Bridge Deformation Monitoring: Fusion of InSAR, Geodesy and Simulations

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A story about… Bridges.

On the relevance and complexity of infrastructure monitoring

Morandi-Bridge, Genua, August 2018
(Photo: Flavio Lo Scalzo, dpa, published in Augsburger Allgemeine)

Need to discuss the potential of InSAR, its purpose, need to validate and to assess its usability for SHM.

- Critical age & increasing operational load
- Cost- and labor-intensive inspections of huge individual structures

  → cost-effective and safety-conscious bridge management systems

- Structural Health Monitoring (SHM) under development:
  - wide range of goals and methods
  - SHM integration into established safety evaluation procedures not yet a standard
  - Slow implementation due to large dimension of structures, very long service life, unique structure properties

Structural Health Monitoring (SHM) of Bridges: Expectations and Reality

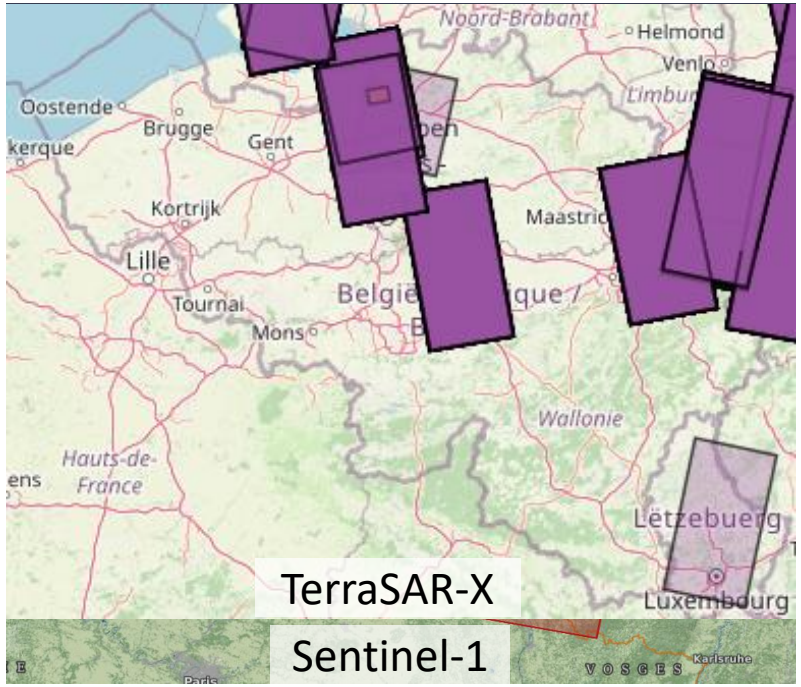
In Germany:

Comprehensive main maintenance every 6 years

Deficiency check every 3 years

Visual inspection yearly

Humanitarian & economic risk due to delayed maintenance



VERHAERT | MASTERS IN INNOVATION

PIP PROGRAMME FOR INNOVATION PROCUREMENT

DEPARTEMENT ECONOMIE WETENSCHAP & INNOVATIE

Vlaamse overheid

Belgian Initiative for a **national bridge monitoring** (2650 Bridges)

InSAR based comparative analysis of free Sentinel-1 and commercial high-resolution SAR data

As **complementary solution** for existing monitoring processes

Alarm for critical situations desired

LEVANGO

Long-term monitoring and determination of critical structural conditions of transport routes through analysis of geodata

Project time: 09/2019-02/2022

Visualization of Wehretalbridge, Germany © DEGES

Gefördert durch:

Bundesministerium für Wirtschaft und Klimaschutz

aufgrund eines Beschlusses des Deutschen Bundestages

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Manuscript in review process for publication in the Journal *Structural Control and Health Monitoring*:

Lorenz, R.; Petryna, Y.; Lubitz, C.; Lang, O.; Wegener, V. "Thermal deformation monitoring of a highway bridge: Combined analysis of geodetic and satellite- based InSAR measurements with structural simulations"

What we focused on:

SHM methods

Real time dynamic response of structures

Static behaviour

Regular non-destructive testing of structural components in use

Overlaying motion frequencies

Temperature

Vibration through traffic and wind

Real deformation

Short- and long-term dynamics

What we wanted to achieve:

Interdisciplinary solution: Knowledge and data fusion

Integration

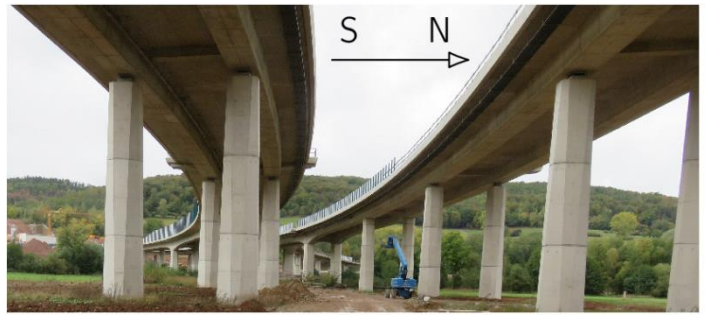
Remote Sensing: InSAR Time series analysis — Regular measurements covering large areas

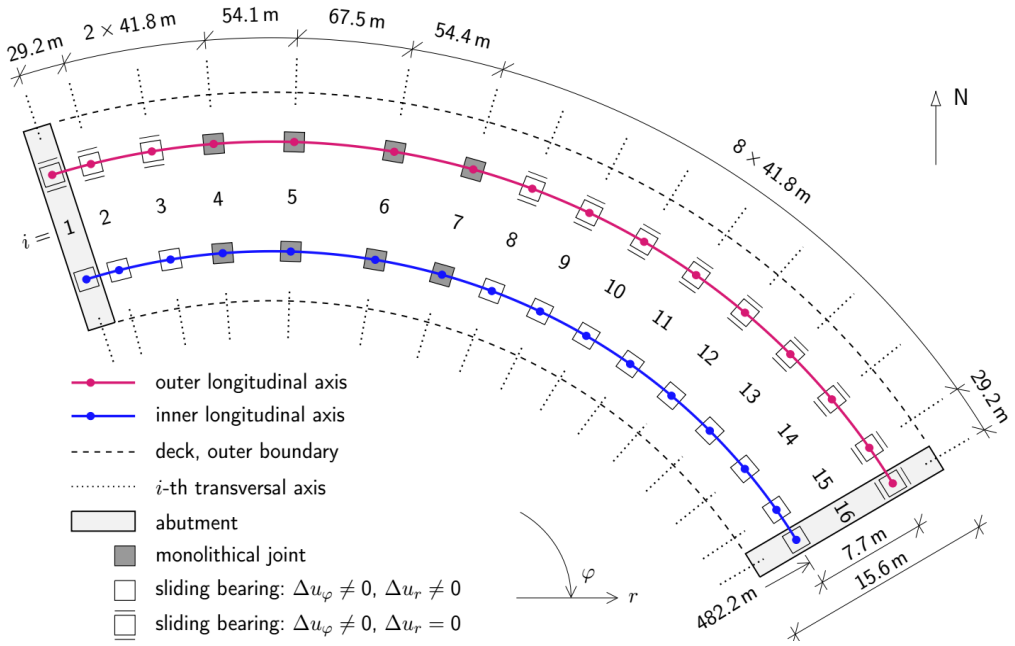
Terrestrial Measurements — Selective, high accuracy, continuously measurements

Structural analysis and modelling — Understanding the bridge‘s behaviour

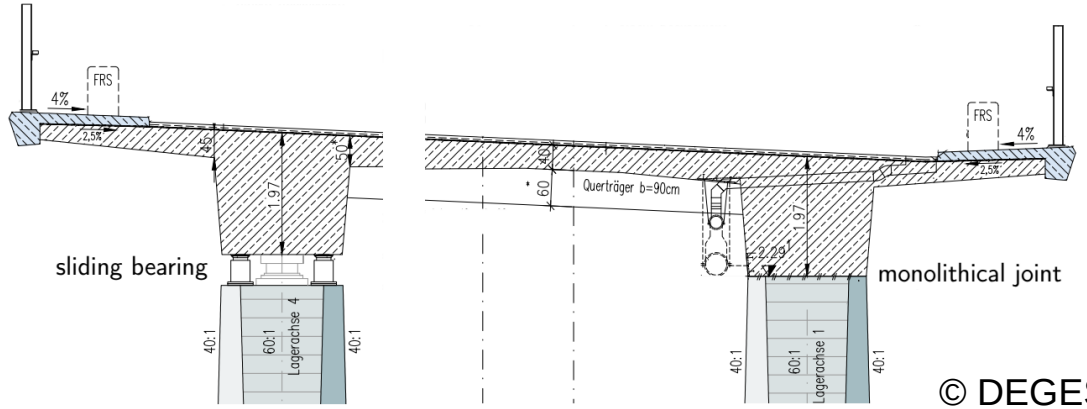
Detect anomalies on the structure through deviations of model <-> measurement

Finite Element Model





Lorenz et al. (in Review), SCHM



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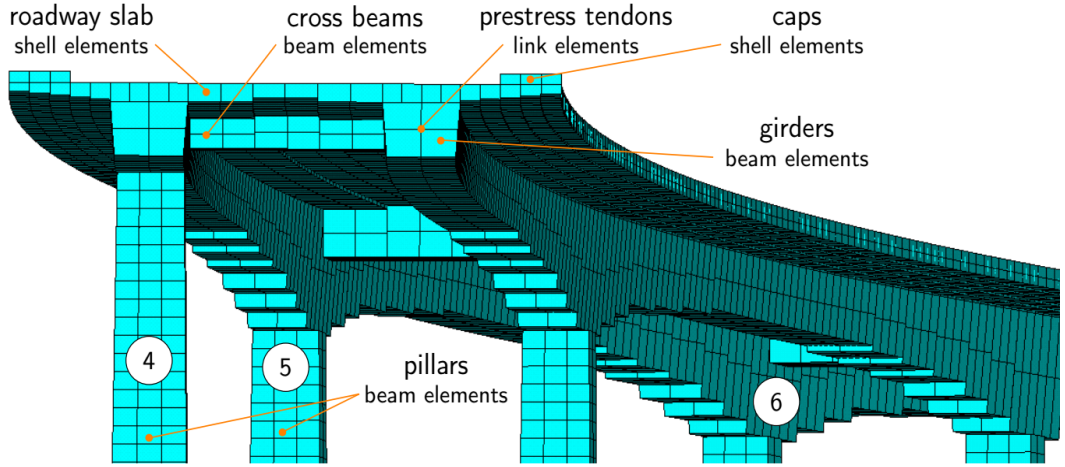
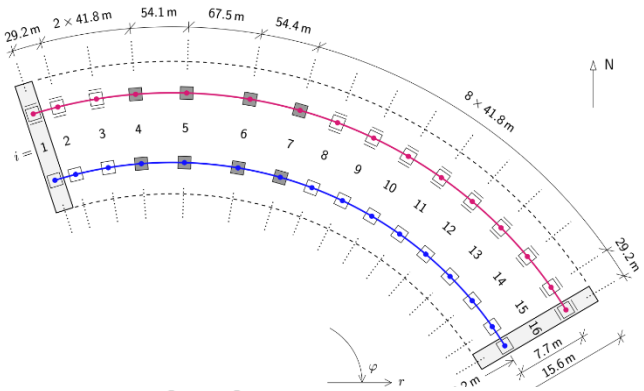
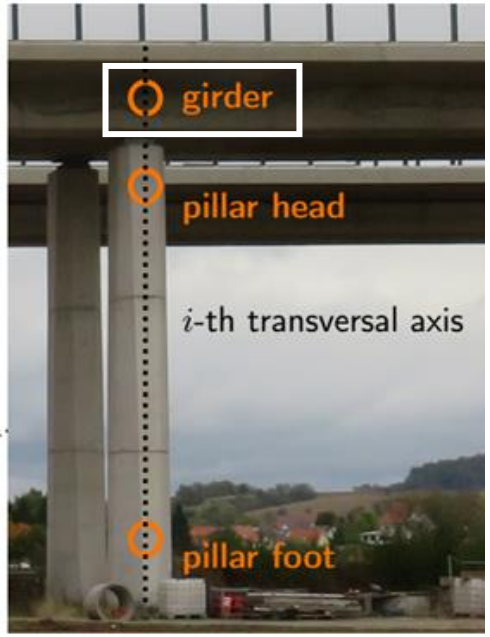


ANSYS software (version 2020 R2)

Finite Element Model

Simulation of temperature induced deformations





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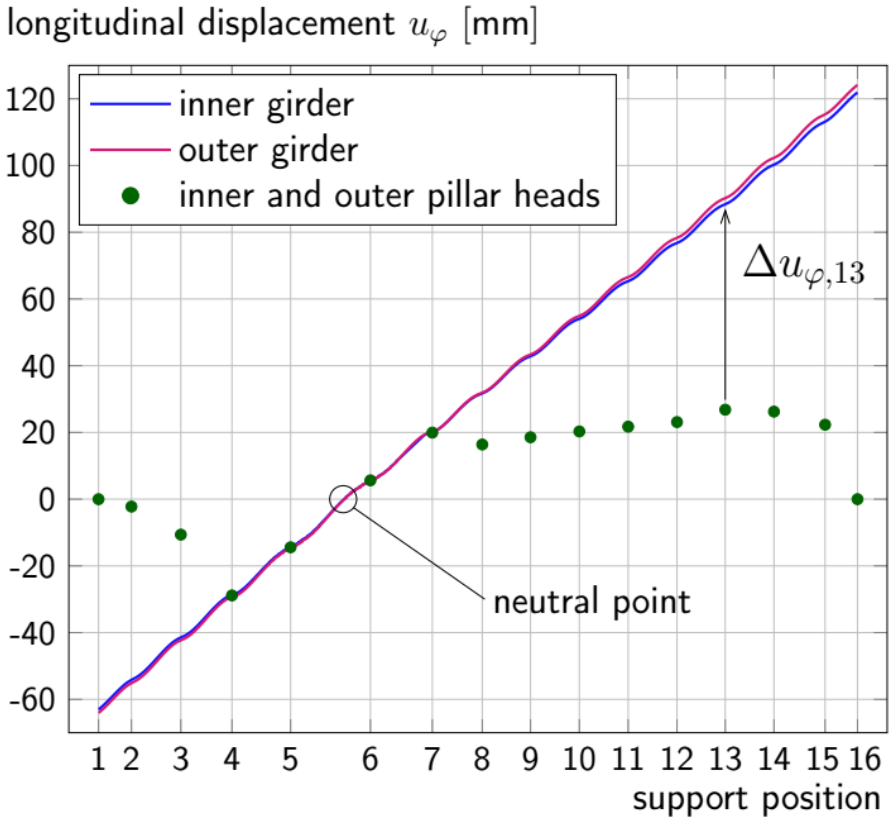
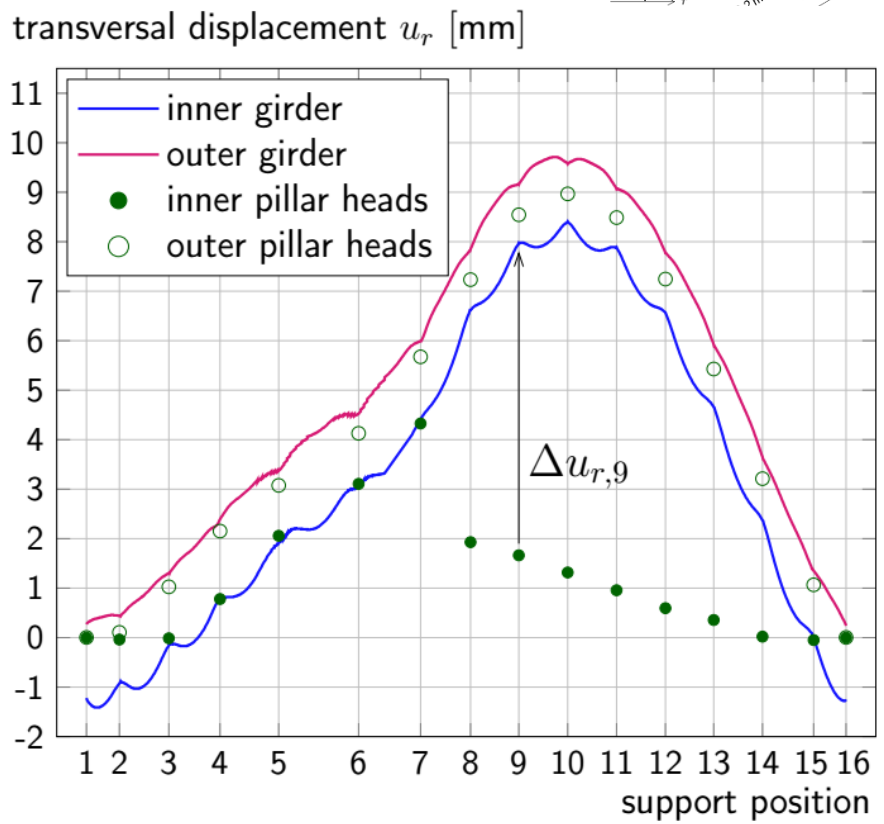
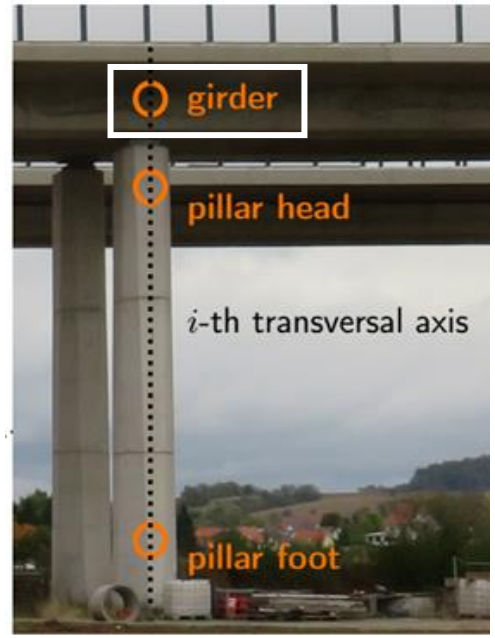
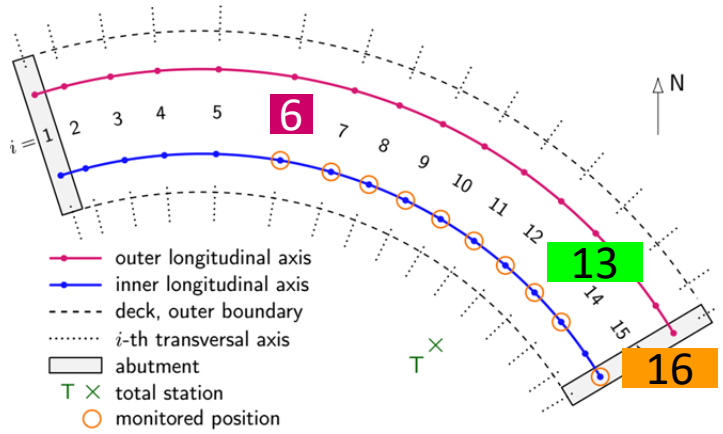




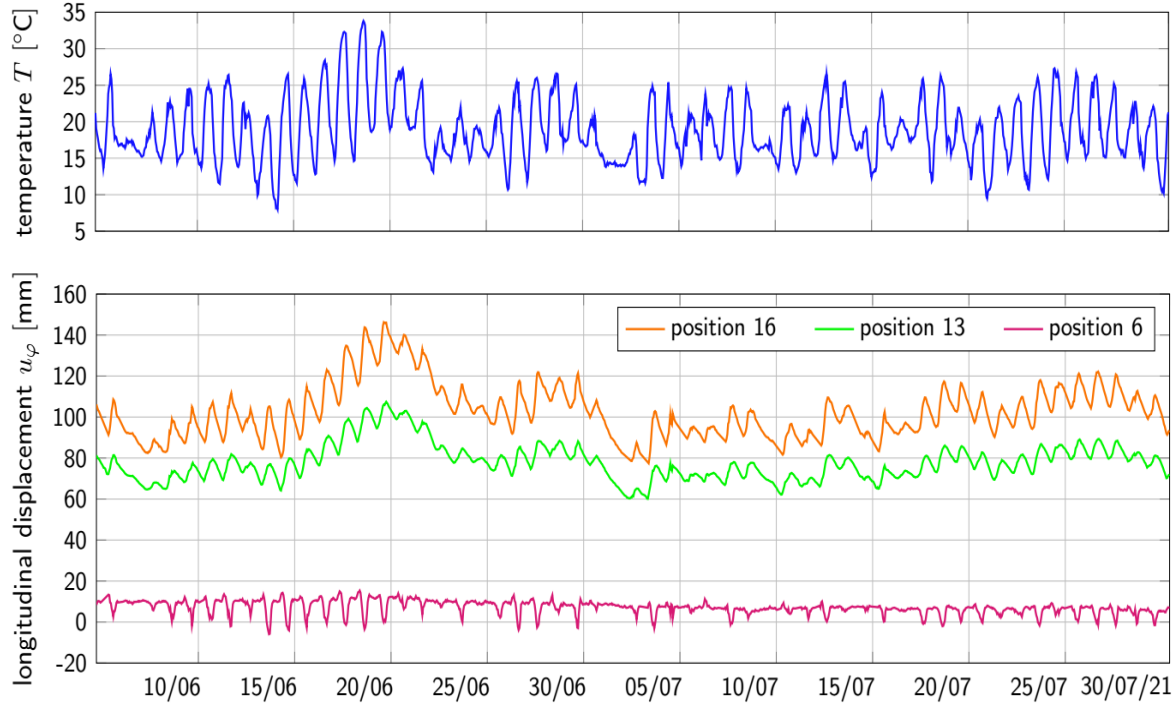
Longitudinal and transversal displacements of the deck and the pillar heads at all support positions under the combination of dead load, prestressing and total temperature increment ΔT=30 K; the unified coefficient of friction is set to μ=0.05

Geodetic Monitoring System





- Automatic measurements every 45 minutes
- Energy supply through solar energy



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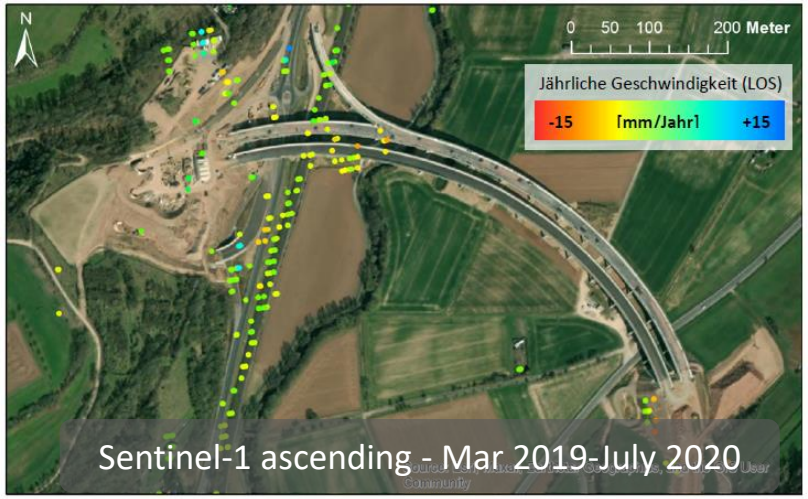
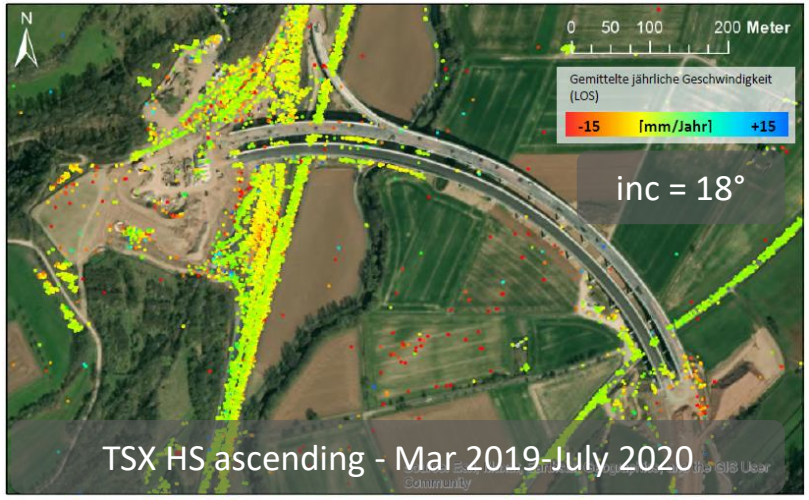
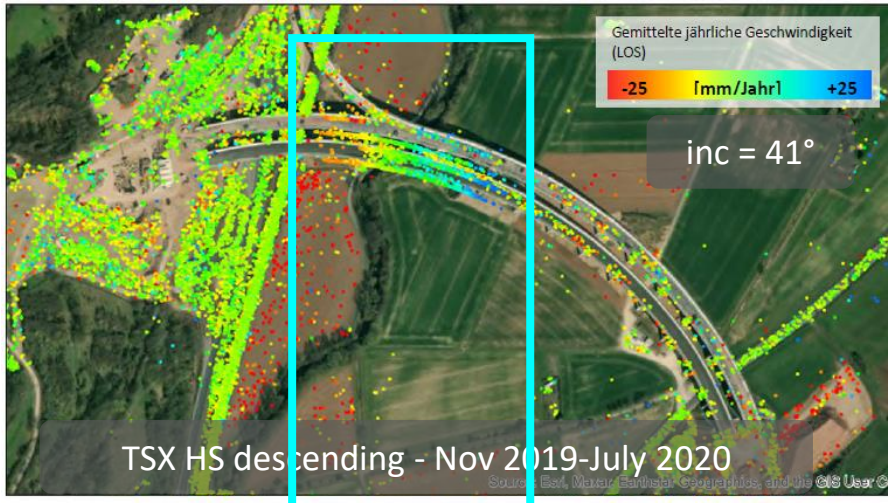
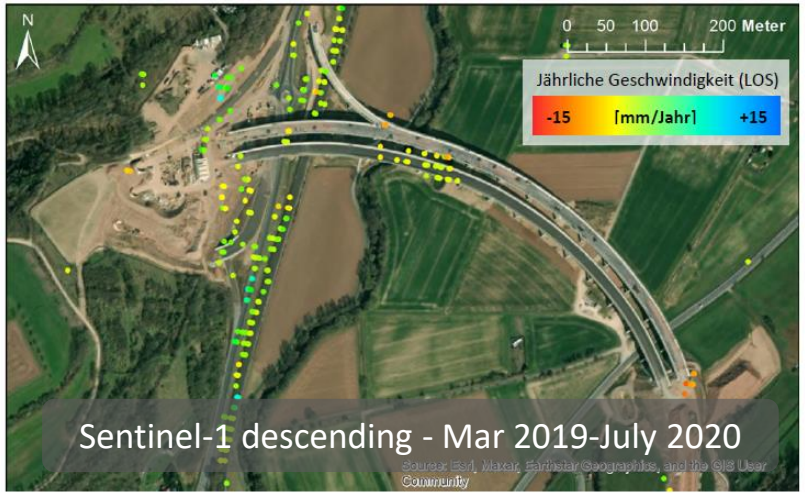
InSAR Measurements

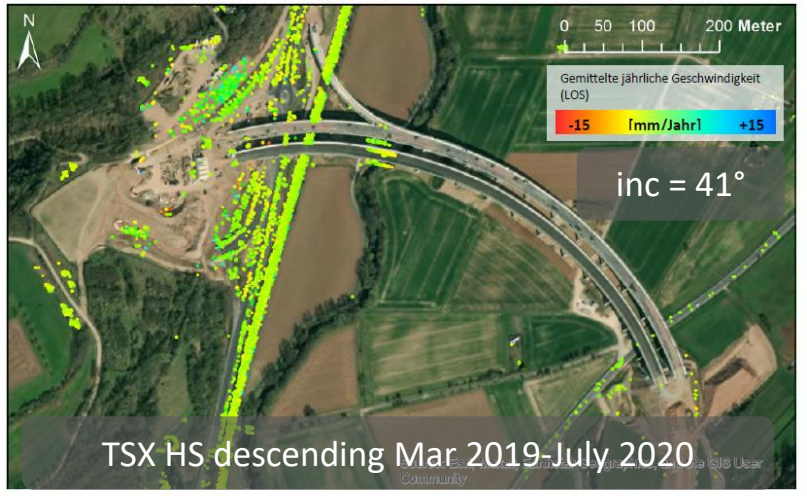
Optimized acquisition geometry, mode and period to be analyzed

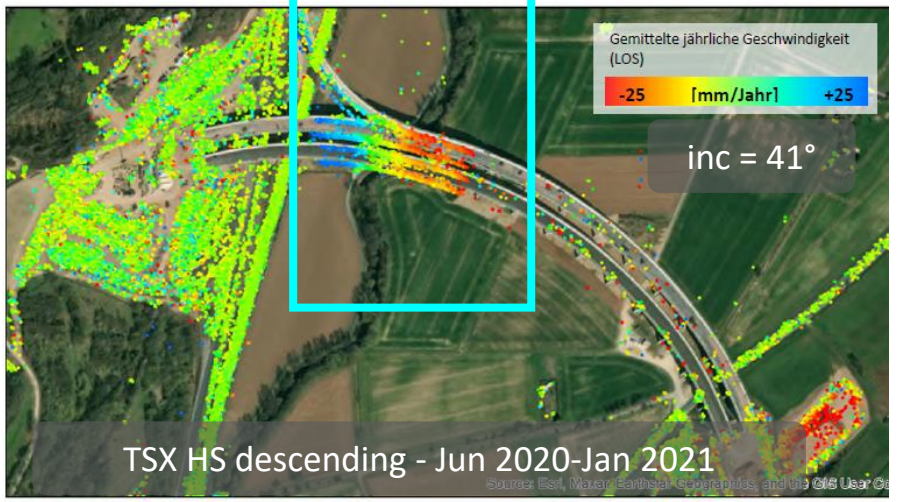












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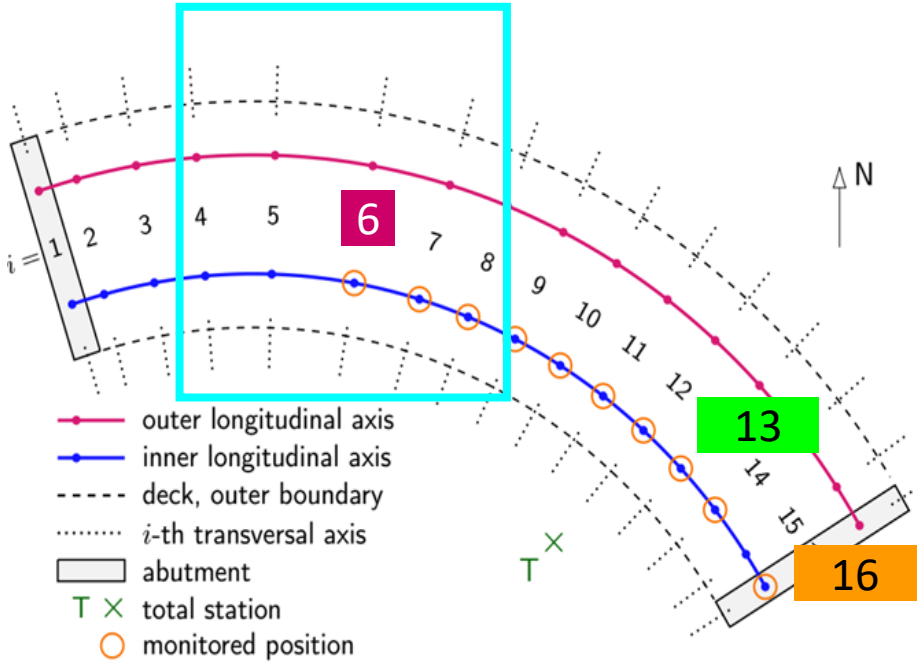
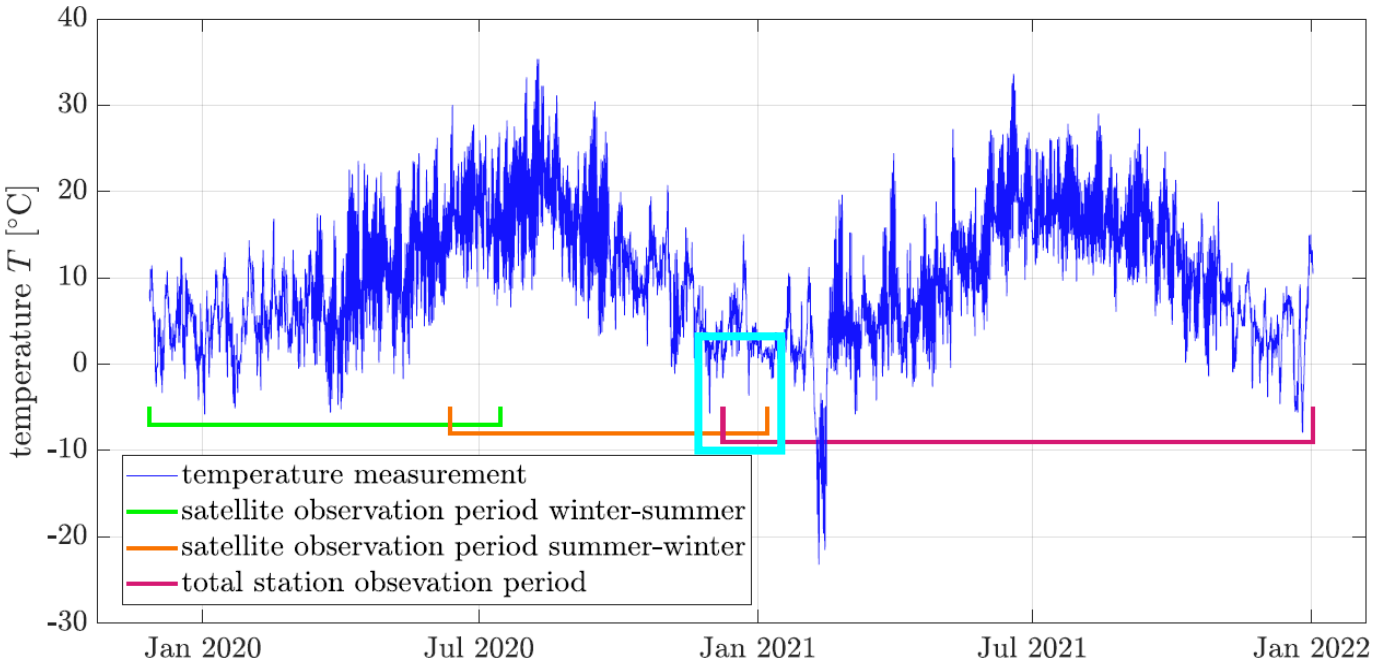
Data Fusion

Challenges both in space and time





Temperature measurements taken from the closest weather station for the entire observation period (source: Deutscher Wetterdienst DWD)

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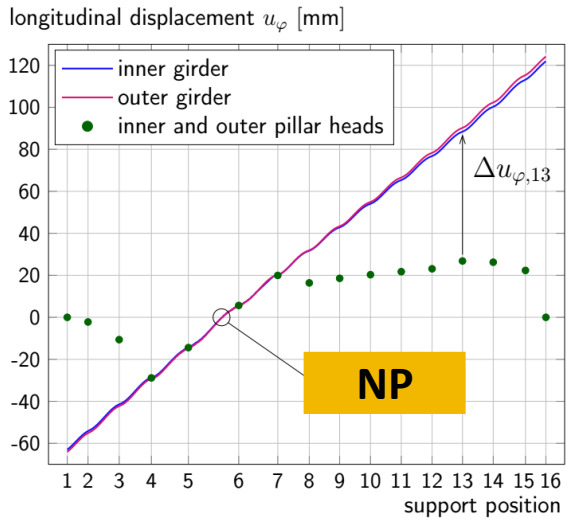
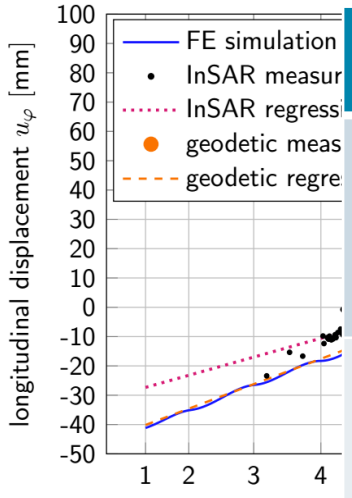
Data Fusion

- Indirect comparison of measurements and simulations
- Total station deformation measurements generally correlate better with the FE simulation
- Quantitative comparison by looking at the neutral point (NP)





ΔT	Type of result	NP position x_0 [m] / E [%]
Winter-Summer maximum period length (ΔT = 7.7 K)	FE simulation	208.8 / 0.0
	InSAR measurement	186.6 / **10.6**
	geodetic measurement	249.5 / **19.5**
Winter-Summer positive maximum ΔT (ΔT = 20.2 K)	FE simulation	208.5 / 0.0
	InSAR measurement	186.4 / **10.6**
	geodetic measurement	203.3 / **2.5**
Winter-Summer arbitrarily selected (ΔT = 13.7 K)	FE simulation	212.5 / 0.0
	InSAR measurement	198.0 / **6.8**
	geodetic measurement	228.6 / **7.6**

Winter-Summer-Period

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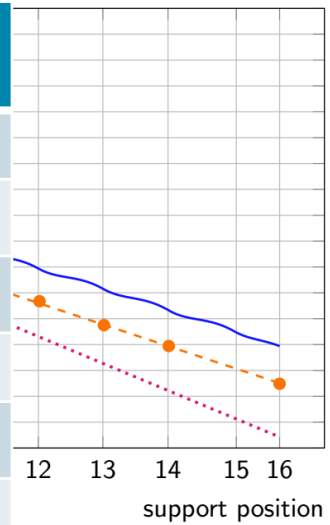
ΔT	Type of result	NP position x_0 [m] / E [%]
Summer-Winter maximum period length (ΔT = -15.2 K)	FE simulation	217.3 / 0.0
	InSAR measurement	197.5 / **9.1**
	geodetic measurement	174.7 / **19.6**
Summer-Winter negative maximum ΔT (ΔT = -20.2 K)	FE simulation	213.2 / 0.0
	InSAR measurement	189.7 / **11.0**
	geodetic measurement	176.1 / **17.4**
Summer-Winter arbitrarily selected (ΔT = -18.2 K)	FE simulation	214.8 / 0.0
	InSAR measurement	190.8 / **11.2**
	geodetic measurement	177.1 / **17.6**



17/08/2020 – 05/12/2020

Limitations

- Different sampling rates (11 d, 45 min)
- Different measurement points
- Quality of measurement points (coherence ≥0.75)
- Orientation of the structure (east-west versus north-south)
- Temperature distribution along the structure
- Unknown value of the coefficient of friction in FE Model

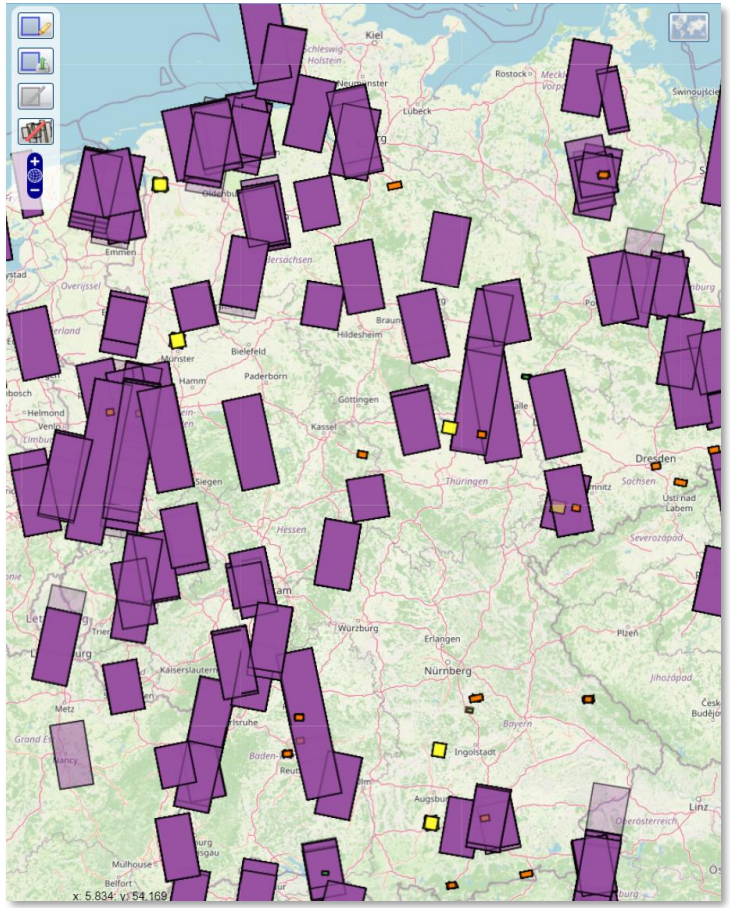
Requirements for using INSAR in SHM

- Thorough planning and implementation in order to make maximum use of the advantages of the respective methods under consideration of the local situation
- Pre-knowledge about the structure
- Numerical model for plausibility checks

Vision: InSAR + Model + Measurment Data Flow = Core of a Digital Twin for SHM

Final Words

High-resolution data availability



TerraSAR-X InSAR Datensacks since 01.09.2019
(min. 20 scenes), archive search: https://terrasar-x-archive.terrasar.com/

- Building and maintaining data stacks is not a no-brainer
  - Acquisition conflicts
  - Waiting time until minimum data volume reached
  - Selection of suitable tasking priority and specifications (incidence angle, orbit direction, mode, ...)
  - Costs

- Supra-regional to European
  - Driven by user community
  - Need for coordinated arrangements of data providers for a *consistent representative data set (sufficient coverage)*
  - Identification of focus areas
  - Intersection with risk and asset maps

Thank you

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