LIFEMACS

Beoordeling van bestaande betonconstructies

Interpretatie van gegevens

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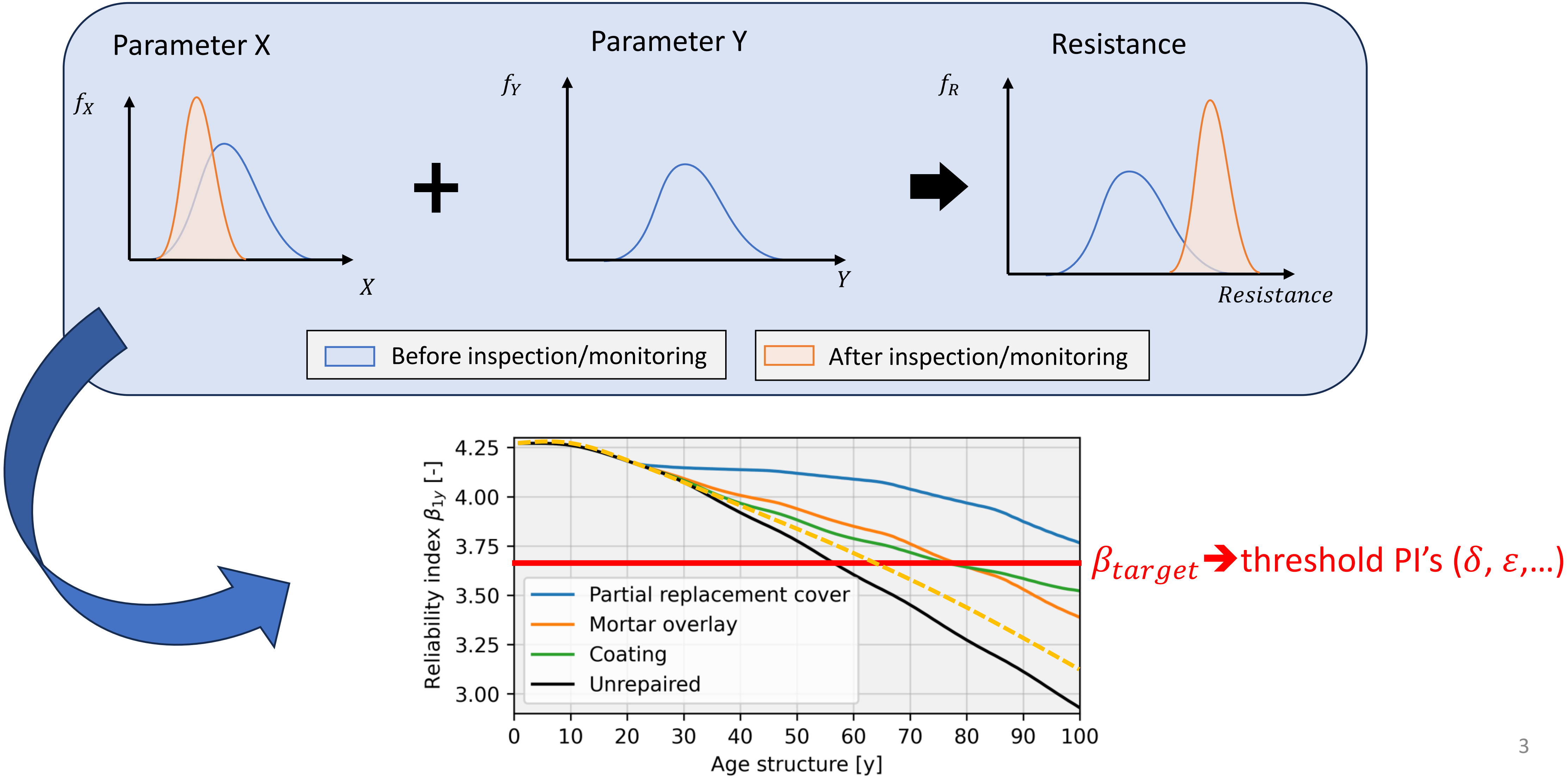
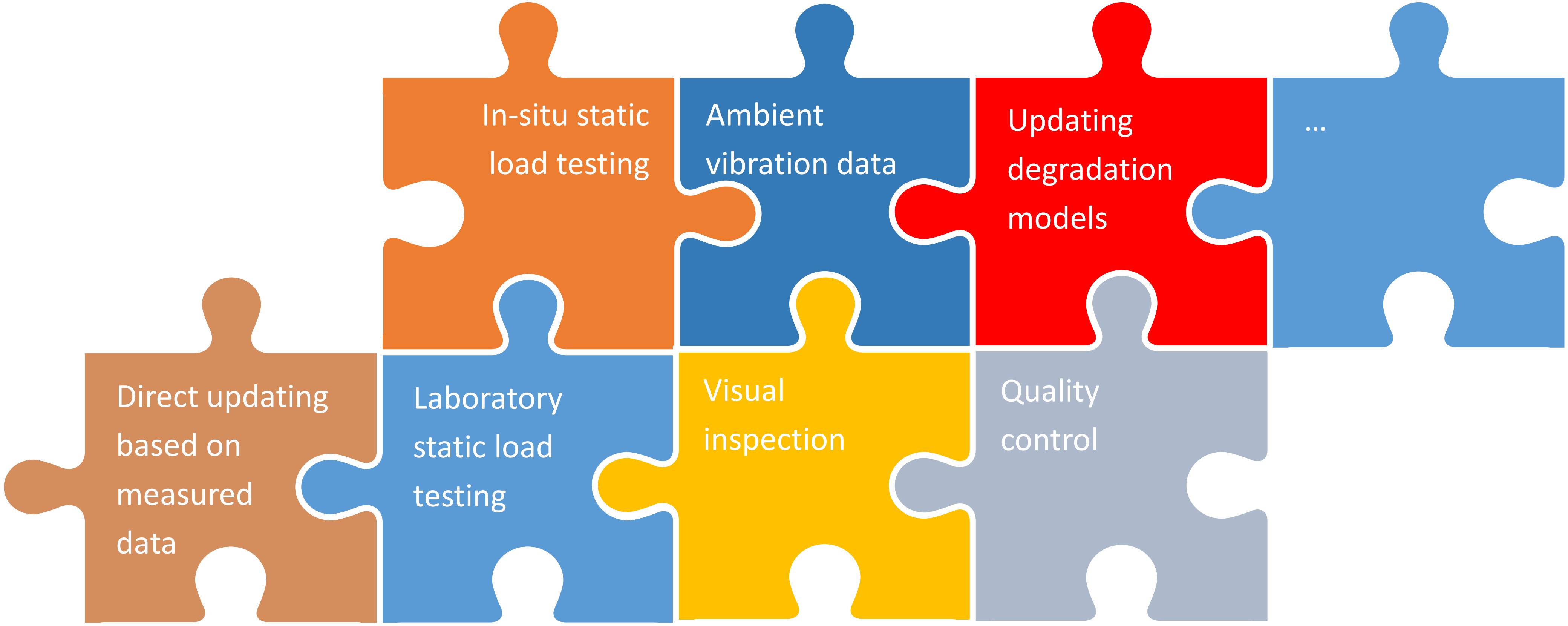
DWARSDOORSNEDE VOLGENS A-B
COUPE TRANSVERSALE SUIVANT A-B
LENGTE DOORSNEDE BALK 5 VOLGENS C-D
COUPE LONGITUDINALE POUTRE 5 SUIVANT C-D
LENGTE DOORSNEDE OP EEN DWARSLIGGER VOLGENS E-F
COUPE LONGITUDINALE SUR UNE ENTRETOISE SUIVANT E-F
€
€
QUALITY CONTROL
APPROVED

Life-time performance prediction

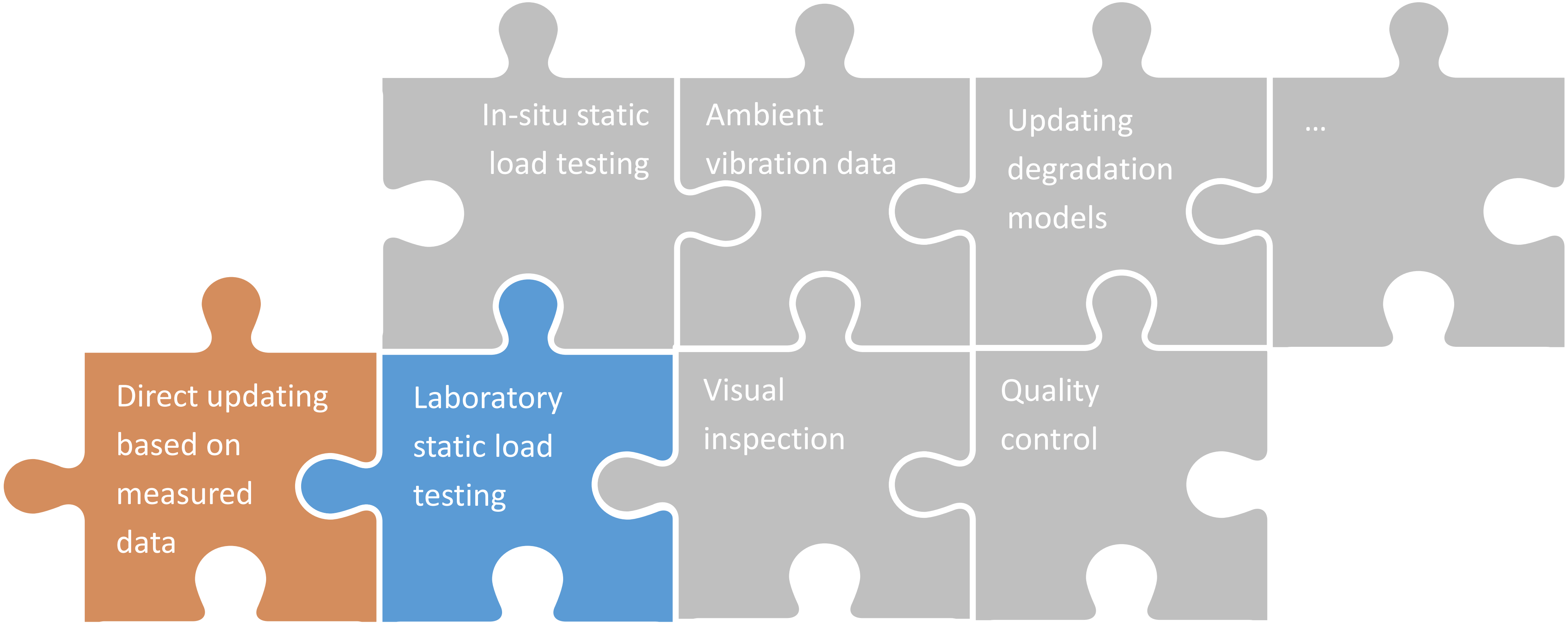
Influence of inspection/monitoring on life-time performance prediction



Updating using different sources of information

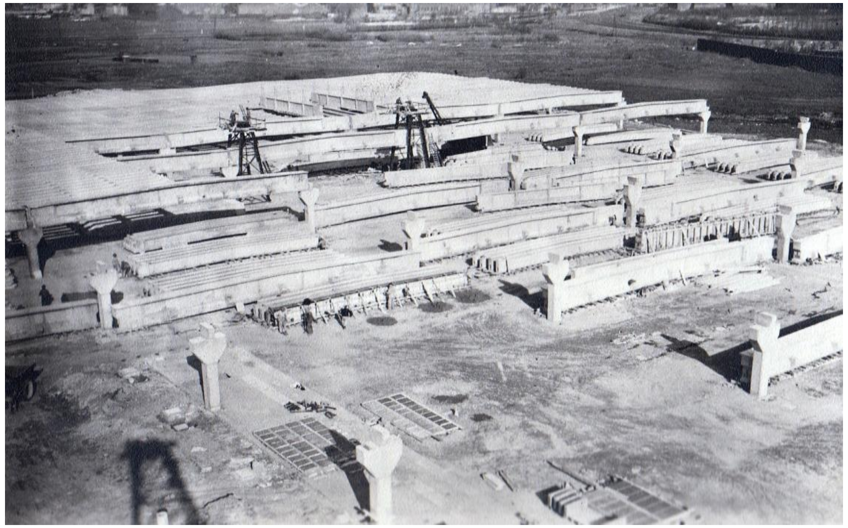


Updating using different sources of information



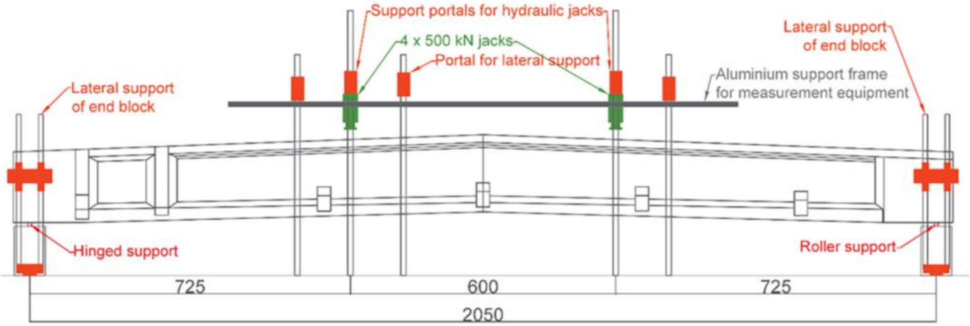
Bayesian updating based on large-scale load testing

- Textile factory 'Union Cottonière' in Ghent constructed in 1947-1948 (design by Gustave Magnel)
- Beams of the flat roof are in prestressed concrete, cast on the ground and lifted into position.
- **Primary beams** have a **nominal span of 20.5 m** - supported on concrete corbels which are monolithically attached to the columns
- **Secondary beams** have a **nominal span of 13.7 m** – supported by corbels of the primary beam
- No other reinforcement except for some stirrups in the anchor blocks



Botte, W., Vereecken, E., Taerwe, L., & Caspeele, R. (2021). *Assessment of posttensioned concrete beams from the 1940s: large-scale load testing, numerical analysis and Bayesian assessment of prestressing losses*. Structural Concrete, 22(3), 1500-1522.

Static load testing Primary beam



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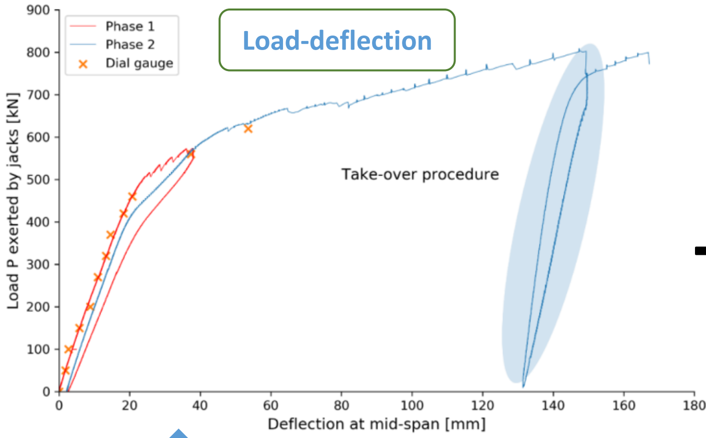
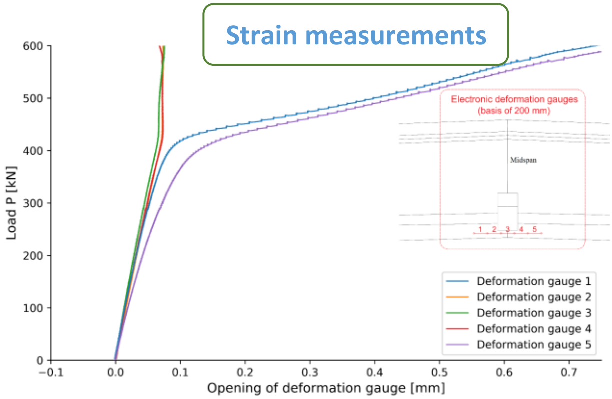
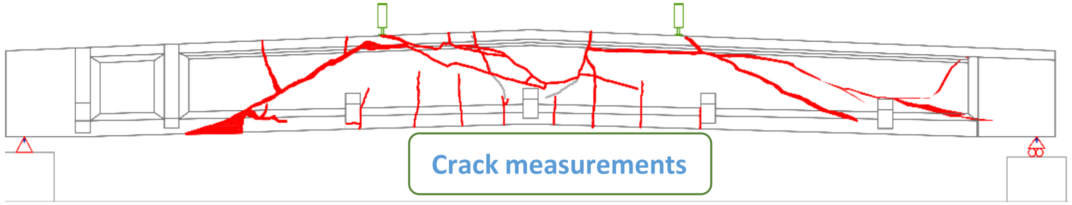
Static Load testing



→ P_0, P_{cr}, P_δ





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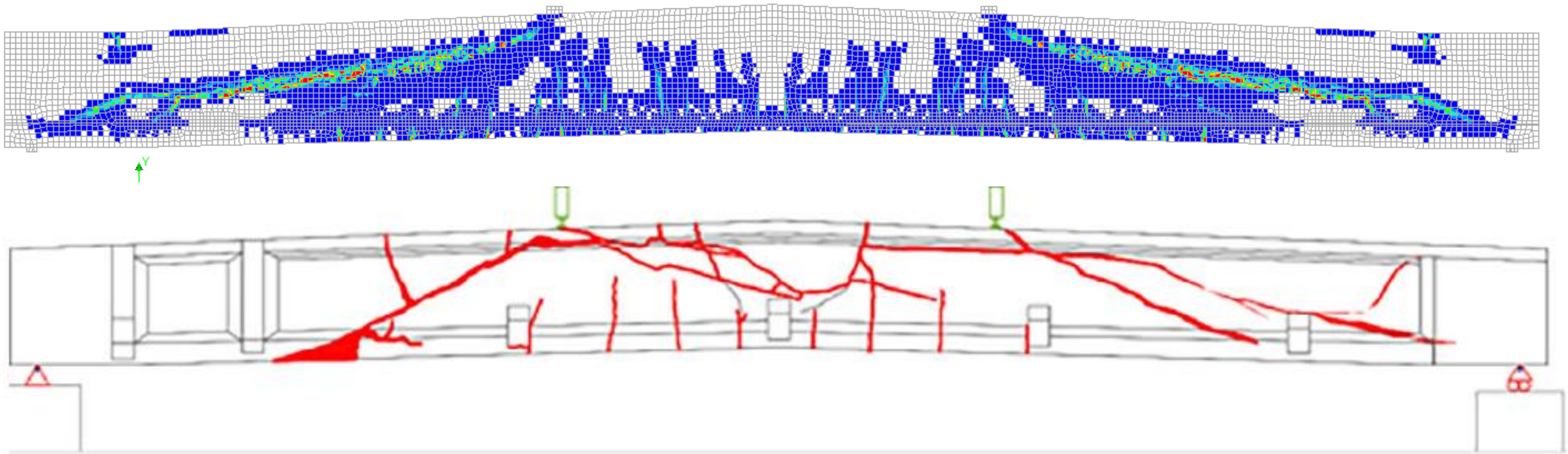
Numerical modelling

Validation of a numerical model based on the measured data (loads, displacements, crack pattern, etc.)



Botte, W., Vereecken, E., Taerwe, L., & Caspeele, R. (2021). *Assessment of posttensioned concrete beams from the 1940s: large-scale load testing, numerical analysis and Bayesian assessment of prestressing losses*. Structural Concrete, 22(3), 1500-1522.

Direct Bayesian updating of measurement data

- *Stepwise Bayesian updating framework supported by non-linear FE analyses* for the assessment of the remaining prestress + associated uncertainties:
  - STEP 1: Bayesian updating of material properties

Prior distributions:
- Historical documents
- Literature data (e.g. JCSS Probabilistic Model Code)

→

Direct measurements of:
- Concrete tensile strength
- Young's modulus of concrete
- Concrete density
- Young's modulus of steel
- Steel yield strength

→

Posterior distributions:
Bayesian updating through analytical expression/numerical tools

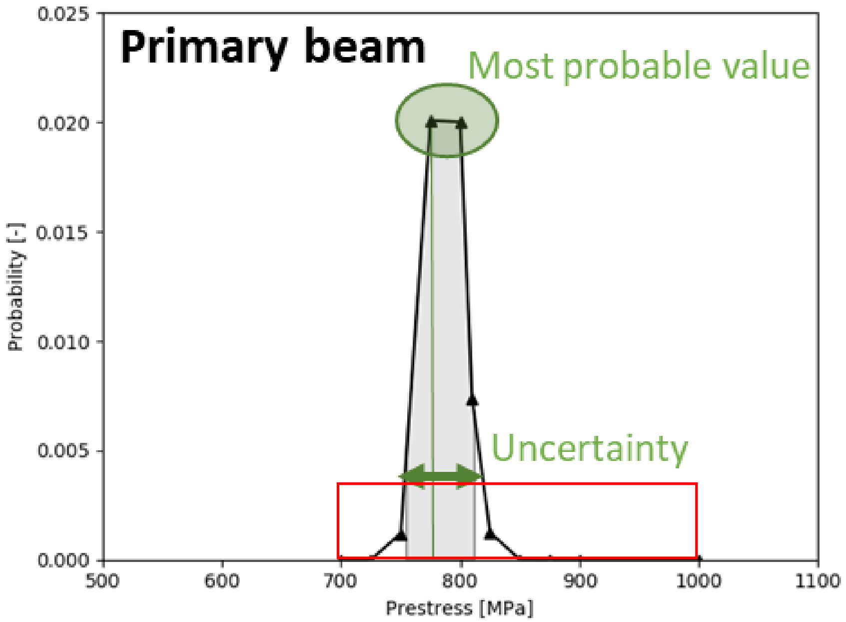
	Concrete		Prestressing steel		
	$f_{c,cyl\ 100x100}$ [MPa]	ρ_c [kg/m³]	$F_{p0.2}$ [MPa]	F_m [MPa]	E_p [GPa]
1	54.7	2300	1525	1730	194.8
2	56.9	2280	1470	1690	194.9
3	46.3	2340	1440	1690	193.5
Mean	**52.6**	**2310**	**1478**	**1704**	**194.4**
Standard deviation	**5.6**	**30**	**43**	**24**	**0.8**

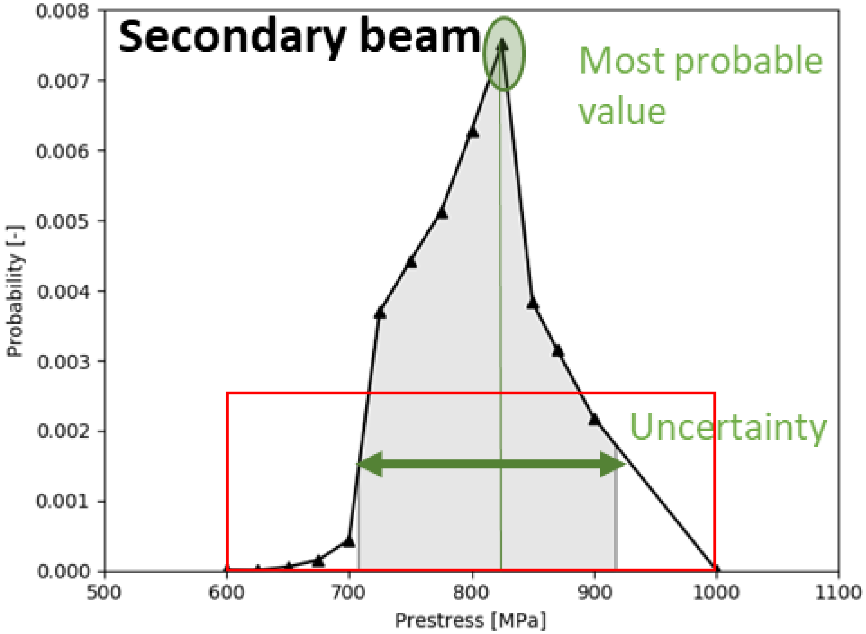
	$\bar{x}'_{lnX}$	n'	s'_{lnX}	ν'
C35 – Concrete for precast elements	3.95	2.5	0.08	4.5
	$\bar{x}''_{lnX}$	n''	s''_{lnX}	ν''
Posterior hyperparameters	3.79	5.5	0.097	7.5

Botte, W., Vereecken, E., Taerwe, L., & Caspeele, R. (2021). ***Assessment of posttensioned concrete beams from the 1940s: large-scale load testing, numerical analysis and Bayesian assessment of prestressing losses*****. Structural Concrete, 22(3), 1500-1522.**

Bayesian updating using indirect load test data

- *Stepwise Bayesian updating framework supported by non-linear FE analyses* for the assessment of the remaining prestress + associated uncertainties:
  - STEP 1: Bayesian updating of material properties
  - STEP 2: Update prestress level using numerical model and updated material properties





Botte, W., Vereecken, E., Taerwe, L., & Caspeele, R. (2021). ***Assessment of posttensioned concrete beams from the 1940s: large-scale load testing, numerical analysis and Bayesian assessment of prestressing losses***. **Structural Concrete, 22(3), 1500-1522.**

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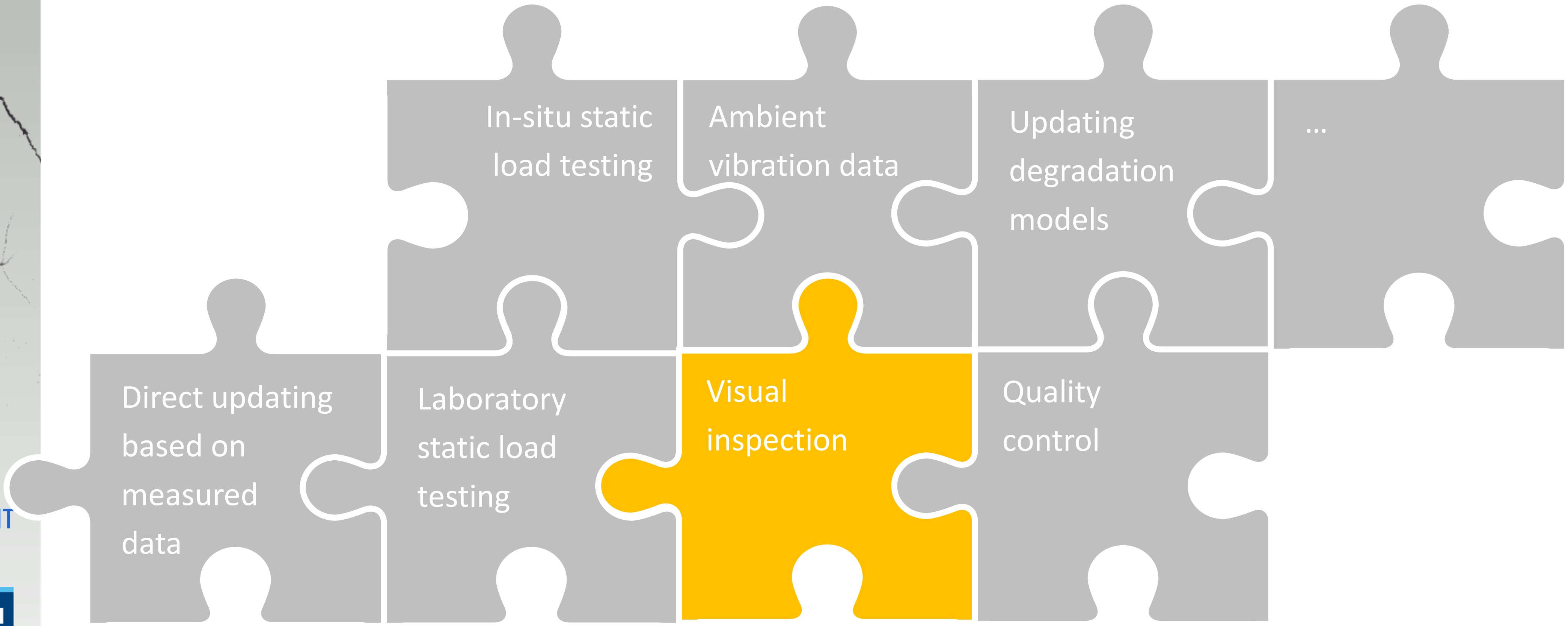
Updating using different sources of information



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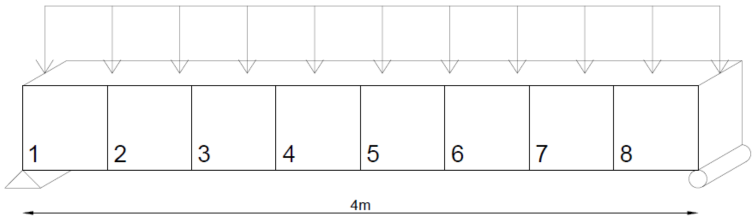
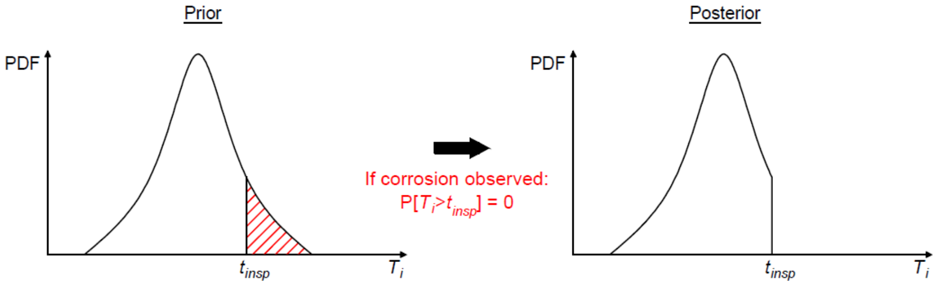


Observation of rust stains

→ Corrosion has already initiated

→ Influences distribution of initiation period T_i

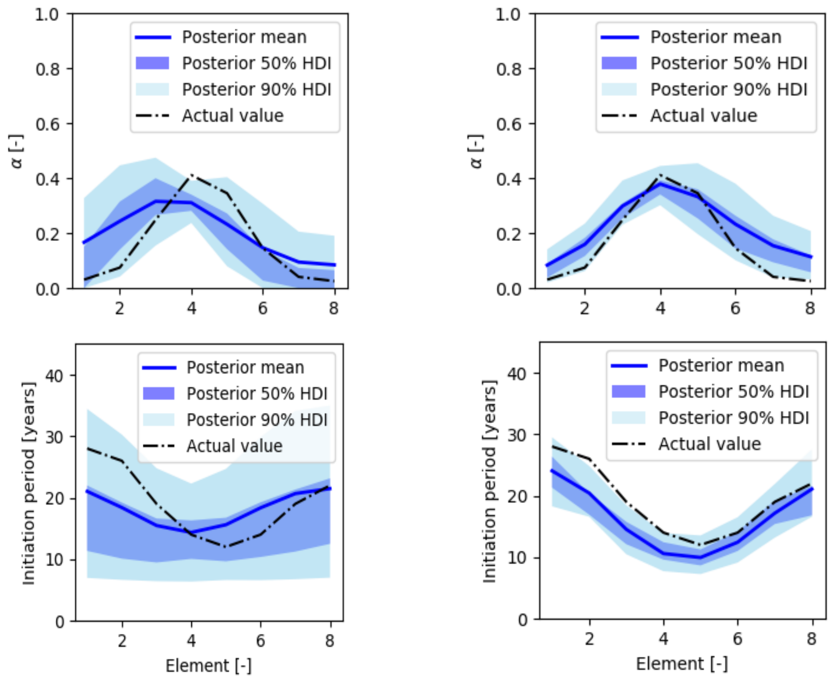


Without visual observations

With visual observations

Corrosion degree

Initiation period



Vereecken, E., Botte, W., Lombaert, G., & Caspeele, R. (2022). ***A Bayesian inference approach for the updating of spatially distributed corrosion model parameters based on heterogeneous measurement data*****. Structure and Infrastructure Engineering, 18(1), 30-46**

Bayesian Updating Based on Crack Width (I)

Application: corroded RC beam (lab)

Ref: C. Martens, W. Botte, R. Caspeele & E. Verstrynge, Proof-of-Concept of a Bayesian Updating Approach for Corrosion Degrees on the Basis of Crack Measurements, Proc. fib symposium 2024, 11-13 November 2024, Christchurch, New Zealand. *(in review)*

- Visual inspections
- Crack width measurements
- Prior assumptions (engineering expertise, …)

Bayesian Updating Based on Crack Width (II)

Application: corroded RC beam (lab)

- Integration of correlation length ρ_{CL} and random field modelling
- Application of Bayesian updating (prior – MCMC – posterior) through crack width – corrosion model

Result: Spatial prediction of the corrosion degree for each sub-element of the RC beam, incorporating relevant uncertainties.

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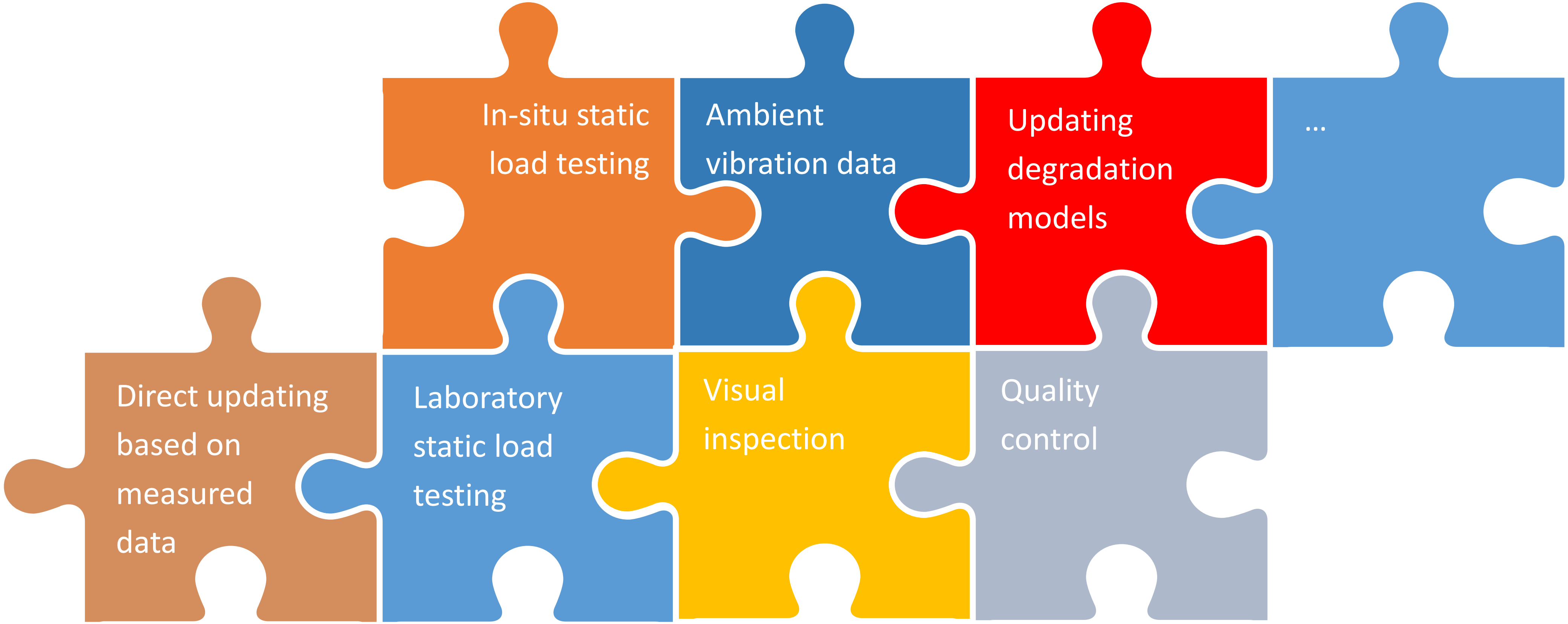
Updating using different sources of information



From the lab to the real world...

- Local and global inspection/monitoring techniques are successfully applied in lab conditions
- The transition from lab conditions to real-life cases studies comes with additional uncertainties related to:
  - Structural health
  - Boundary conditions
  - Material characteristics
  - Geometry
  - Environmental conditions
  - …
- Uncertainties are accounted for by combining different types of information
  - Design drawings
  - Structural and damage modelling
  - Historical reports
  - Inspections & monitoring

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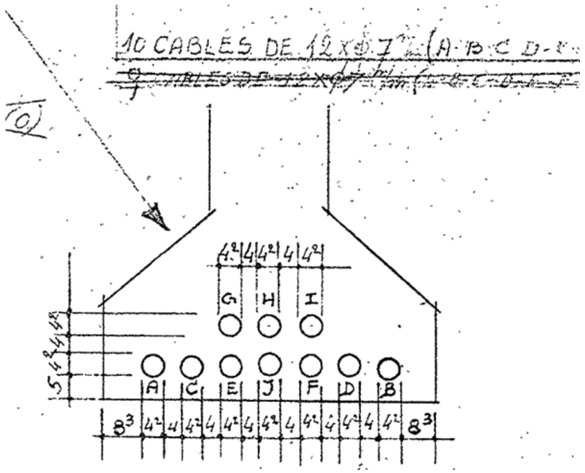
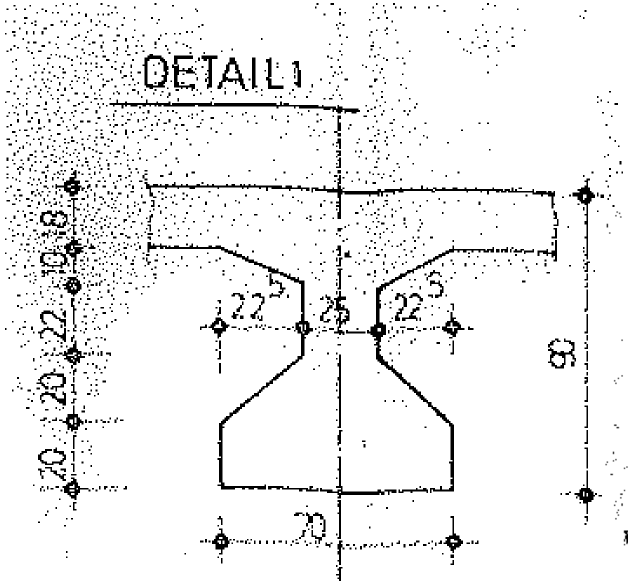
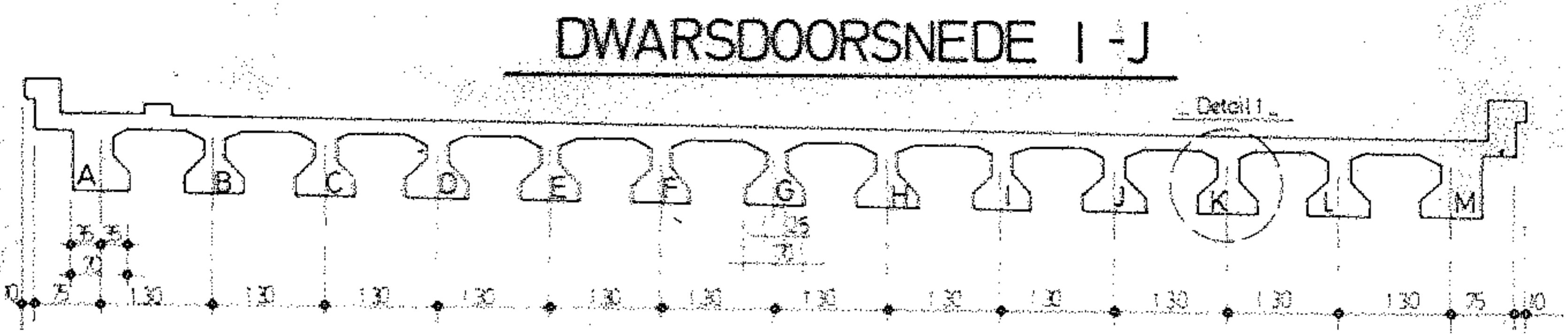
The case of the W20 bridge







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Inspection and monitoring

- Local inspection techniques
  - Visual inspections
  - Crack measurements (widths and lengths)
  - Sclerometric measurements
  - Potential measurements
  - Corrosion rate measurements
  - Core drilling for carbonatation depths, chloride content, ..
- Global tests and monitoring
  - Static load test in 1957, measuring displacements and rotations
  - Static load test in 2023, measuring displacements and strains
  - Continuous quasi-static strain measurements
  - Continuous dynamic measurements



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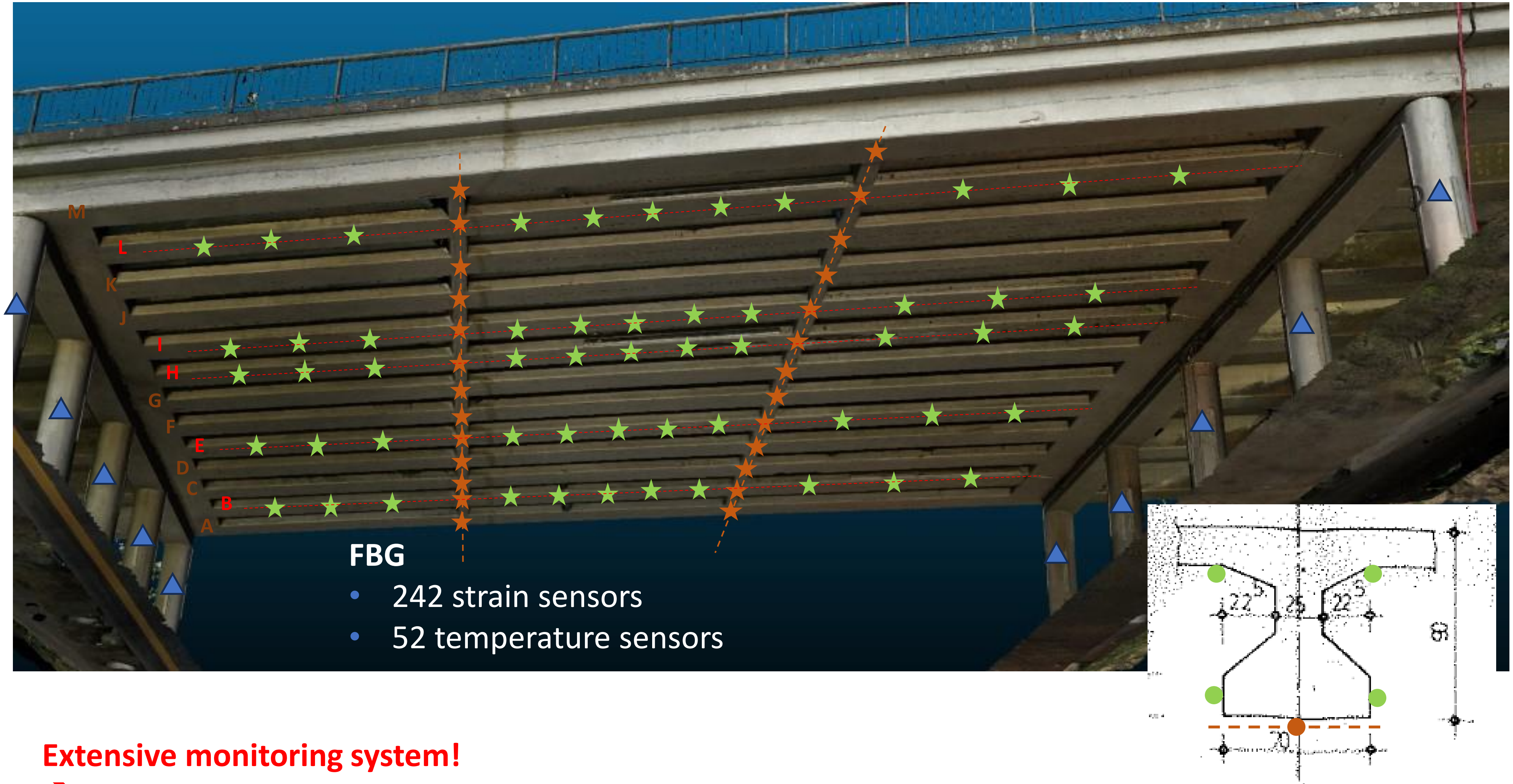
Optical fiber monitoring



FBG

- 242 strain sensors
- 52 temperature sensors

Extensive monitoring system!

➔ Case study only

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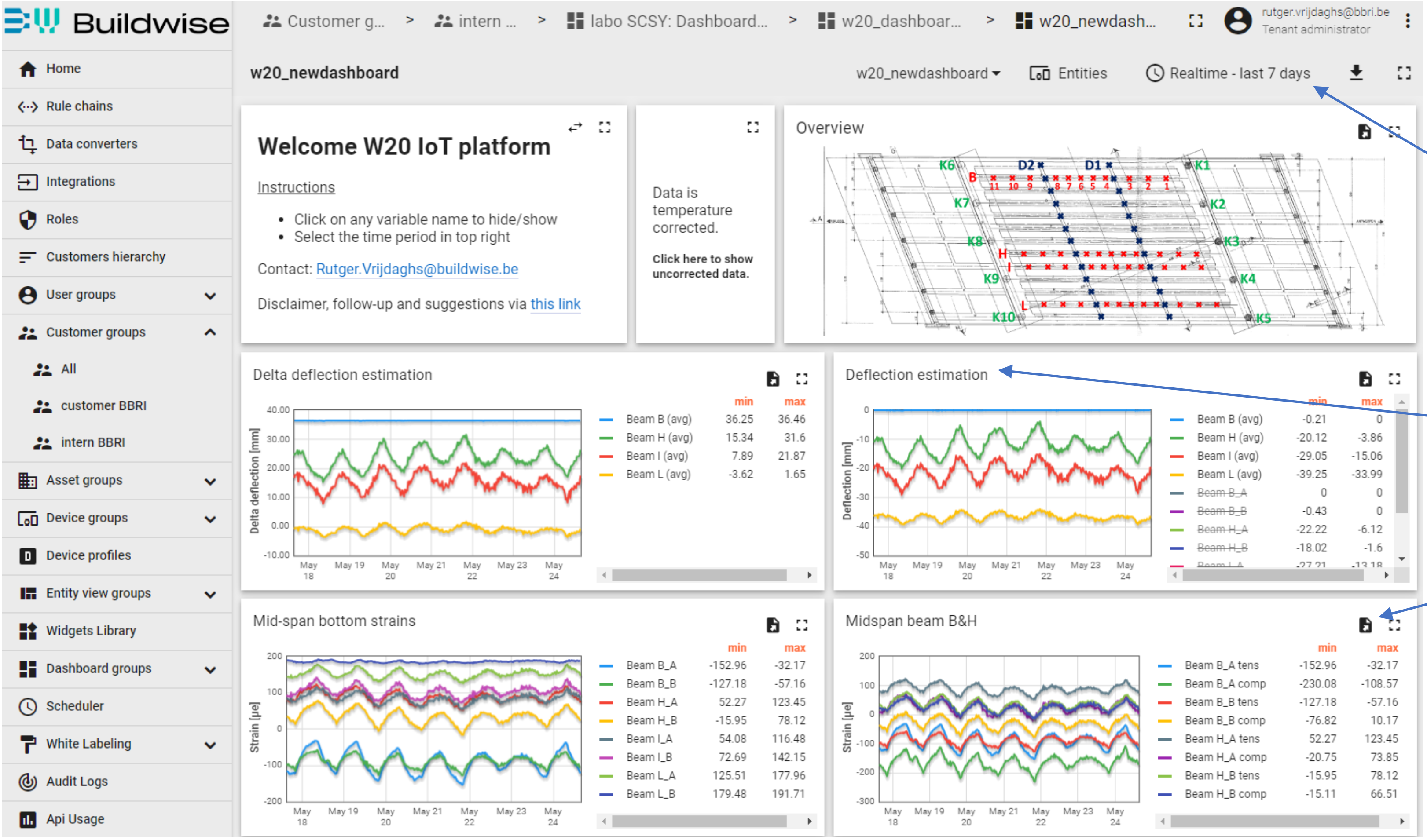
IoT platform



Last 5 minutes to last month

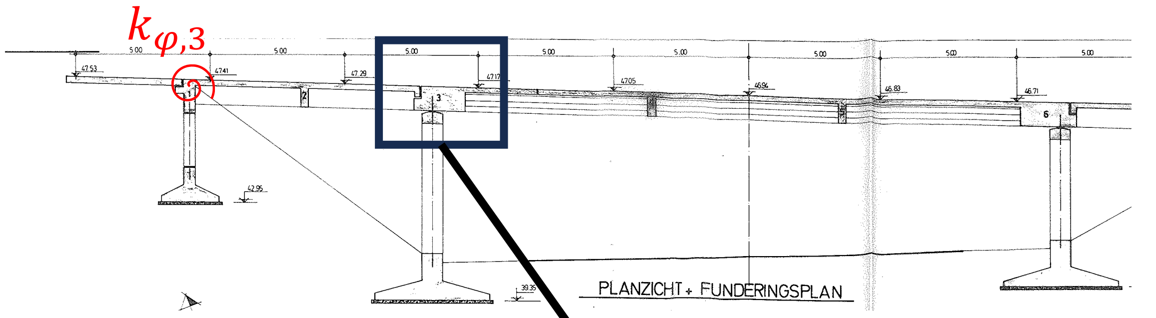
Live deflection and strain updates

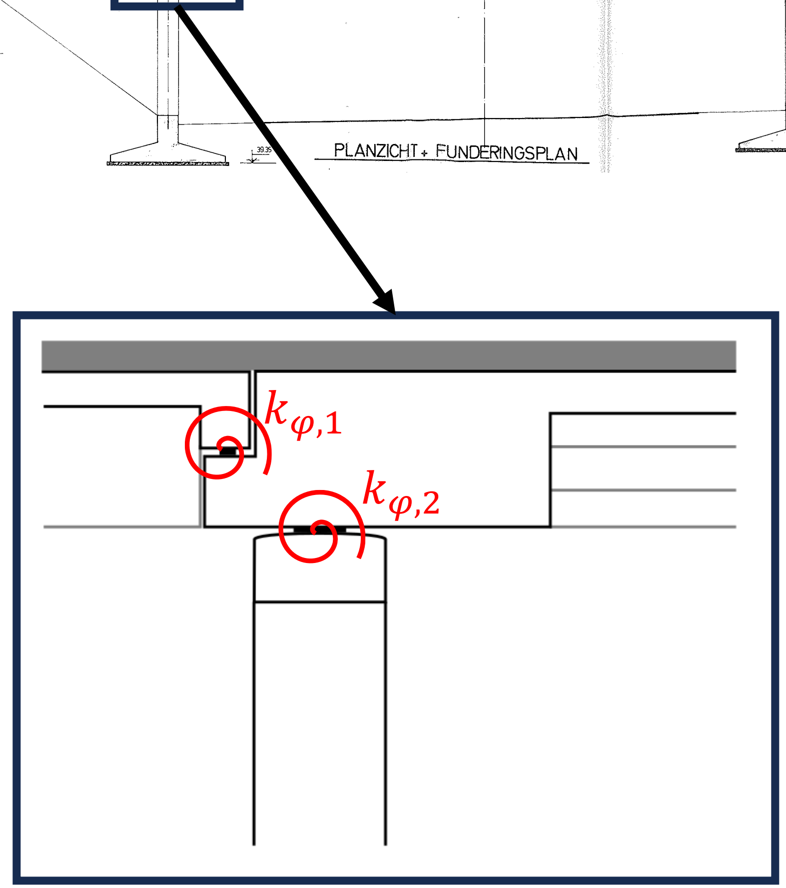
Raw data export

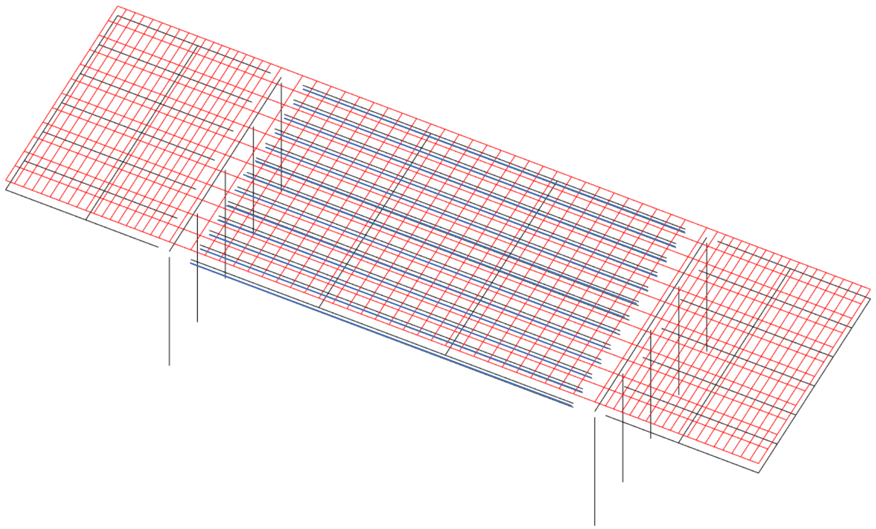
To be extended with early-warning system based on threshold values for PI's

Modelling

- 3D finite element model of the bridge is constructed
  - Geometry based on initial design drawings
  - Combination of beam elements and plate elements
  - Inclusion of rotational springs at the boundaries and at locations of internal hinges

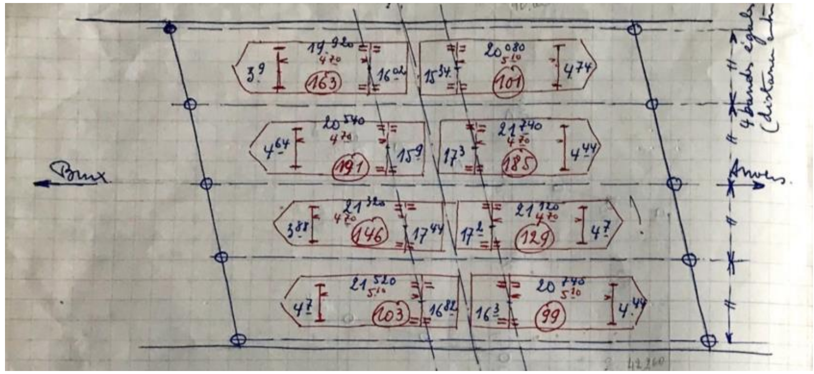


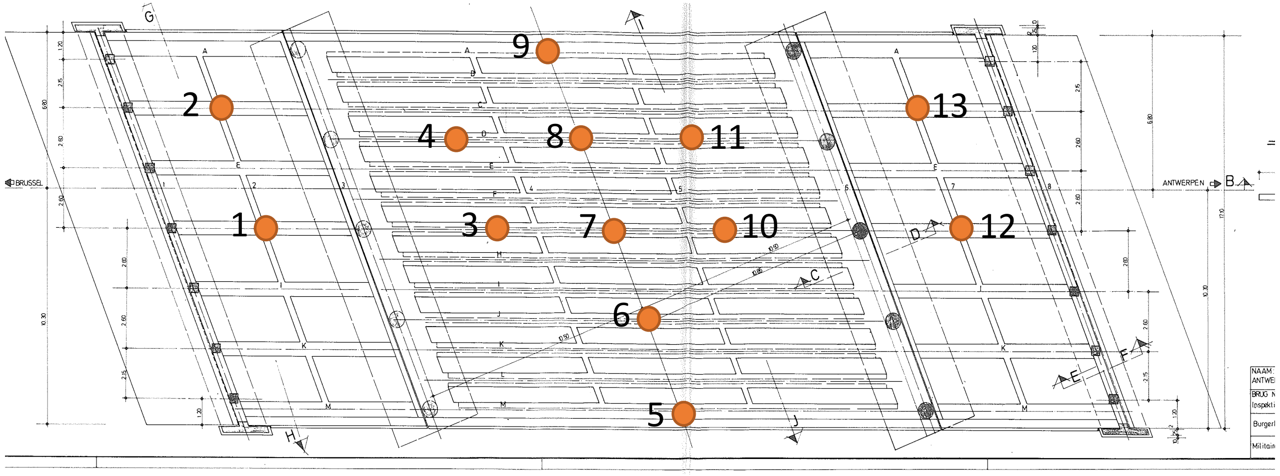




Load test 1957

- Loading: 8 trucks (167t) and known axle loads
- Deflection measurements at 13 locations (measurement accuracy: 0,05mm)
- Simulations with boundary conditions according to the design
- Good agreement between measurements and simulations





Location	Measurement [mm]		Simulation [mm]
1	-0,2		-0,4
2	-0,2		-0,3
3	8,3		7,7
4	7,8		7,3
5	9,7		9,9
6	11,2	≈	11,3
7	11,7	⟷	11,6
8	11,0		11,1
9	9,5		9,5
10	8,2		8,0
11	8,0		7,7
12	-0,2		-0,4
13	-0,2		-0,4

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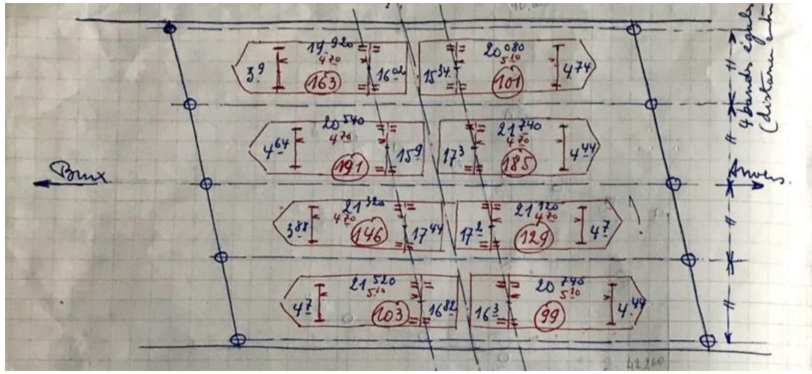
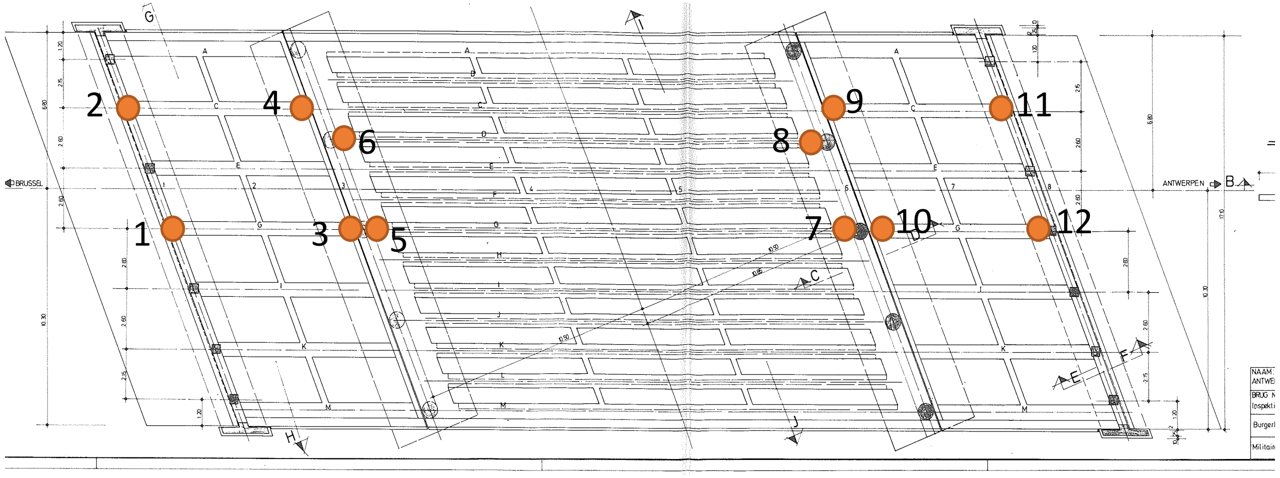
Load test 1957

- Loading: 8 trucks (167t) and known axle loads
- Rotation measurements at 12 locations (measurement accuracy: 20 $\mu m/rad$)
- Simulations with boundary conditions according to the design
- Good agreement between measurements and simulations



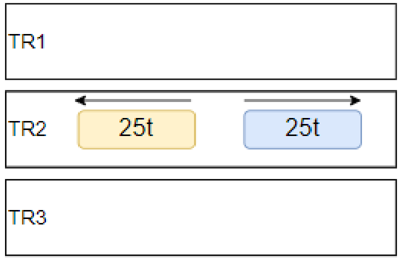


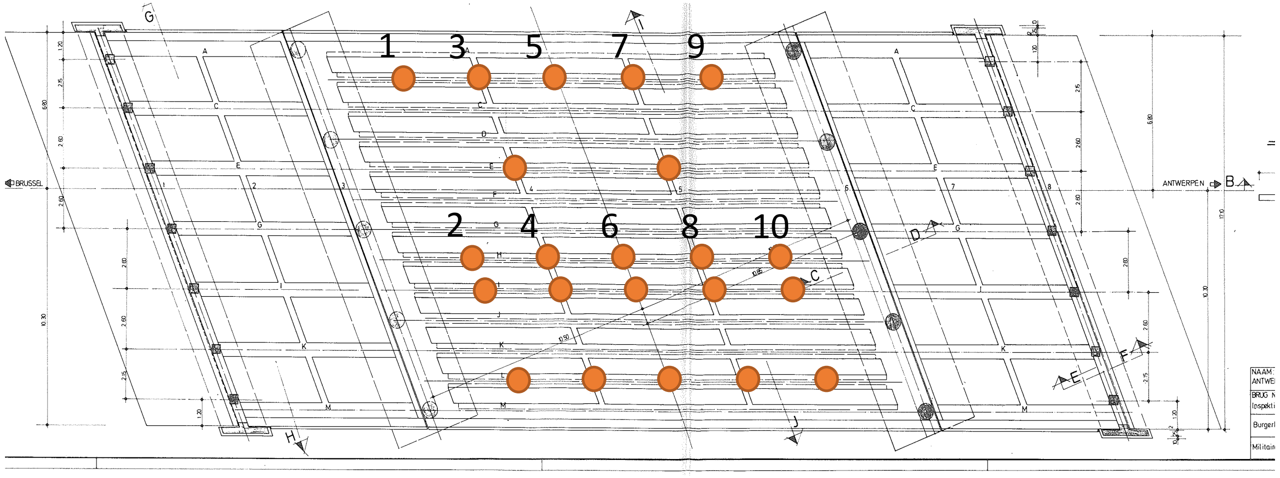
Location	Measurement [$\mu m/rad$]	Simulation [$\mu m/rad$]
1	-30	0
2	-45	0
3	-25	-40
4	-15	-80
5	1400	1430
6	1410	1370
7	-1510	-1500
8	-1495	-1450
9	30	40
10	25	40
11	30	0
12	0	0

≈

Load test 2023

- Loading: 2 trucks (50t) and known axle loads
- Deflection measurements at 22 locations
- Simulations with boundary conditions according to the design
- Overestimation of the displacements





Location	Measurement [mm]	Simulation [mm]
1	0,8	1,4
2	1,5	2,1
3	1,4	2,3
4	2,7	3,5
5	1,6	2,7
6	3,0	4,1
7	1,4	2,4
8	2,7	3,4
9	0,9	1,5
10	1,7	2,0

≠

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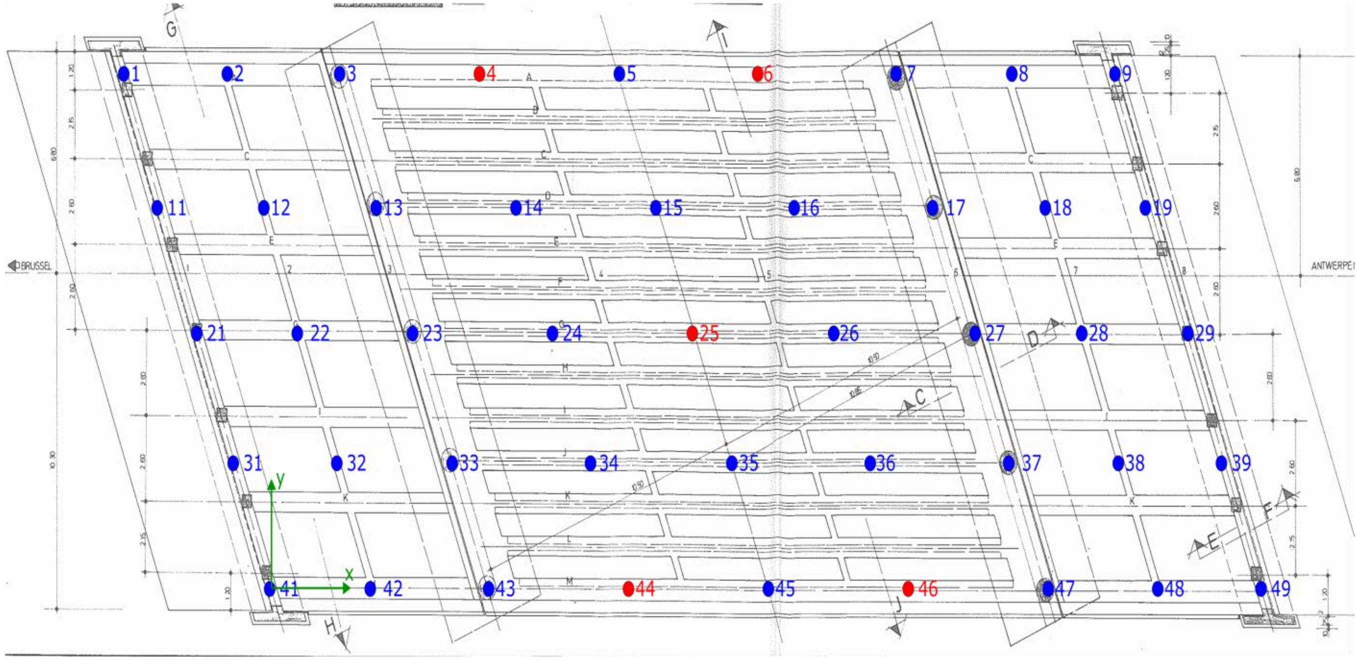
Vibration-based monitoring

- Reference dynamic measurements using 12 accelerometers measuring accelerations in three directions
- 6 different set-ups with 45 measurement locations



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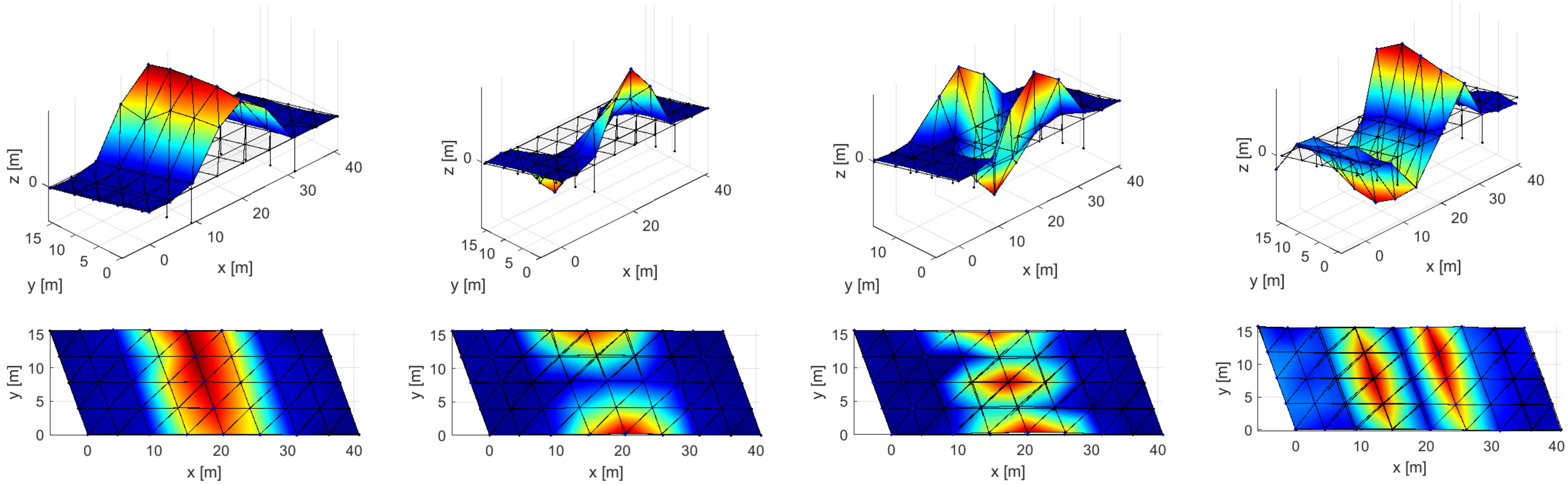
Vibration-based monitoring

- 6 identified modes in frequency range between 0 – 20 Hz
- Overestimation of the natural frequencies, which (again) relates to an underestimaton of the stiffness

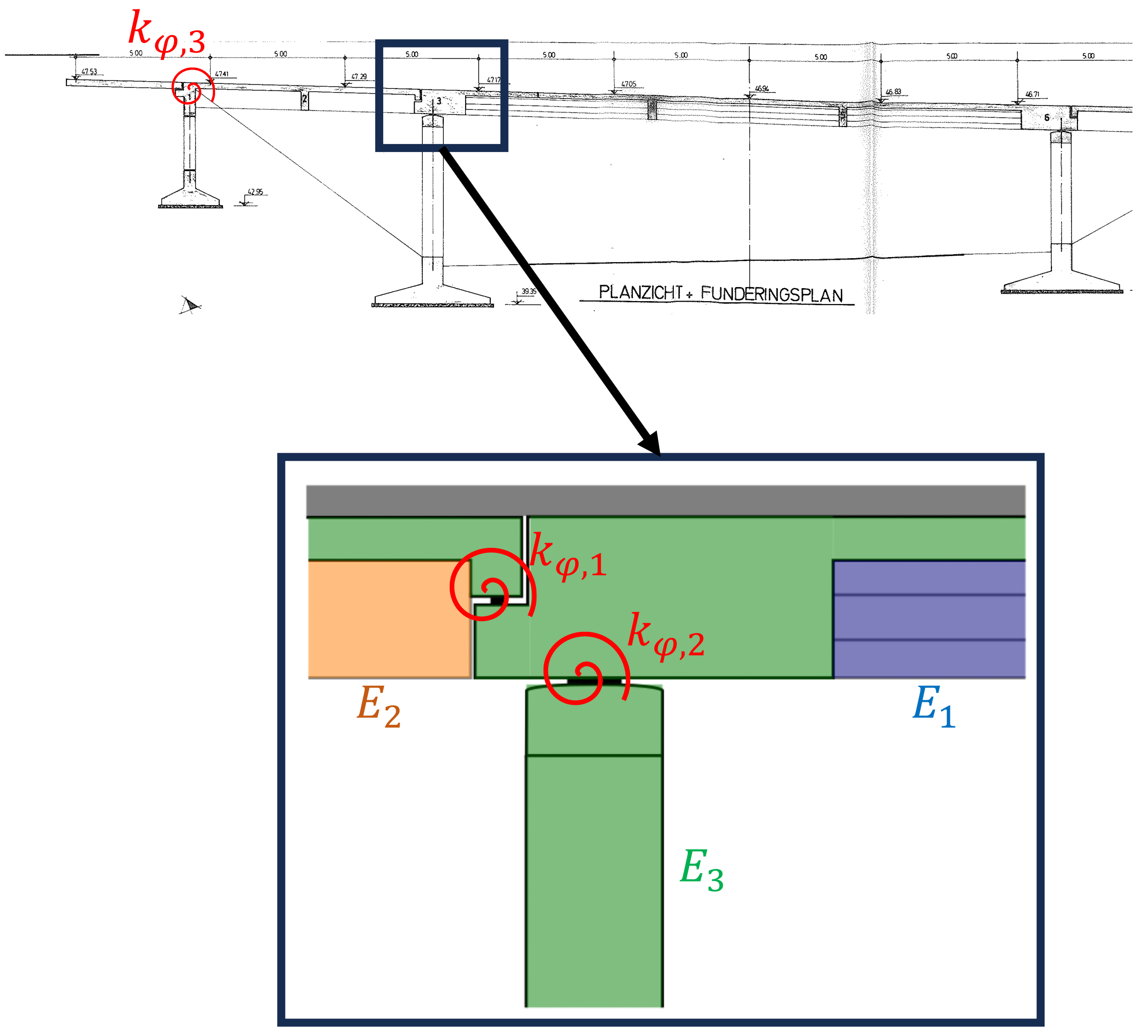
Nr.	f_{id} [Hz]	f_{sim} [Hz]
1	4,71	3,52
2	5,83	4,67
3	9,66	9,30
4	14,70	13,96
5	16,33	14,29
6	17,54	17,00

$\neq$



Bayesian updating

- Both displacement measurements and natural frequencies indicate an underestimation of the stiffness in 2023/2024 when compared to 1957
- The structural stiffness in this period might have changed due to several factors
  - Ageing and hardening of the concrete
  - Deterioration of the steel and concrete
  - Changing boundary conditions
  - (Temperature)
- FE model of the bridge is updated based on different global measurement data
- Updated parameters: Young's moduli of the beams and stiffness of the rotational springs



Future work

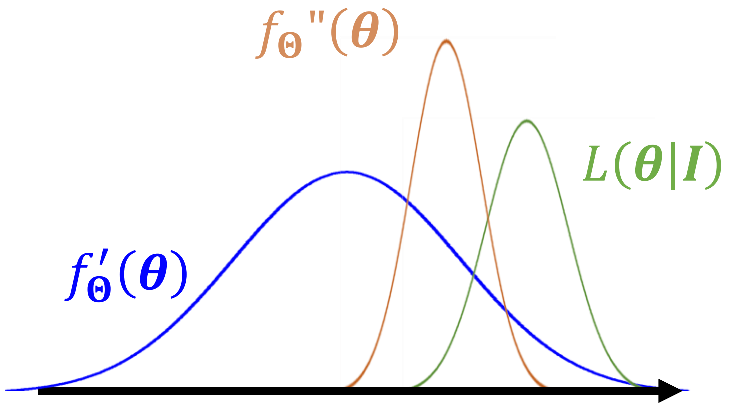
$$f_{\boldsymbol{\Theta}}"(\boldsymbol{\theta}) \equiv f(\boldsymbol{\theta}|\boldsymbol{I}) = \frac{L(\boldsymbol{\theta}|\boldsymbol{I}) \cdot f'_{\boldsymbol{\Theta}}(\boldsymbol{\theta})}{\int L(\boldsymbol{\theta}|\boldsymbol{I}) \cdot f'_{\boldsymbol{\Theta}}(\boldsymbol{\theta})\, d\boldsymbol{\theta}}$$

Posterior distribution

New state of knowledge

Prior distribution

Vague or informative prior; can incorporate data from previous assessments

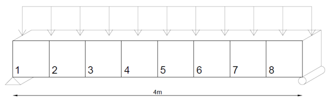


Likelihood

Accounts for measurement data, model uncertainties, expert knowledge, …

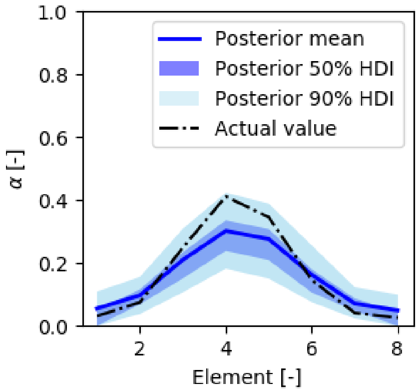
ENABLES TO COMBINE SOURCES OF INFORMATION

The power of combining information



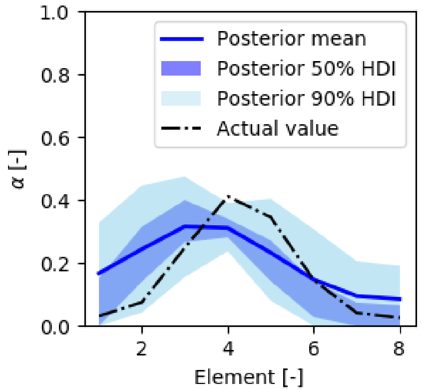
Modal parameters from vibration data

→ Localization but not accurate quantification

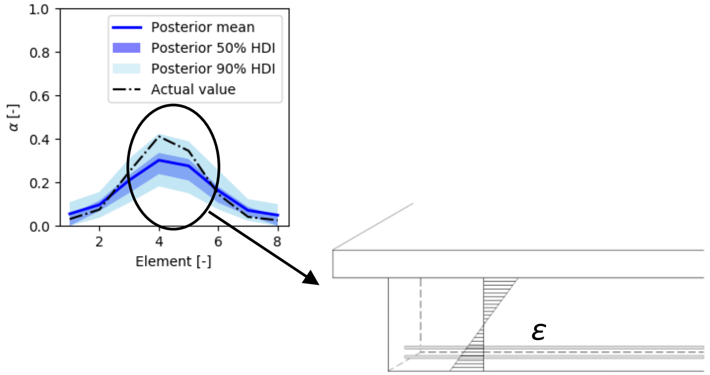


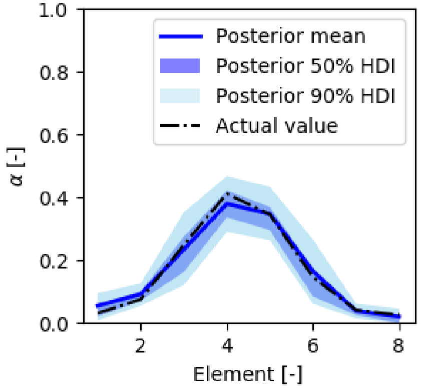
Strain measurements under proof-loading at el. 4

→ Quantification only at measurement location



Combination of data: strain measurements at critical locations from vibration data





→ Accurate representation of actual corrosion degree

Vereecken, E., Botte, W., Lombaert, G., & Caspeele, R. (2022). *A Bayesian inference approach for the updating of spatially distributed corrosion model parameters based on heterogeneous measurement data*. Structure and Infrastructure Engineering, 18(1), 30-46

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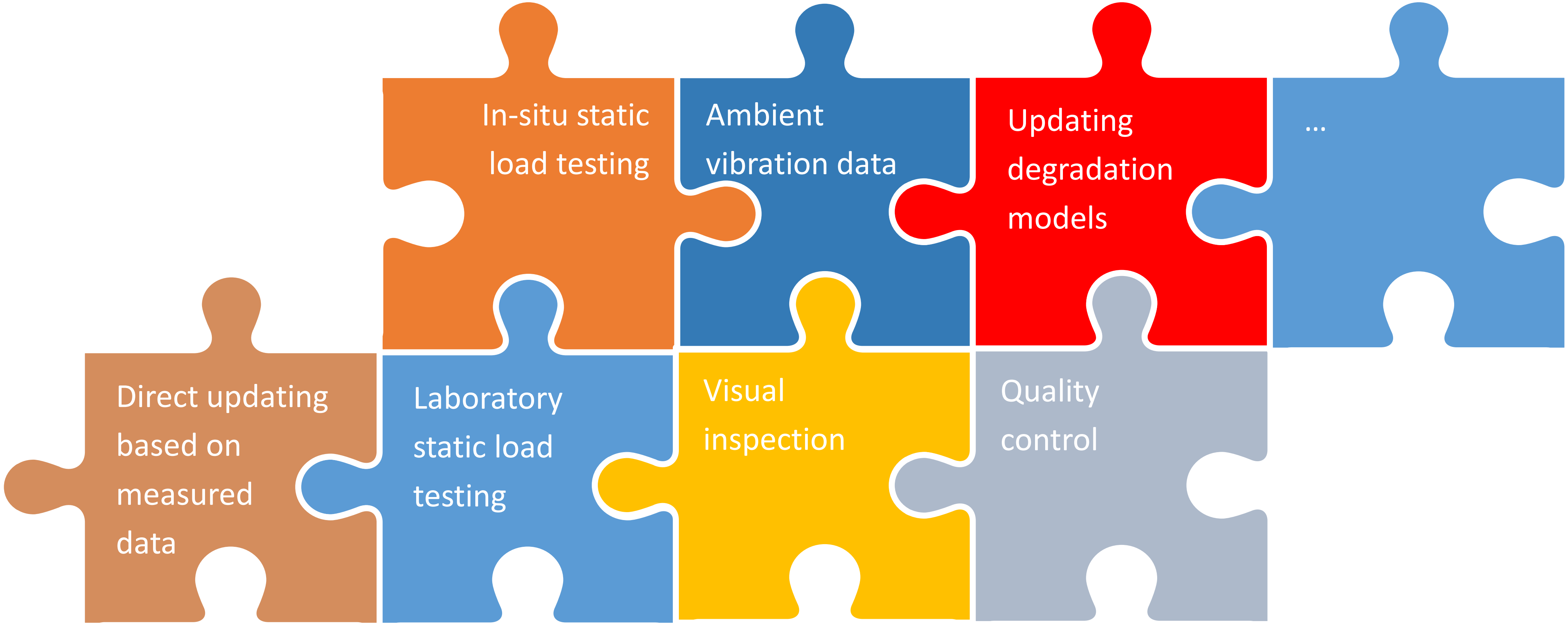
The power of combining information



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