Advantages of additive manufacturing for biomedical applications of polyhydroxyalkanoates

Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 84 (2026) 401–408

Structural Integrity Procedia

www.elsevier.com/locate/procedia

III Fabre Conference: Existing Bridges, Viaducts, and Tunnels: Research, Innovation, and Applications

Pre- and post-collapse analysis of infrastructures using COSMO-SkyMed satellite data

Raffaele Tarantini[a]*, Stefania Coccimiglio[a], Gaetano Miraglia[a,b], Irene Matteini[a], Maurizio Grassi[c], Rosario Ceravolo[a,b] and Giuseppe Andrea Ferro[a]

[a]*Department of Structural, Geotechnical and Building Engineering (DISEG), Politecnico di Torino, Corso Duca degli Abruzzi, 24, Torino, 10129, Italy*
[b]*Responsible Risk Resilience interdepartmental Centre (R3C), Politecnico di Torino, Corso Duca degli Abruzzi, 24, Torino, 10129, Italy*
[c]*Firmiter S.r.l., Via Sanfront, 12, Torino, 10138, Italy*
[*]*raffaele.tarantini@polito.it*

Abstract

The Italian territory is characterized by a large number of bridges and viaducts that have reached or exceeded their service life. The primary issue lies in the lack of adequate maintenance and effective monitoring systems. This is confirmed by the growing number of collapses and structural failures that have affected several infrastructures across the country in recent years. These events highlight the urgent need to widely implement Structural Health Monitoring (SHM) techniques across as many structures as possible. In this context, SHM experts are increasingly focusing on the development of innovative technologies capable of monitoring a broad series of infrastructures at a reduced cost. Specifically, contactless methods, such as satellite remote sensing, are gaining particular relevance. Among the various satellite-based techniques, Differential Interferometric Synthetic Aperture Radar (DInSAR) has proven to be an effective tool for monitoring the structural health of existing infrastructure. It enables the detection of millimeter-scale displacements over time, supporting long-term assessments of structural integrity. Although such data have been available and used for many years, several challenges still persist in the SHM context. The only way to address these challenges is through broader application of these data, alongside in-depth studies to understand their characteristics, capabilities, and limitations. This paper presents a study on the investigation the structural behavior of the Albiano-Magra Bridge, which collapsed on April 8, 2020. The analysis is based on the use of high-resolution SAR data from the COSMO-SkyMed constellation, processed using Persistent Scatterer (PS) InSAR approach. Both pre-collapse and post-collapse phases were examined, with the primary aim of detecting potential early warning signals. Additionally, the study focused on identifying Temporary Scatterers (TS) located on the bridge. The results confirm the potential of integrating satellite-based interferometry into SHM strategies.

* Corresponding author.
E-mail address: raffaele.tarantini@polito.it

10.1016/j.prostr.2026.06.052

Keywords: Satellite data, Interferometric Synthetic Aperture Radar (InSAR), Structural Health Monitoring (SHM), Bridge collapse, Albiano-Magra Bridge.

1. Introduction

A large portion of existing bridges and viaducts has now reached or exceeded its original design reference period. Ageing, increased traffic loads, climate change and the growing frequency of extreme events such as floods and earthquakes have highlighted the fragility of transport infrastructure. In Italy, the collapses of the Morandi viaduct in Genoa and the Albiano–Magra Bridge (Fig. 1) in Tuscany are emblematic examples (Calvi et al., 2019; E. Farneti et al., 2023). These events have prompted the development of national guidelines for systematic inspection and monitoring (MIT & CLSP, 2020) and have stimulated significant research on Structural Health Monitoring (SHM) strategies for existing bridges. Traditional SHM relies on contact sensors (accelerometers, displacement transducers, GNSS and fibre-optic systems) installed on a limited number of structures (Ceravolo et al., 2017; Coccimiglio et al., 2024). In parallel, seismic and structural vulnerability assessments increasingly exploit advanced numerical models and non-linear analyses to quantify failure mechanisms, residual capacity and the effect of strengthening interventions (Mairone et al., 2025; Tarantini et al., 2025). There is therefore a strong demand for monitoring solutions that can complement detailed local analyses with spatially distributed long-term observations.

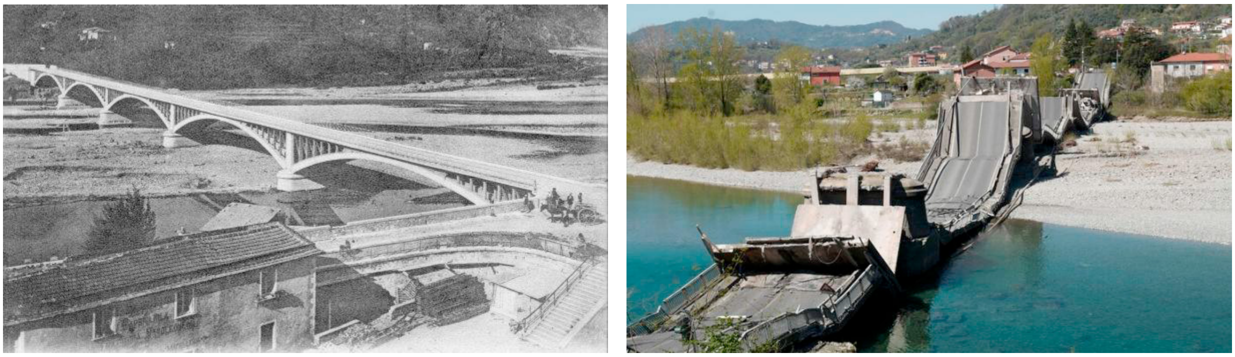
Remote-sensing technologies, and in particular satellite Interferometric Synthetic Aperture Radar (InSAR), have emerged as powerful tools to observe the displacement behaviour of large sets of structures in an entirely contactless way. Multi-temporal (MT) InSAR techniques can retrieve millimetre-scale line-of-sight (LOS) displacements over time from stacks of tens to hundreds of SAR acquisitions, with typical mean-velocity precision of about 1–2 mm/year for coherent targets, depending on wavelength, geometry and processing strategy (Berardino et al., 2002; Crosetto et al., 2016; Ferretti et al., 2001). Services such as the European Ground Motion Service (EGMS) demonstrate that such techniques can be systematically applied at continental scale using Sentinel-1 data, providing homogeneous ground-motion products that include urban areas, linear infrastructure and natural slopes. In bridge engineering, early studies showed that persistent scatterers on decks, piers and approach embankments can reveal abnormal deformations indicative of scour, foundation settlements or structural distress (Lazecky et al., 2015). Subsequent works explored correlations between InSAR-derived displacements and visual inspections, comparisons with on-site topographic measurements and the associated uncertainty budget (Tonelli et al., 2023), and the inclusion of InSAR within broader SHM frameworks for bridges and surrounding territories (Coccimiglio et al., 2024).

Within this context, the present paper investigates how high-resolution COSMO-SkyMed data and a Persistent Scatterer InSAR (PS-InSAR) approach can be exploited for pre- and post-collapse analysis of bridge infrastructures. The focus is on the role of satellite-based deformation time series in identifying long-term trends and potential early-warning patterns, and on the contribution of temporary or short-lived scatterers located on decks and adjacent pavements. Compared to previous studies on the Albiano–Magra Bridge, which primarily used COSMO-SkyMed time series to derive span-averaged deformation components and to feed probabilistic residual-life or collapse modelling, this work adopts a fully user-driven PS-InSAR workflow centred on the detailed behaviour of individual scatterers. Particular attention is paid to temporary scatterers whose life span is closely related to the collapse chronology and to the combined interpretation of pre- and post-collapse COSMO-SkyMed data within a single, consistent processing chain. In this sense, the paper aims to bridge the gap between population-based ground-motion products and structure-specific, forensic analyses of bridge failures.

2. Background and related work

Repeat-pass DInSAR measures phase differences between complex SAR images acquired at different times, which, after correction for topography, orbital errors and as far as possible atmosphere, can be related to LOS displacement (Bürgmann et al., 2000; Massonnet and Feigl, 1998). Single-pair DInSAR, however, is strongly affected by atmospheric artefacts and temporal decorrelation. MT-InSAR techniques address these limitations by exploiting stacks of SAR images. In Persistent Scatterer Interferometry (PSI), phase-stable point targets are identified, and a parametric phase model is solved over an interferogram network to estimate residual height and LOS deformation time series (Crosetto et al., 2016; Ferretti et al., 2001). Small Baseline Subset (SBAS) methods use interferograms with limited baselines to retrieve deformation on a grid (Berardino et al., 2002). For coherent targets and sufficiently long time series, MT-InSAR typically achieves LOS velocity precision of 1–2 mm/year and displacement accuracy of a few millimeters to about one centimeter, depending on wavelength and temporal sampling (Lanari et al., 2004). X-band missions such as COSMO-SkyMed increase the density of coherent scatterers on man-made structures, which is crucial for bridge-scale analyses (Bonaldo et al., 2023; Macchiarulo et al., 2022).

In the last decade, MT-InSAR has been increasingly applied to bridges and transport infrastructure, demonstrating that coherent scatterers on decks, piers and abutments can be used to track millimeter-scale deformations and settlements (Biondi et al., 2020; Lazecky et al., 2015). Comparisons with conventional monitoring systems on case studies such as the Colle Isarco viaduct have shown good agreement in trends and seasonal components, while highlighting the impact of acquisition geometry and noise (Valentini et al., 2023). Recent works have quantified the metrological performance of InSAR for road bridges and proposed SHM frameworks and risk-based management schemes that explicitly integrate satellite products into decision-support pipelines for bridge portfolios (Talledo et al., 2025; Tonelli et al., 2023).



(a) (b)

Fig. 1 Albiano–Magra bridge: historical view, source: www.commons.wikimedia.org (a); collapse, source: www.ansa.it (b).

3. Methodology

The proposed framework aims to extract structurally meaningful information from COSMO-SkyMed time series for bridges that are either still in service or have already experienced partial or total collapse. A multi-year stack of high-resolution StripMap SLC images, ideally in both ascending and descending geometries, is processed using a PS-InSAR approach consistent with the POLIMI PS/QPS formulation (Ferretti et al., 2001; Perissin and Rocca, 2006; Perissin and Wang, 2012). For each orbit, all available acquisitions are treated as a single multi-temporal dataset covering both pre- and post-collapse years, yielding a unique PS-InSAR solution with LOS displacement and velocity estimates, amplitude statistics, temporal coherence and associated quality indicators. The distinction between pre- and post-collapse behavior is carried out a posteriori, by interpreting the reconstructed time series with respect to the known failure date: the pre-collapse portion is used to assess long-term trends and differential settlements at span, pier and abutment level, while the post-collapse portion documents discontinuities, the disappearance of on-deck targets, the emergence of new scatterers on debris or temporary works, and the evolution during demolition and reconstruction. Within this framework, a practical distinction is made between persistent scatterers (PS) and temporary scatterers (TS). PS are pixels that remain coherent over most of the observation period, with low phase noise and stable amplitude, typically located on robust structural elements (parapets, stiff members, piers) and nearby buildings. TS are defined in an operational sense as scatterers that can be unambiguously associated with structural parts that later collapse or are removed and whose amplitude and displacement histories exhibit a clear “death date” around the failure, while still satisfying a single, acceptable temporal coherence value over the full stack. This definition is consistent with the diagnostics available in SARPROZ (Perissin, 2025), where per-pixel coherence is estimated over the entire interferogram network rather than as a function of time.

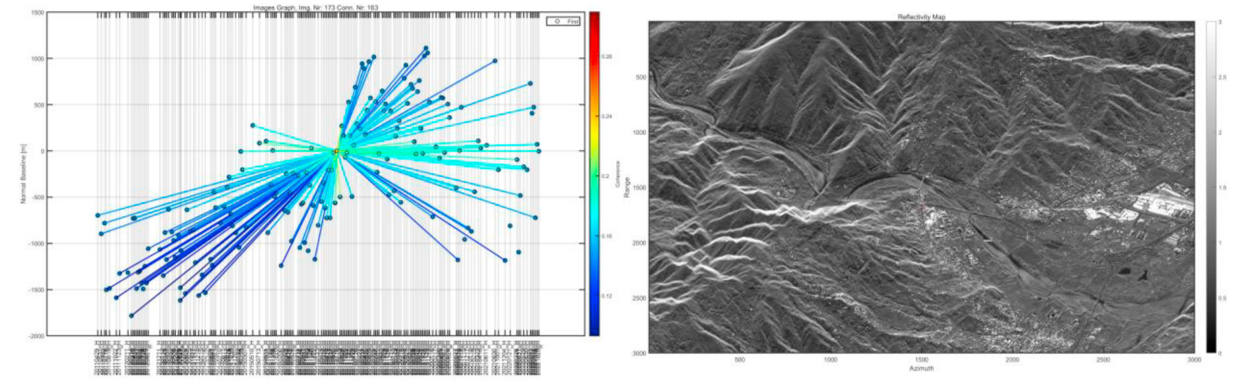
4. Application on the case study of Albiano-Magra Bridge

The case study is the reinforced-concrete arch bridge crossing the Magra River between Caprigliola and Albiano Magra in north-western Tuscany, commonly referred to as the Albiano–Magra or Caprigliola Bridge. The structure, approximately 260m long and about 7m wide, consisted of five slender reinforced-concrete arch spans supported by four river piers and two abutments. Originally completed in 1908 and later reconstructed after World War II, the bridge carried a single carriageway along state road SS330 and played a key role in regional connectivity. On 8 April 2020, the bridge abruptly collapsed into the Magra River, involving the entire deck and most of the arches, while some substructures remained partially standing; the event, which occurred during the COVID-19 lockdown, fortunately caused only minor injuries.

Following the collapse, the Albiano–Magra Bridge has become a reference case for satellite-based pre- and post-collapse analysis. Farneti et al. (2023) proposed a method for structural monitoring of multi-span bridges using satellite InSAR with explicit uncertainty quantification and applied it to this bridge by exploiting COSMO-SkyMed data in ascending and descending geometries; for each span, they reconstructed LOS deformation histories and decomposed them into vertical and longitudinal components in a bridge-aligned reference frame. In a subsequent contribution, Farneti et al. (2023) introduced a residual service-life prediction framework for bridges subject to slow-acting damage processes and illustrated it again on Albiano–Magra, showing how the reliability of residual-life estimates depends on monitoring duration and on assumptions about future deterioration. Scattarreggia et al. (2022) complemented these works by integrating pre-collapse InSAR deformation patterns with non-linear FE collapse simulations, exploring alternative failure mechanisms and the role of different structural components and boundary conditions. Together, these studies demonstrate that satellite InSAR can provide valuable information for both diagnosis and forensic analysis, while also highlighting challenges such as sparse and geometry-dependent sampling, the uncertain mapping between scatterers and structural elements, and the difficulty of interpreting quasi-static trends in terms of damage. Building on this literature, the present paper focuses on high-resolution COSMO-SkyMed PS-InSAR processing over the Albiano–Magra Bridge and on the combined analysis of pre- and post-collapse data, with particular emphasis on scatterers located on the deck, piers, abutments and adjacent approaches.

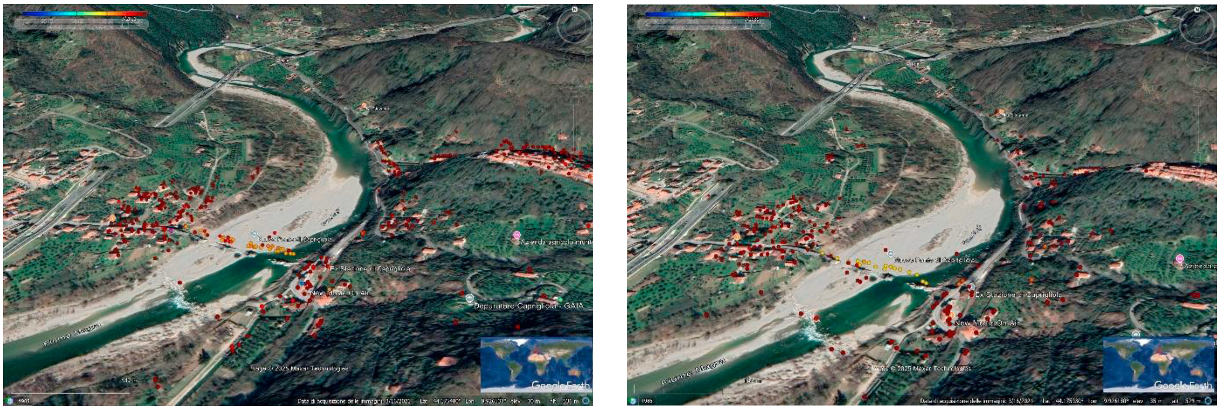
4.1. InSAR processing workflow

The analysis is based on high-resolution X-band SAR data acquired by the first-generation COSMO-SkyMed constellation in StripMap (HIMAGE) mode. A multi-year stack of Single Look Complex (SLC) images was collected over the Albiano-Magra area in both ascending and descending orbits. The COSMO-SkyMed dataset consists of 173 acquisitions in ascending and 94 in descending geometry, covering the period 2011–2022. For each orbit, the full COSMO-SkyMed SLC stack, covering both the pre- and post-collapse phases, was processed as a single multi-temporal dataset. The workflow included: (i) master selection, based on optimization of spatial and temporal baselines and Doppler centroid differences across all acquisitions (resulting in 20170718_HH for the ascending geometry and 20180719_HH for the descending geometry); (ii) precise co-registration of all slave images to the selected master; (iii) construction of a star-graph interferometric network centered on the master for PS inversion (Fig. 2a); and (iv) integration of an external digital elevation model (Copernicus DEM) to remove the bulk topographic phase. Subsequently, (v) reflectivity maps were generated, and a Ground Control Point (GCP) is selected in presumed stable areas (Fig. 2b); (vi) sparse point selection was performed using a targeted local-maxima approach; and (vii) multi-image InSAR analysis was carried out on the sparse points to extract LOS displacement time series, with particular attention to temporary scatterers that might be located on structural elements. Finally, (viii) geocoding and quality assessment were performed using the Google Earth reference system (Fig. 3), applying a minimum coherence threshold of 0.50 as a quality-control criterion to retain only measurements with acceptable phase stability. This choice is consistent with common practice in multi-temporal PS-InSAR analyses over urban areas and infrastructures, where minimum temporal coherence thresholds in the range 0.4–0.6 are typically adopted to filter out unreliable phase histories and to retain stable man-made targets (Kikon et al., 2025; Ramirez et al., 2022). The outcome of this workflow consists of PS and TS characterized by LOS displacement histories, velocities, and amplitude statistics (Fig. 4) which are then interpreted in structural terms for both the pre- and post-collapse phases. The standard PSI practice and the POLIMI PS/QPS formulation implemented in SARPROZ (Perissin, 2025; Perissin and Rocca, 2006; Perissin and Wang, 2012) was followed.



(a) (b)

Fig. 2 Star graph of interferometric connections (a) and reflectivity map with GCP in red (b), ascending orbit.



(a) (b)

Fig. 3 PS and TS in Google Earth, ascending (a) and descending orbit (b).

5. Results

A user-driven SARPROZ analysis of the full COSMO-SkyMed SLC stacks revealed, in both ascending and descending orbits, several TS whose life span is closely linked to the chronology of the event. These TS are located approximately along the bridge deck and show a clear “death date” coinciding with the collapse phase, after which they either disappear completely from the sparse-point solution or exhibit such a degradation in phase stability that they become unusable for deformation analysis. In the pre-collapse interval, the amplitude–temporal baseline plots (Fig. 4) associated with these targets display compact, high-amplitude clusters for short temporal baselines, followed by a rapid amplitude decay as the temporal separation increases. This behavior is typical of scatterers that remain coherent only within a limited time window, consistent with transient scattering configurations on the deck.

The corresponding displacement time series (Fig. 4) exhibit relatively consistent trends up to the failure date, closely matching the behavior of nearby persistent scatterers on the deck edges and parapets. Immediately after the collapse, however, these time series become highly dispersed, with increased scatter and, in many cases, abrupt loss of continuity. This dispersion reflects the drastic change in the scattering scenario: the structural elements hosting the TS are either removed or heavily damaged, and the new backscattering surfaces (debris, exposed substructure, temporary works) no longer support a stable interferometric phase. When analyzed together with long-lived PS, the pre-collapse TS thus provide additional, localized information on the kinematics of the deck portions that later failed, while their sudden disappearance and the post-event dispersion of the data offer an interferometric signature of the collapse in the time domain.

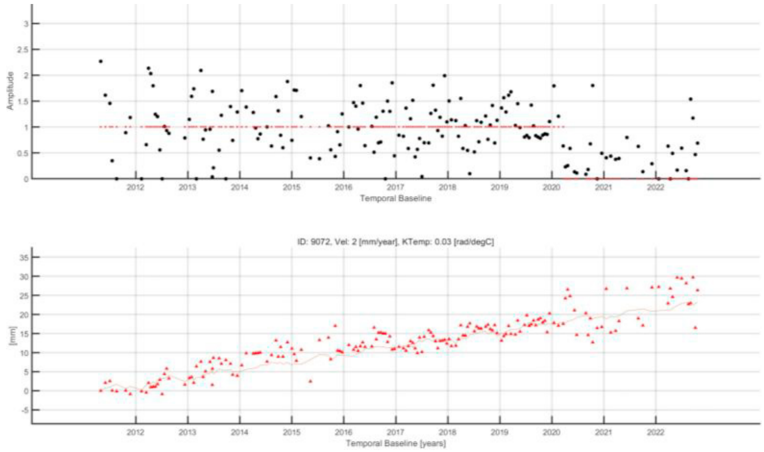


Fig. 4 Amplitude–temporal baseline plot and displacement time series of a TS located on the viaduct deck, ascending orbit.

5.1. Potential early warning signals

Some points located on the spans that later failed exhibit localized and persistent positive LOS trends in the years preceding the collapse. For these scatterers, the average LOS velocities remain modest, but they cumulate to displacements of up to approximately 10–15 mm by the time of failure. These cumulative values are spatially correlated with the spans that eventually collapsed, which suggests that they may be related to progressive structural degradation or changes in boundary conditions. From an SHM perspective, cumulative LOS displacements approaching 1–2 cm cannot be regarded as negligible, even though they are superimposed on seasonal components and affected by atmospheric noise and processing uncertainties. This calls for cautious interpretation within a broader mechanical framework rather than as stand-alone evidence of damage. In addition, the statistical significance of apparent accelerations or trend changes is limited by the length of the pre-collapse record and by the uncertainties associated with atmospheric residuals and reference-frame choices. At this stage, therefore, the observed anomalies are better regarded as suggestive kinematic symptoms rather than as robust early-warning indicators, highlighting the need for explicit uncertainty quantification and for combining InSAR with complementary information (inspections, material tests, structural models) when designing operational warning thresholds.

6. Conclusion and discussion

From a structural engineering perspective, the pre-collapse deformation patterns observed on Albiano-Magra are compatible with long-term processes such as creep, shrinkage, temperature-induced movements and possible localized degradation of materials or supports (Elisabetta Farneti et al., 2023; Scattarreggia et al., 2022). However, the catastrophic collapse of the bridge cannot be attributed solely to the observed quasi-static displacements. InSAR captures only a subset of the structural response and is blind to sudden brittle failures, hidden internal degradation or dynamic phenomena occurring at time scales much shorter than the revisit interval. The anomalies identified in this study should therefore be seen as possible kinematic symptoms of underlying issues, not as direct causes. Their main value lies in their potential to guide inspections and modelling efforts towards specific spans or components, rather than to provide a complete explanation of the failure by themselves.

The Albiano-Magra case highlights several strengths of COSMO-SkyMed PS-InSAR for collapse investigation. High spatial resolution and X-band wavelength result in dense scatterer populations on bridges and surrounding infrastructure, allowing a detailed reconstruction of pre-collapse kinematics and post-collapse deformation field The availability of multi-year archives enables back-analysis of structural behavior even when no dedicated SHM system was installed before the event, providing unique insight into the temporal evolution of displacements.

At the same time, limitations remain significant. Measurement noise, atmospheric artefacts and reference-frame uncertainties constrain the detectability of small trends and require careful uncertainty modelling. The mapping between scatterers and structural elements is often non-trivial, particularly when TS and PS are mixed and when geocoding errors are comparable with structural dimensions (Macchiarulo et al., 2022). Furthermore, the temporal sampling of COSMO-SkyMed, while adequate for monitoring slow deformations, is insufficient to capture rapid dynamic effects or short-lived precursors. In forensic engineering, InSAR should therefore be regarded as a complementary source of evidence to be combined with structural models, inspections, material tests and other monitoring data, rather than as a stand-alone diagnostic tool. Its main contribution is to add a spatio-temporal layer of information that would otherwise be unavailable.

The findings of this study support the integration of high-resolution PS-InSAR products into multi-level SHM and asset-management strategies for bridges. At network level, services such as EGMS can provide a first screening to identify corridors and structures exhibiting anomalous motions. For critical or suspicious bridges, dedicated COSMO-SkyMed analyses can then be commissioned to obtain higher-resolution deformation histories, including the identification of TS on decks and other key elements. In operational practice, the role of InSAR should be twofold: (i) to provide long-term contextual information on the deformation environment of a bridge, helping to distinguish local anomalies from regional ground movements; and (ii) to support the prioritization and planning of inspections and local monitoring, by highlighting spans, piers or abutments with unusual kinematic behavior. To fulfil this role effectively, asset owners and SHM practitioners need clear protocols for data acquisition, processing, uncertainty quantification and interpretation, as emphasized by recent guidelines (Prota et al., 2025).

References

Berardino, P., Fornaro, G., Lanari, R., Sansosti, E., 2002. A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. IEEE Transactions on Geoscience and Remote Sensing 40, 2375–2383. https://doi.org/10.1109/TGRS.2002.803792

Biondi, F., Addabbo, P., Ullo, S.L., Clemente, C., Orlando, D., 2020. Perspectives on the Structural Health Monitoring of Bridges by Synthetic Aperture Radar. Remote Sensing 12. https://doi.org/10.3390/rs12233852

Bonaldo, G., Caprino, A., Lorenzoni, F., Porto, F. da, 2023. Monitoring Displacements and Damage Detection through Satellite MT-InSAR Techniques: A New Methodology and Application to a Case Study in Rome (Italy). Remote Sensing 15. https://doi.org/10.3390/rs15051177

Bürgmann, R., Rosen, P.A., Fielding, E.J., 2000. Synthetic Aperture Radar Interferometry to Measure Earth's Surface Topography and Its Deformation. Annual Review of Earth and Planetary Sciences 28, 169–209. https://doi.org/10.1146/annurev.earth.28.1.169

Calvi, G.M., Moratti, M., O'Reilly, G.J., Scattarreggia, N., Monteiro, R., Malomo, D., Calvi, P.M., Pinho, R., 2019. Once upon a time in Italy: the tale of the Morandi Bridge. Structural Engineering International 29, 198–217. https://doi.org/10.1080/10168664.2018.1558033

Ceravolo, R., De Marinis, A., Pecorelli, M.L., Zanotti Fragonara, L., 2017. Monitoring of masonry historical constructions: 10 years of static monitoring of the world's largest oval dome. Structural Control and Health Monitoring. https://doi.org/10.1002/stc.2017

Coccimiglio, S., Scussolini, L., Matteini, I., Ceravolo, R., Ferro, G.A., 2024. Interferometric Satellite Data For The Structural Health Monitoring Of Infrastructures. Procedia Structural Integrity, II Fabre Conference – Existing bridges, viaducts and tunnels: research, innovation and applications (FABRE24) 62, 840–847. https://doi.org/10.1016/j.prostr.2024.09.113

Crosetto, M., Monserrat, O., Ferro, A., Serra, M., 2016. Persistent Scatterer Interferometry: A review. ISPRS Journal of Photogrammetry and Remote Sensing 115, 78–89. https://doi.org/10.1016/j.isprsjprs.2015.10.011

Farneti, E., Cavalagli, N., Costantini, M., Trillo, F., Minati, F., Venanzi, I., Ubertini, F., 2023. Remote monitoring to predict bridge scour failure using Interferometric Synthetic Aperture Radar (InSAR) stacking techniques. International Journal of Applied Earth Observation and Geoinformation 118, 103279. https://doi.org/10.1016/j.jag.2023.103279

Farneti, Elisabetta, Cavalagli, N., Venanzi, I., Salvatore, W., Ubertini, F., 2023. Residual service life prediction for bridges undergoing slow landslide-induced movements combining satellite radar interferometry and numerical collapse simulation. Engineering Structures 293, 116628. https://doi.org/10.1016/j.engstruct.2023.116628

Ferretti, A., Prati, C., Rocca, F., 2001. Permanent scatterers in SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing 39, 8–20. https://doi.org/10.1109/36.898661

Kikon, N., Kumar, D., Ahmed, S.A., 2025. Extracting urban patterns in undulating landscapes from SAR data with thresholding approach. Appl Geomat 17, 411–429. https://doi.org/10.1007/s12518-025-00626-6

Lanari, R., Mora, O., Manunta, M., Mallorqui, J.J., Berardino, P., Sansosti, E., 2004. A small-baseline approach for investigating deformations on full-resolution differential SAR interferograms. IEEE Transactions on Geoscience and Remote Sensing 42, 1377–1386. https://doi.org/10.1109/TGRS.2004.828196

Lazecky, M., Perissin, D., Bakon, M., de Sousa, J.M., Hlavacova, I., Real, N., 2015. Potential of satellite InSAR techniques for monitoring of bridge deformations, in: 2015 Joint Urban Remote Sensing Event (JURSE). pp. 1–4. https://doi.org/10.1109/JURSE.2015.7120497

Macchiarulo, V., Giardina, G., DeJong, M., Milillo, P., others, 2022. Multi-Temporal InSAR for Transport Infrastructure Monitoring: Recent Trends and Challenges. Proceedings of the Institution of Civil Engineers – Bridge Engineering 176, 92–104. https://doi.org/10.1680/jbren.21.00039

Mairone, M., Tarantini, R., Ferro, G.A., Masera, D., Corrado, M., 2025. Seismic behaviour at ultimate limit state of reinforced concrete structures retrofitted with glass fiber reinforced polymer rebars. fib. The International Federation for Structural Concrete.

Massonnet, D., Feigl, K.L., 1998. Radar interferometry and its application to changes in the Earth's surface. Reviews of Geophysics 36, 441–500. https://doi.org/10.1029/97RG03139

MIT & CLSP, 2020. Linee guida per la classificazione e gestione del rischio, la valutazione della sicurezza ed il monitoraggio dei ponti esistenti.

Perissin, D., 2025. SarProZ©.

Perissin, D., Rocca, F., 2006. High accuracy urban DEM using Permanent Scatterers. IEEE Transactions on Geoscience and Remote Sensing 44, 3338–3347. https://doi.org/10.1109/TGRS.2006.877754

Perissin, D., Wang, T., 2012. Repeat-Pass SAR Interferometry with Partially Coherent Targets. IEEE Transactions on Geoscience and Remote Sensing 50, 271–280. https://doi.org/10.1109/TGRS.2011.2160644

Prota, A., Savoia, M., Ponzo, F.C., 2025. Linee guida per l'utilizzo dei dati interferometrici satellitari ai fini dell'interpretazione del comportamento strutturale delle costruzioni. Doppiavoce, IT.

Ramirez, R.A., Lee, G.-J., Choi, S.-K., Kwon, T.-H., Kim, Y.-C., Ryu, H.-H., Kim, S., Bae, B., Hyun, C., 2022. Monitoring of construction-induced urban ground deformations using Sentinel-1 PS-InSAR: The case study of tunneling in Dangjin, Korea. International Journal of Applied Earth Observation and Geoinformation 108, 102721. https://doi.org/10.1016/j.jag.2022.102721

Scattarreggia, N., Salomone, R., Moratti, M., Malomo, D., Pinho, R., Calvi, G.M., 2022. Collapse analysis of the multi-span reinforced concrete arch bridge of Caprigliola, Italy. Engineering Structures 251, 113375. https://doi.org/10.1016/j.engstruct.2021.113375

Talledo, D.A., Saetta, A., Talledo, D.A., Saetta, A., 2025. A Multi-Level Semi-Automatic Procedure for the Monitoring of Bridges in Road Infrastructure Using MT-DInSAR Data. Remote Sensing 17. https://doi.org/10.3390/rs17142377

Tarantini, R., Mairone, M., Ferro, G.A., Corrado, M., Givonetti, M., Gallina, G., Masera, D., 2025. Seismic vulnerability assessment of RC bridge piers strengthened with GFRP rebars: A case study, in: Engineering Materials, Structures, Systems and Methods for a More Sustainable Future. CRC Press.

Tonelli, D., Valentini, A., Rocca, A., Zorzi, S., Lotti, A., Zonta, D., 2023. Uncertainty quantification of satellite InSAR-monitoring of bridges: a case study. ce/papers 6, 900–906. https://doi.org/10.1002/cepa.1991

Valentini, A., Tonelli, D., Rocca, A., Lotti, A., Zorzi, S., Zonta, D., 2023. Satellite InSAR technology for displacements monitoring of bridges: A comparison with on-site topographic measurements and uncertainty quantification, in: Proceedings of the 10th International Workshop on Structural Health Monitoring.