Landslides
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Research and development of advanced technologies for landslide hazard analysis in Italy

Abstract The Research Centre on Prediction, Prevention and Control of Georisks, "Sapienza Università di Roma" (CERI) was selected as one of the World Centres of Excellence on Landslide Risk Reduction (WCoE) under the title of "Research and development of advanced technologies for landslide hazard analysis in Italy" in the period 2008–2011. The present paper provides background information on the activities carried out by the CERI, in the frame of the WCoE network. Pre-defined purposes have been achieved by the implementation of integrated monitoring systems and early warning systems for landslides movements. The application of GBInSAR technique for monitoring landslides interacting with infrastructures is discussed, and two case histories are presented. It is shown that this technique is particularly suitable for the displacements monitoring of landslides interacting with infrastructures, thanks to its peculiar features (i.e. areal mapping, operability under every weather and lighting conditions and continuous and completely remote monitoring). Hence, it can be considered a very important tool for the reduction of risks connected to the realisation and activity of large infrastructures.

Keywords Ground-based SAR interferometry · Landslide monitoring · Infrastructures

Introduction

Landslides are part of the natural evolution of slopes. However, interacting with human structures and infrastructures, they take on much greater importance since they represent a major threat to mankind. Furthermore, landslides are often caused or accelerated (with respect to their natural evolution) by human activities as it happened in the case of the Vajont (Muller 1964) and Stava (Sammarco 2004) disasters.

The design of structures compatible with the physical characteristics of land and an accurate analysis of risks connected to planned works must be considered the starting points to approach the realization of a major infrastructure. Nevertheless, in spite of a well-done design and a complete risk analysis, accidents can occur. One of the most common accidents is the instability of the land where the structure is located (e.g. landslides, subsidences, earthquakes, etc.). Therefore, the monitoring of areas hosting large structures must be considered a key requirement for the safety of the structure and mankind.

With regard to landslides, instrumental monitoring has long been a priority (Angeli et al. 2000). Many are the examples, at an international level too, of instrumented slopes, whose evolution is monitored because of their impact on local communities (Varnes et al. 1996; Jaboyedoff et al. 2004).

However, monitoring of unstable slopes affected by human works poses serious problems from the technical point of view. On the one hand, as the slope would be significantly altered during construction, different stability problems would arise (i.e. stability of the natural slope, man-made slopes, debris accumulation during excavations, structures for slope reinforcements, etc.) which could be significant or not for the overall stability of the slope and the hosted structures. On the other hand, the installation of permanent monitoring systems with sensors (e.g. inclinometers, strain gauges, crack meters, Differential Global Position Systems) or benchmarks (e.g. prisms for Total Stations) could not be sufficient since their operation on a large part of the slope would be hindered by construction works.

With the aim to overcome these problems, CERI experimented in the last 2 years the ground-based SAR interferometry technique for monitoring landslides interacting with infrastructures. This is one of the main goals of CERI within the activities carried out in the frame of the WCoE network (Sassa 2009), oriented to the research and development of advanced technologies for landslide hazard analysis. As a matter of fact, implementation of integrated monitoring systems and early warning systems for landslides and slope scale movements in rock and soil slopes is considered a fundamental tool for hazard and risk reduction. In the following sections are described two case histories of landslides monitored by ground-based SAR interferometry (GBInSAR) as a report on the first year activity of CERI within the WCoE network.

The CERI

The Research Centre on Prediction, Prevention and Control of Georisks (CERI) is an interdepartmental centre of the "Sapienza Università di Roma" in the field of geological risks (landslides, floods, earthquakes and volcanic eruptions) and rehabilitation of polluted sites, involving about 30 researchers. The "Sapienza Università di Roma" is one of the oldest (it dates back to 1303 AD) and the largest universities in Europe. The CERI was established upon Decree of the Rector on 31 July 2003 and since its beginning it promotes, co-ordinates and implements research on methodologies through the following activities:

- Experimental (lab and field) research and theoretical research for analysing landslide hazards and risks
- Experimental (lab and field) research and theoretical research for analysing flood hazards and risks
- Experimental (lab and field) research and theoretical research for analysing pollution hazards and risks including rehabil-

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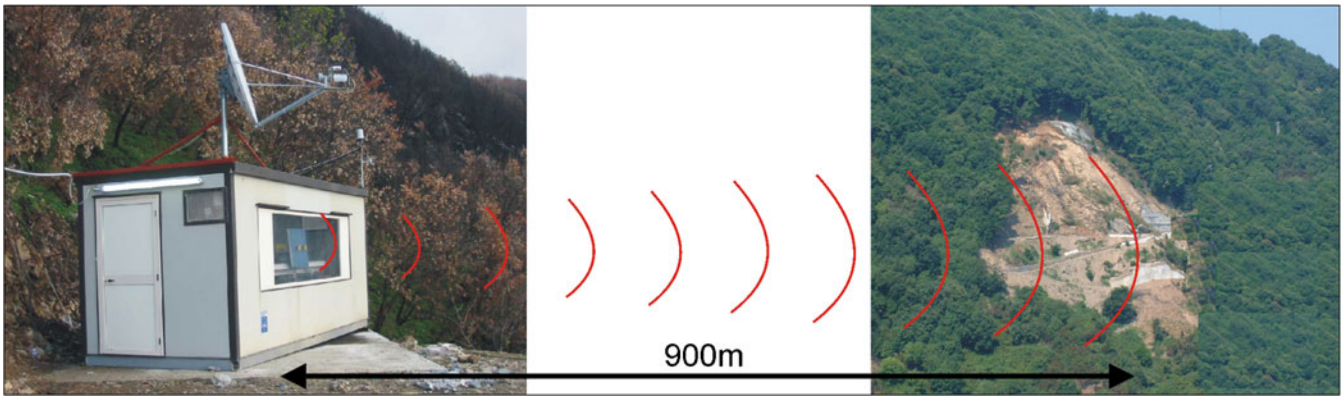


Fig. 1 Schematic diagram of the monitoring system with photo of the monitoring platform (on the *left*) and photo of the unstable slope (on the *right*)

itation of polluted sites and of large aquifers for drinking uses which may have become polluted owing to various causes including flood events

- Experimental (lab and field) research and theoretical research for analysing seismic hazards and risks
- Experimental and theoretical research for analysing with a view to developing systems for monitoring natural events associated with hydrogeological and seismic risks and related early warning/alarm systems for civil defence

CERI is also promoting the dissemination of scientific data through its scientific international journal: *Italian Journal of Engineering Geology and Environment*, published by "Casa Editrice La Sapienza".

CERI has been the promoting partner of NHAZCA S.r.l. (Natural HAZards Control and Assessment), a spin-off company of the "Sapienza Università di Roma" specifically devoted to consulting and service activities carried out by the new technologies developed in the frame of CERI research activities.

The Centre's headquarter is in Valmontone (Rome) and includes classrooms, offices and laboratories located in Palazzo Doria Pamphjli.

With reference to landslides, CERI is mainly active in the research and development of advanced technologies for landslide hazard analysis. In the last years, landslide monitoring is becoming one of the main research topics of CERI with three professors and some six research units involved. A specific interest has been devoted to the development, testing and application of GBInSAR as a tool for analysis and monitoring of different types of landslides.

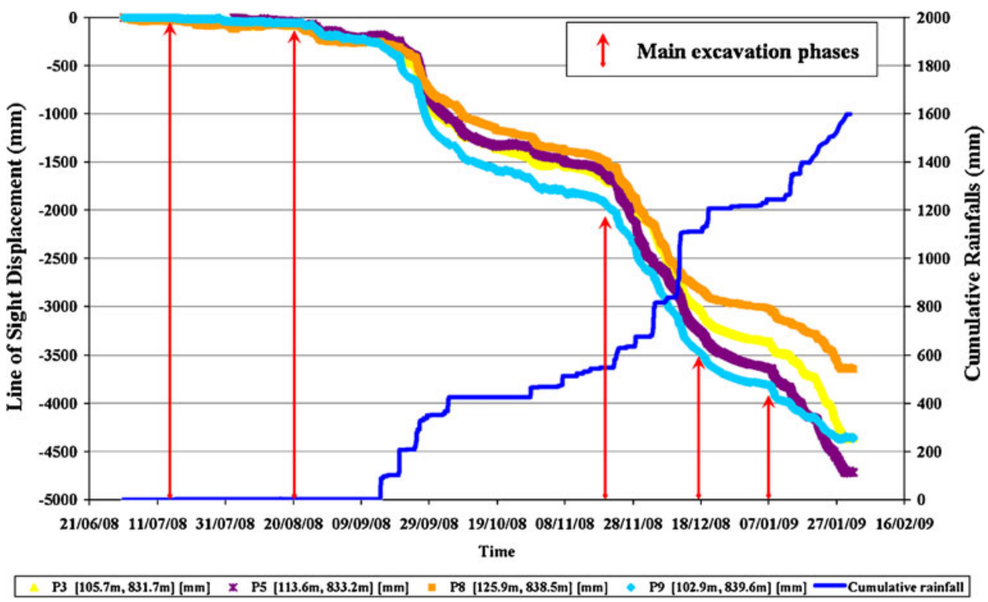


Fig. 2 Cumulative rainfalls (*dark blue line*) and time series of displacement (*orange, yellow, purple, and sky-blue lines*) of pixels located in a portion of the slope covered by excavated debris

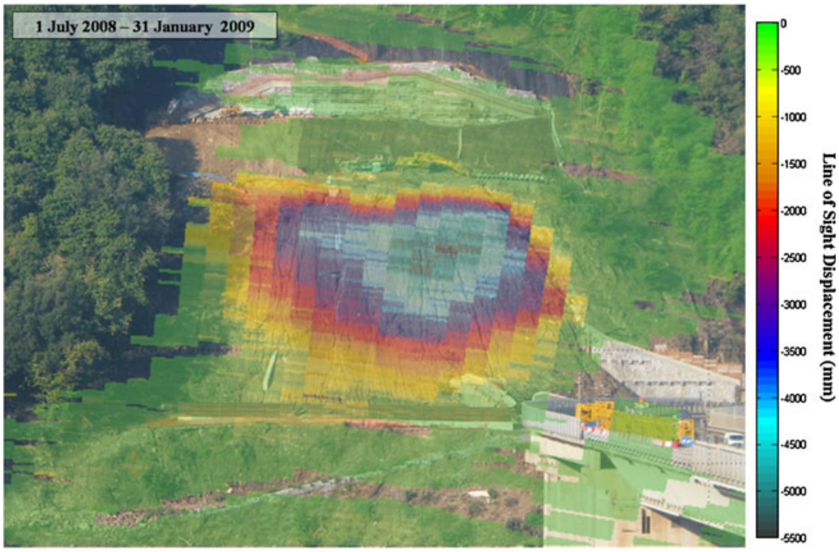


Fig. 3 Picture of the slope overlaid by the cumulative line of sight displacement map

Ground-based SAR interferometry

The GBInSAR (Tarchi et al. 1997; Pieraccini et al. 2002; Antonello et al. 2004) is based on the same operational principles as that of satellite SAR interferometry (Massonnet and Feigl 1998). In the case of GBInSAR, the synthetic aperture is obtained by an antenna moving along a rail, instead of a satellite moving along an orbit. Nevertheless, this aspect leads to several differences between the two techniques. GBInSAR offers a very short measurement time interval (i.e. few minutes) vs. satellite-based interferometry. However, a ground-based system (though with an operability range of some kilometres) has a very limited observation radius as compared to a satellite-based one. These differences suggest that GBInSAR has a high potential for the study of individual phenomena which occur in small areas that are characterized by a relatively fast evolution. As in the satellite SAR interferometry, the information about the displacements is computed along the line of sight of the instrument, by the phase difference between two SAR images (Bamler and Hartl 1998). With regard to the monitoring of landslides interacting with infrastructures, the following operational features of GBInSAR must be particularly taken into account: (1) ability of yielding data and answers within a short time (few minutes), (2) efficacy under any weather and lighting conditions, (3) completely remote operability (it does not require the installation of sensors or targets on the monitored slope), (4) continuous areal monitoring of the entire slope with a high pixel resolution (from 0.5 m to a few meters depending on the distance between the monitoring system and the observed slope) and (5) long-range monitoring (up to some kilometres).

Case studies

The above described approach has been tested on two case studies, both located in Italy. The first one is a rocky unstable slope that hosts an under construction main communication road, while the second one consists of an earth flow interacting with a pipeline and some houses.

Case 1 In the first case, a continuous real-time monitoring platform, made of a ground-based SAR interferometer (GBInSAR),

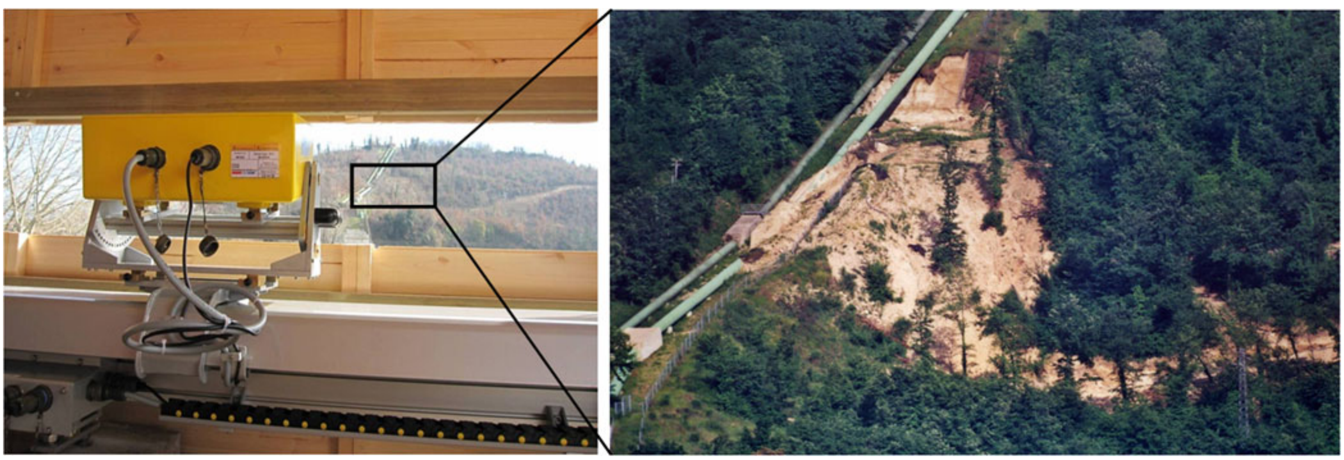


Fig. 4 Picture of the monitoring system (*left*) and picture of the landslide (*right*)

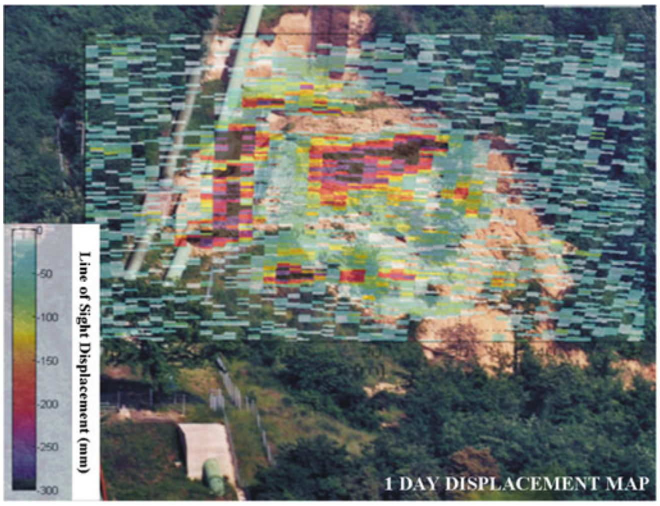


Fig. 5 Picture of the slope overlaid by 1-day cumulative line of sight displacement map

a weather station and an automatic photo camera has been developed (Bozzano et al. 2008) and, since December 2007, it is operating (Fig. 1).

Since December 2007 until now, some 200,000 SAR images, 300,000 weather data and some 20,000 pictures have been collected. These data have been analysed on a daily basis in order to analyse the response of the unstable slope during the different steps of works, thus permitting a continuous control of the stability condition. Furthermore, modifications of the original project and countermeasures have been suggested during the working phases in response to critic phases. The monitoring platform has been continuously operating under all weather and lighting conditions and during working activities.

Displacement time series of single pixels (Fig. 2) and 2D displacement maps (Fig. 3) have been produced, thus identifying different patterns of displacement affecting both the natural slope and stabilisation structures (gabions, anchored bulkhead, etc.) (Bozzano et al., submitted for publication).

The recorded patterns of displacement of the slope and man-made structures, during the different phases of works, can be seen as reference data for a similar study and engineering designs of structures interacting with landslides and unstable slopes.

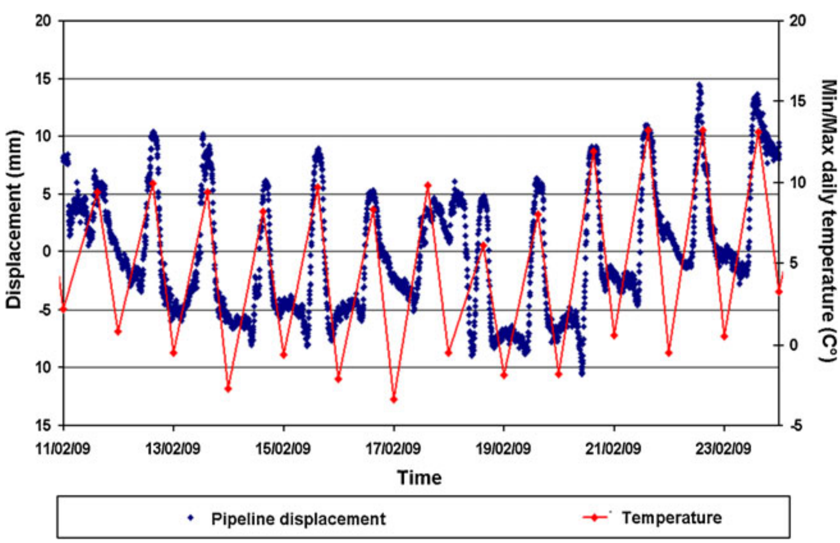
Case 2 In the second case, a continuous monitoring platform (Fig. 4) made of a ground-based SAR interferometer (GBInSAR) has been installed in January 2009 to continuously control the evolution of an earth flow interacting with a pipeline and some houses (Bozzano et al. 2009).

During the first 3 months of monitoring, the landslide moved at a rate ranging from a few millimetres to 1 m per day, mainly depending on rainfalls conditions. However, displacements did not involve the entire mass but they were localized in some specific sectors (Fig. 5). The lack of movements in the scar area suggested that retrogressive processes, that could involve the pipelines, were not occurring. Also, the pipelines showed an overall stability during the entire period of monitoring and only cyclic displacements, in the order of a few millimetres, were recorded and they have been related to night and day temperature variation (Fig. 6).

Conclusions

Application of GBInSAR to real cases allowed to demonstrate the effectiveness of this technique for monitoring landslides interacting with infrastructures and landslides affected by human works. In particular, the areal mapping of displacements over the entire slope is very useful in the case of complex slopes characterized by different deformation patterns. Furthermore, the complete remote monitoring (without the need of any targets on the slope) allowed to control events like earth flows characterized by rapid or very rapid movements that cannot be followed by conventional techniques. Hence, GBInSAR can be considered a new frontier in

Fig. 6 Displacement of the pipeline vs. temperature



monitoring of slopes interacting with infrastructures and a basic tool for mitigating hazard due to landslides.

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