New developments in static and dynamic monitoring of bridges and viaducts

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Introduction

In the 1960s, Italy was proud of its innovations in roads and motorway networks. Each country in the world remembers the Autostrada del Sole building, inaugurated three months before the scheduled date.

In the latest years, in Italy, bridges, viaducts, and infrastructures are threatened by continuous collapses. This situation arises the need to assess their health and to monitor and maintain their assets. It would be an investment that goes against those rules based on "spending cuts," which has been the most used modus operandi in the last years.

Today we have enough knowledge to design new infrastructures with a high degree of safety and act on those already existing by improving them from both a static and seismic point of view. We are aware buildings need scheduled check-up, and nowadays, we can monitor the entire cycle of the building with innovative technologies which allow us to identify any damage anytime. Thus, it is feasible to take action in due time before the level of damage becomes challenging to deal with, saving economic resources and time. What we are talking about is predictive maintenance, the method that safeguards today to avoid disasters tomorrow.

It is interesting to see how many different materials (such as steel, masonry, reinforced concrete) have been used in Italy to build a considerable bridge heritage. Many of them are designed with entirely different technical standards than the

current ones, therefore assuming moving loads different from those of the current technical standards.
The safeguarding of these infrastructures, so the guarantee of their efficiency, duration, and reliability, is certainly important from a social, economic, and safety perspective. It can happen through a good maintenance program. Detailed knowledge of the infrastructure is essential to define a maintenance program or an improvement.

While recognizing the fundamental role of visual inspections, it should be noted that they are always very subjective. Even in-depth inspections, which are often not possible due to the limited funding available, generally do not detect deficiencies not already detectable with routine inspections.
The best and unique option is to monitor, which can keep a large number of bridges under control with little effort and reduce or even eliminate inspection costs, offering a higher level of reliability. The goal is to reduce maintenance costs with an increase in reliability, thanks mainly to reducing inspection costs and the increase in preventive maintenance, less expensive than on-demand, with significant savings.

Monitoring for predictive maintenance

The best approach is certainly that of on-demand preventive maintenance based on the monitoring. The bridge's health is checked continuously, and, in case of damage, the intervention is performed based on the level of damage found. In a long-term vision, using this Permanent Maintenance tool, Utilities will avoid irreparable disasters and/or high-level damage because, with the tool's information, users can check and/or act in advance before the damage could occur.
This approach has several benefits and economic effects: by acting in advance, it avoids the maintenance on request or situations such as traffic disruption due to a collapse.
The monitoring includes static and dynamic monitoring, able to highlight the main problems through weigh-in-motion. The weight-in-motion is the measurement of some significant displacement and deformation parameters at the passage of moving loads and the analysis of behaviour during seismic events. The weight-in-motion cannot disregard the systematic analysis, such as those on materials also by extraction of samples and related laboratory tests.

Efficient monitoring should be based on a large number of sensors, which should be both reliable, to obtain useful data, and low-cost to be able to predict large-scale use. The use of terrestrial radar interferometry has become more widespread in the last decades. Despite the difficulties in analyzing data and interpreting the results, these measurements have the indisputable advantage of not installing tools on the structure or requiring direct access on it.

Figure 1. The San Giorgio Bridge in Genoa is equipped with an advanced monitoring system, which also includes two robots (from INGENIO).

Valis alternatives are:

- Detailed knowledge of an infrastructure, pursued through experimental tests, including dynamic ones, but of limited duration;
- and accurate mathematical modeling that allows the definition of damage scenarios (or behavior, in general) according to the earthquake level

The use of few sensors would then be enough: for example, by putting one at the base and a few others on the infrastructure to estimate the likely effects and decide in real-time the closure or the need to inspect a bridge or viaduct.

The technology currently offers us various types of sensors and advanced data transmission systems. Traditional sensors can be replaced or supported by MEMS sensors (Micro-Electro-Mechanical Systems) and fibre optic sensors with advantages both in costs and installation times.
Optical fibers also allow distributed sensing devices. Further, wireless sensors offer huge advantages even if with limitations in number and reliability.
The analysis of the obtained data allows to improve the prediction and reduce the overall maintenance costs. Inspections can be drastically reduced and made using drones. On the other hand, systems based on video footage and sensors inserted in vehicles crossing the bridge (crowdsourcing) have been developed for dynamic monitoring. The monitoring system must withstand harsh environments, and the sensors must be robust and durable so that their measured data is reproducible and reliable for the duration of the monitoring.

Future research is addressed to develop and use innovative wireless sensor systems based on innovative system components available on the market (e.g., MEMS) and software, enabling the early remote diagnosis.
Very fascinating are the materials which provide information on what happens inside them, for example, by changing some properties, such as electrical resistance, as the stress varies. Such materials can also be incorporated by little sensors at a low price, providing information on temperature, humidity, and more.
For periodic measurements of the structural elements' mechanical properties, mobile laboratories can be used, equipped with dynamic vibrometer, percussion hammer, signal generator, and the corresponding amplifiers, and accelerometers. Typically, software for data acquisition and results interpretation is included, as well as software for structural modelling.

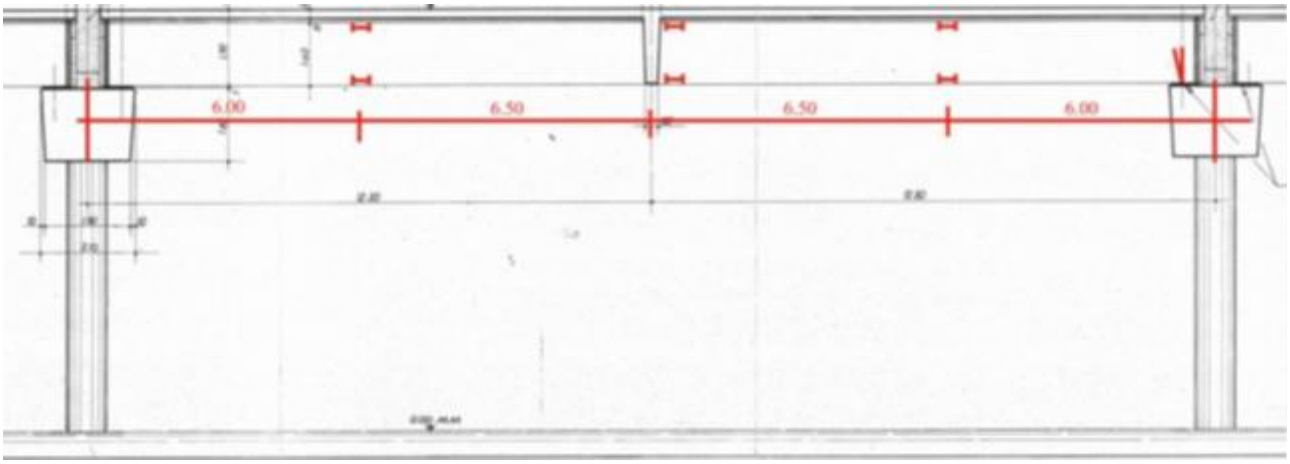

Figure 2. A typical positioning scheme of fibre optic sensors: inclinometer at the support and pairs of deformometers at the ends of three sections of the bridge span (beam bridge).

Satellite monitoring

The monitoring of infrastructure over large areas requires considerable economic and time resources and is often complex to implement. The use of satellite technologies allows to overcome these limits and to have frequent, accurate and substantially accessible information, thanks to the wide availability of territorial information, even open data.
The use of satellite images allows the monitoring of large areas over which the infrastructures are placed, allowing the planning of inspections, the definition of a priority scale of on-site investigations, and consequently the planning of maintenance interventions.
Using radar data is possible to monitor the surface movements of the territory to identify and prevent landslides and soil instability that can damage buildings and infrastructures. Radar systems are active sensors, meaning they send a signal reflected from the Earth's surface and received by the sensor. All radar system works in the same way: a transmitting device illuminates the surrounding space with an electromagnetic wave that affects any objects undergoing a phenomenon of not homogeneous reflection (scattering).

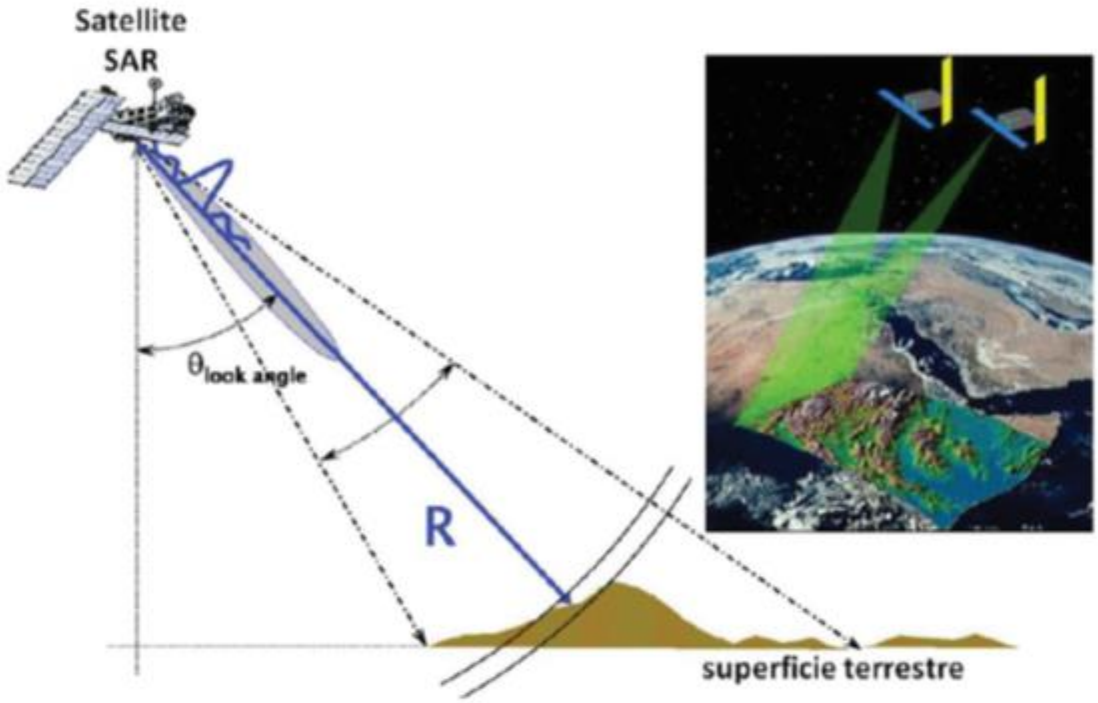

Figure 3. Acquisition geometry of the SAR interferometric satellite system (from Bignami C., Chini M., Stramondo S., 2011)

Satellite interferometry is based on the measurement of phase variations between two satellite acquisitions of the same point. The satellite passes over a point, acquiring a signal whose phase is dependent on the sensor-target distance at that given moment. In the event of ground movement, the sensor-target distance increases or decreases, and consequently, the phase undergoes a measurable variation. This type of processing is commonly called differential interferometry (DInSAR) and has been used several times to extract recent earthquakes' deformation maps.
The PSInSAR technique uses a long time series of satellite radar images to identify and measure the Earth's surface's deformation phenomena and is based on the observation of Permanent Scatterers' (PS) targets, which maintain the same "electromagnetic signature" over time. The PS generally correspond to anthropogenic structures (buildings, roads, bridges, etc.), or natural elements such as rocky outcrops. Therefore, the infrastructures represent visible targets that do not require corner reflectors as they are easily identifiable and reflective.

The techniques of using satellite radar analysis are recent. In fields such as oil exploration and subsidence assessment, experts typically use the method.

As far as it concerns the control of landslide phenomena on a local scale, the technique is more widespread and is applied by geologists and engineers to preserve historical centres. Recently, the method is used also for planning on a regional scale and large land portions.

A precise and accurate knowledge of potential phenomena is essential for professionals and organizations working in infrastructure design, construction, and civil protection. Therefore, the existence today of web platforms that simultaneously monitor extensive areas can be of great help for professionals and Public Administrations for territory monitoring activities.

Some regions in recent years have decided to undertake these strategic projects that use interferometry for the control of hydrogeological instability and spatial planning.

Interesting is the agreement signed by the Metropolitan City of Milan with the Italian Space Agency (ASI). ASI provides data from the COSMO-SkyMed space platform to monitor and analyze the City of Milan road network's stability. Images taken from the decade 2008-2018 have also been made available, allowing to carry out a trial study aimed at monitoring and analyzing the changes in the territory near the roads of the City. The information resulting from the analysis of satellite data can be accessed through the web platform called Rheticus®, which, integrating archive satellite data and new acquisitions, allows to analyze and monitor the trend of soil instability phenomena. The entire network is divided into road sections. The platform can immediately highlight which sections or bridges are undergoing a higher displacement and therefore to be inspected and subjected to further investigation with priority over the others.

Figure 4. Demo Rheticus® Displacemet Platform (Planetek UK)

Rheticus can adopt the same application to monitor bridges and viaducts over wide areas, even regional ones. It would be desirable to monitor the entire national territory, with considerable savings of economic resources and time. The objective is to detect any displacement due to subsidence or uplift, keeping under control the infrastructures and the surrounding area, allowing to decide quickly where to intervene with a more detailed analysis.

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