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

• 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

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.
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

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

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
- Overlaying motion frequencies
- Temperature
- Real deformation
- Vibration through traffic and wind
- Short- and long-term dynamics
- Regular non-destructive testing of structural components in use
What we wanted to achieve:

**Interdisciplinary solution: Knowledge and data fusion**

- **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

ANSYS software (version 2020 R2)

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Finite Element Model

Simulation of temperature induced deformations

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

Lorenz et al. (in Review), SCHM
Geodetic Monitoring System

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

Lorenz et al. (in Review), SCHM
InSAR Measurements

Optimized acquisition geometry, mode and period to be analyzed

Sentinel-1 ascending - Mar 2019-July 2020

TSX HS ascending - Mar 2019-July 2020

inc = 18°

TSX HS descending - Nov 2019-July 2020

inc = 41°

TSX HS descending - Jun 2020-Jan 2021

inc = 41°

Sentinel-1 descending - Mar 2019-July 2020

TSX HS descending Mar 2019-July 2020

Lorenz et al. (in Review), SCHM
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)

Lorenz et al. (in Review), SCHM
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)

### Table: NP Position

<table>
<thead>
<tr>
<th>Period</th>
<th>NP position $x_0$ [m] / E [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Winter-Summer positive maximum</strong></td>
<td>Fe simulation: 208.5 / 0.0</td>
</tr>
<tr>
<td>Winter-Summer maximum period length ($\Delta T = 7.7 \text{ K}$)</td>
<td>InSAR measurement: 186.6 / 10.6</td>
</tr>
<tr>
<td>Winter-Summer arbitrarily selected ($\Delta T = 13.7 \text{ K}$)</td>
<td>Geodetic measurement: 249.5 / 19.5</td>
</tr>
<tr>
<td><strong>Summer-Winter negative maximum</strong></td>
<td>Fe simulation: 213.2 / 0.0</td>
</tr>
<tr>
<td>Summer-Winter maximum period length ($\Delta T = -15.2 \text{ K}$)</td>
<td>InSAR measurement: 197.5 / 9.1</td>
</tr>
<tr>
<td>Summer-Winter arbitrarily selected ($\Delta T = -18.2 \text{ K}$)</td>
<td>Geodetic measurement: 176.1 / 17.4</td>
</tr>
</tbody>
</table>
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 + Measurement Data Flow = Core of a Digital Twin for SHM
Final Words
High-resolution data availability

- 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

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

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