# Summer School

## Thermo-mechanical experiments of RC structures correlated to distributed coda signals

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CoDA

CONCRETE DAMAGE ASSESSMENT BY CODA WAVES

## Vision

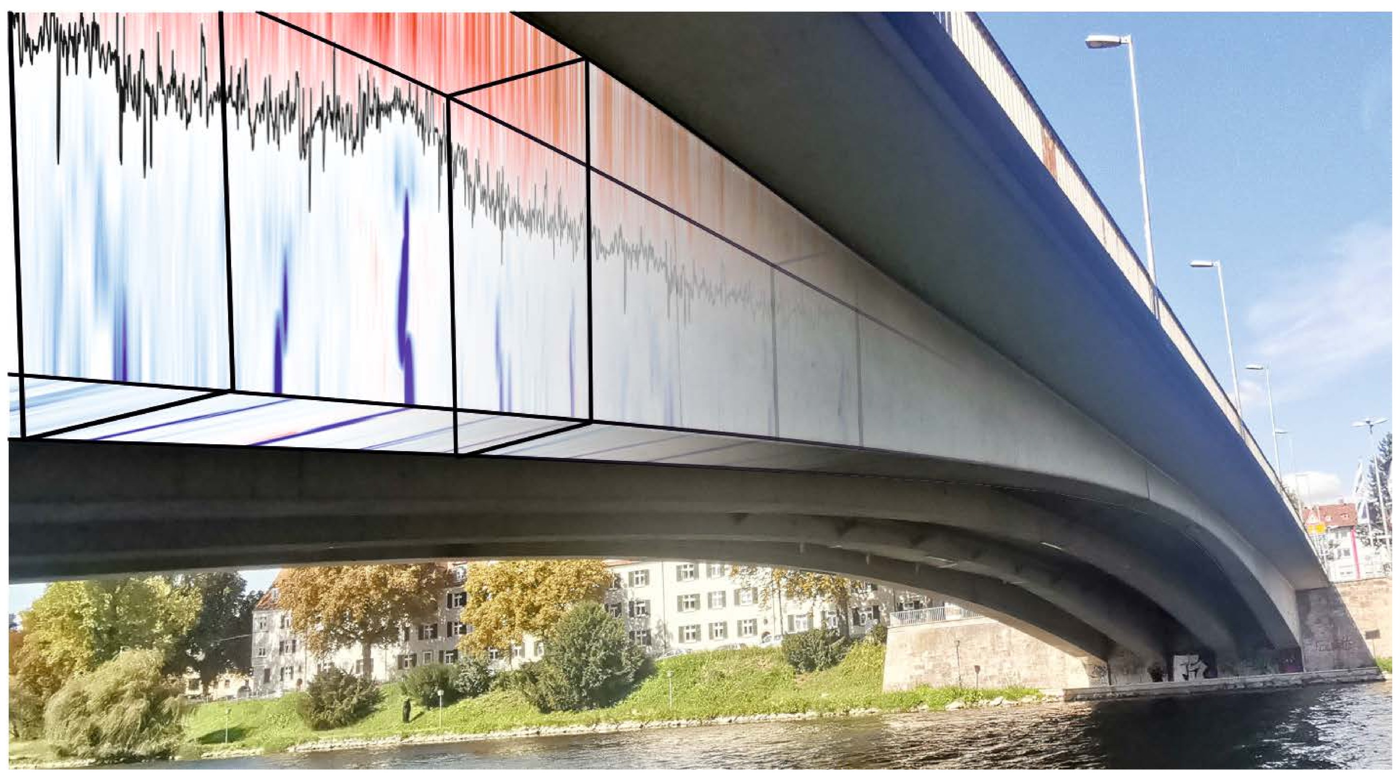


**Figure 1:** Transparent infrastructure; internal strains made visible by coda waves

- Monitoring the health status of RC and prestressed concrete structures with coda waves
- Detect deficiencies already when forming, *far before* they become *visible* and reach critical levels

## Mechanical

### Experiments

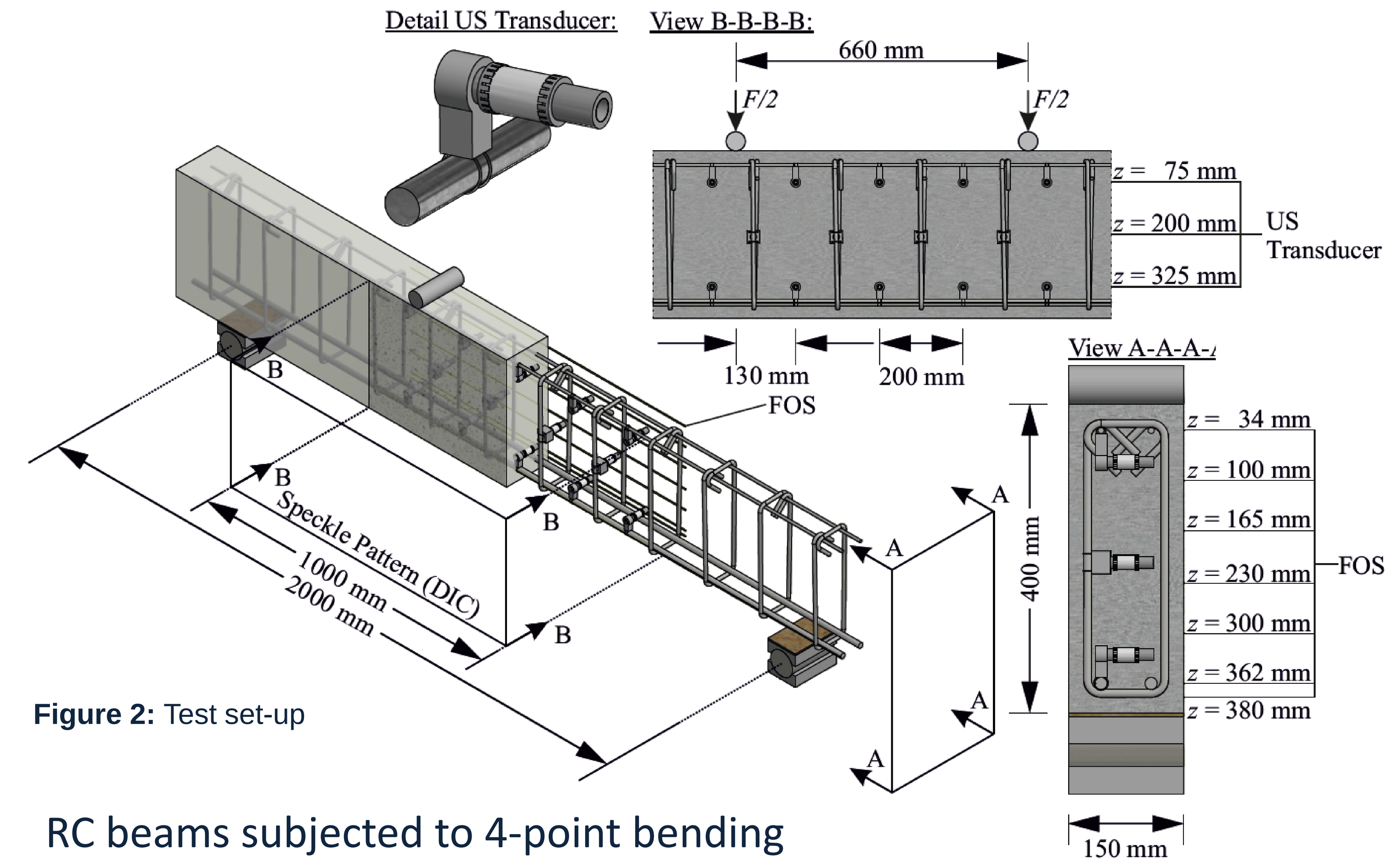
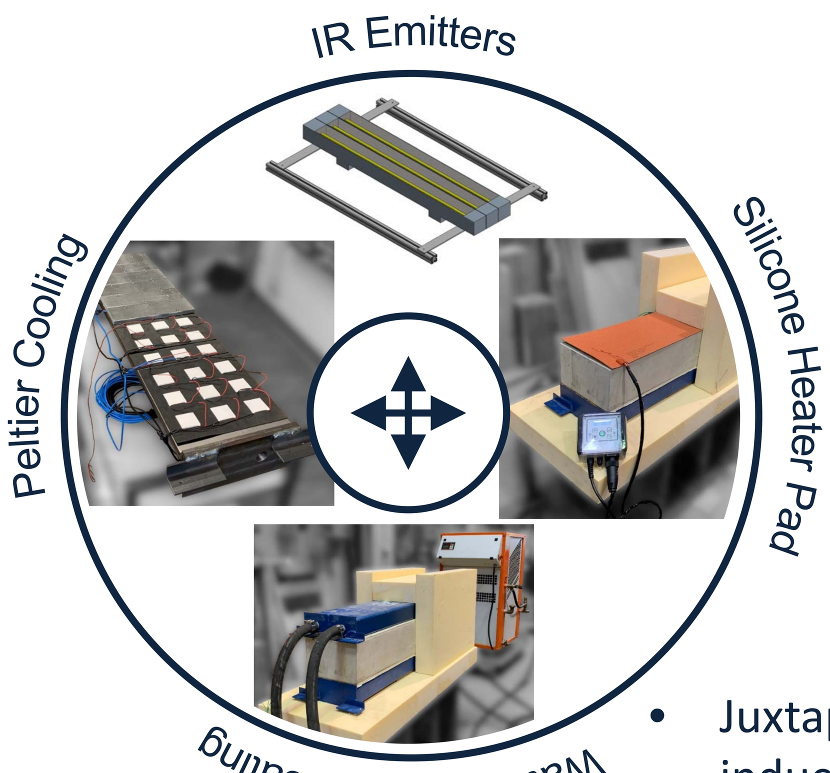



**Figure 2:** Test set-up

- RC beams subjected to 4-point bending

## Thermal

### Suitable Method for Heat Induction into RC Members



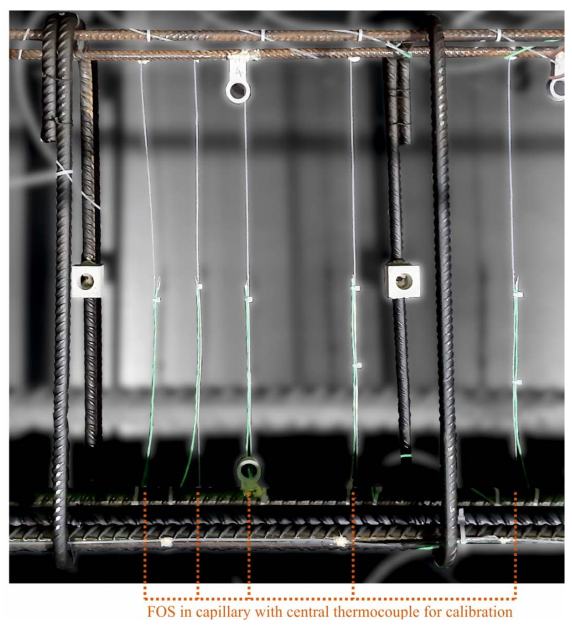




**Figure 3:** FOS guided in capillaries

- Juxtaposition of methods for heat induction
- Optimized cooling by combining water cooling and Peltier elements

### Qualification of Measuring Methods for Strains

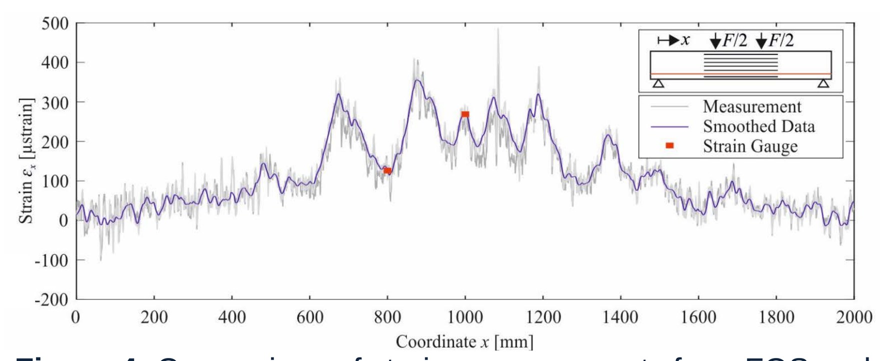



**Figure 4:** Comparison of strain measurements from FOS and strain gauges

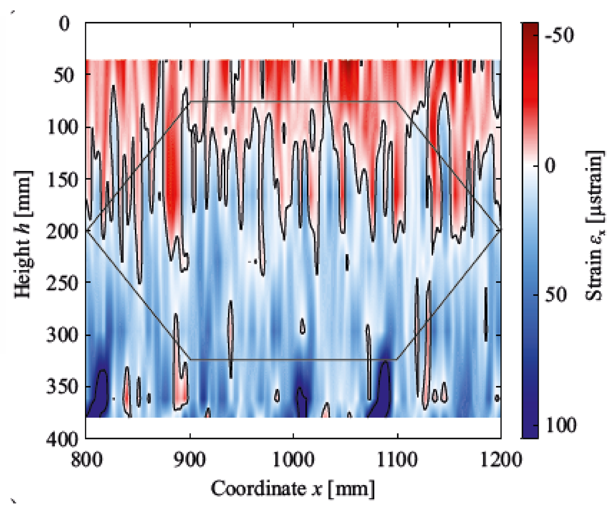



**Figure 5:** Strain fields derived from FOS strain measurements (10 kN)

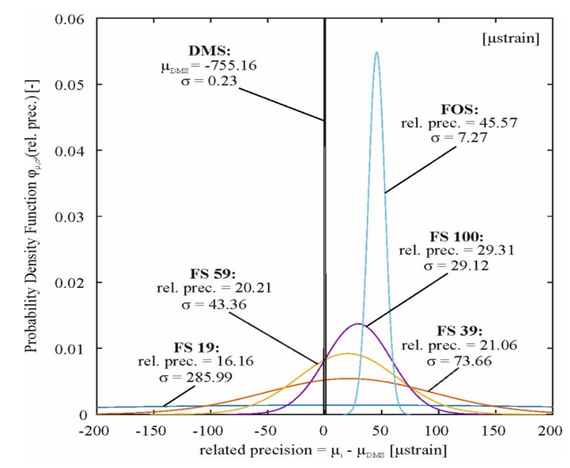



**Figure 6:** Comparison of repeatability and accuracy of DIC, FOS and strain gauges

- 2D strain distributions from line-like FOS measurements
- Evaluation of the accuracy of strain measurement techniques (FOS > DIC)

## Thermo-Mechanical

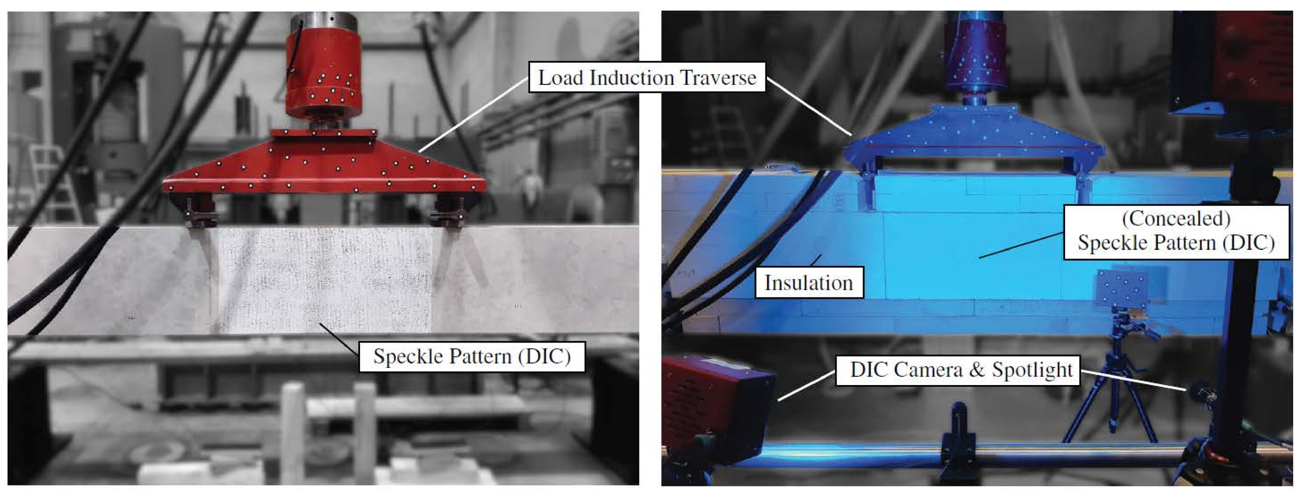



**Figure 7:** Photos of beams during mechanical and thermo-mechanical testing

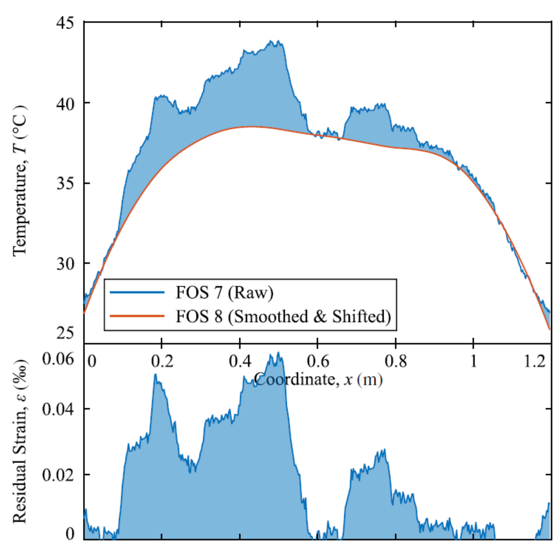



**Figure 8:** Sound separation of coupled effects in fiber optic measurements

- Mechanical strains impair temperature measurements with fiber optic sensors significantly
- Vice versa, mechanical strains are less affected by temperature

## Correlation

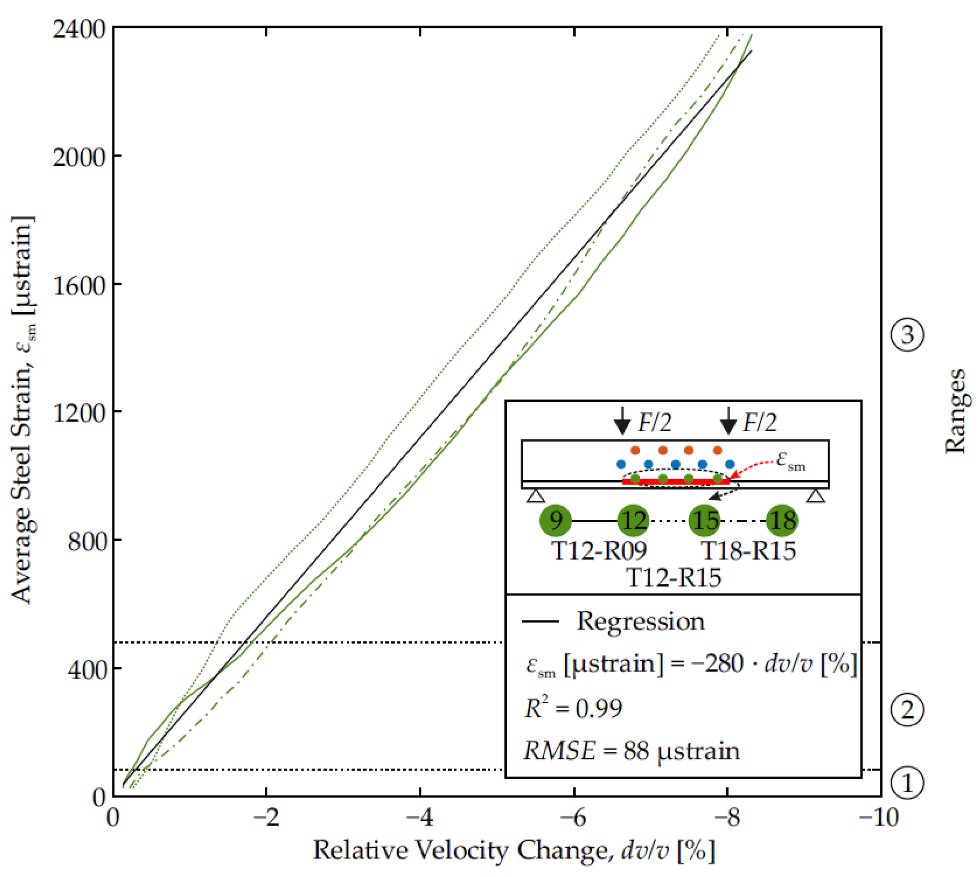



**Figure 9:** Strong correlation of the average steel strain and the relative velocity change

- Striking similarity of force vs. relative velocity change and moment-curvature relationships
- Correlation covers 90 % of the complex load-bearing behavior of RC members
- Generalizability is currently being tested

$$\varepsilon_{sm} = c \cdot \frac{dv}{v} \quad \text{with: } c = const.$$

## Publications

(1) Konertz, D.; Loeschmann, J.; Clauß, F.; Mark, P.: *Fiber optic sensing of strain and temperature fields.* Bauingenieur, 2019.

(2) Clauß, F.; Epple, N.; Ahrens, M. A.; Niederleithinger, E.; Mark, P.: *Comparison of Experimentally Determined Two-Dimensional Strain Fields and Mapped Ultrasonic Data Processed by Coda Wave Interferometry.* Sensors 20, 2020.

(3) Clauß, F.; Ahrens, M. A.; Mark, P.: *Evaluation of Strain Measuring Techniques in Reinforced Concrete Structures – Evaluation of Application, Accuracy, and Dimensionality.* Structural Concrete, 2021.

(4) Clauß, F.; Loeschmann, J.; Ahrens, M. A.; Mark, P.: *Temperature induction into RC structures.* Beton- und Stahlbetonbau, 2021.

(5) Grabke, S.; Clauß, F.; Bletzinger, K.-U.; Ahrens, M. A.; Mark, P.; Wuechner, R.: *Damage detection at a reinforced concrete specimen with coda wave interferometry.* Materials, 2021.

(6) Clauß, F.; Epple, N.; Ahrens, M. A.; Niederleithinger, E.; Mark, P.: *Correlation of Load-Bearing Behavior of Reinforced Concrete Members and Velocity Changes of Coda Waves.* Materials, 2022.

(7) Clauß, F.; Ahrens, M. A.; Mark, P.: *Thermo-mechanical experiments on reinforced concrete beams: Assessing thermal, mechanical, and mixed impacts on fiber optic measurements.* Structural Concrete, 2022.

(8) Clauß, F.; Mark, P.: *The transparent bridge – Coda wave analysis on prestressed concrete structures.* BFT International, 2022.

(9) Clauß, F.; Ahrens, M. A.; Mark, P.: *Damage without indication—Detection of tendon rupture using coda wave interferometry*, In: Proceedings of International Workshop on Structural Health Monitoring 2021, 2022.

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