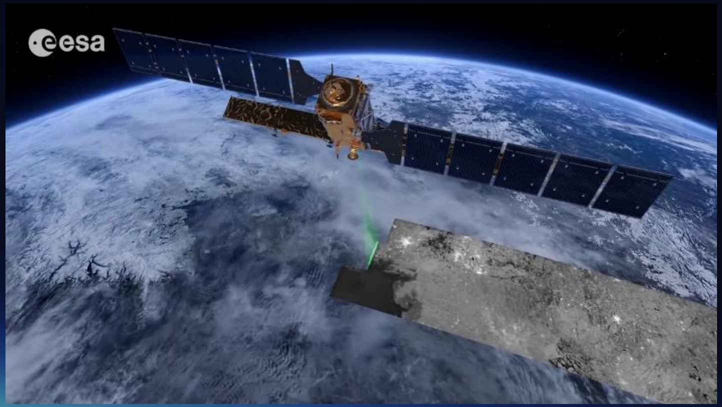
Health Monitoring of Masonry Arch Bridges by Integration of GPR and InSAR Techniques



Valerio Gagliardi[1]**,** Luca Bianchini Ciampoli[1], Fabio Tosti[2], Andrea Benedetto[1], Amir M. Alani[2]

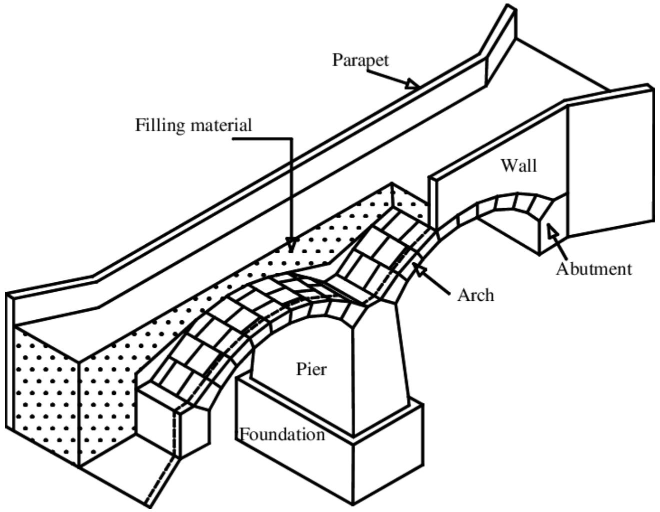
[1]Department of Engineering, Roma Tre University, Via Vito Volterra 62, 00146, Rome, Italy

[2]School of Computing and Engineering, University of West London (UWL), St Mary's Road, Ealing, London

1. Introduction

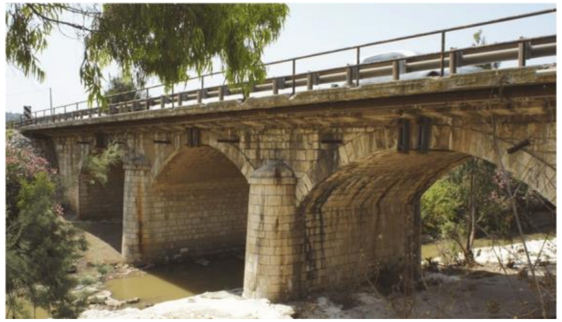
By looking at the amount of funds allocated on maintenance of transport infrastructures and bridges, it is evident that there is a

NEED FOR OPTIMISING THE MAINTENANCE ACTIVITIES



The major challanges are represented by:

- Multiple sources of damage
- Different required inspection accuracy
- General lack of network-scale monitoring techniques
- Lack of integrated solutions



the Old Aylesford Bridge in Kent, UK – a 13th century bridge, crossing the river Medway

•2. Aims & Objectives

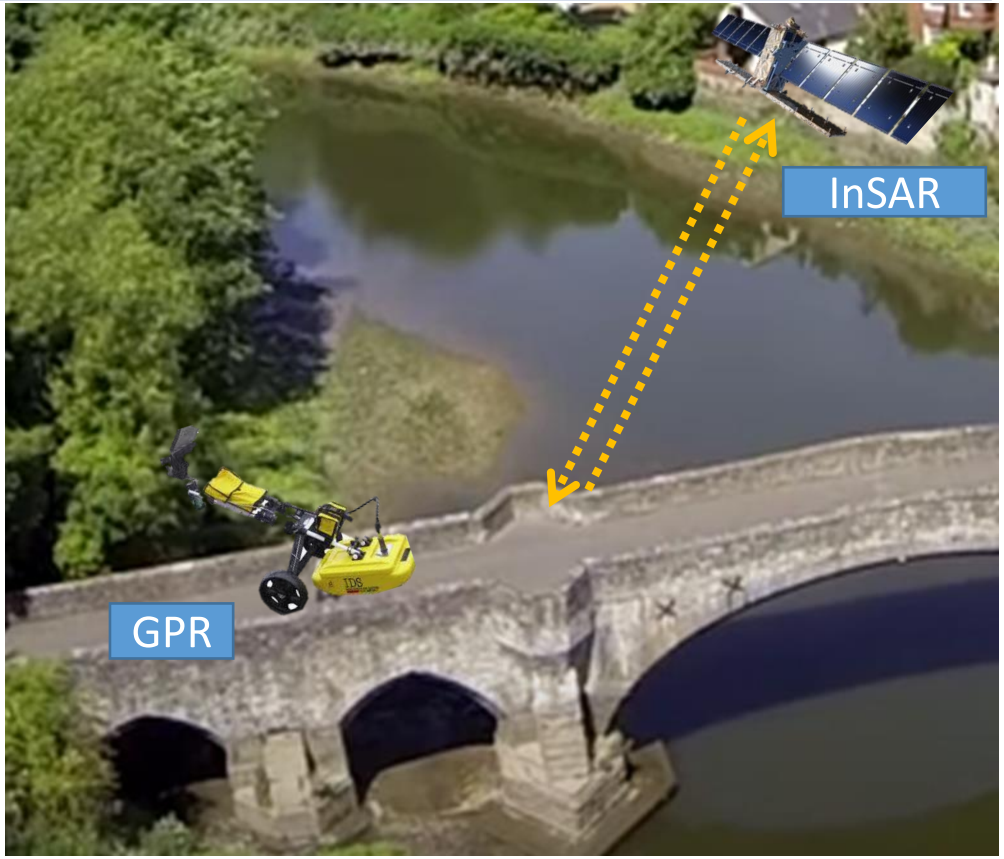
Aims & Objectives	Evaluating the effectiveness of the integration of InSAR and GPR methodologies for monitoring linear transport infrastructures, Masonry Arch Bridges

Methodology: Integration of information

Satellite Remote-Sensing	*Non-destructive testing (NDT) ground based techniques*
InSAR: Synthetic Aperture Radar Interferometry	*GPR: Ground Penetrating Radar*

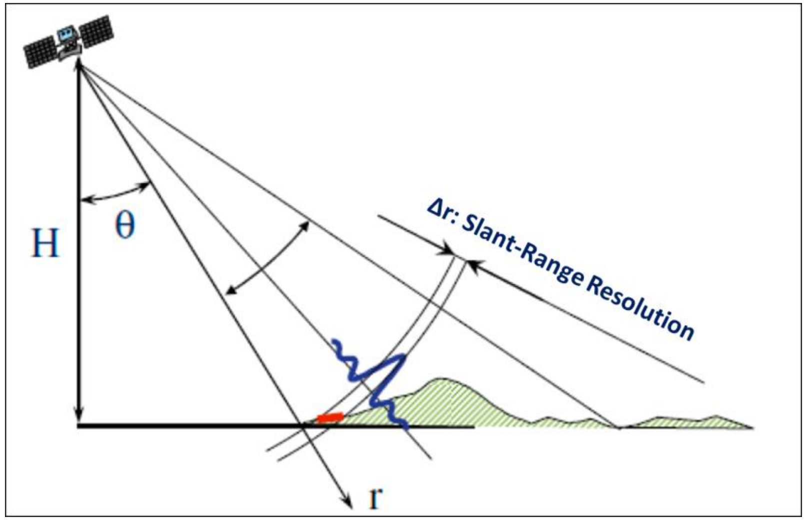
«Data Fusion» - Advantages of an integrated approach

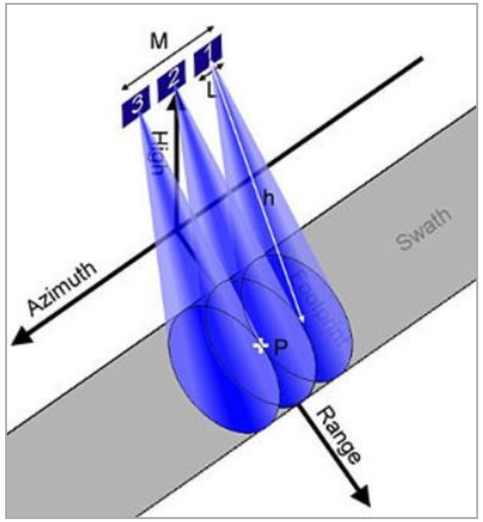
- Flexibility of the analysis (multi-resolution)
- Full knowledge of the asset condition
- Assessment of the interaction between the infrastructure and the surrounding environment
- High suitability for large-scale monitoring



3. The Interferometric Syntethic Aperture Radar (InSAR)

ACTIVE REMOTE SENSING TECHNIQUE





Various devices mounted onto satellites
500 – 36000 km height

Band	P	L	S	C	X	K
f (GHz)	1	2	4	8	12	
λ (cm)	30	15	7.5	3.8	2.5	

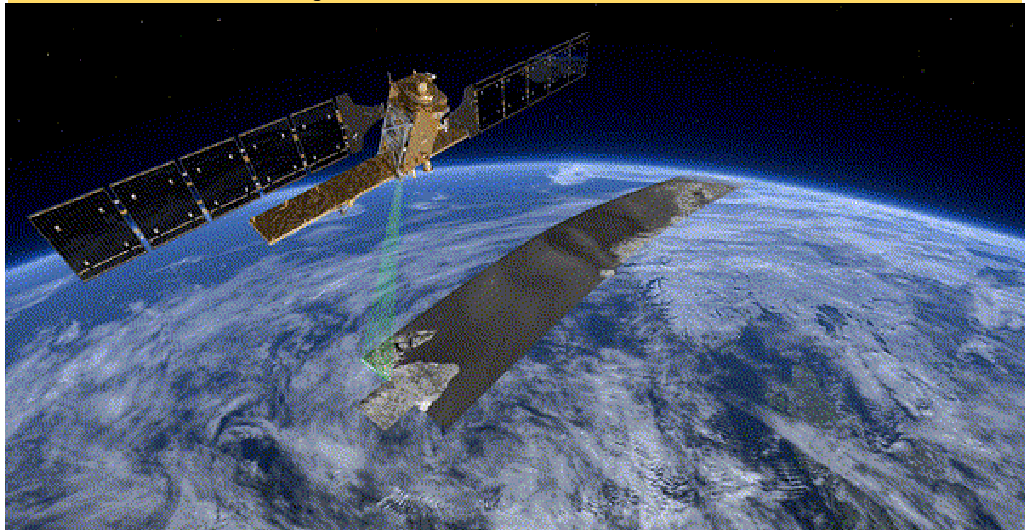
Different Bands and Wavelengths

- *The SAR, by exploiting the motion of the satellite, synthesizes a large virtual antenna, obtaining high definition images*

SATELLITE REMOTE SENSING

- **No need for external energy sources**
- **Operating frequency allows for the penetration of the waves through clouds and rain**
- **Coherent system: permits very precise measure of distance of the target from the radar by means of interferometry**

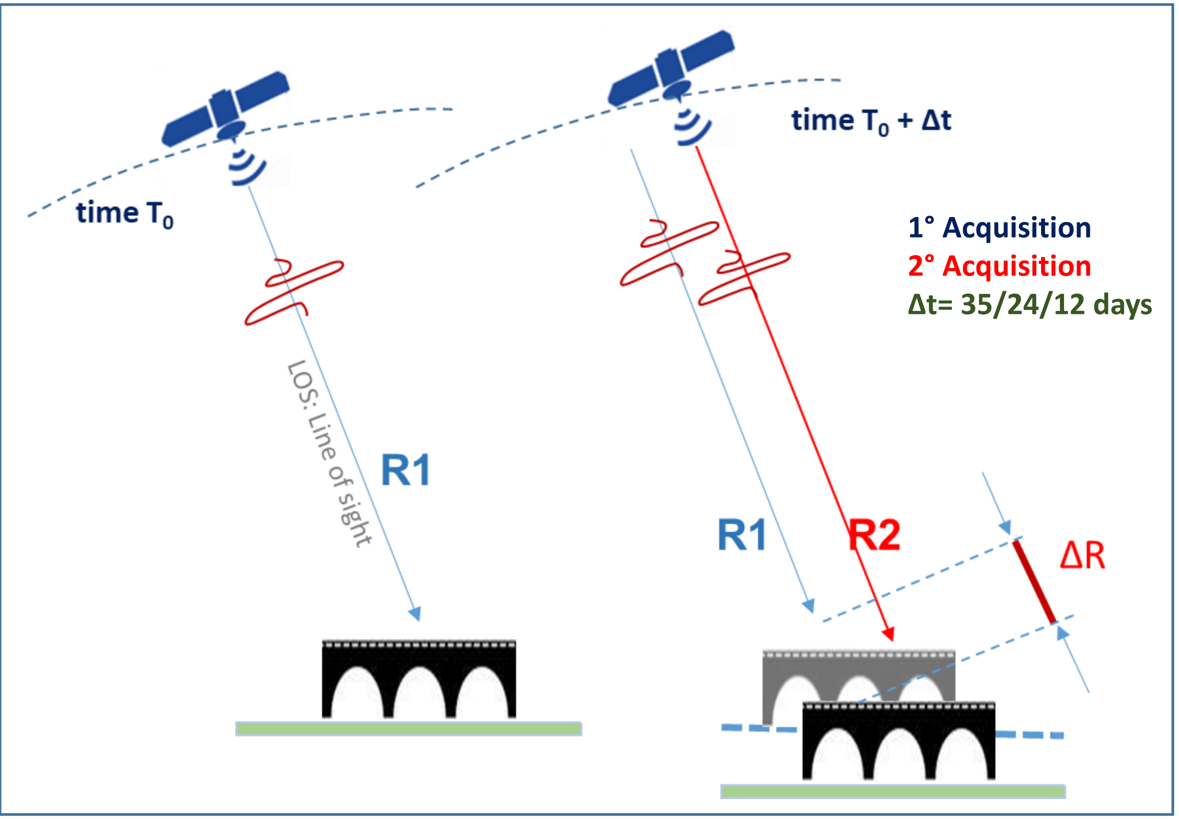
- **Provide a Quasi-daily updated dataset**
- **Availability of free data**



Copernicus Missions: Sentinel-1, C-band sensor

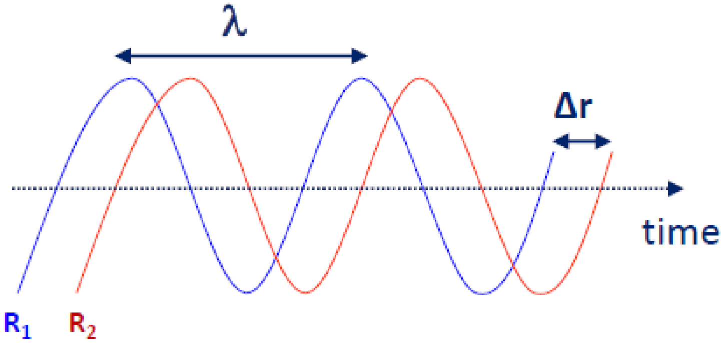
3. The Interferometric Syntethic Aperture Radar (InSAR)

- Interferometry (InSAR): Comparison of pairs of images
- → Measurement of sensor-target distance variations



Permanent Scatterers: remain stable in terms of amplitude of the signal back-reflected

- **Area affected by surface deformation**



Lunghezze d'onda:

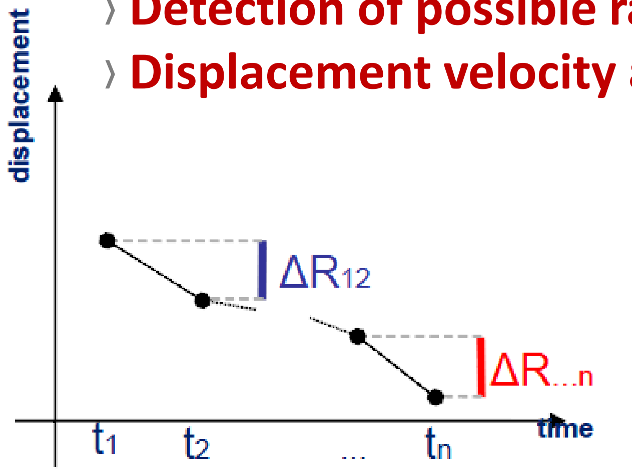
Banda C = 5.66 [cm]

Banda X = 3.10 [cm]

Banda L = 24.0 [cm]

- The surface displacement determines a phase shift between two measurements of the sensor-target distance on the ground

- **Detection of possible range variations**
- **Displacement velocity assessment**



Near-Real Time Monitoring

4. Ground Penetrating Radar (GPR)

- The ground penetrating radar is a well acknowledged EM technology, which is based on the emission of an EM pulse towards an inspected body.

- Each time a inhomogeneity in physical terms is encountered, part of the energy is back-reflected, while part is trasmitted beyond.

The propagation of the waves throughout the media is ruled by the maxwell's equations, while the materials properties are described by the constitutive equations

Maxwell's equations

$$\nabla \cdot \mathbf{D} = \rho_I$$

$$\nabla \cdot \mathbf{H} = 0$$

$$\nabla x \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$

$$\nabla x \mathbf{H} = \sigma \mathbf{E} + \frac{\partial \mathbf{E}}{\partial t}$$

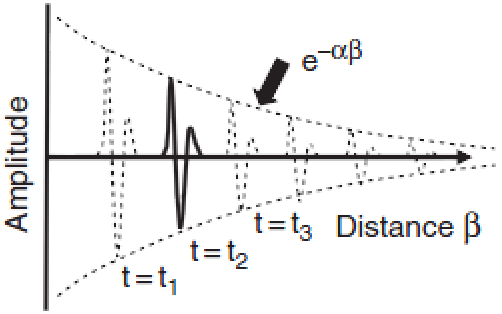
Constitutive equations

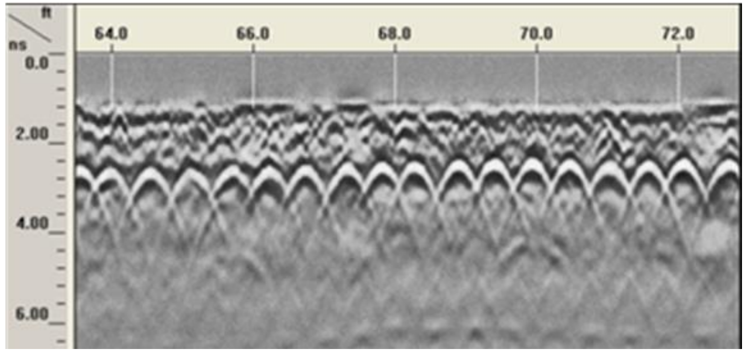
$$\mathbf{J} = \sigma \mathbf{E}$$

$$\mathbf{D} = \varepsilon \mathbf{E}$$

$$\mathbf{B} = \mu \mathbf{H}$$

Wave Propagation





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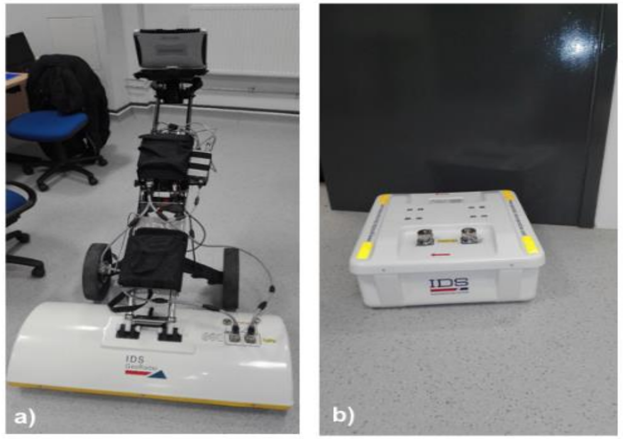
4. Application

- Case study: the “Old Bridge” at Aylesford, Kent, UK– a 13th century bridge

GPR Equipment



- The test were performed by using pulsed GPR system equipped with a multi-frequency Horn Antennas.

  - *Antenna*: Horn
  - *Frequency*: 200 –600 (low frequency)and 1500 – 2000 MHz (High frequency)
  - *Polarization*: HH-VV
  - *Time window*: 15-25 ns

Testing Equipment

Integrated Health monitoring Approach

InSAR Equipment

PS-InSAR analyses were carried out on dataset from Sentinel 1 A mission provided by ESA: European Space Agency

- *Sensors*: SENTINEL-1
- *Band:* C /
- *Frequency*: 5.4 GHz
- *Orbit height*: 693 km
- *Spatial Resolution*: 20 m x 20 m

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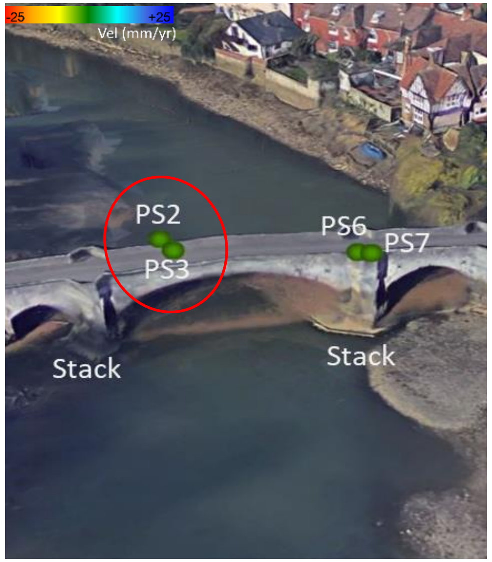
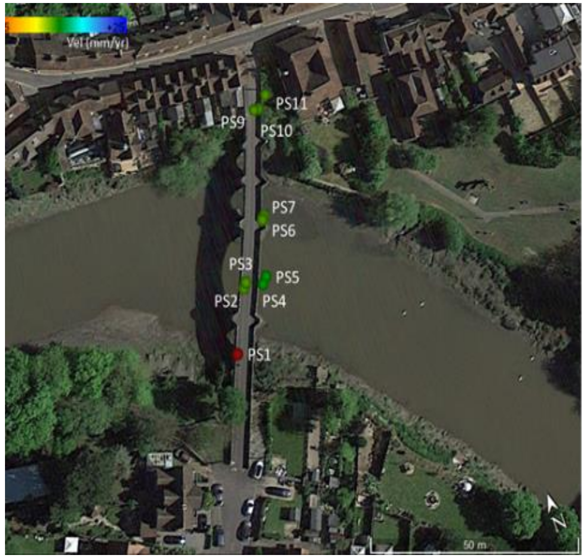
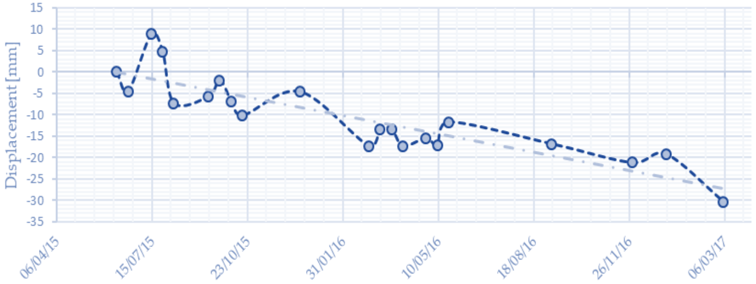
4. Results

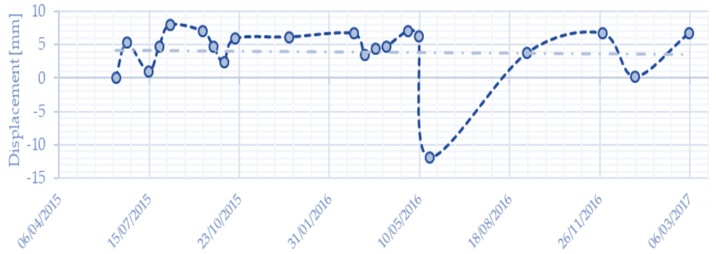
PSI InSAR application: time-series displacement analysis (2015-2017)



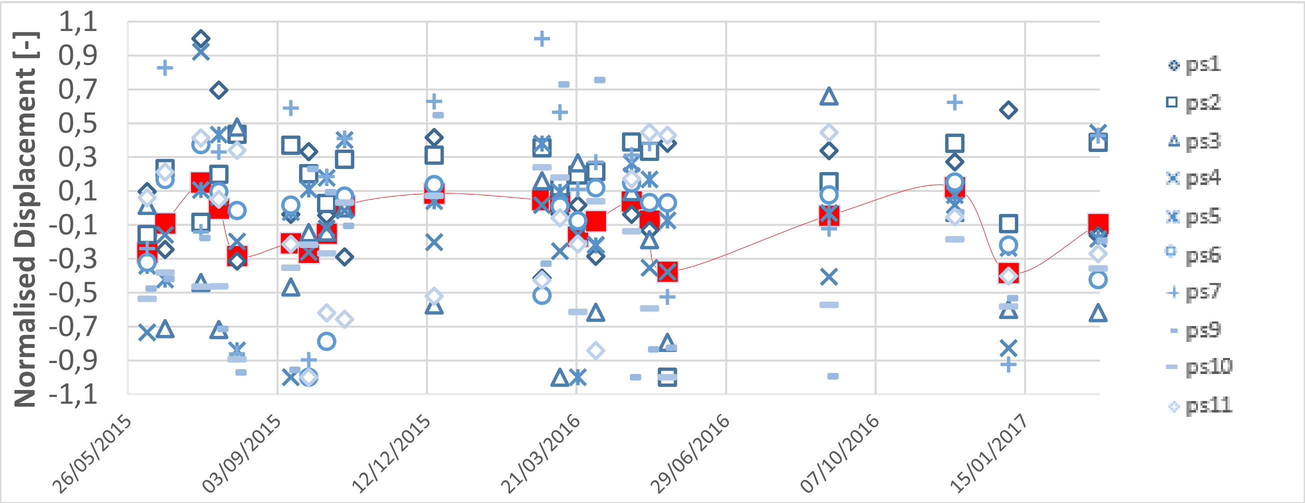


- PS-InSAR analyses were carried out on dataset from Sentinel-1A, provided by ESA (European Space Agency), operating at a frequency of 5.4 GHz.
- The PSI Insar Analysis was implemented using the Interferometric Stacking Module of the ENVI SARscape® software.
- The license for the use of ENVI SARscape® software is granted by the **ESA approved Project MOBI (id 52479).**

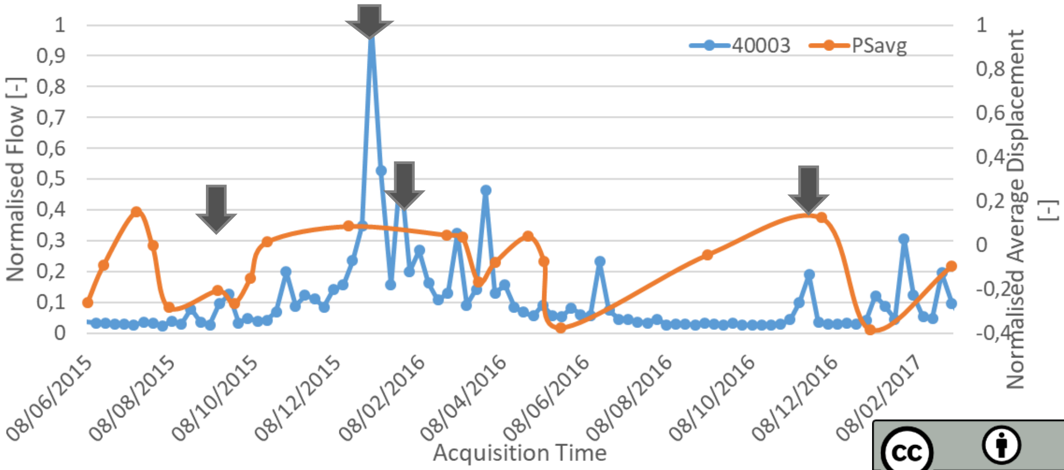




Idenfification of a deformation trend of the PS related to the seasonal-behaviour of the river flow (m3/s)

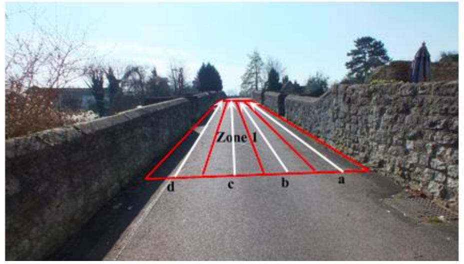


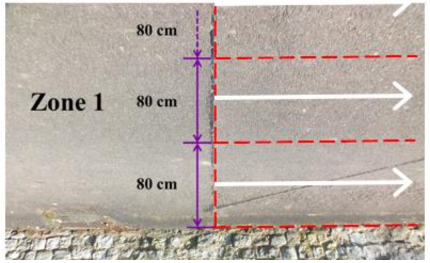
Comparison between the average trend of identified PS and the hydrometric trend (Station 40003), June 2015 and March 2017



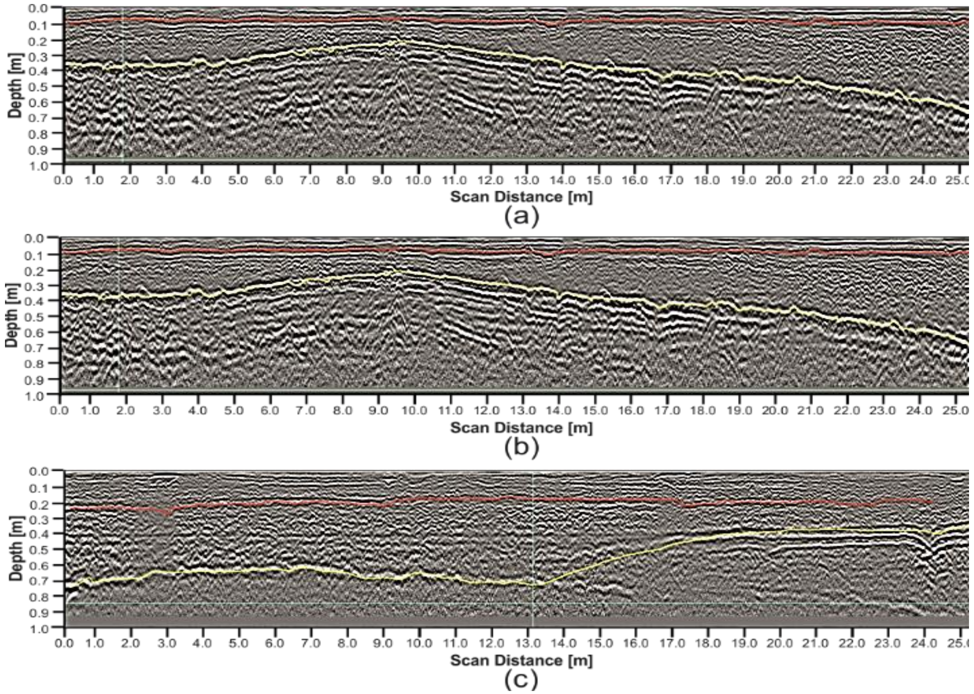
4. Results 〉 Multi-frequency GPR on-site inspection

1. Identification of the GPR survey





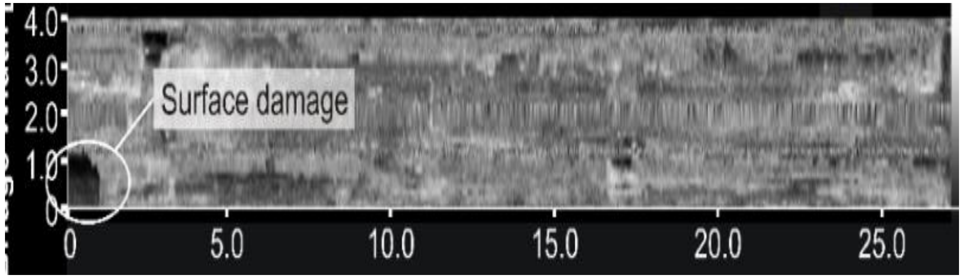
2. B-SCAN of the Inspected Bridge



- Identification of the Thickness values of the asphalt layer. There is a variation from 3 cm to 12 cm in Zone 1, 3÷13 cm in Zone 2 and 4÷12 cm in Zone 3

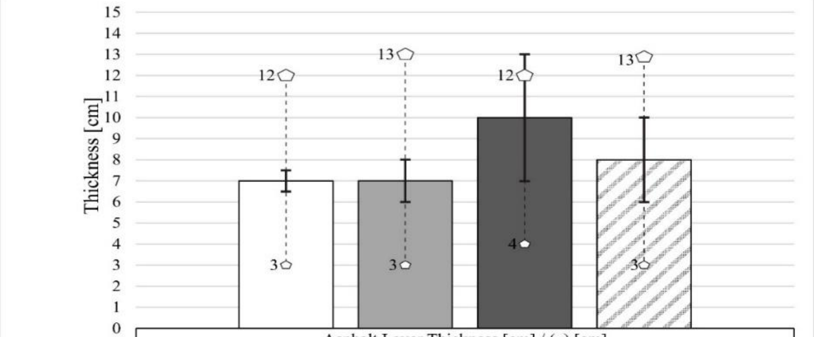
3.C-SCAN of the inspected Bridge

- Identification the sources of surface damage zones on the bridge deck



4. Interpretation of the GPR results

- Identification of the thickness (cm) of the identified layers of the bridge
- Solid lines on each bar graph represent the standard deviation of the values. Dashed lines stand for the range of values between maximum and minimum values observed within the dataset of each zone.



	Asphalt Layer Thickness [cm] / (σ) [cm]
Zone 1	7 (1)
Zone 2	7 (2)
Zone 3	10 (6)
Full Length	8 (4)

5. Conclusions

- **InSAR was found to be a valuable mean for detecting the critical spots over the inspected bridge, where to focus further assessment**
- **The integration of NDTs (e.g GPR) allows for a comprehensive knowledge about the evolution and even the causes of the distresses**
- **The methodology stands as extremely suitable for network monitoring purposes, due to the high spatial coverage of InSAR and high productivity of GPR equipped with horn antennas**

6. Future developments

- **Extension of the analysis at the network-scale**
- **Automatization of the processes**

Acknowledgements

- The authors would like to take this opportunity and acknowledge the support received from the Rochester Bridge Trust for facilitating the original study on the Aylesford Bridge.
- The PSI InSAR Analysis was implemented using the Interferometric-Stacking Module of the ENVI SARscape® software. The license is granted by the ESA-approved project “MOBI: Monitoring Bridges and Infrastructure Networks” (EOhops proposal 2045 (id 52479)) accepted and funded by ESA: European Space Agency.
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[1]*Department of Engineering, Roma Tre University, Via Vito Volterra 62, 00146, Rome, Italy*
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