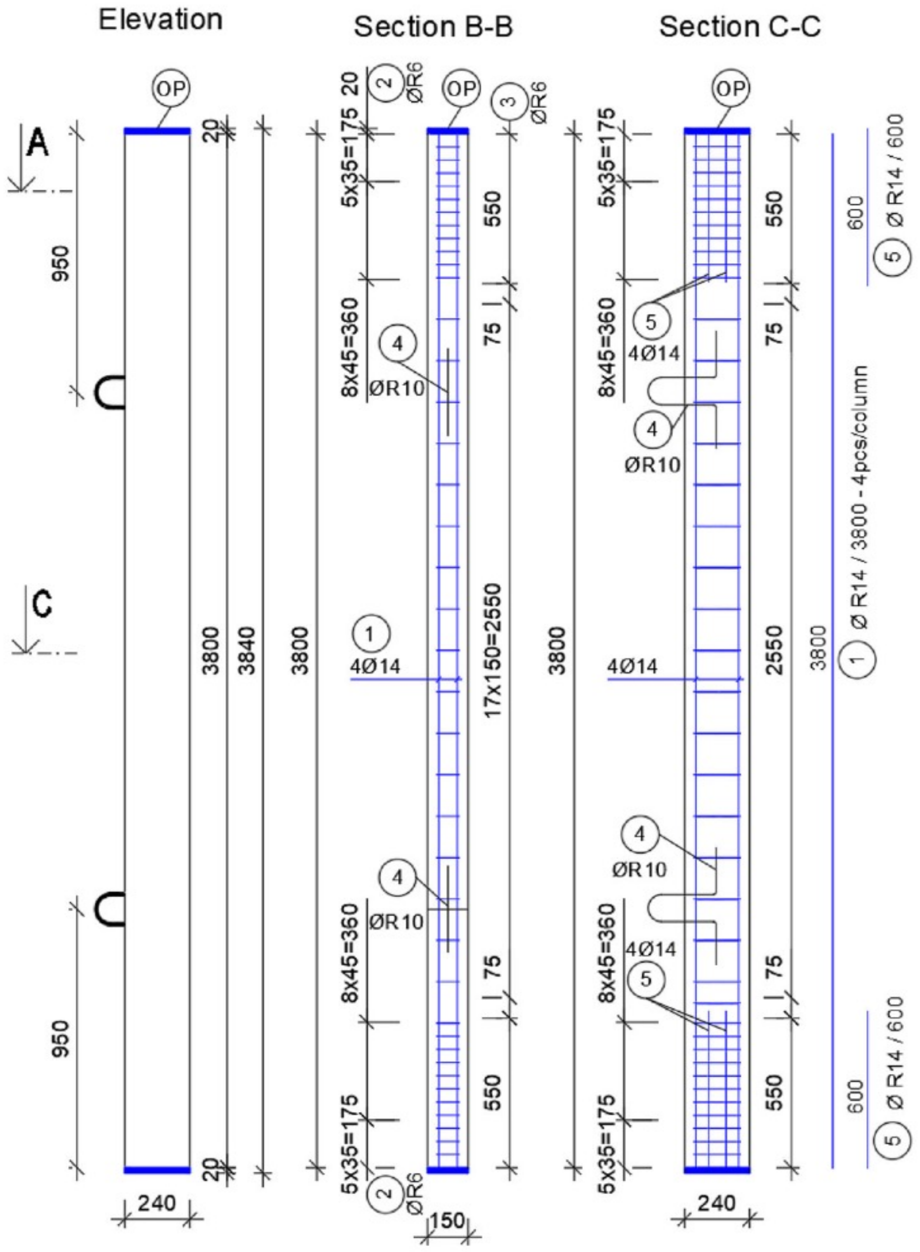
Journal data: August 2021, Applied Sciences 11(17):8009, DOI:10.3390/app11178009

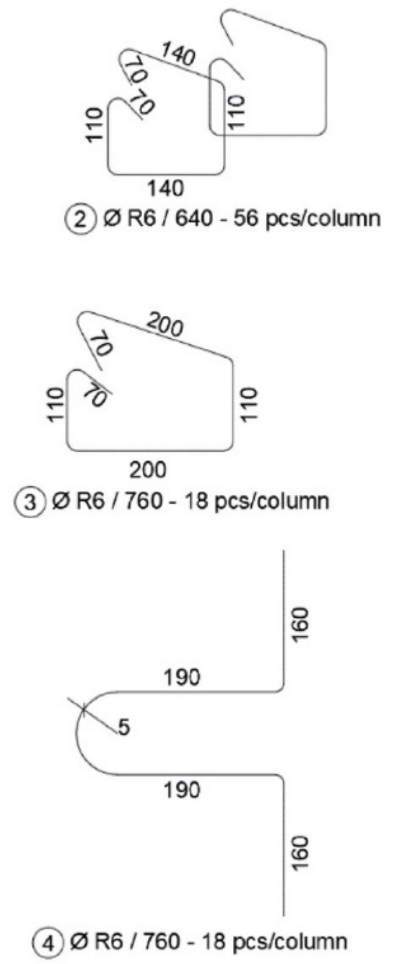


REINFORCEMENT STEEL B 500B

BAR NUMBER	DIAMETER OF BAR Ø [mm]	LENGTH OF BAR [m]	AMOUNT OF BAR [m]	OVERALL LENGTH [m] Ø 6	Ø 10	Ø 14
1	14	3,80	4			15,20
2	6	0,64	56	35,84		
3	6	0,76	18	13,68		
4	10	0,84	2		1,68	
5	14	0,60	8			4,80
SUMMARIZED			LENGTH [m]	49,52	1,68	20,00
			WEIGHT [kg/m]	0,222	0,617	1,208
			WEIGHT [kg]	10,99	1,04	24,16
			WEIGHT [kg]	36,19		

CONCRETE: 0,137 m³





Safety formats | worldwide
Round robin NLFEA modeling
NLFEA bearing capacity 37%
Amendment of NLFEA provisions

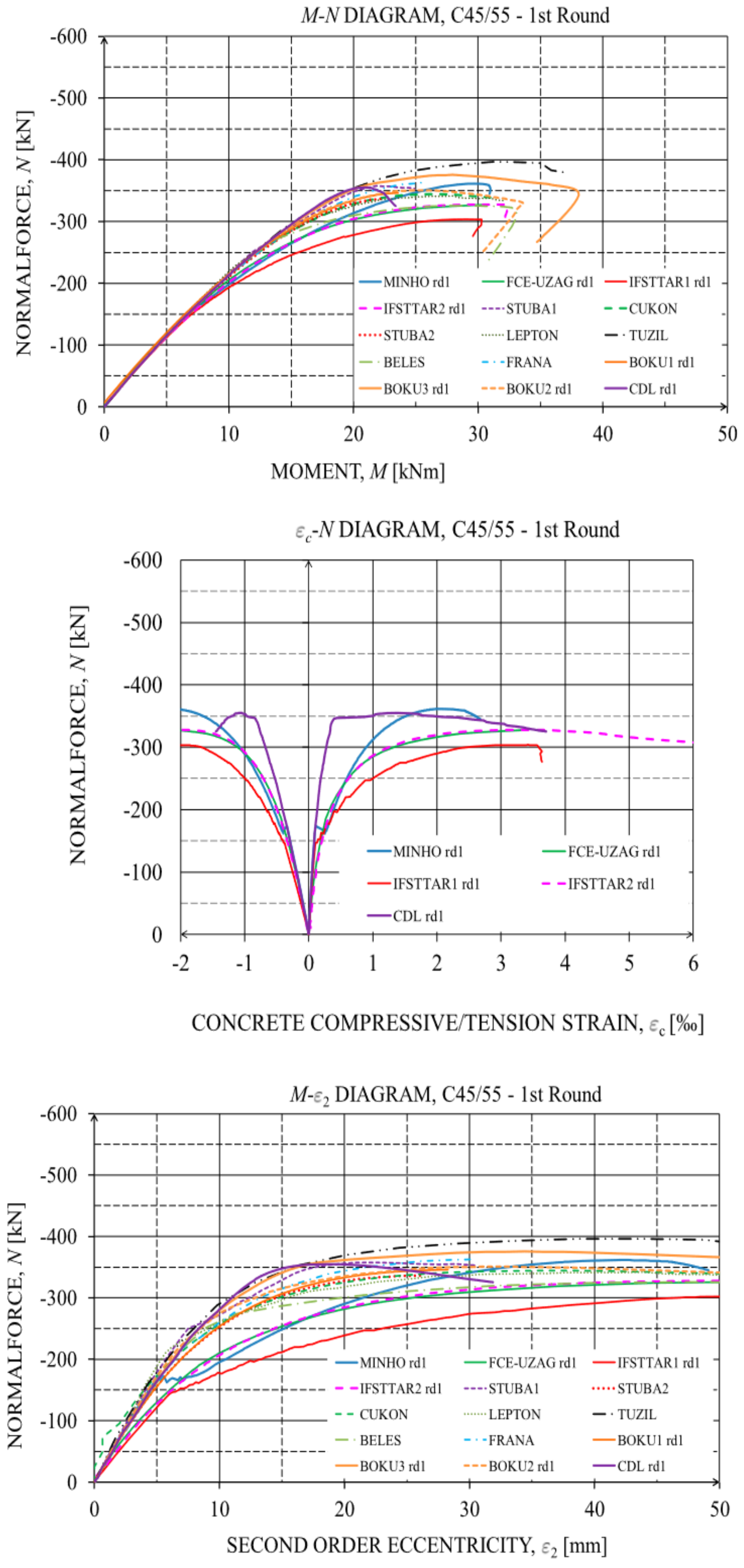


Fig. 9: Performance graphs of the slender column made of concrete C45/55 based on the code-based characteristics

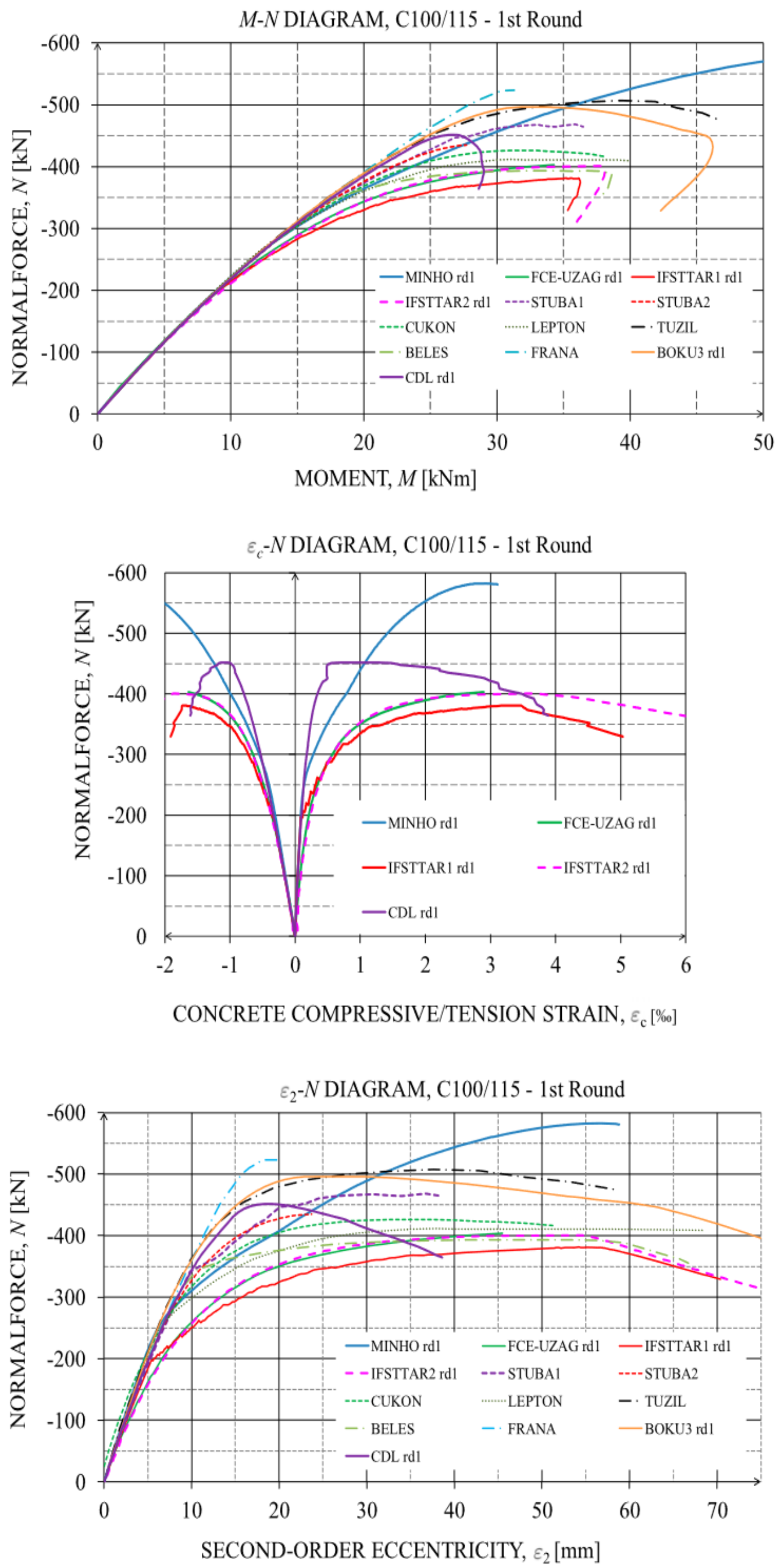
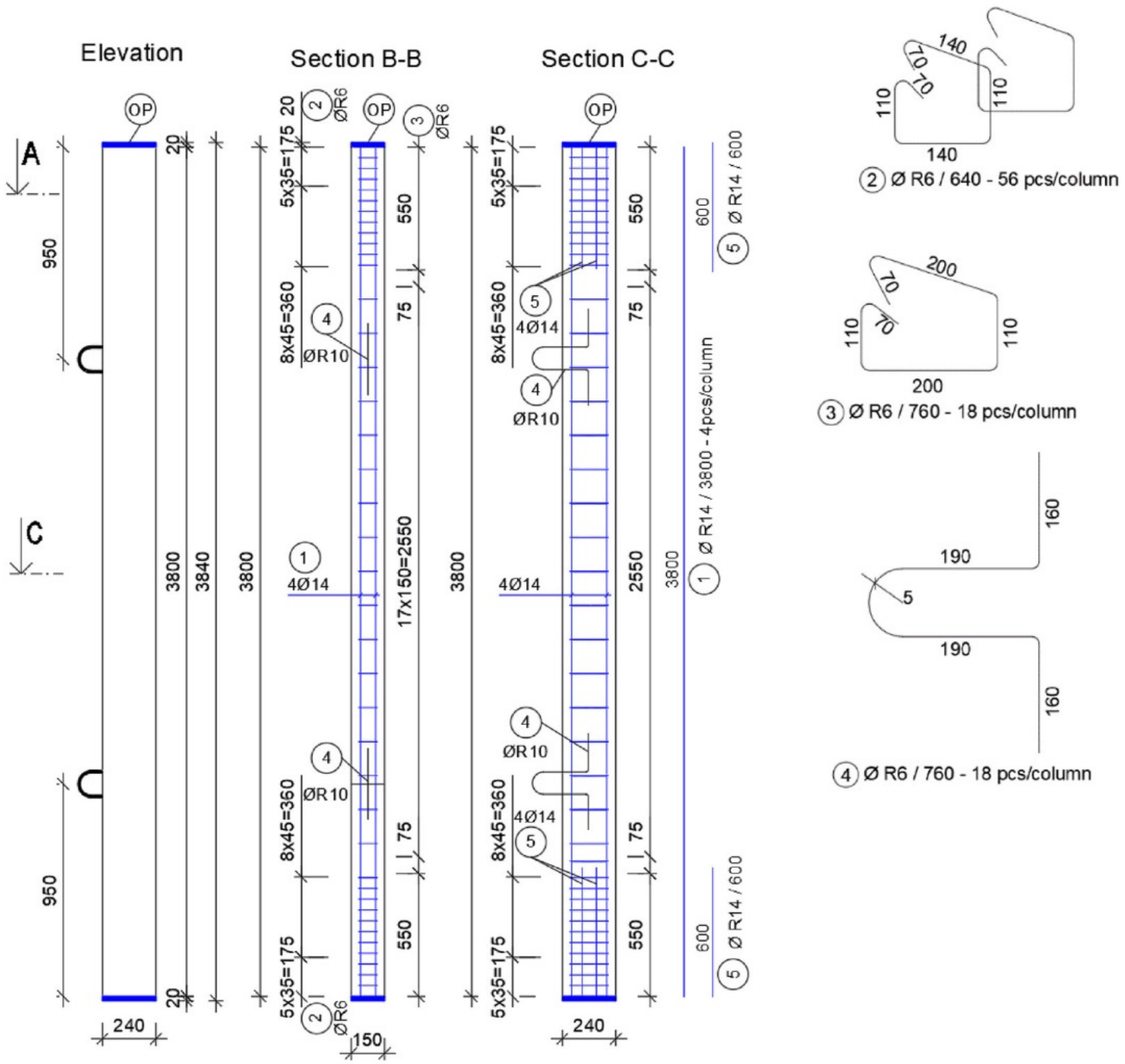


Fig. 10: Performance graphs of the slender column made of concrete C110/115 based on the code-based characteristics



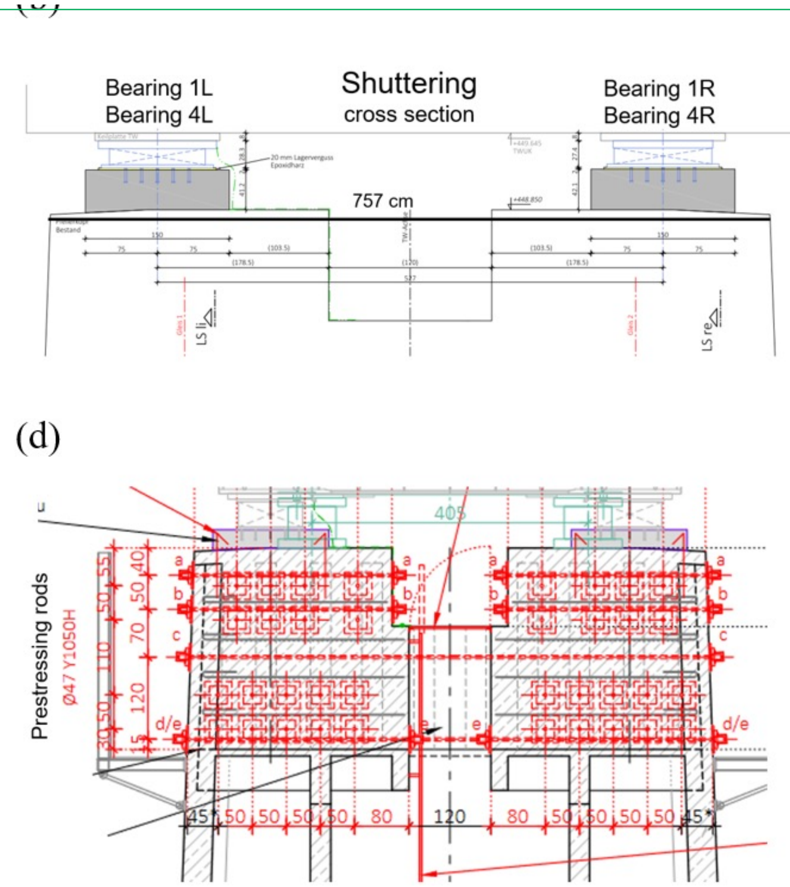
Structural Engineering Document (SED) Probabilistic Finite Element Analyses

SED Probabilistic Finite Element Analysis

- Non-linear finite element modelling
  Design and validation of solution strategies, modeling uncertainties
- Limit state formulations
  Serviceability, load-bearing capacity, durability, linear and non-linear
- Sampling techniques
  Test procedure and updating procedures
- Stochastic models and databases
  Historical and new materials, geometries, load models | Code-based
- Prediction models
  Degradation modeling and service life modeling
- Analysis and interpretation | Proofloading & monitoring
  Probability theory instruments, sensitivity formats
- Safety formats and interpretation
  Reporting for decision-makers

Interfaces between old and new materials and components

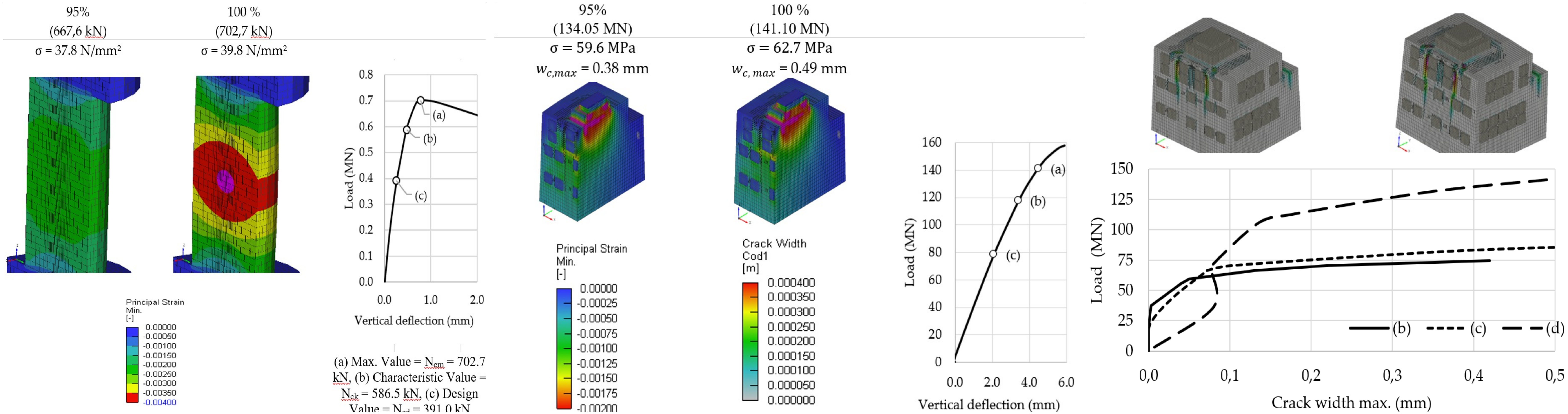
Interfaces between old and new



Strauss, A.; Täubling-Fruleux, B.; Novák, D.; Novák, L.; Frangopol, D.M. (2024): **Advanced non-linear probabilistic modelling methods for the existing 100 m high columns of the Jauntal railway bridge**.[11th International Conference on Bridge Maintenance, Safety and Management IABMAS 2024, Copenhagen, Denmark, 2024], In: CRC Press. Submitted

safety formats and levels
modeling strategy and detailing
amendment of provisions

Interfaces between old and new



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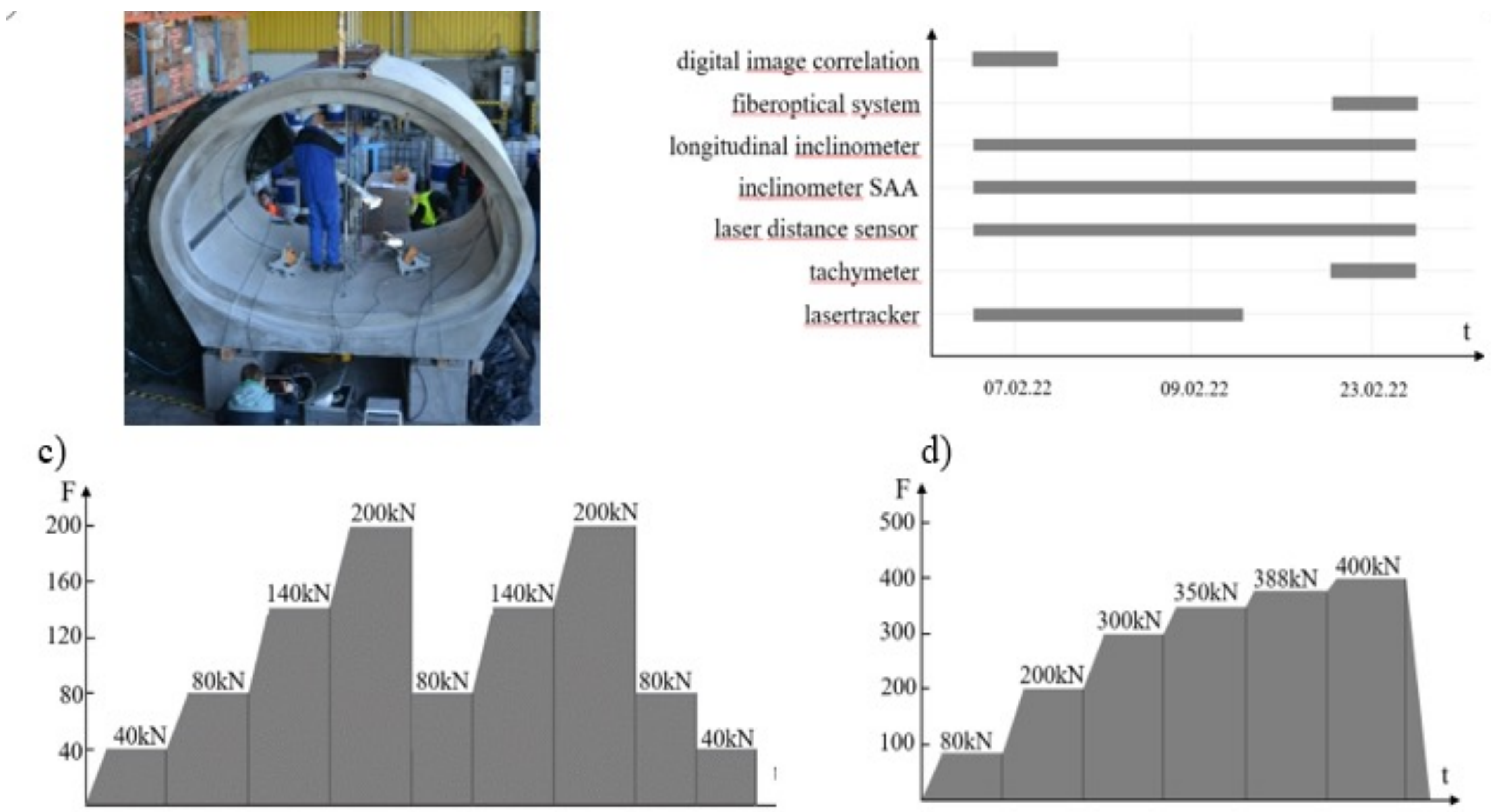
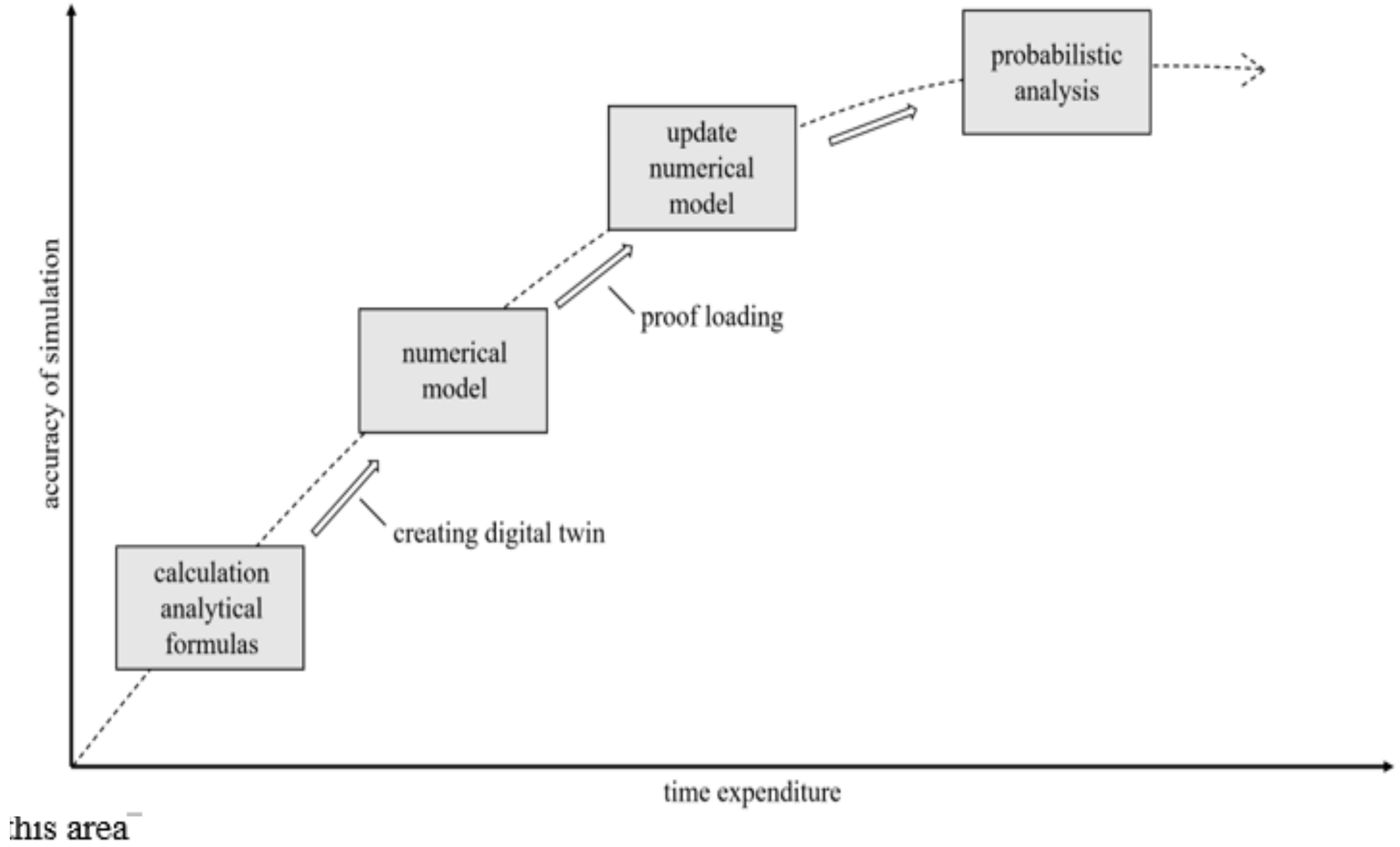
safety formats and levels
modeling strategy and detailing
ULS vs. SLS limit states

Characterization of Digital Twins for tunnel monitoring

Characterization of Digital Twins





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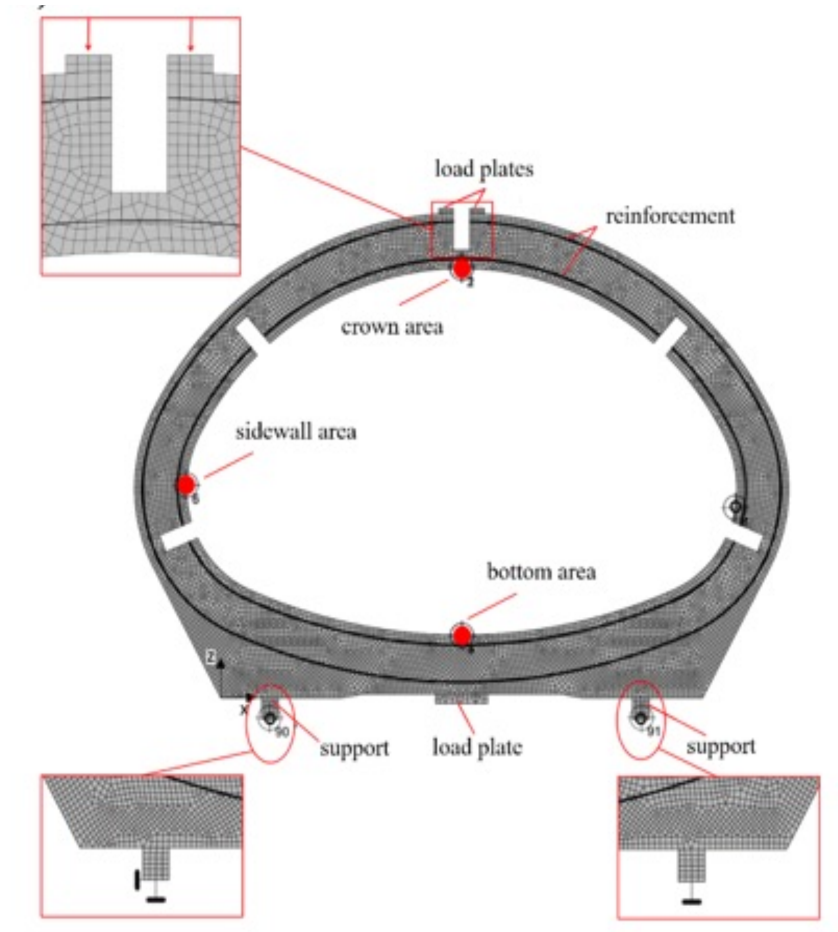
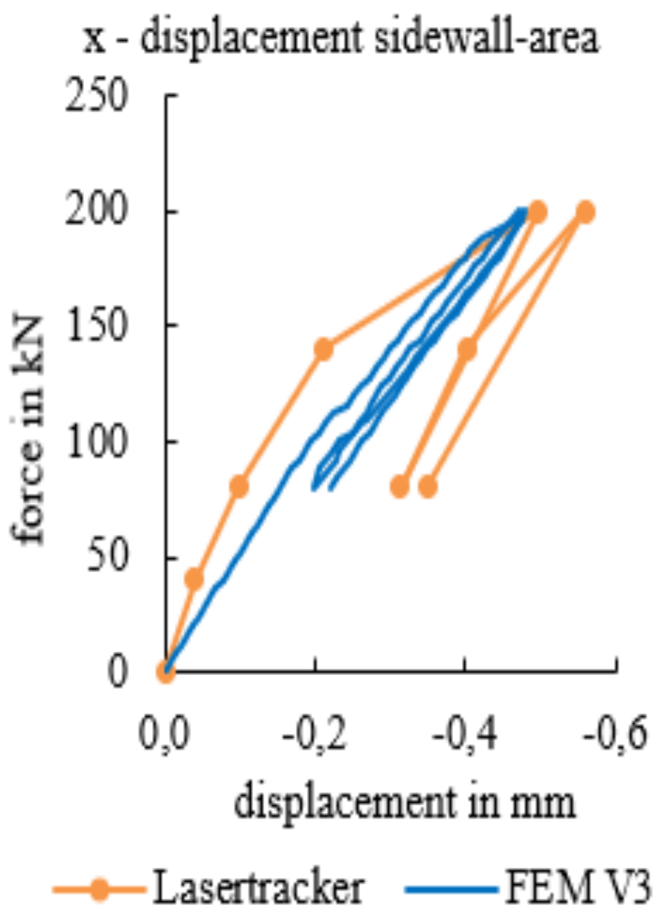
applicable monitoring systems
proof loading up to ULS
required level of detailing

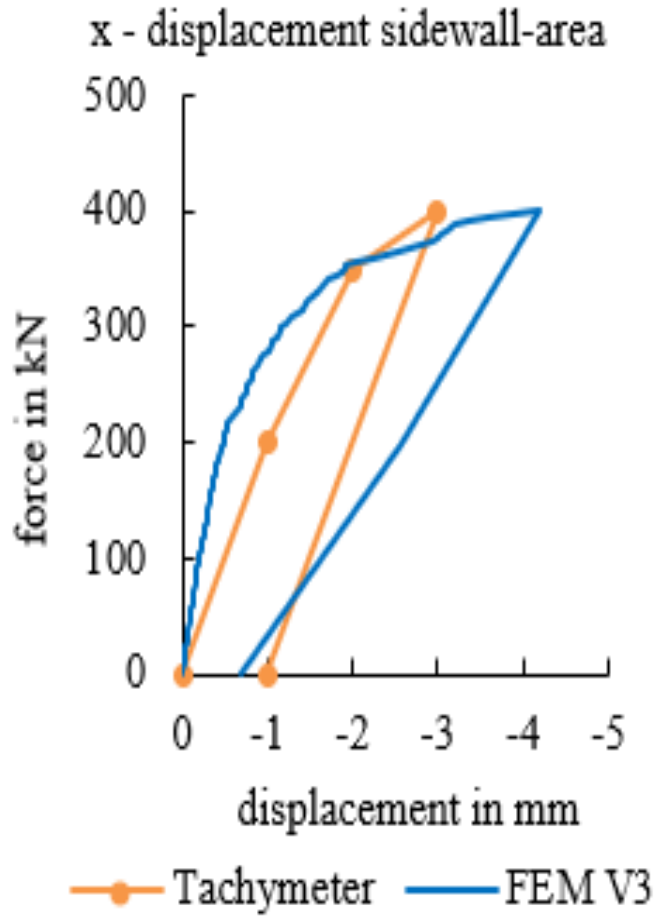
Characterization of Digital Twins

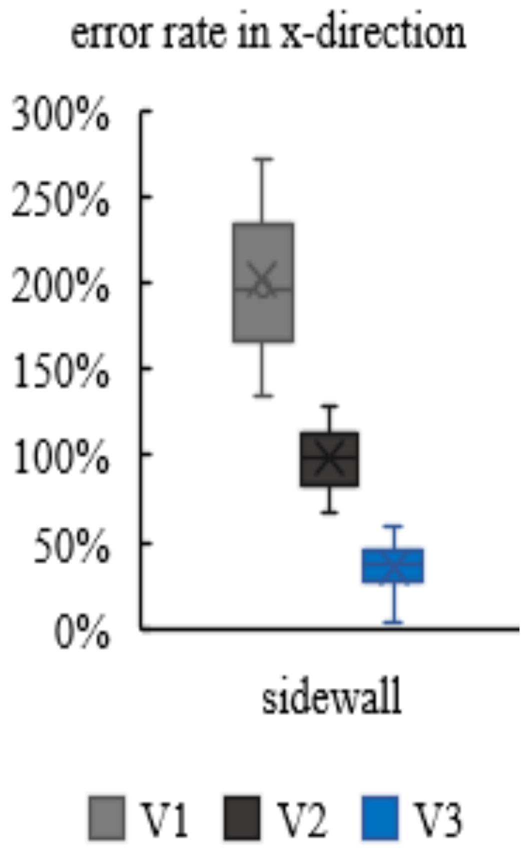


Parameter	Value
$f_{c,cu}$	50 MPa
Young modulus E	30000 MPa
Poisson-ratio μ	0,2
Tension strength f_t	3,598 MPa
Compressive strength f_c	-39 MPa
Fracture energy (MC2010)	$1{,}237 \cdot 10^{-4}$ MN/m

Material	Model
concrete	non-linear 3D cement model plane deformation state
reinforcement	linear material model







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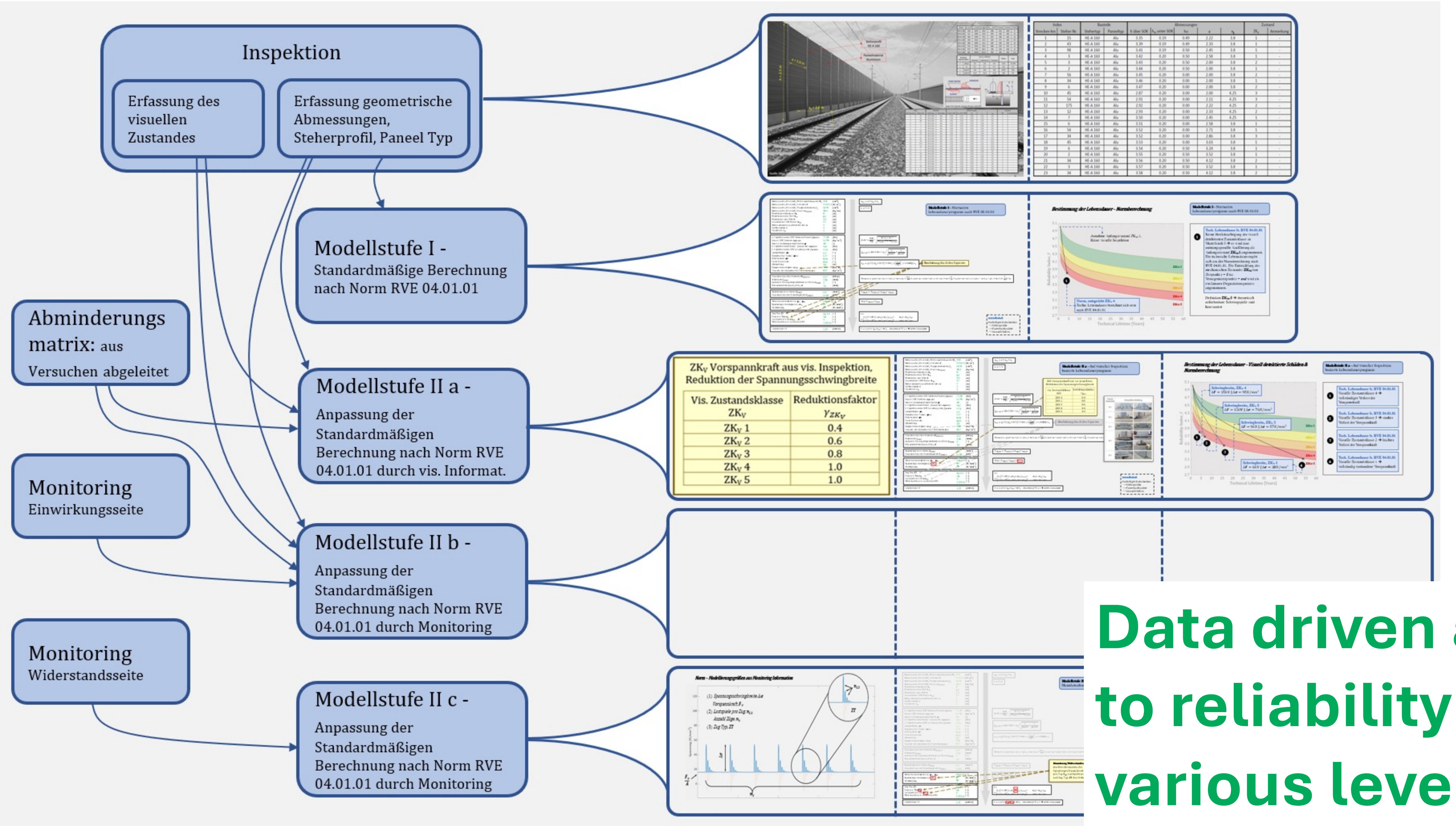
safety formats and levels, modeling strategy and detailing

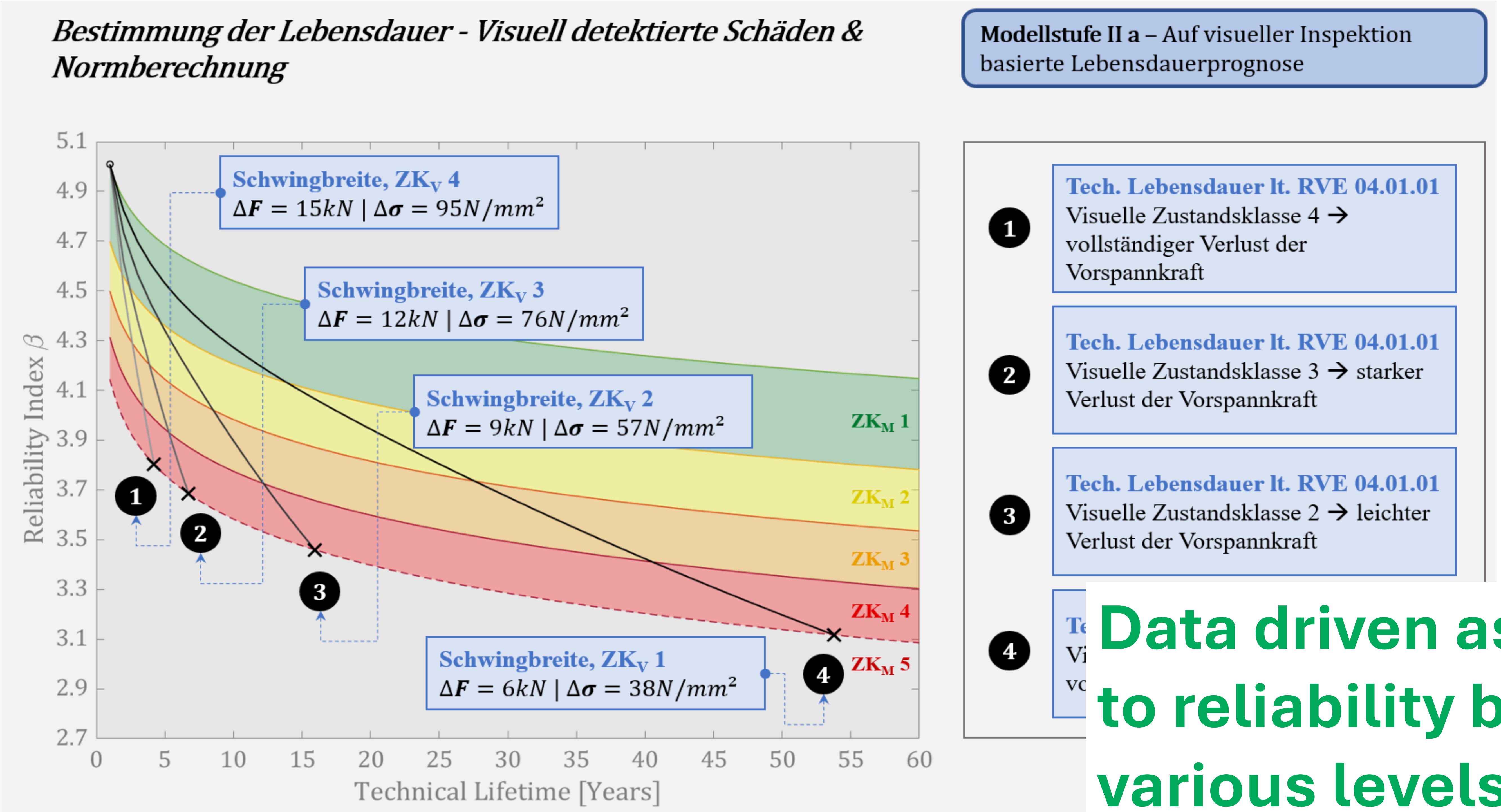
Service life of engineering details - its extension

Service life of engineering details



Data driven assessment
to reliability based assessment
various levels triggering actions
relevance of NLFEA

Service life of engineering details



Data driven assessment
to reliability based assessment
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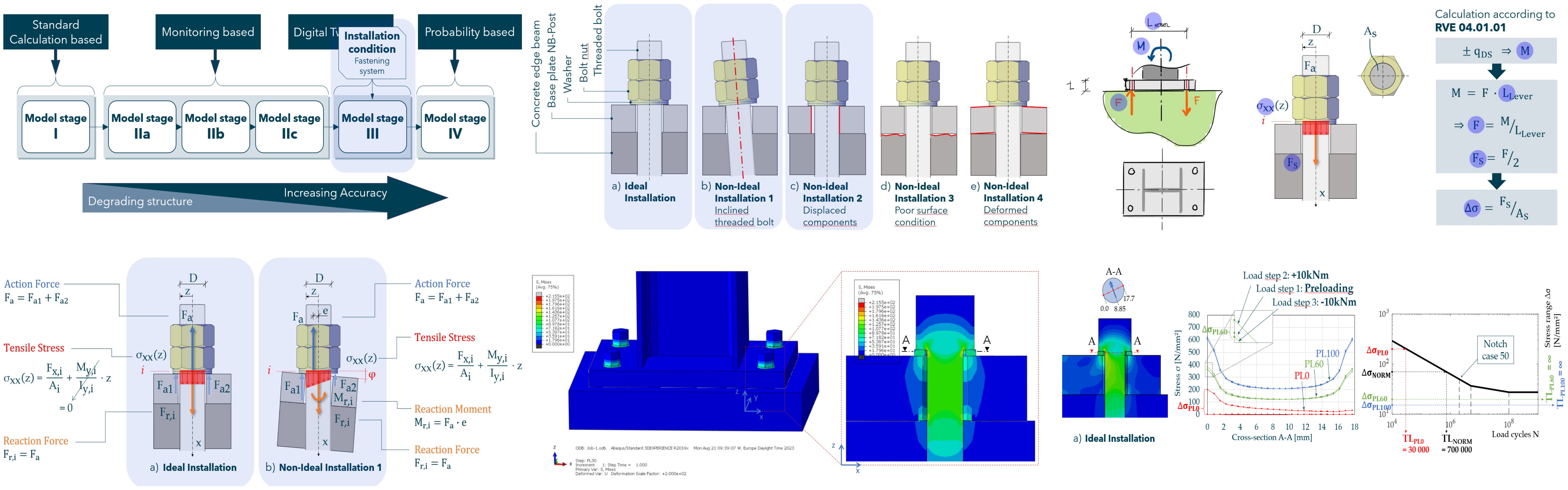
Service life of engineering details



P-NLFEA strategy for adapting service life design formulation and the monitoring and assessment concepts

Conformity test procedures
Design formats vs. test formats

Conformity test procedures

Production status	Minimum Number (n) of Results	1. Criterion	2. Criterion
		Mean value of "n" Results (f_{cm})	Individual Result (f_{ci})
Initial Production	3	$\geq f_{ck,cube} + 4$	$\geq f_{ck,cube} - 4$
Continuous Production	15	$\geq f_{ck,cube} + 1{,}48 * \sigma$	$\geq f_{ck,cube} - 4$

Table.1: Conformity criterions for compressive strength according to EN 206

- Due to the storage conditions for the samples in Austria this results in the following:

Production status	Minimum Number (n) of Results	1. Criterion	2. Criterion
		Mean value of "n" Results (f_{cm})	Individual Result (f_{ci})
Initial Production	3	$\geq (f_{ck,cube}/0{,}92) + 4$	$\geq (f_{ck,cube}/0{,}92) - 4$
Continuous Production	15	$\geq (f_{ck,cube}/0{,}92) + (1{,}48 * \sigma)$	$\geq (f_{ck,cube}/0{,}92) - 4$

Table.2: Conformity criterions for compressive strength according to ÖNORM B 4710-1

Production status	*Minimum Number (n) of Results*	*1. Criterion*	*2. Criterion*
		Mean value of "n" Results (fcm)	*Individual Result (fci)*
Initial Production	*3*	$f_{ck,cube} = (f_{cm} - 4) * 0{,}92$	$f_{ck,cube} = (f_{ci} + 4) * 0{,}92$
Continuous Production	*15*	$f_{ck,cube} = (f_{cm} - (1{,}48 * \sigma)) * 0{,}92$	$f_{ck,cube} = (f_{ci} + 4) * 0{,}92$

Table.3: Calculation of the actual achieved characteristic strength from conformity tests according to ÖNORM B 4710-1

Conformity testing of sample for cylinder compressive strength values & converted existing β

$$f_{ck,cube} = (f_{cm,cube} - (1{,}48 \cdot \sigma_{cube})) \cdot 0{,}92$$

$$f_{cm} = f_{cm,cube} \cdot 0{,}81$$

$$f_{cd} = f_{ck} \cdot \eta_{cc} \cdot k_{ct} / \gamma_c$$

$$\beta_{vorh} = (1 - f_{cd} / f_{cm}) / (\alpha \cdot COV)$$

$$f_{cd} = f_{cm} - \alpha \cdot \beta_{vorh} \cdot f_{cm} \cdot COV$$

Required standard cylinder compressive strength values based on β_{target}:

$$f_{cd} = f_{ck} \cdot \eta_{cc} \cdot k_{ct} / \gamma_c$$

$$f_{cm,erf} = \max(f_{ck} / (1 - 1{,}645 \cdot COV); f_{cd} / (1 - \alpha \cdot \beta_{target} \cdot COV) / \eta cc / k_{ct})$$

$$f_{ck} = f_{cm} - 1{,}645 \cdot f_{cm} \cdot COV$$

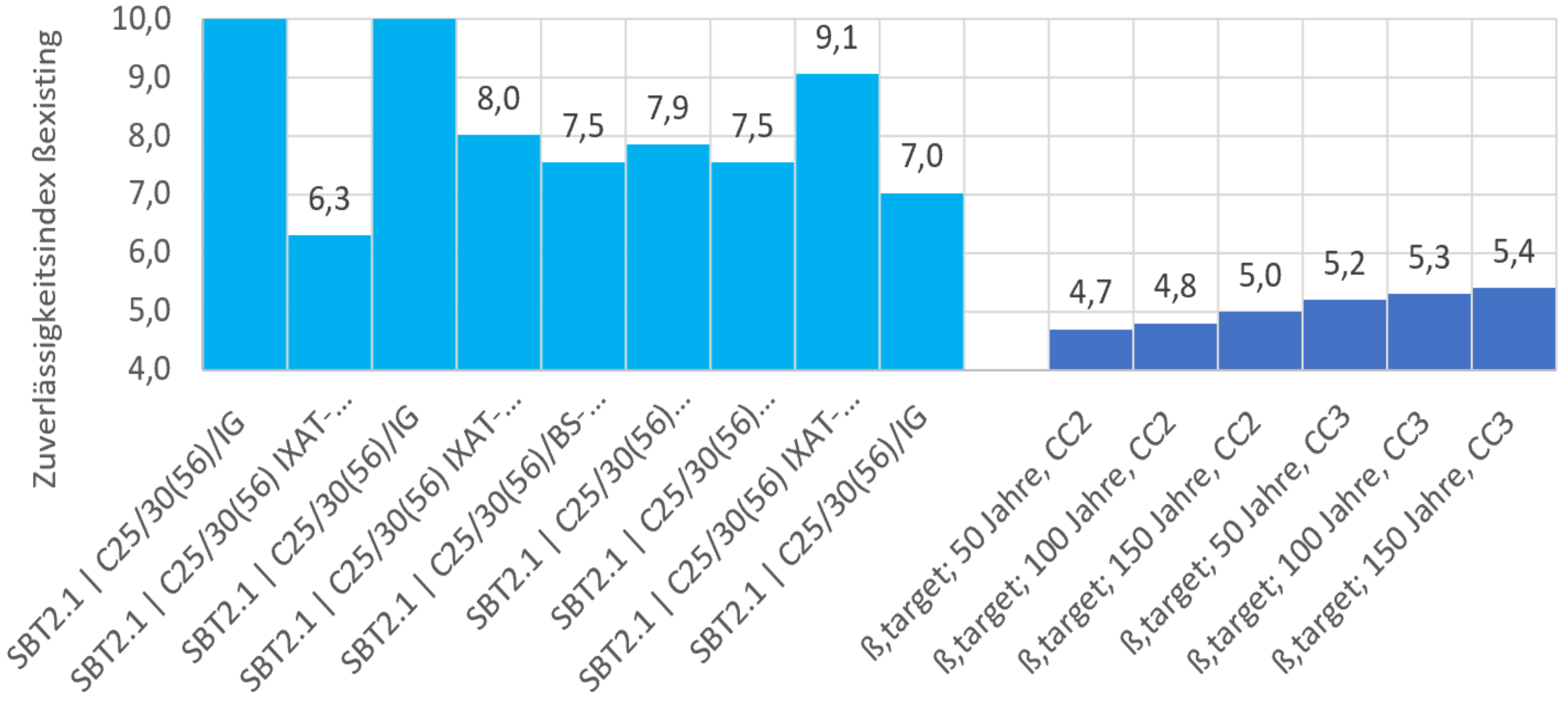
$$f_{cd} = f_{cm} - \alpha \cdot \beta_{target} \cdot f_{cm} \cdot COV$$

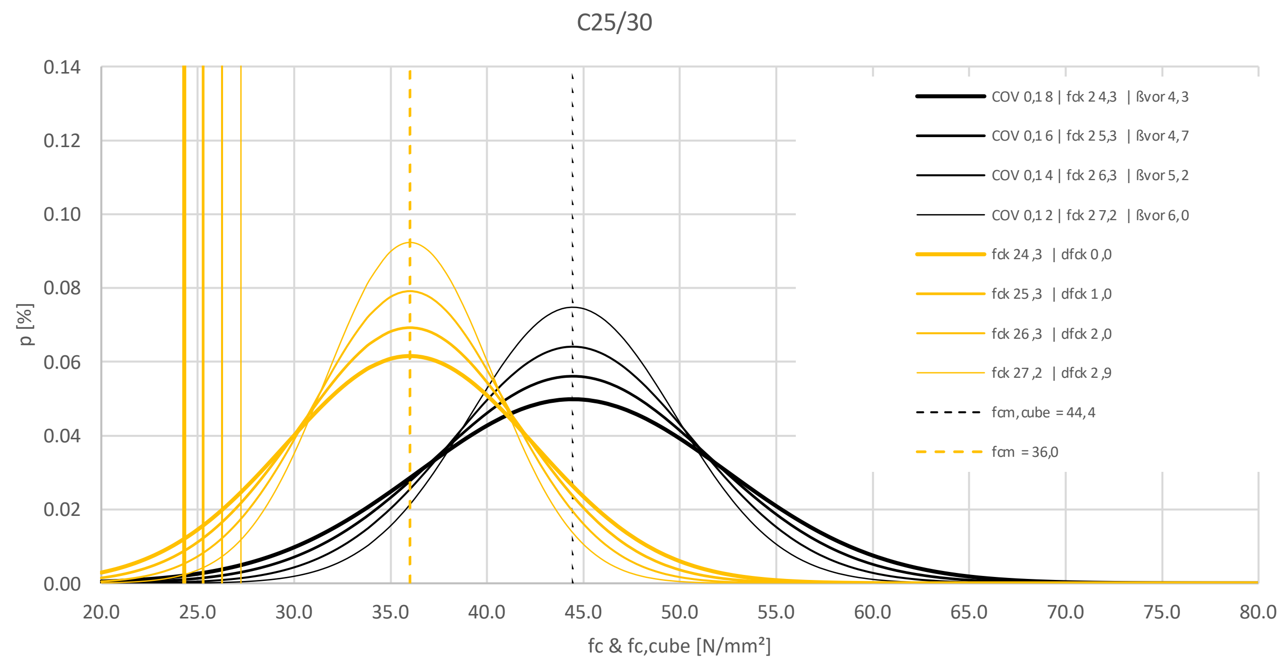
$$\sigma_{erf} = f_{cm,erf} \cdot COV$$

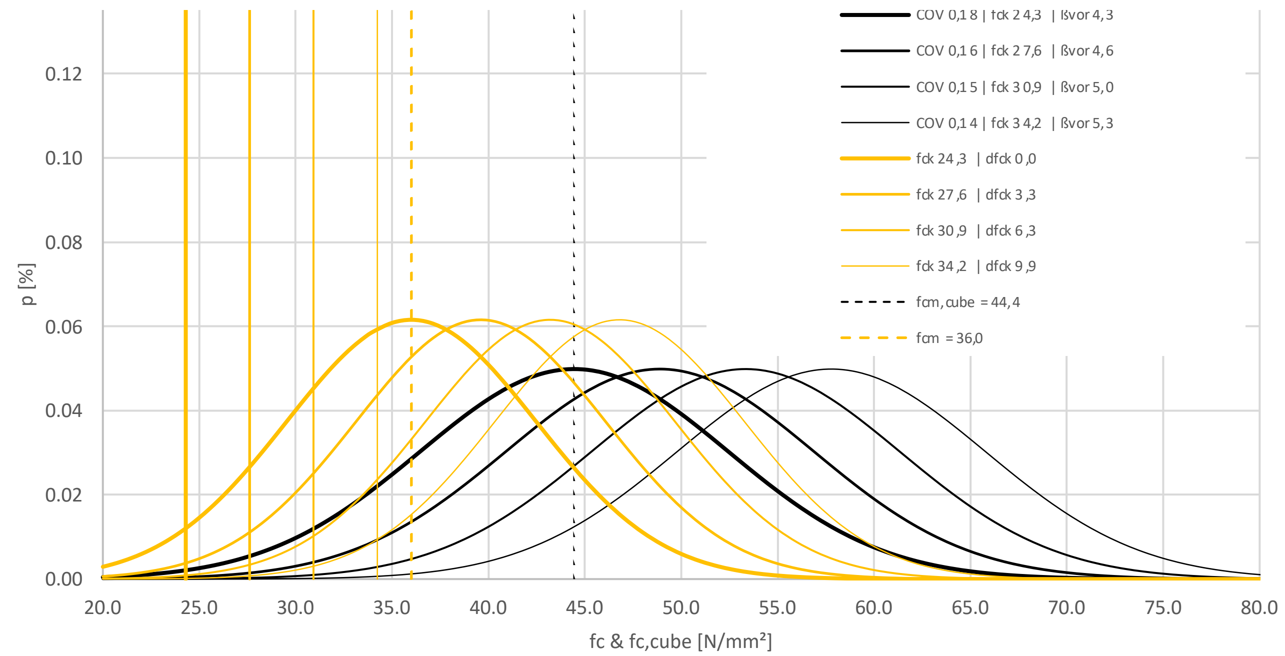
Reliability level of test standards vs. design standards

Conformity test procedures

	$f_{cm,cube}$	σ_{cube}	COV_{cube}	$f_{ck,cube}$	f_{cm}	f_{ck}	f_{cd}	$ß_{existing}$
	N/mm²	N/mm²		N/mm²	N/mm²	N/mm²	N/mm²	
Prüflos								
SBT2.1 | C25/30(56)/IG	41,7	2,5	0,06	34,9	33,7	28,3	16,0	10,8
SBT2.1 | C25/30(56) IXAT-B/G	45,8	5,1	0,11	35,2	37,1	28,5	16,1	6,3
SBT2.1 | C25/30(56)/IG	49,1	2,8	0,06	41,4	39,8	33,5	19,0	11,4
SBT2.1 | C25/30(56) IXAT-B/G	46,4	3,9	0,08	37,4	37,6	30,3	17,1	8,0
SBT2.1 | C25/30(56)/BS-TU/C3A-fı	46,3	4,2	0,09	36,9	37,5	29,9	16,9	7,5
SBT2.1 | C25/30(56) I/BBG/G	55,5	4,8	0,09	44,5	44,9	36,0	20,4	7,9
SBT2.1 | C25/30(56) I/BBG/G/IXAT	50,0	4,5	0,09	39,8	40,5	32,2	18,3	7,5
SBT2.1 | C25/30(56) IXAT-B/G	44,7	3,3	0,07	36,6	36,2	29,6	16,8	9,1
SBT2.1 | C25/30(56)/IG	49,9	4,9	0,10	39,2	40,4	31,7	18,0	7,0







Reliability level of test standards significant higher as design standards

Thank you
for your interest

- **Prof. Dr. Alfred Strauss**
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- Institute for Structural Engineering (IKI)