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Cross fertilization in Geoscience: the contribution of ICT to enhance resilience by web-assisted geohazard monitoring for road infrastructures

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Extended Abstract

INTRODUCTION

Non-structural mitigation measures, such as monitoring systems, are broadly used for risk reduction (Angeli et al. 2000; Arattano & Marchi 2008; Lacasse & Nadim 2009) as their impact on the environment and on the vulnerable elements is quite low (Dai et al. 2002). A properly designed monitoring program provides the most important information accurately, precisely and cost-effectively avoiding data loss (De Graff 2011). As the technical possibilities increase with the availability of lighter and cheaper instruments (Baroň & Supper 2013), the focus needs to be switched on data management. In fact, the need for a proper framework to organize, analyse and share data increases when the amount of information gathered from the monitoring network scales (Jaboyedoff et al. 2004; Malet et al. 2013). To this aim ICT (Information and Communication Technology) becomes crucial (Fabbri & Weets 2005) to handle data, automatically identify failures of the system and to enable advance data analysis by a clear and user friendly representation of the monitoring data (Frigerio et al. 2013).

STUDY AREA

In this study an integrated monitoring system in a road tunnel located in Passo della Morte (UD) that serves the National Road 52 is presented. The tunnel is located between the settlements of Ampezzo (East entrance) and Forni di Sotto (West entrance). The tunnel is 2200 m long with both entrances almost at the same elevation, about 730 m a.s.l.. The maximum rock covering is around 370 meters high; the Tagliamento river flows in the valley bottom, at 600 m a.s.l..

A large block slide of 24 million m^3 (Marcato 2007) intersects the tunnel (Fig. 1) causing the formation of tension cracks in the tunnel lining. The national road connects the provinces of Belluno and Udine therefore stopping completely the traffic to avoid the risk of impacts between vehicles in transit and pieces of concrete detaching from the tunnel vault is not an option. There is, however, the old road but it is threatened by collateral movements that were the reason for which the new tunnel was constructed.

Actually, since the construction works started, concerns about the presence of the landslide arose but, as it usually happens in narrow valleys, there were no alternative track for the new structure and it was evident that the tunnel and the landslide needed inevitably to coexist. Therefore, the tunnel was built working with segments of lining hoping to allow some play to dissipate the slow but unremitting movements of the landslide. The displacements though are still inducing tensions inside the tunnel near the sliding surface causing the formation of

evident cracks in the concrete lining. Some small pieces of concrete have already detached, luckily no one was passing in the tunnel in the meantime, however it is clear that the fall of little slabs pose a great hazard for local traffic.
Along the years, the landslide has been investigated by means of GB-SAR (Ground-Based SAR) (Noferini et al. 2007), GNSS (Global Navigation Satellite System), piezometers and inclinometers, some of them fixed and working in real time mode. Nevertheless, these data only partially allow delineating the landslide dynamic, especially in the upper zone, where there is the intersection with the tunnel and the slip surface that in the area is 300 m deep. Moreover, in the tunnel evidences of large subterranean water circulations are present with peak discharges measured in the drainage system after storm events. We believe that this element may trigger accelerations in the movements of the landslide and in the future we want to select a threshold above which trigger an alarm to the local authorities to divert the traffic to the old road.

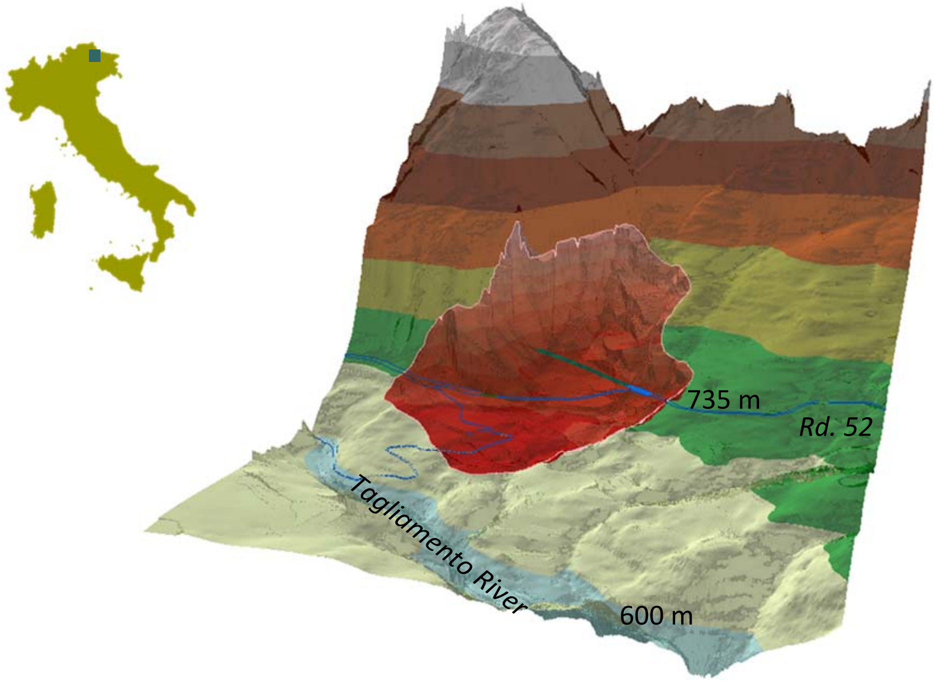

Fig. 1: 3D view of the affected area DTM, in red highlighted the reconstructed slip surface of the block slide, in blue the road network, in green the tunnel

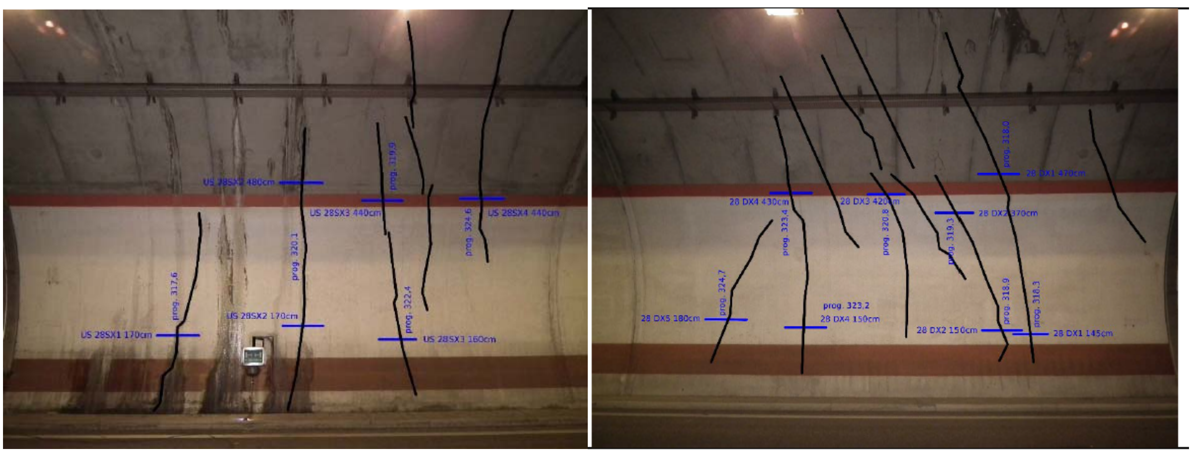

Fig. 2: Tension cracks in the tunnel

NEW MONITORING SYSTEM

To mitigate the hazard of sudden collapse of small portions of the crown of the structure and to monitor the whole phenomenon a system consisting of 8 clinometers and 24 crackmeters has been deployed. The instruments are located nearby the slip surface along major cracks on the vault and between tunnel lining segments. Every element of the monitoring system is now accessible through a user friendly web-based platform which allows researchers and the infrastructure manager to analyse data in real time. Data will be used to analyse correlations between precipitations, temperature variations, subterranean flows and deformations. This analysis will lead to an improved understanding of the phenomenon and, consequently, better mitigation strategies.

Software framework of the platform

A web-based platform with user-friendly interface has been implemented to serve as an effective tool for stake holders and researchers. It is an evolution of the platform presented by Frigerio et al. (2013).
The architecture that is behind the platform is composed by the following components:
A) framework of scripts to serve for data gathering and data fusion and for alarm triggering;
B) database for data storage;
C) web server that hosts the web monitoring portal;
D) php and javascript codes for user interface.
By exploiting the specific features of each component, the platform guarantee an autonomous, real time monitoring platform, capable of triggering alarms. Further, it is capable of integrating different types of sensors, also with different time base. This feature makes the system easily scalable and possibly compatible with redundancy.
In the following, each aforementioned component will be briefly described at the light of the specific contribution given to the platform.

Framework of scripts

The framework of scripts is a collection of codes, written in different programming languages (Bash, C, C++, Python, SQL), that constitutes the skeleton of the platform. Among them, some codes are responsible of collecting the data from instruments (form sources to platform): depending on the specific instrument/data source, this could be implemented by direct request to the sensor, via its own communication protocol, by gathering the data from dataloggers, via any specific protocol implemented by them (e.g. FTP, Telnet, SSH, HTTP,...), by collecting data from file sources (e.g. local files, remote files, files hosted on web,...) or by querying data from other monitoring portal providing a minimum procedure for exporting data. The scripts are modular, so that when new data source are available, a specific script can be written and integrated into the system.
Then, other scripts are responsible for normalization and loading of data into the database structure of the platform. Any aspect about data and information fusion (i.e. integration of data and knowledge from several sources representing the same real-world object into a consistent, accurate, and useful representation) is managed by those script. Finally, other additional scripts are responsible for data analysis and triggering of alarms (from platform to users). Different types of alarms are managed at this level; basically, it is possible to distinguish among three types of alarms: alarms raised when a communication problem occurs, those triggered by anomalous data from sensors, that can be imputed to sensor failure, and those corresponding to dangerous events in the site. Please not that the alarms belonging to the last two classes are not always easily distinguishable, so anytime one of them is raised, it is recommendable to ask for human intervention. Different communication channels are available, e.g. tweets, SMS, emails, etc., and they exploit existing APIs. Finally, an automatic procedure for running the scripts is active: the time period at which each sensor source is interrogated, i.e. each script is run, can be modified, accordingly to hazard status, type of monitoring, speed of events, etc.

Database

The database serving the platform is based on a standard installation of a MySQL server with extension for spatial data. Some basic operations on the data, like moving average and decimation, are realize at database level, due to speed considerations. Further, the databse collects also information of authorized users and user sessions. Backup function for the database is implemented for increasing self-robustness of the platform. The platform, at database level, can communicate to other databases, mostly independently to the specific database management system (e.g. MySQL, SQL, PostGreSQL), via specific connector, like JDBC. This feature, can be consider an additional way for data retrieving and sharing.

Web server

The web server is based on an Apache installation and provides the framework to process the http requests to the portal. Together with the php scripts it provides the frontend of the platform. Large part of the webpages of the portal are indeed written in php. These codes are responsible to ask data and information from the database. Additional codes, written in javascript, are responsible of rendering the graphs of the platfom, and are based on open source visualization APIs. Actually all plots on the platform are based on Dygraphs (www.dygraphs.com), but any other visualization kit can be integrated within the platform. The actual framework of codes at the basis of the user interface of the platform is partially miming some features of the Model-View-Controller achitectural pattern (Burbeck 1987), in particular regarding the division of application functions with respect to the specific problem domain.

As one can note, the system developed is basically a LAMP architecture (Linux-Apache-MySQL-Php) tailored to the specific application of hazard monitoring.

The web-based platform

In Fig. 2, the main web page of the monitoring platform, that reports, graphically, the evolution of the clinometers (two axis for each of the four devices) and of the crackmeters (24 devices) along with their positions inside the gallery is shown.

Data from the two different types of sensor are represented in different plots for clarity but they can be compared to the data about precipitation or with the data about water flow in the drainage system of the tunnel. An opportune time range selector is available to zoom in or out the data. Further, for signals from clinometers and crackmeters, it is possible to calculate the linear rate of variation over a specific time range and represent the corresponding linear fit, for analysis purpose and simple forecasting. Other features exploit functions present in dygraphs APIs, like smoothing average with selectable time window length.

Finally, fig. 3 displays an additional page that shows graphically (i) the actual growth/contraction of the cracks as measured by the crackmeters as colormap, and (ii) the inclination measured by clinometers as arrow map. In particular, the upper graph represents the modulus of the crack width, therefore it does not distinguishing between growth and contraction, but it shows the most active cracks. The graph below instead, shows in blue and red contracting and growing cracks respectively, with more intense color corresponding to more active cracks. In each graph, crackmeters signals have been represented with respect to colorbars with two different magnitude ranges because devices from 17 to 24 show a grow/contraction rate one order of magnitude grater than sensors from 1 to 16

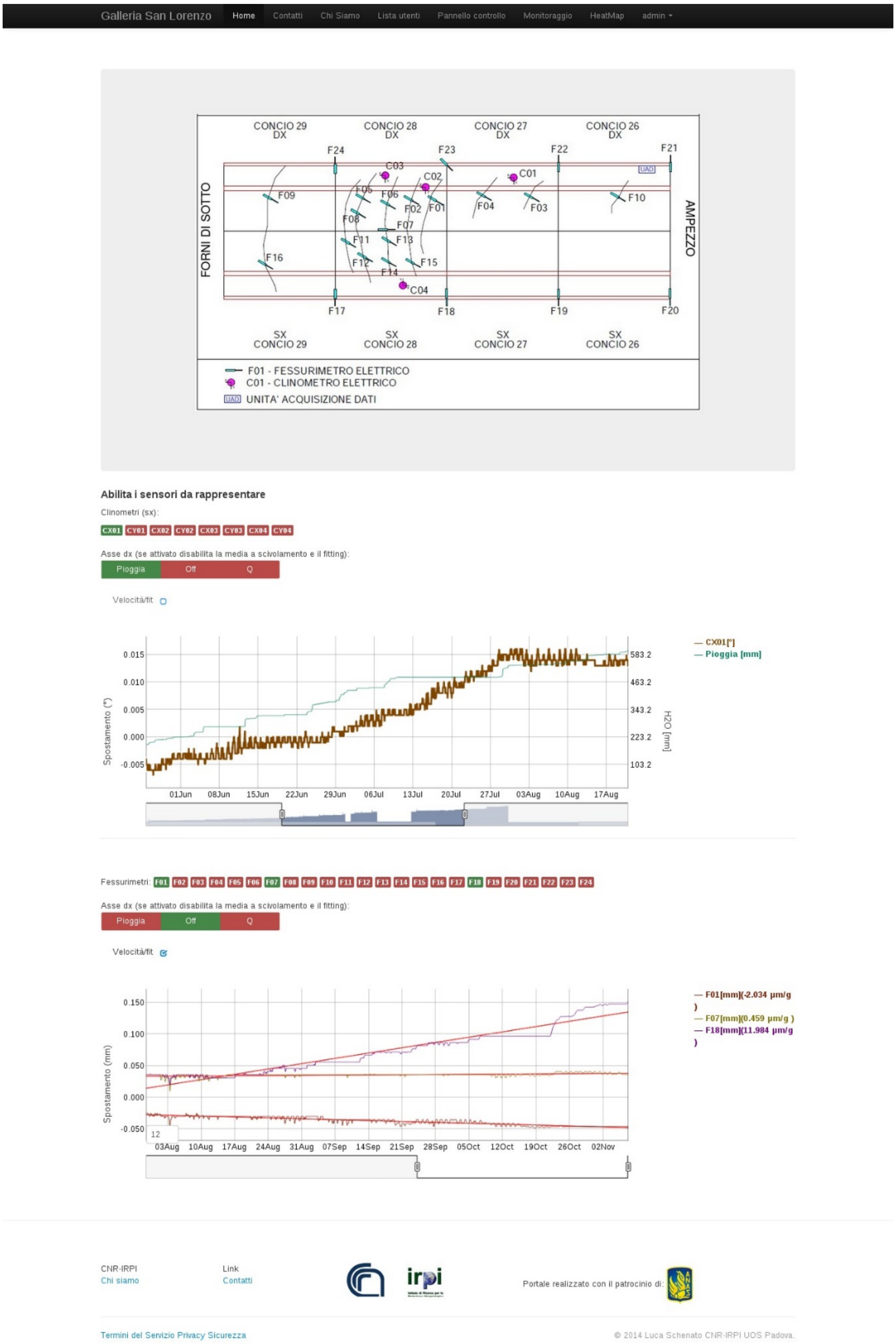

Fig. 2: Main web page of the monitoring platform, with the evolution of the clinometers (two axis for each of the four devices) and of the extensometers (24 devices) along with their positions inside the gallery. Rainfall and water flow can be enabled on request. Other features are the time range slider, the linear regression calculator and the smoothing average on represented signals.

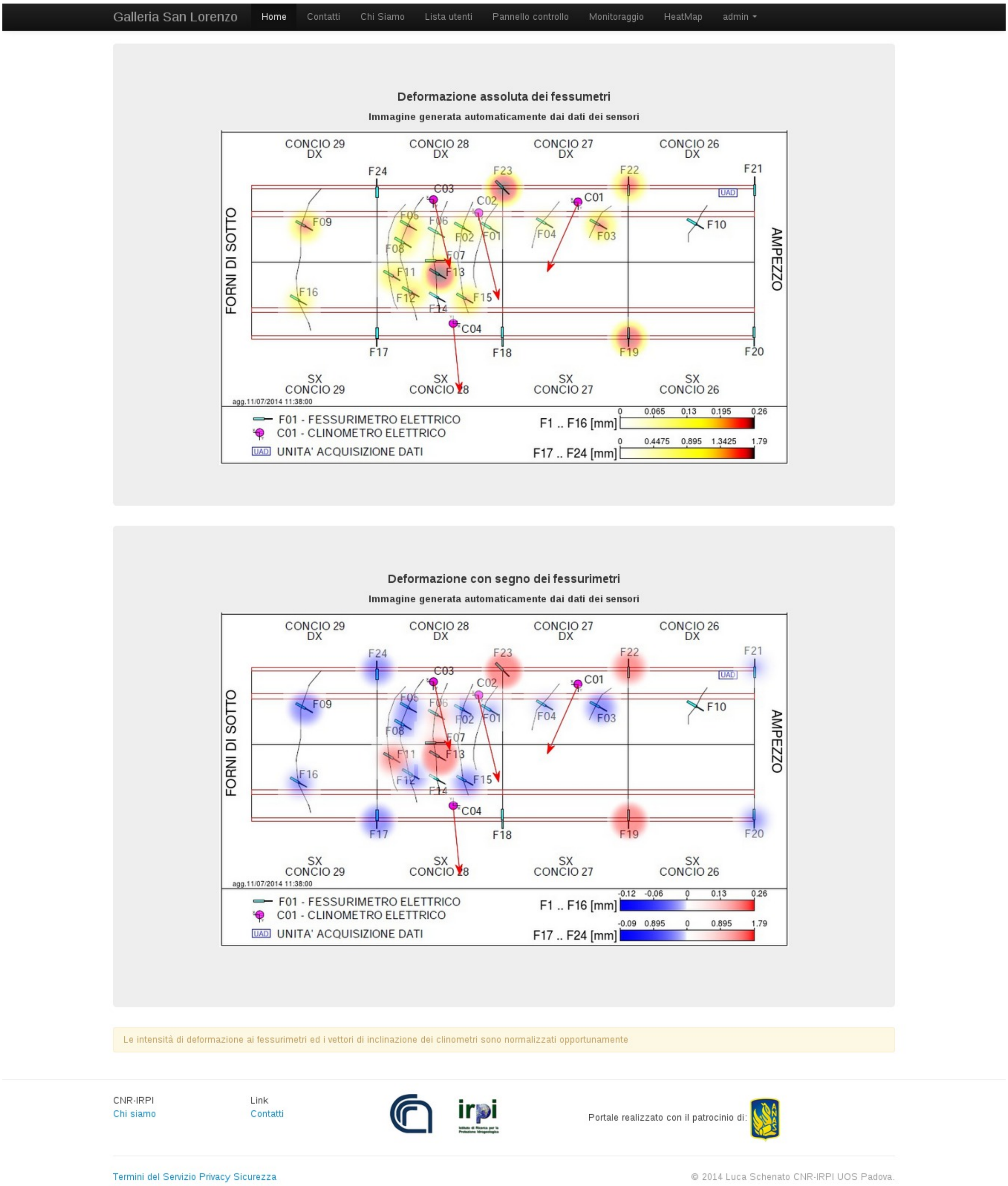

Fig. 3: section on the platform about actual growth/contraction of the cracks as measured by the extensometers as colormap, and inclination measured by clinometers as arrow map. Upper graph represents the modulus of the crack width with respect to the shown colormap. The graph below, instead show in blue and red, contracting and growing cracks, respectively, with more intense color

FUTURE DEVELOPMENT AND FINAL REMARKS

In the following month, a novel optical fiber sensor system based on polymer optical fiber and optical phase interrogation technique will be integrated in the system. That sensor will enable the measurements of cumulative strain along most of the cracks, indeed allowing the monitoring of large areas of the tunnel ceiling. Ultimately, it will allow a more quantitative dynamic fracture analysis of the mechanisms running inside the gallery.

Data gathered from the monitoring system will be analysed for thresholds identification as soon as a significant dataset accumulates, however already a trend of accelerations is evident when important precipitations occur.

The Passo della Morte landslide/tunnel interaction is an interesting example of collaboration for risk management between private and public agencies and research institutions. Moreover, the contribution of ITC enables to analyse in real time data and to communicate between agencies working on the same database. The monitoring network would therefore contribute in reducing the inconveniences to traffic circulation blocks along the National Road. In fact, all the data would probably led to a definite, and hopefully precise, threshold for the failure of parts of the tunnel vault, helping significantly to mitigate the risk.

Redundancy, scalability and integration of different types of sensors in the monitoring system, along with proper data handling, are the keys for an improved overall robustness of complex monitoring system. Ultimately, in the Passo della Morte road tunnel context or, in general, when fundamental infrastructures need to cross hazardous areas, resilience may come from real-time constant monitoring. The associated in-depth knowledge of the phenomenon that such a monitoring definitely provides also to better define possible structural mitigation works.

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