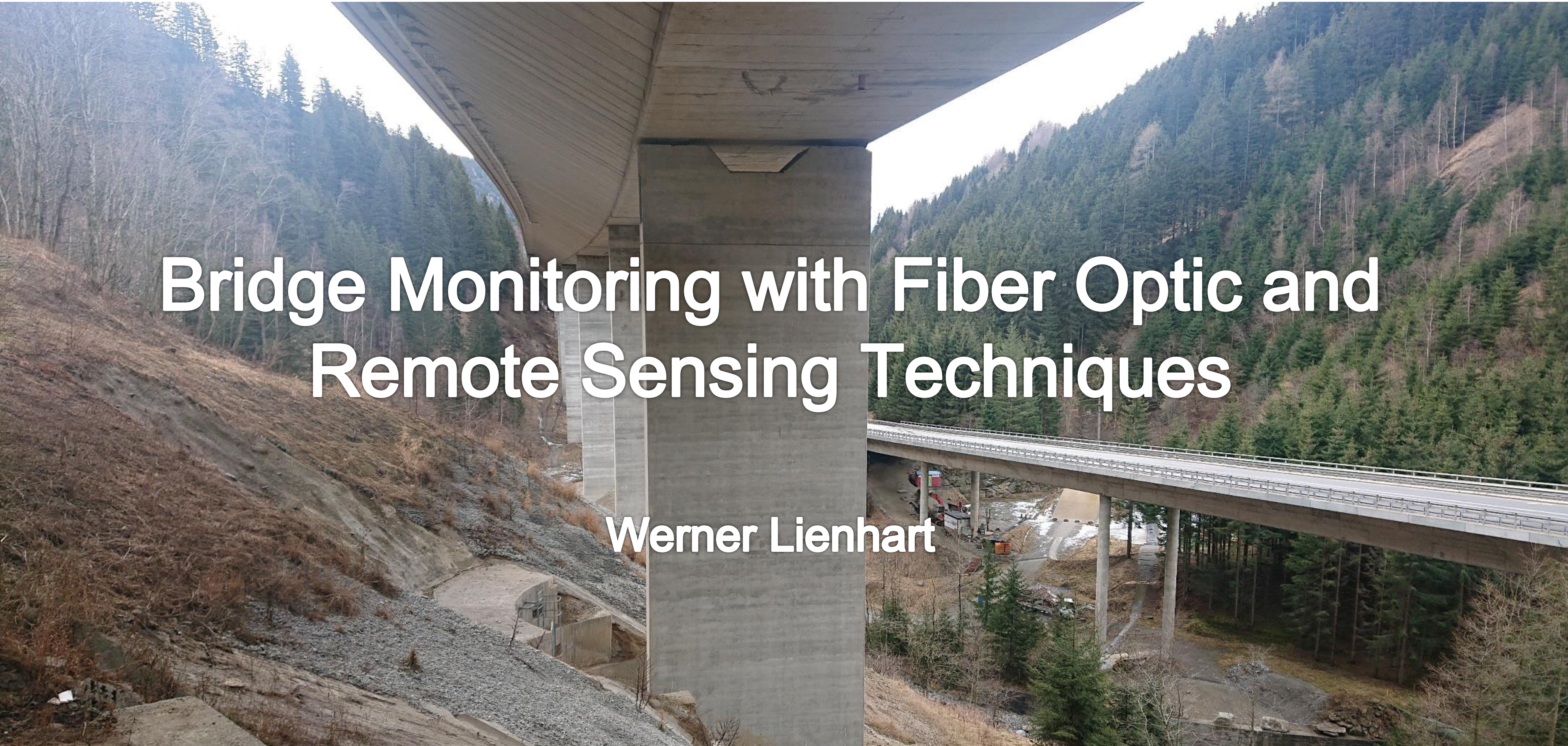
TU Graz

INSTITUTE OF ENGINEERING GEODESY AND MEAUSUREMENT SYSTEMS



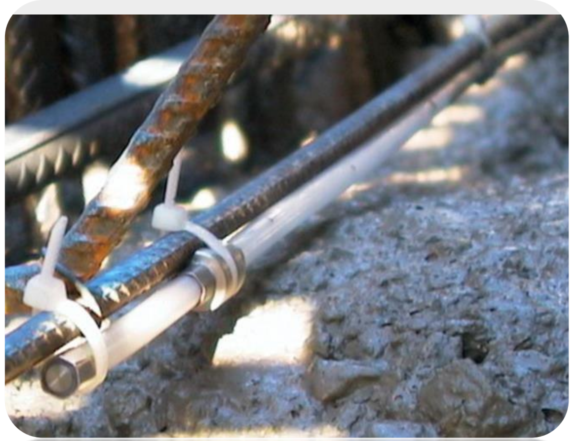
Bridge Monitoring with Fiber Optic and Remote Sensing Techniques

Werner Lienhart

Who are we?

IGMS (Institute of Engineering Geodesy and Measurement Systems)

- University institute of TU Graz, Austria
- Special focus on monitoring of civil structures and natural phenomena
- Fibre optic sensing since 1999



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- More than 30 years of experience in the development, installation and operation of automated warning and alarming systems
- www.igms.tugraz.at







Fibre Optic Sensors | Total Stations | Radar Interferometer | Laser Scanner | Digital Levelling Systems | GNSS | UAVs | Tilt Sensors

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ACI Monitoring

- TU Graz Spin-off
- Focus on distributed fiber optic sensing
- Design, development, installation and operation of DFOS monitoring systems
- www.aci-monitoring.at

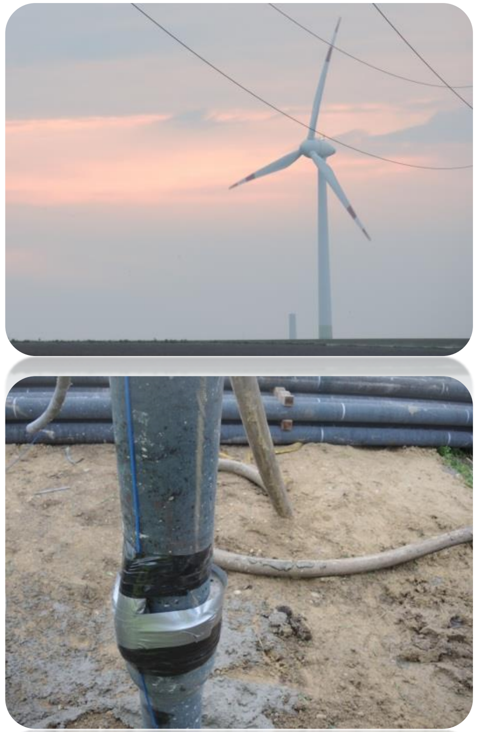
IGMS Fibre Optic Applications

Landslides

Earth Filled Dams

Concrete Dams

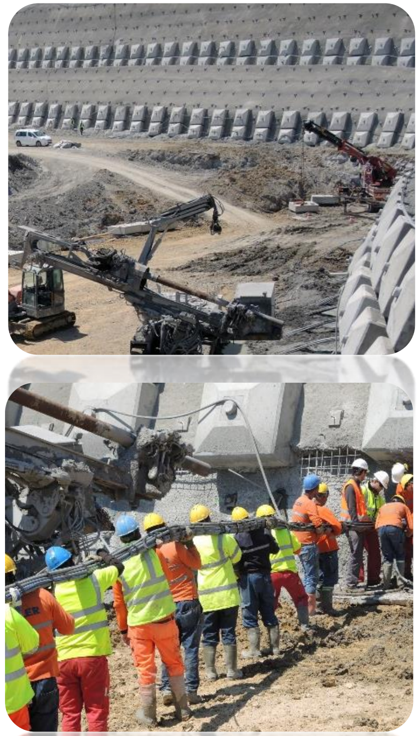
Reinforced Earth Structures



Piles

IGMS Fibre Optic Applications

Pipelines



Anchors

Tunnels

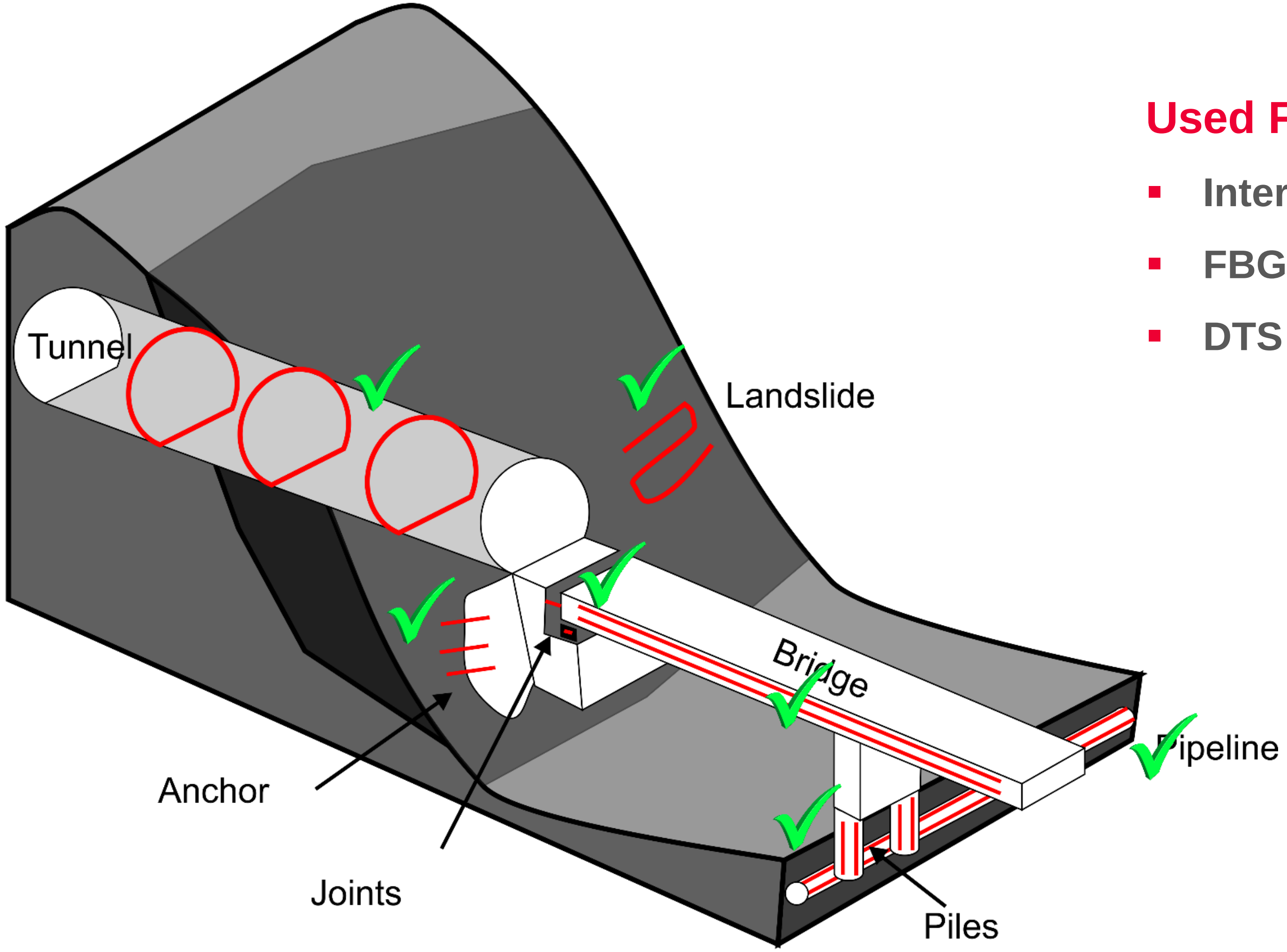
Railway Lines

Bridges

Fibre Optic Real World Installations

Coverage

- Austria
- Germany
- Switzerland
- Slovenia
- Czech Republic
- Denmark
- Italy
- Turkey
- Singapore
- …



Used FOS technologies

- Interferometric
- FBG
- DTS / DSS / DAS

Bridges

Many structures at the end of their lifetime

- Example German A8 Highway April 2023

IGMS Bridge Projects

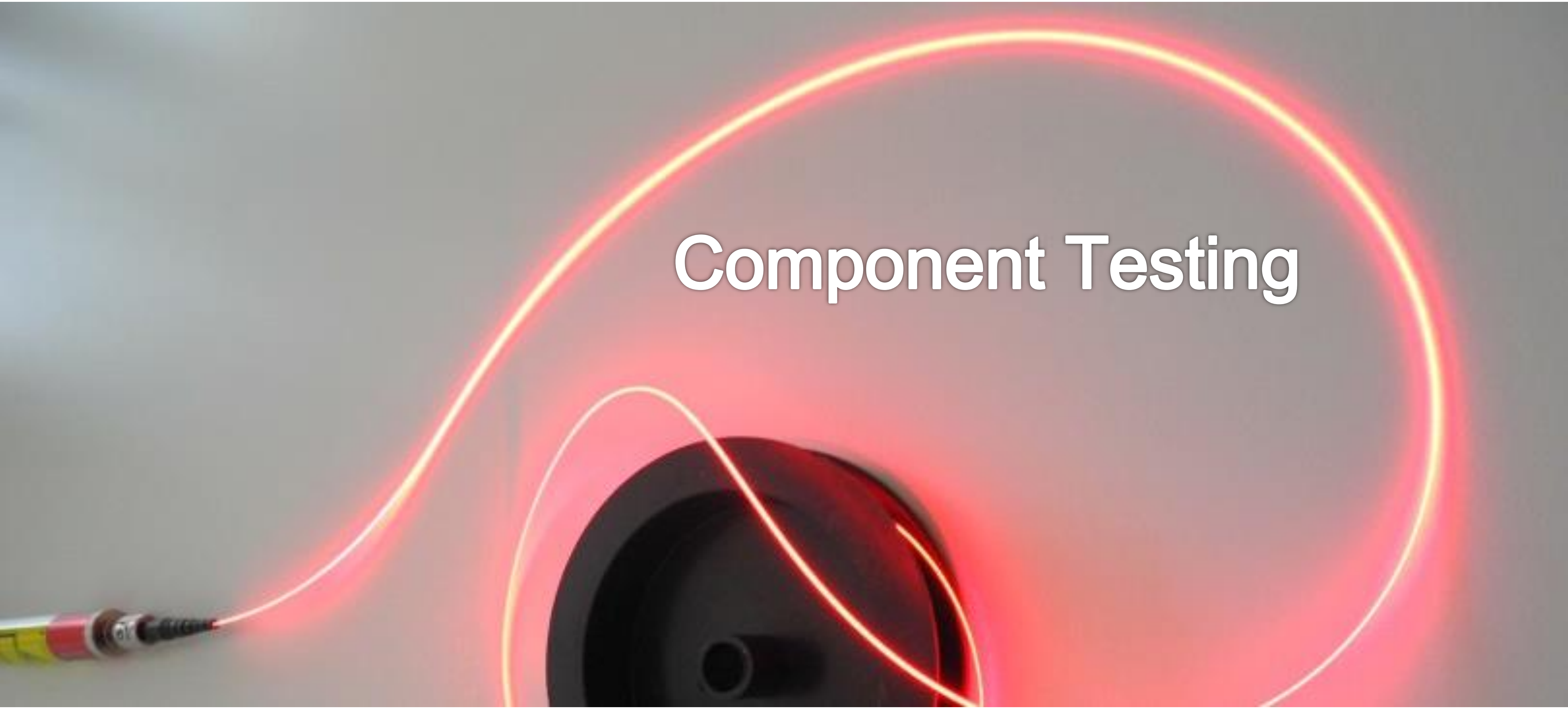
Existing structures

- Monitoring to ensure a safe operation
- Monitoring to extend the lifetime

Important monitoring parameters

- Cracks
- Static structural reaction (e.g. temperature changes)
- Dynamic structural reaction (e.g. due to traffic)

Component Testing



Component Testing & Calibration

IGMS measurement lab

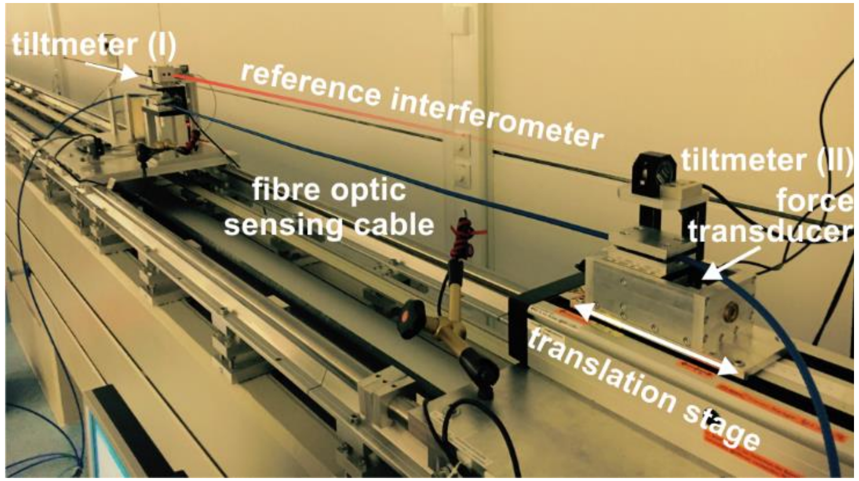
- Fully airconditioned 20°C ± 0.3°C
- Vibration isolated foundations

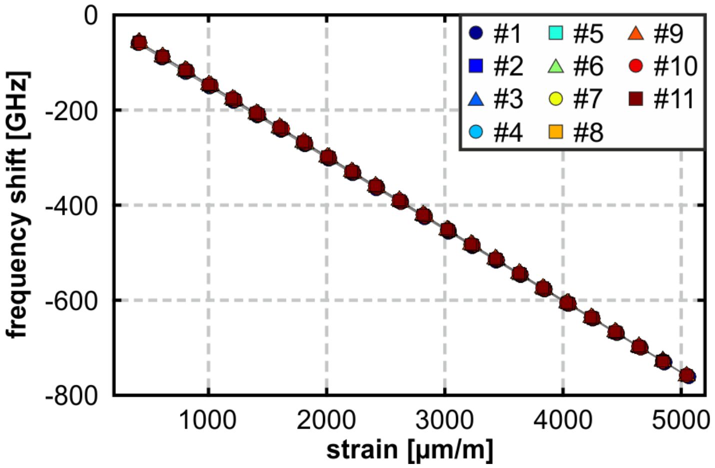
- Static strain calibration
- Temperature calibration
- Dynamic testing
- Long term evaluation

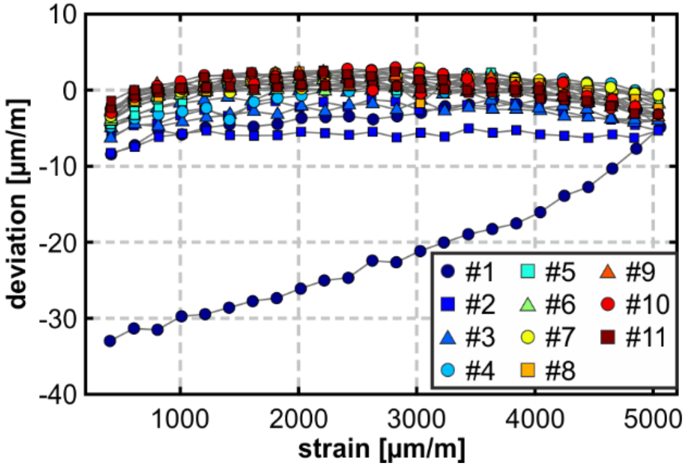
Static Strain Calibration

Automated calibration facility

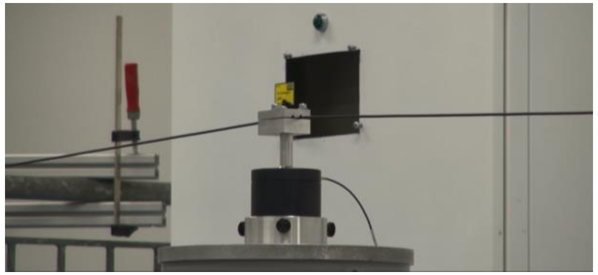
- Interferometric reference system
- Sensor lengths from 0.1 to 30 m
- Modular mounting systems
  - Strain transducers (SOFO, FBG)
  - Bare Fibers
  - Distributed sensor cables







Dynamic Strain Evaluation



Local mechanical excitation

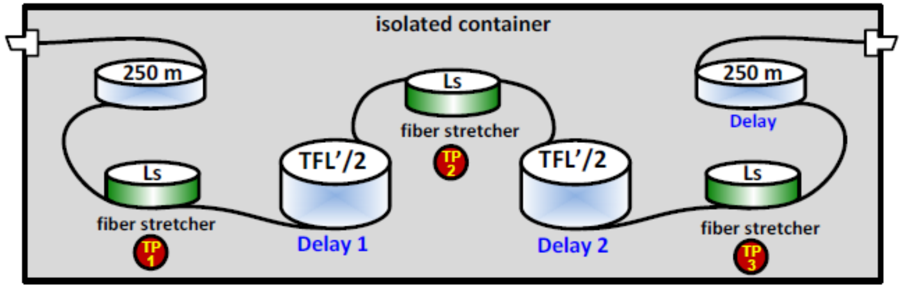
- Mechanical shakers
- Piezo stretchers

Acoustic excitation

- 8 stretched segments with 10 m each
- Speakers for constant frequencies or sweeps

SEAFOM MSP-02 setup

- 40 km with 3 stretchers

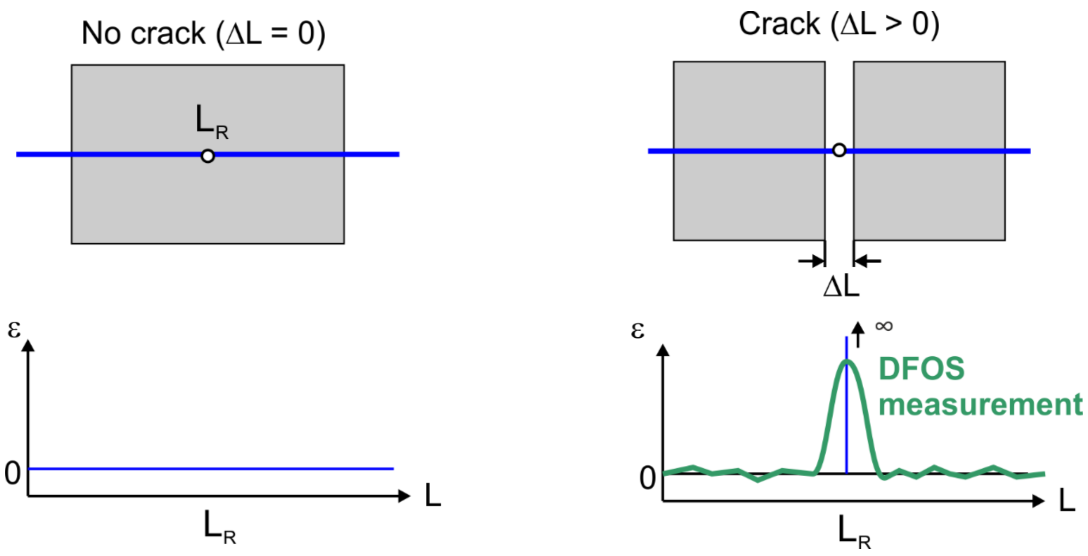


Crack Monitoring

Crack and Strain

Strain

$$\varepsilon = \frac{\Delta L}{L}$$



Strain pattern in case of a crack depends on

- Crack width
- Spatial resolution of instrument
- Used cable
- Used adhesive

Components of Surface Mounted DFOS Crack Monitoring

High resolution instrument

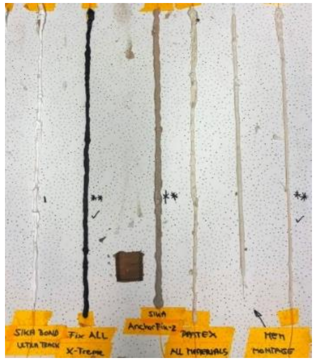
- Spatial resolution 10 mm or better required
- E.g. OFDR

Sensing cable

- Fibre has to survive the installation
- Strain has to be transferred reliably from the cable surface to the fibre core

Adhesive

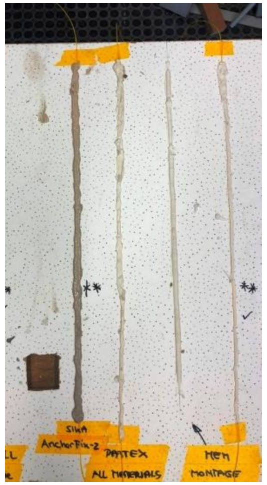
- Homogeneous bonding of cable along entire length
- No creep, no temperature effects, …



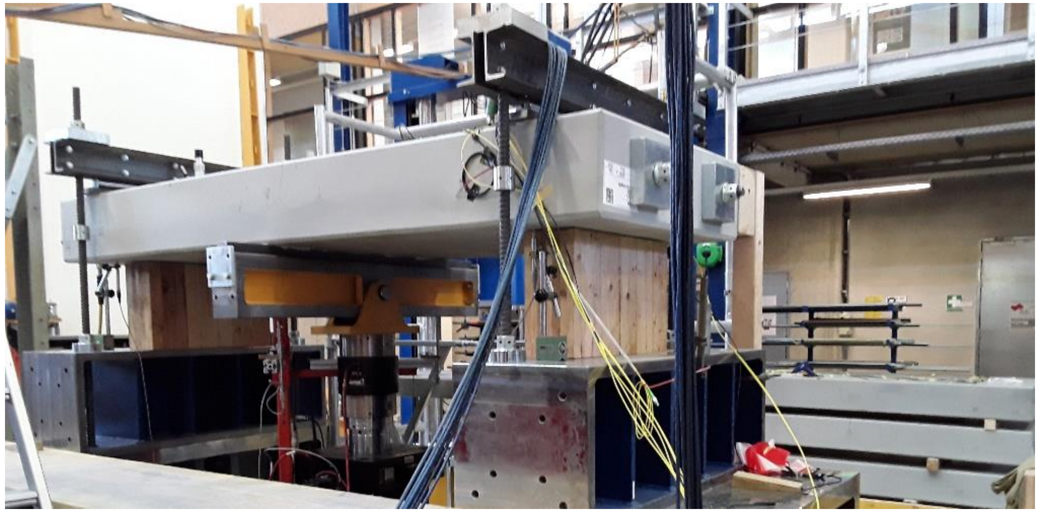
Laboratory Investigations

Mounting and loading tests

- Different cables/fibres
- Different adhesives
- Different surface preparation
- Different environment



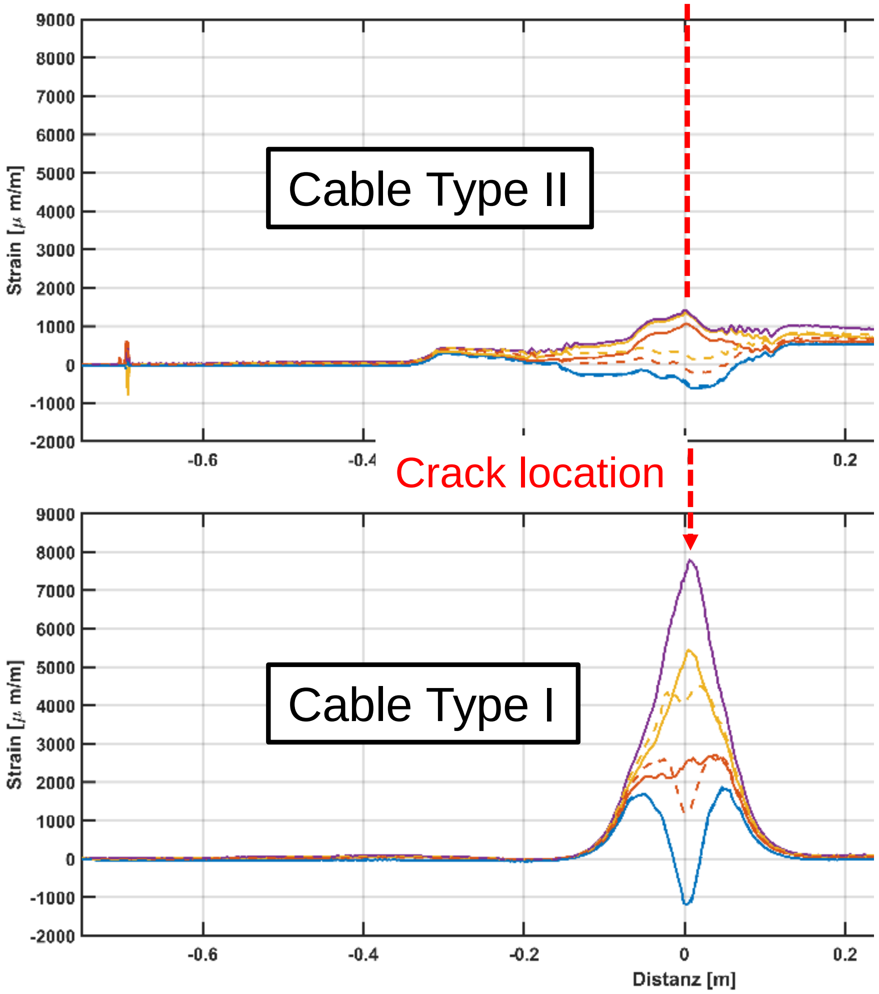


Example of Laboratory Investigations

Test specimens

- 3 plates
- 2.5 m x 0.9 m x 0.2 m
- Different cables applied to the surface



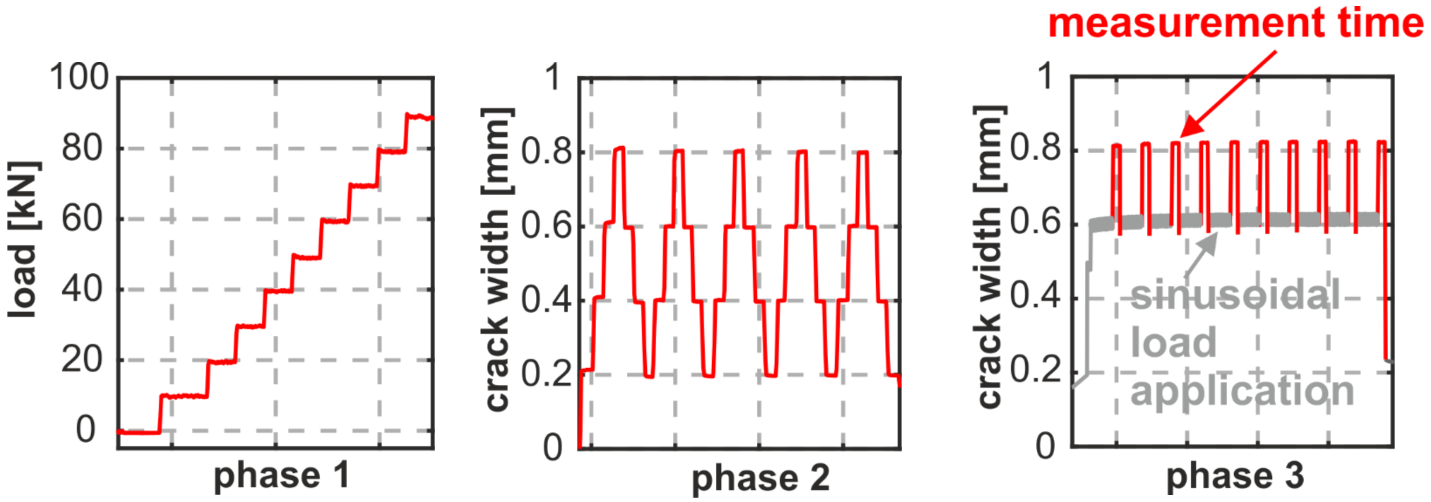
Laboratory Investigations

Vertical loading

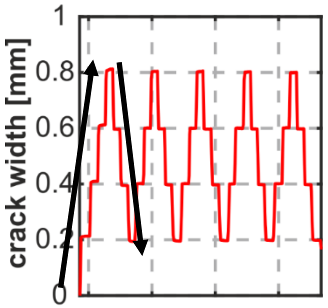
- Linear increase
- Cyclic change
- Ageing simulation

Reference measurements

- LVDTs
- Visual measurements

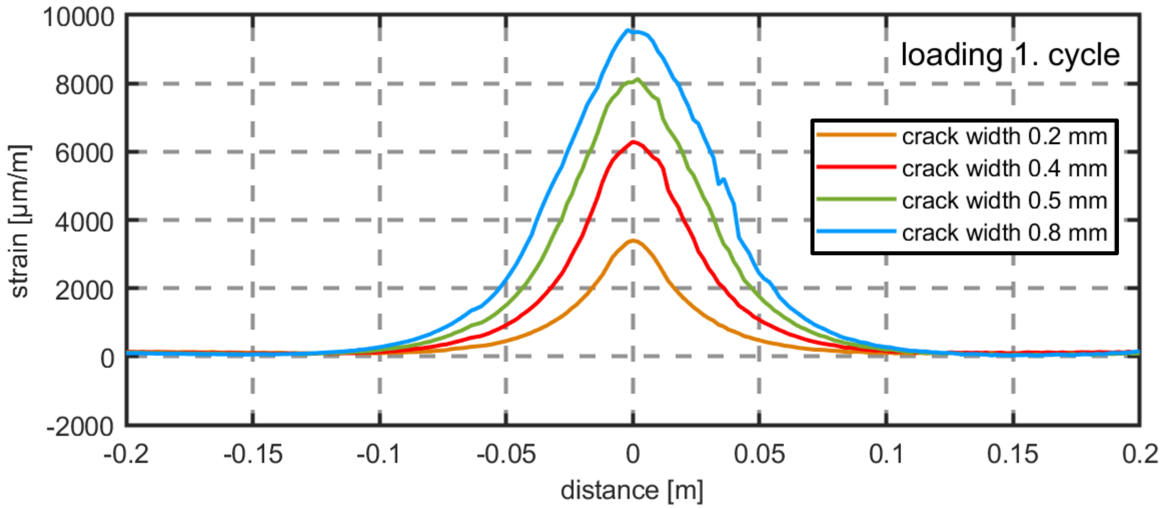


Laboratory Investigations



New crack occurring

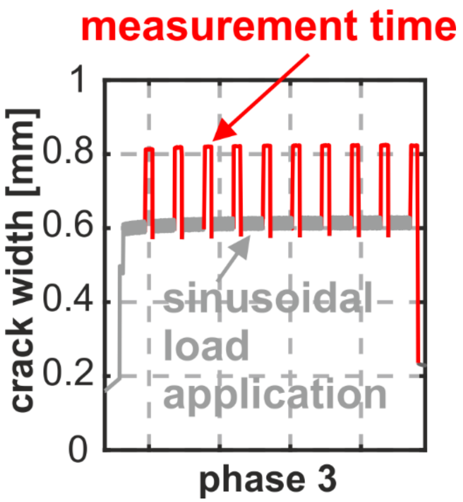
- Clean strain peaks visible as crack is opening



Laboratory Investigations

Accelerated ageing

- 1000 cycles for 1 h
- Measurements
- Another 1000 cycles
- …



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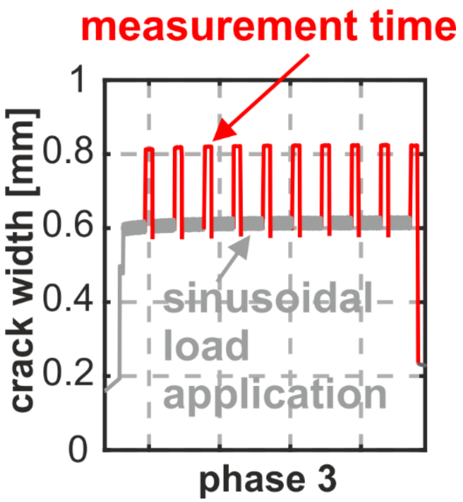

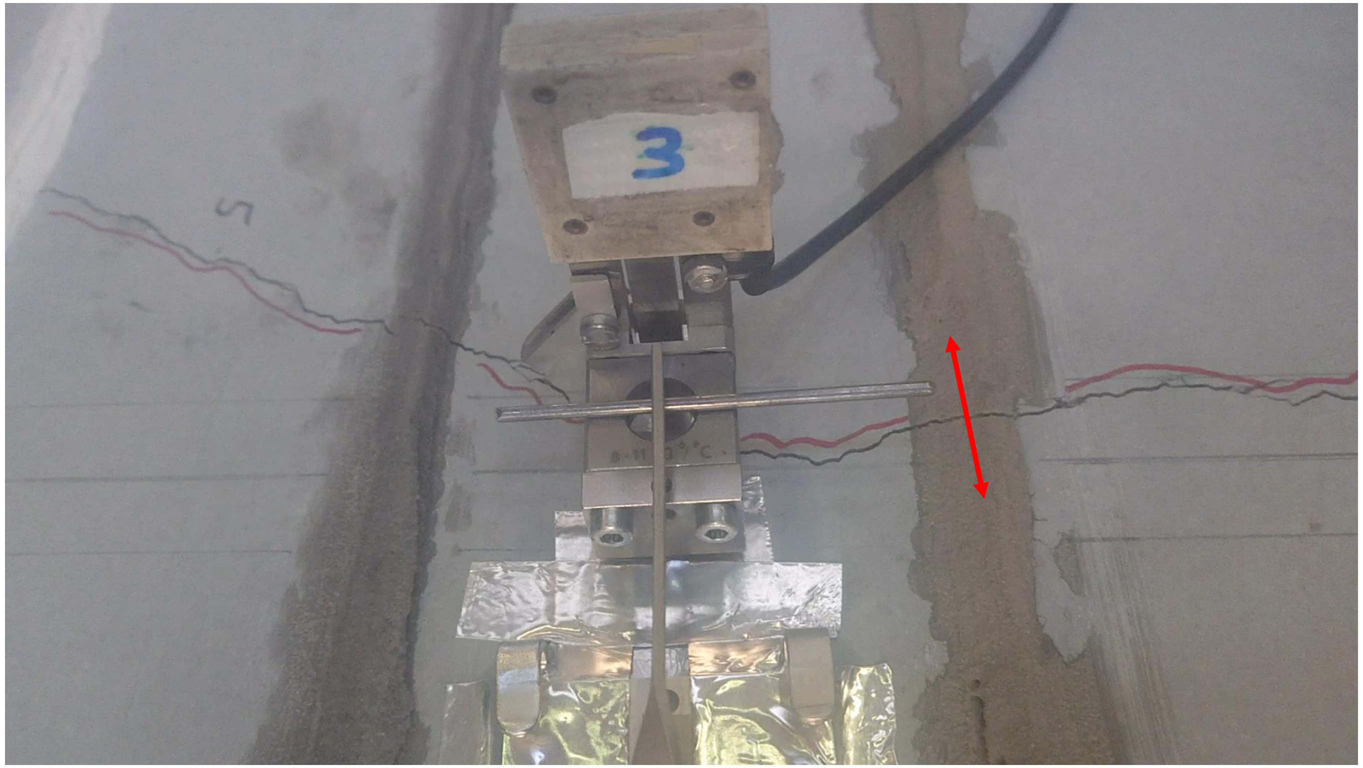

Laboratory Investigations

Accelerated ageing

- 1000 cycles for 1 h
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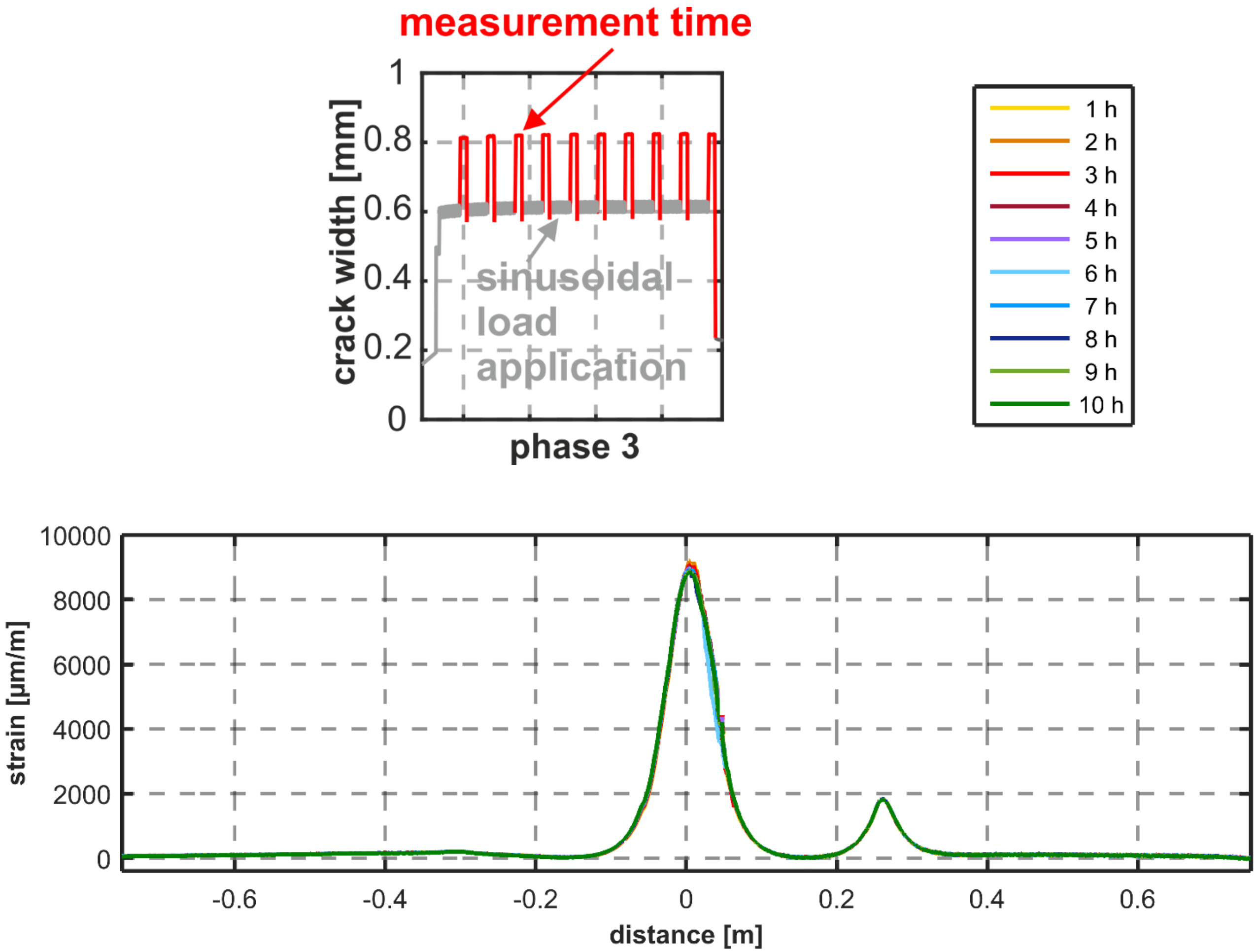
- Another 1000 cycles
- …

Result

- Well reproducible strain profiles
- No hysteresis



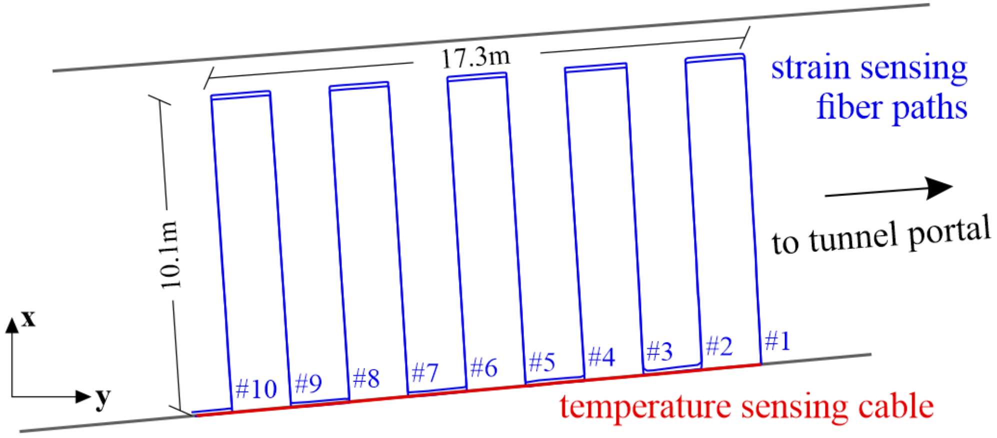
Structural Reaction to Temperature Changes

Monitoring of Bridge Beams

Bridge construction

- Entrance area of tunnel
- 10 Beams
- Surface covered with fiber protection plates

Monitoring of Bridge Beams

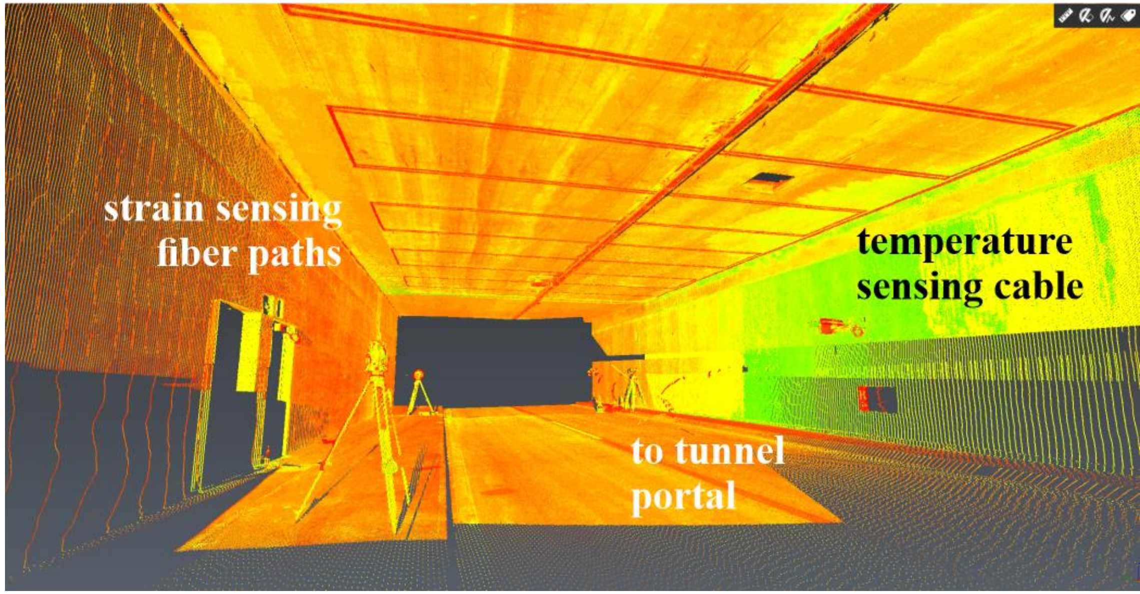


Bridge construction

- Entrance area of tunnel
- 10 Beams
- Surface covered with fiber protection plates

DFOS Sensing layout

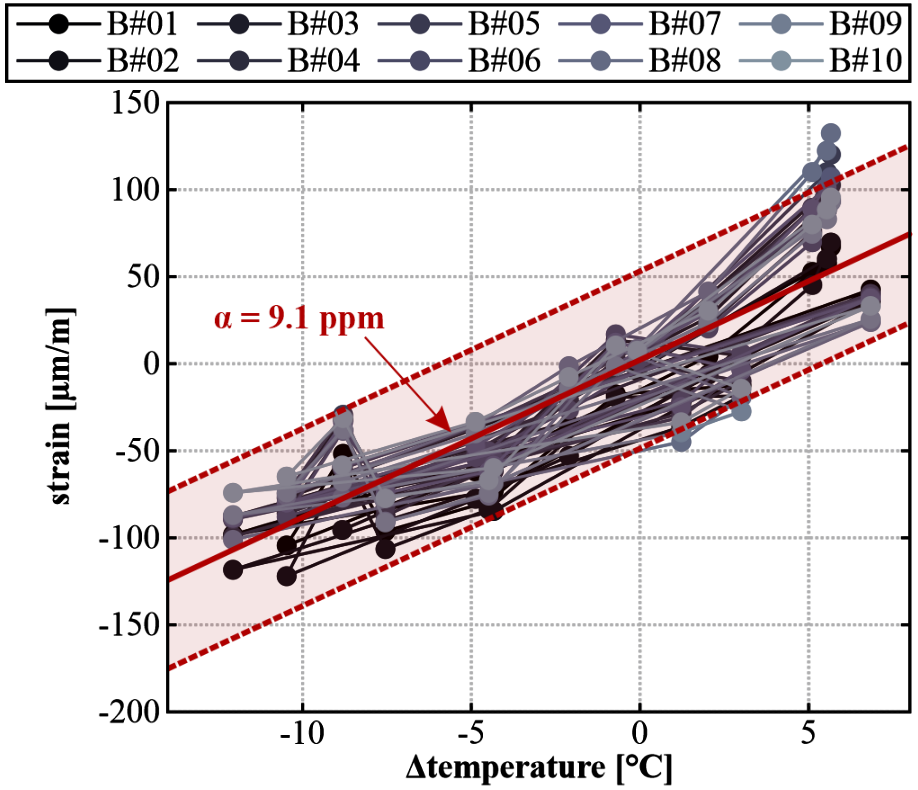
- 1 loop with
  - 10 strain sensing sections orthogonal to driving direction
  - temperature sensing cable in driving direction
- Fully integrated into the communication network of the tunnel
- Measurement can be performed from the maintenance building without physical access to the tunnel



Monitoring of Bridge Beams

Strain / temperature reaction

- Thermal stresses resulting in temperature depended length changes of the tunnel itself
- Almost linear relation for all individual beam structures



Interpretation

- Estimated coefficient (about 9.1ppm) within specifications for concrete in literature
- Local distortions potentially result in significant deviations within the strain/temperature relation
- Confidence interval (3σ) indicates normal working range of realized DFOS system

Structural Reaction to Traffic

Wide Range of Sensors

Geotechnical Sensors

- IoT tilt sensor nodes
- Accelerometers

Geodetic Sensors

- Laser scanners
- Total stations

Wide Range of Sensors

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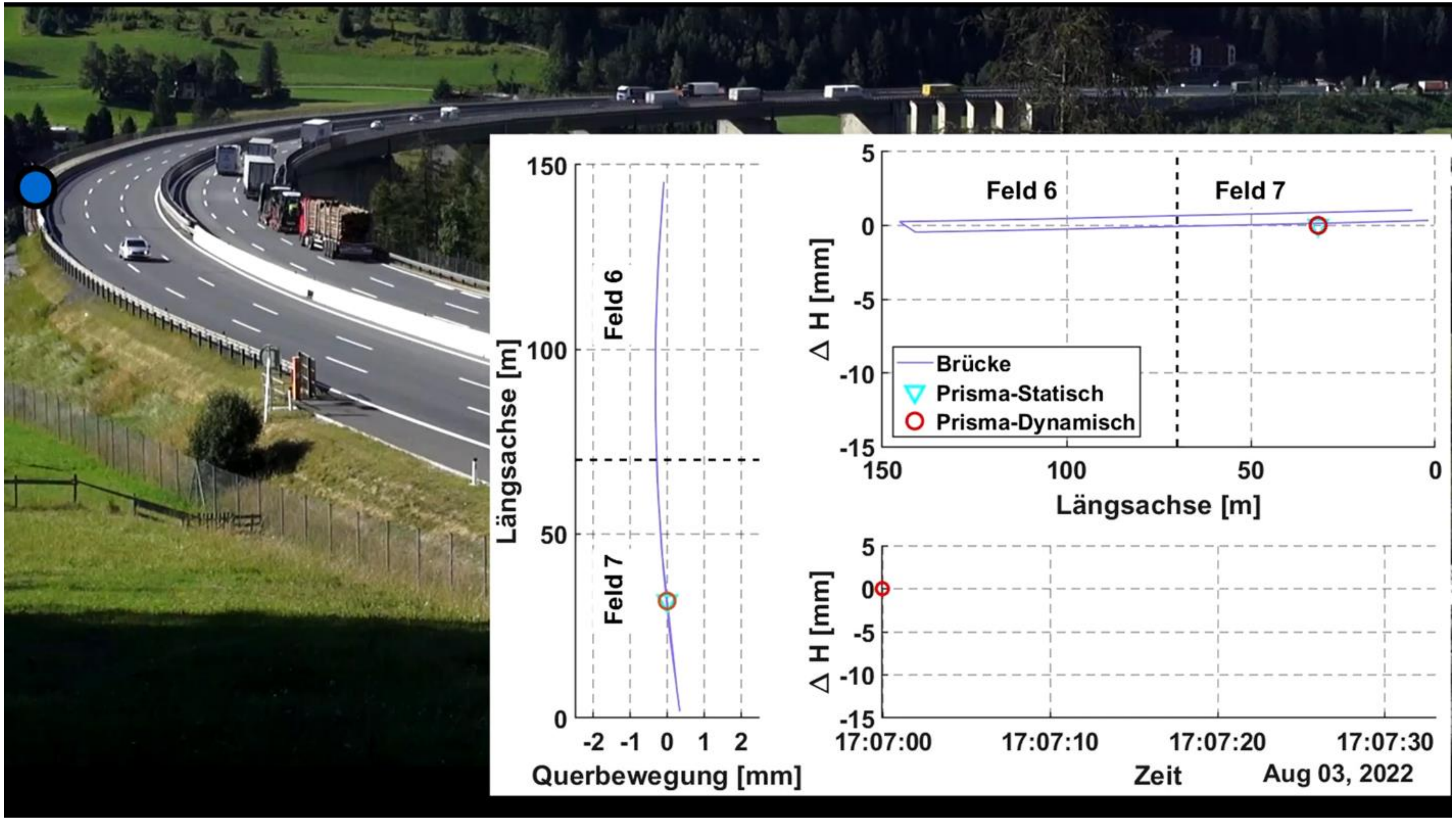
Distributed Fibre Optic Sensors

- Rayleigh measurements
- Brillouin measurements

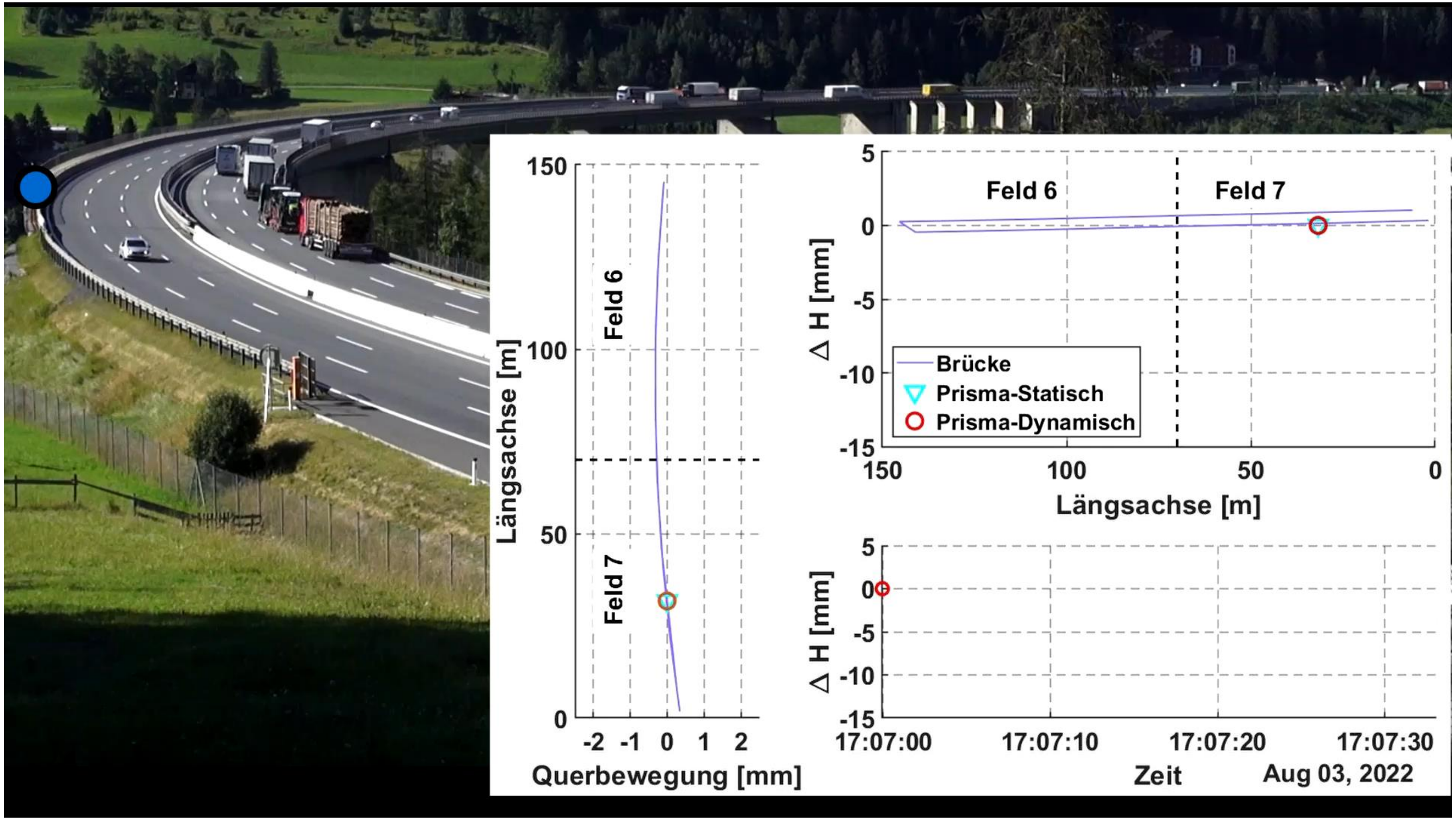
Bridge Deformation

Target Installation

Bridge Deformation



Bridge Deformation



Fiber Optic Installation

Cable routing

- 2 loops of strain and temperature sensing cable

Standard setup

- Brillouin instrument

Fiber Optic Installation

Cable routing

- 2 loops of strain and temperature sensing cable

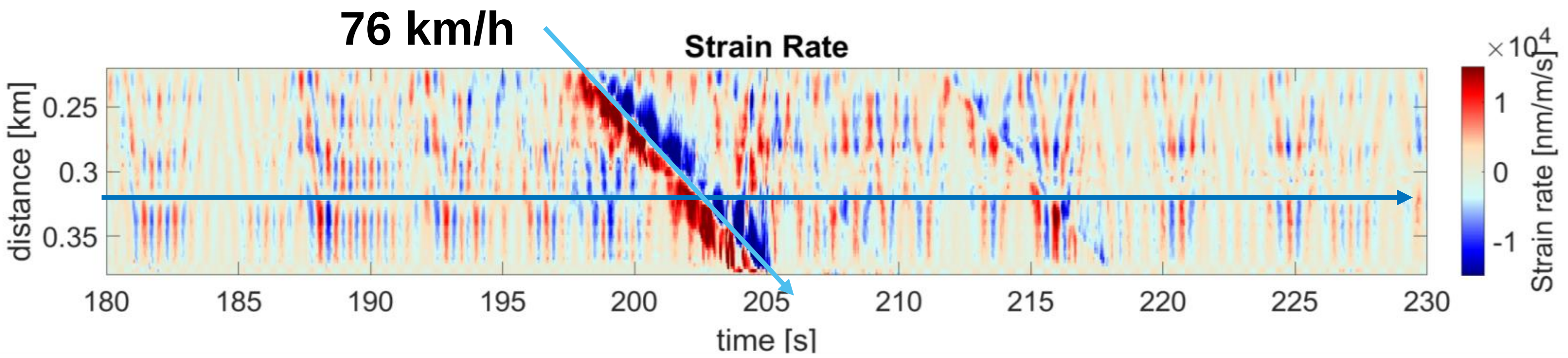
Dynamic measurement

- Brillouin => too slow
- High res. DSS => too short

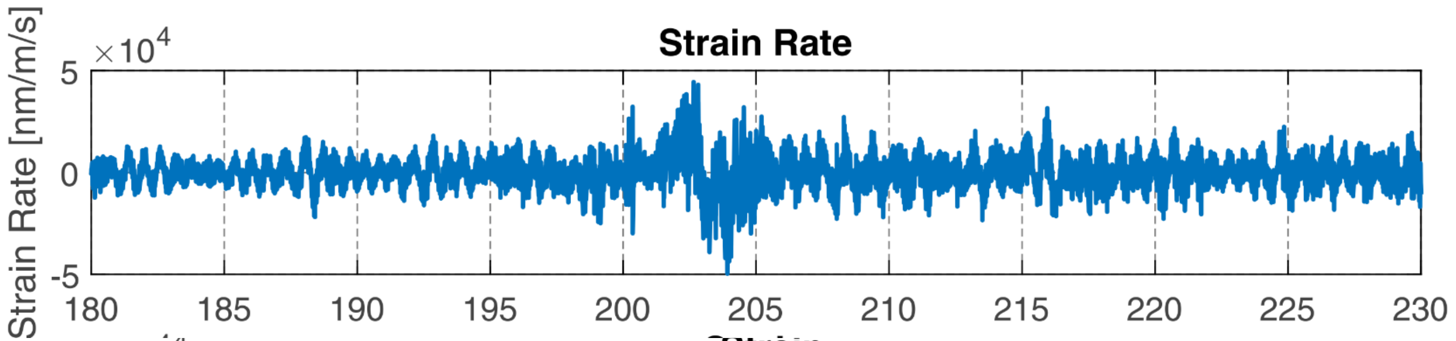
Distributed Acoustic Sensing

General

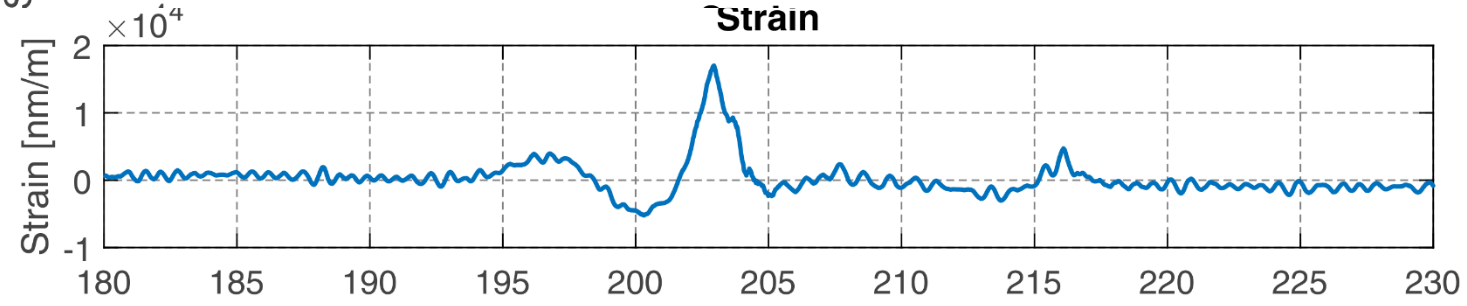
- Measurement of strain rates along the entire fiber
- Measurement rate of several kHz



- Strain rates at individual positions



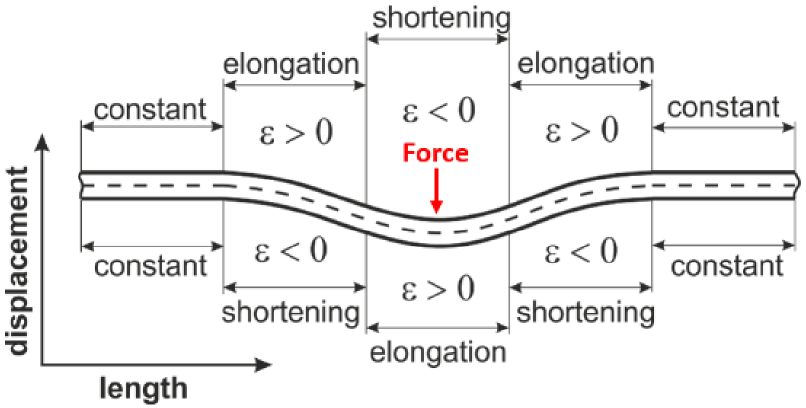
- Strain via integration

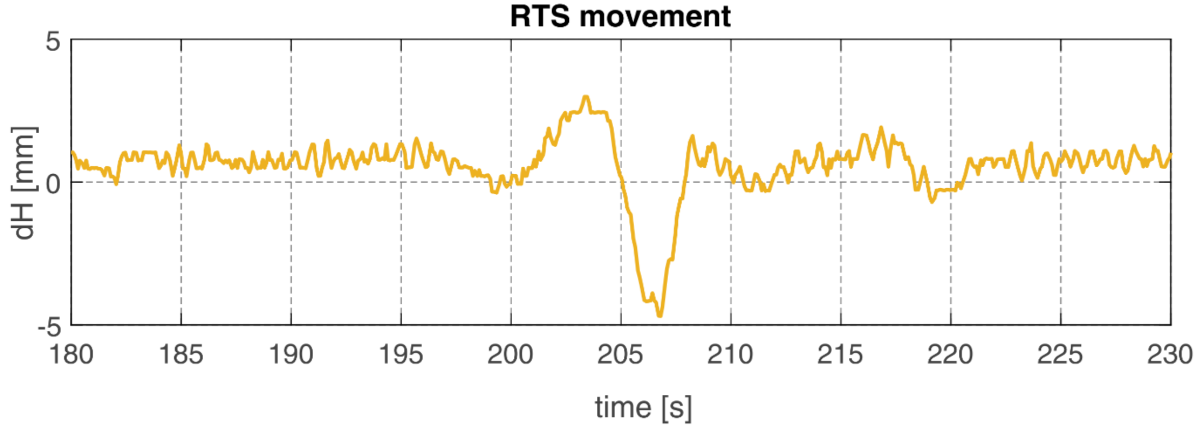


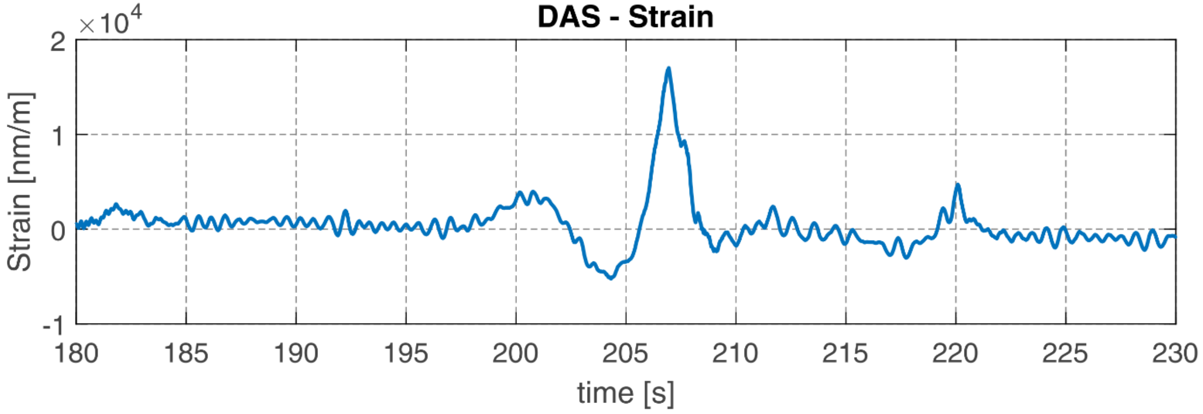
Comparison to Total Station Measurements

Total station

- Permanent tracking of prism
- Recording of angle and distance changes
- Calculation of 3D position changes







Comparison to strain changes

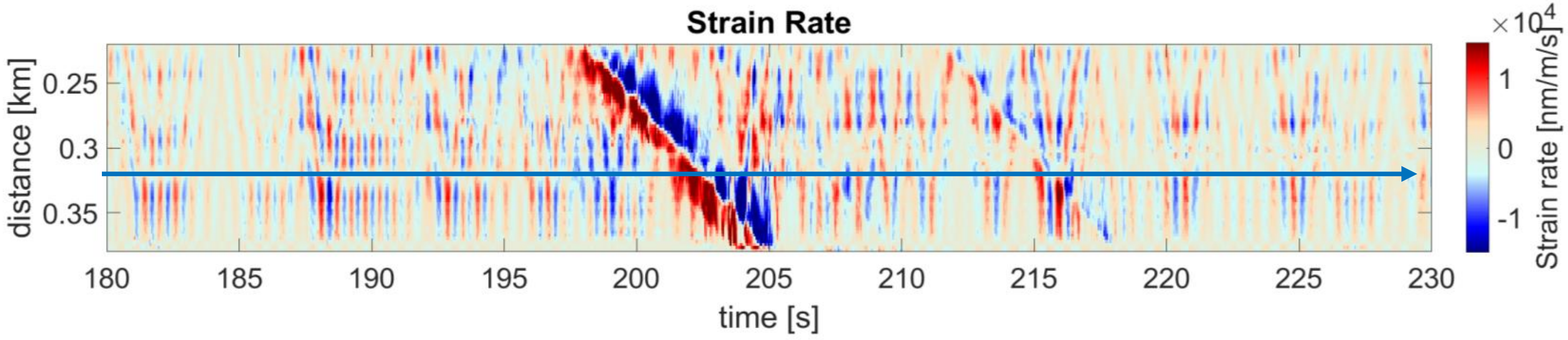
- Settlement of bridge deck causes negative strain at bottom of bridge beam

[Lienhart at al., 2023]

Dynamic Analysis

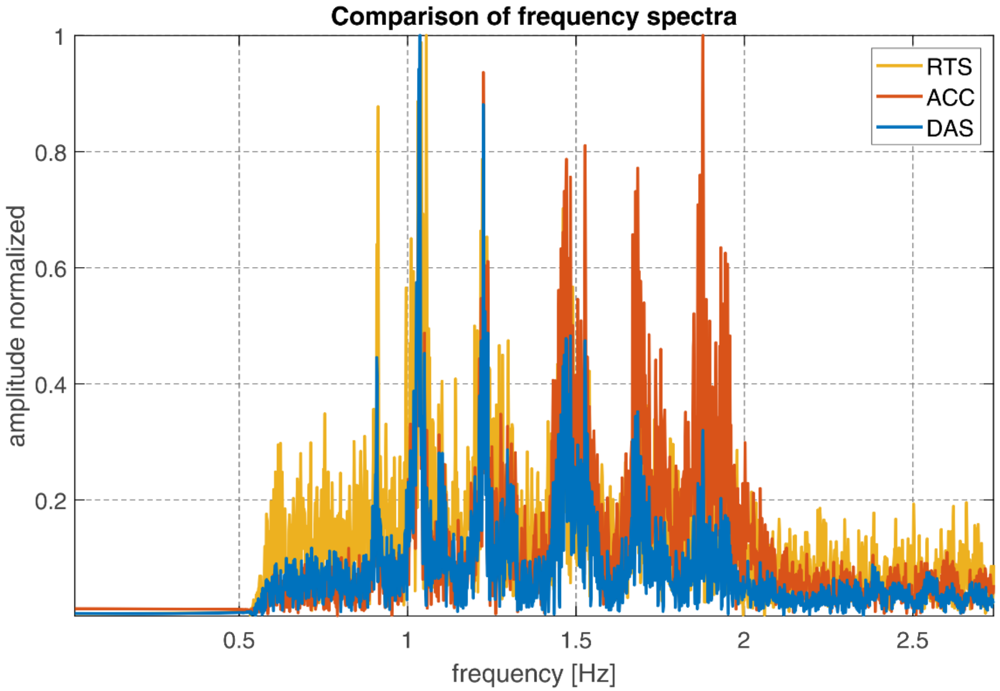
Vibration behaviour

- Can be assessed at any position of the fiber



Comparison to other techniques

- Identified frequencues fit well



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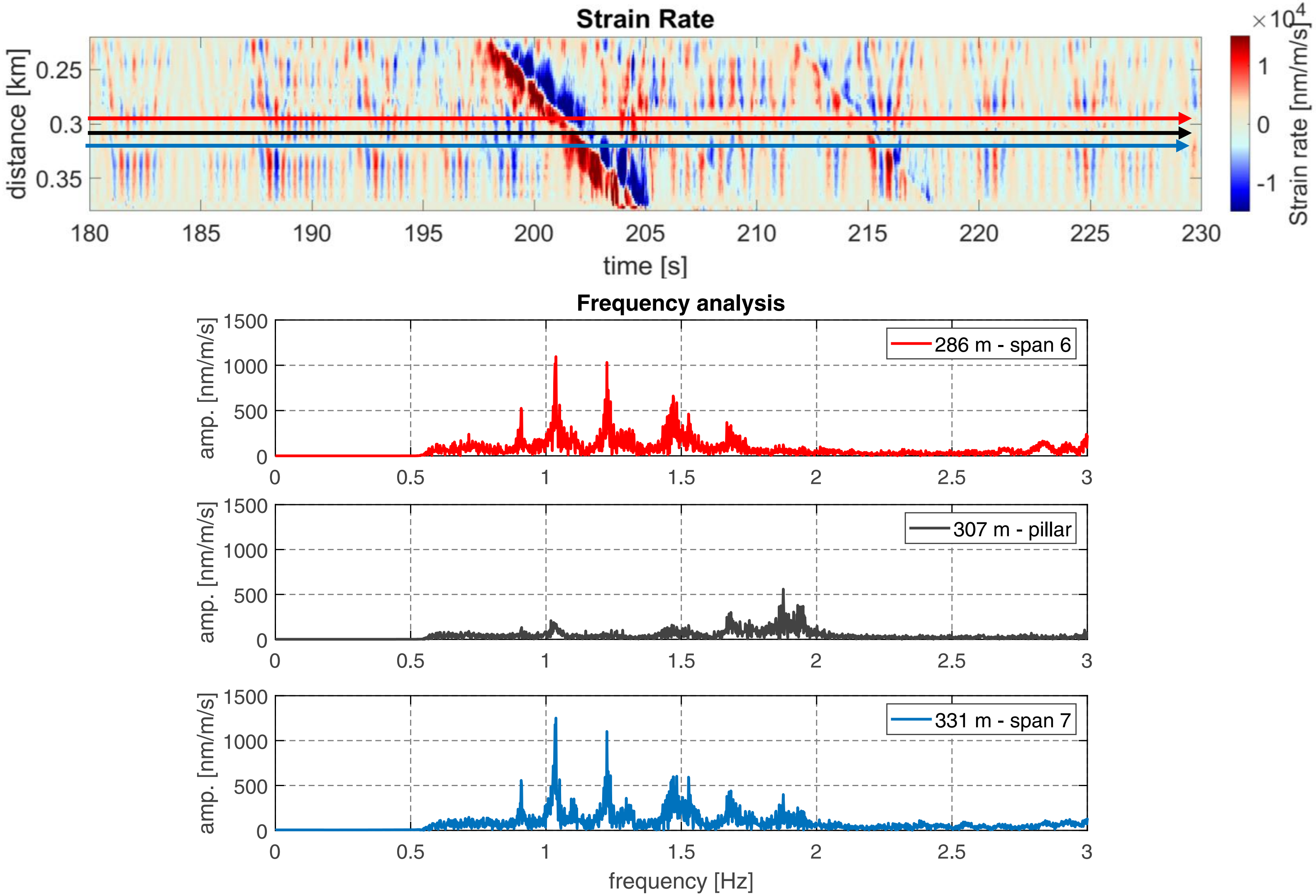

IGMS Bridge Projects

Existing structures

New structures

Bridges

New structures

- SHM interesting during construction phase
- Long term monitoring
  - Crucial is high accurate and complete zero measurement
  - Interesting phase starts 20 to 30 years after construction

Does FOS work after decades?

Robustness

Summary

Fiber optic based bridge monitoring

- Failure is not an option
- FOS is part of the solution but not the only solution
- FOS offers unique opportunities

Path to move forward

- FOS has to become standard solution in tenders
  - => standards and guidelines are important
- Prove advantages in successful case studies


Looking forward to collaborating with you!
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References

Publications

- Winkler M, Monsberger C, Lienhart W, Vorwagner A, Kwapisz M (2019) Assessment of crack patterns along plain concrete tunnel linings using distributed fiber optic sensing, Proc. 5th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures (SMAR): 8 pages
- Monsberger CM, Lienhart W (2022) Long-term structural integrity monitoring of inner tunnel linings using distributed fiber optic sensing. Proc. 11th International Conference on Structural Health Monitoring of Intelligent Infrastructure (SHMII-11), Montreal: 4 p
- Monsberger CM, Lienhart W (2021) Distributed Fiber Optic Shape Sensing of Concrete Structures. Sensors 2021, 21, 6098: https://doi.org/10.3390/s21186098
- Lienhart W, Strasser S, Dumitru V (2023) Distributed vibration monitoring of bridges with fiber optic sensing systems, 10 p., to be presented at EVACES conference in September 2023