Some examples of landslide monitoring using Trimble equipment in Europe

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Abstract

A better understanding of landslide processes requires a characterization of the triggering factors and their impacts on landslide motion. These factors are often time dependent and for this reason it is very complex to have a quantitative approach without permanent and long-term in-situ observations. To better assess landslide hazards, it is important to document the surficial displacements in space and time and correlate them to meteorological and hydrological conditions. We describe here some examples of geodetic monitoring of landslides using Trimble instruments provided by two companies: Cautus Geo and Spektra Srl. Cautus Geo is a specialist in geomonitoring solutions, automatic monitoring of stability, deformation and environmental parameters (https://cautusgeo.no/). Cautus Geo has installed monitoring systems in some of Europe's largest landslides using different Trimble Total Stations and GNSS receivers. "Spektra Srl – a Trimble Company" monitoring team - has in Italy many case studies of Landslide Monitoring, due to its geomorphology, where human intervention meets areas with geological discontinuities. As an example, the Emilia Romagna region has an expert team (composed by University of Bologna, Modena and members of local Civil Protection Department) that manage the major landslide monitoring systems located in Forlì and in different places along the regional Apennines where Total Station, Monitoring GNSS, geotechnical sensor (tiltmeters, multi parameter chains, meteorological station, etc.) are combined to achieve surface deformation and deep displacement analysis. Hourly based automated measurements ensure trend analysis for safety operations. These systems have been in operation for at least 2 years and remain for an undefined period.

Keywords: Landslides, Monitoring, Trimble equipment

1 Introduction

Landslides are one of the most devastating natural hazards, causing significant loss of life, destruction of infrastructure and economic setbacks worldwide. Triggered by factors such as heavy rainfall, earthquakes, deforestation and human activities, landslides pose a serious threat to both urban and rural communities. The unpredictable nature of landslides makes early detection and continuous monitoring essential to minimise their impact.

Landslide monitoring involves the use of advanced technologies, including remote sensing, ground-based instruments and real-time data analysis, to track land movement and detect warning signs. By implementing effective monitoring systems, authorities can issue timely warnings, plan mitigation strategies and reduce disaster risks. In an era of rapid urbanisation and climate change, landslide monitoring is not just a precaution, but a necessity to ensure safety, environmental sustainability and economic stability.

In this paper, we focus on different landslides in Europe using Trimble equipment (Figure 1). In France, an automated station Trimble S9 monitoring the La Valette landslide (Southern Alps) have been installed by the French Landslides Observatory OMIV “Observatoire Multidisciplinaire des Instabilités de Versants” (Malet et al., 2016, www-ano-omiv.cnrs.fr) (Figures 1 and 2).

In Norway, the companies Cautus Geo and Spectra Srl. Cautus Geos have installed several monitoring systems. These systems cannot be developped here for contractual reasons. In Italy, Spektra Srl – a Trimble company have installed monitoring systems in the Apennines mountains and the coastal region of Ancona (Italy) (Figure 1).

Figure 1. Location of the study landslides in France (La Valette) and Italy (Bagno di Romagna, Dovadola, Vigna and Ancona)

2 La Valette landslide, France

2.1 Geological and geotechnical settings

The La Valette landslide is a well-documented landslide located in the Ubaye Valley, in the French Alps. It is a slow-moving, deep-seated landslide that has been active for several decades, with movement rates varying over time. The landslide was triggered in March 1982 at the contact between these two main geological units. The deformation is attributed to the steep slopes and the increase in pore-fluid pressure resulting from the different hydraulic conductivities of the two geological units (Samyn et al., 2012). The landslide has been subject to numerous investigations using a variety of direct and indirect methods, such as remote sensing (terrestrial and airborne LiDAR), geotechnical analysis of samples recovered from boreholes, and geodetic measurements (e.g., extensometers, inclinometers, GPS), for the spatio-temporal assessment of surface de-formation (Raucoules et al., 2013; Malet et al., 2013; Travelletti et al., 2013).

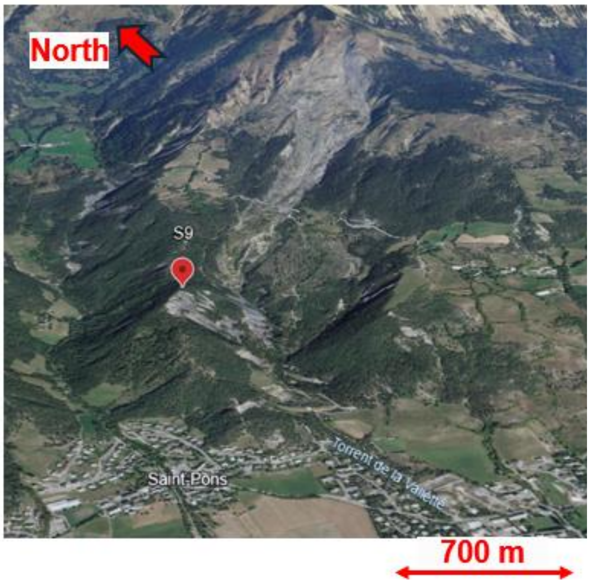

Figure 2. La Valette landslide in France and location of the Trimble S9 total station (Ferhat et al. 2024)

2.2 La Valette monitoring system

In September 2019, a Trimble S9 total station has been installed and observed reflectors every 1 or 3 hours (Figures 3 and 4; Ferhat et al., 2020, 2024). The targets are distributed along the whole landslide with a higher density in the lower zone which is supposed to be more susceptible to accelerating and because it is closer to the inhabited area downstream (Figure 3).

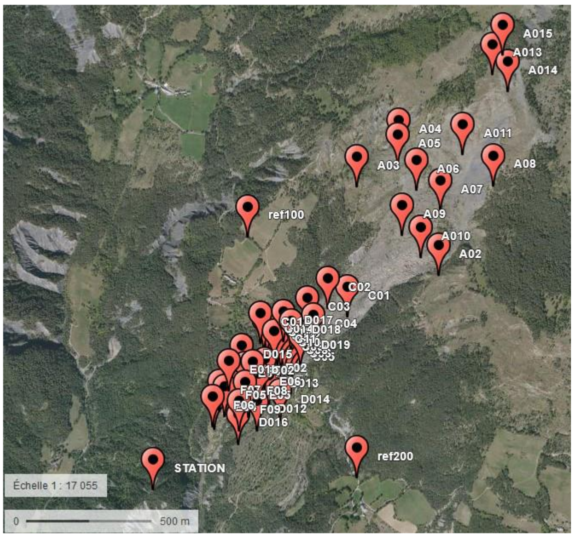

Figure 3. Location of the total station and the 54 targets at the La Valette landslide. The targets are positioned at distances from 350 to 2300 m and elevation from 1300 to 2100 m (Ferhat et al., 2020).

Figure 4. The Trimble S9 automated total station installed at la Valette landslide (Southern Alps, France)

3 Bagno di Romagna landslide, Italy

3.1 Geological and geotechnical settings

Bagno di Romagna, located in the Savio river valley in the Tuscan-Romagna Apennines, is an area characterized by a complex interaction between geology, morphology and hydrological dynamics, making it particularly prone to landslides (Figure 5). The valley, cut by the river, has steep slopes and a very active surface and underground hydrography, creating ideal conditions for the development of soil instability.

The geology of the area is dominated by the Marly-Arenaceous Formation, a succession of sedimentary rocks that alternate layers of sandstone (more resistant) with layers of marl and pelite (more fragile and susceptible to alteration). This alternation of layers, with different geotechnical and hydraulic properties, creates a complex underground architecture that facilitates the triggering of landslides.

In addition to the Marly-Arenaceous Formation, there are also colluvial deposits consisting of heterogeneous detrital material accumulated along the slopes because of erosion and gravitational transport phenomena. These deposits, which are often not consolidated, represent another factor of instability in the area.

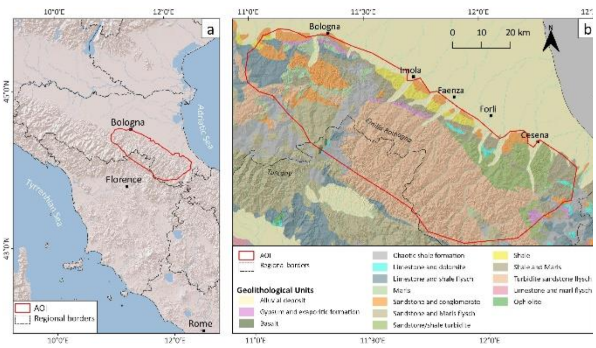

Figure 5. a) Location of part of the Apennines mountains (Notti et al., 2024) (b) simplified lithological map based on 1:500.000 scale lithological map of Italy (MASE, 2009)

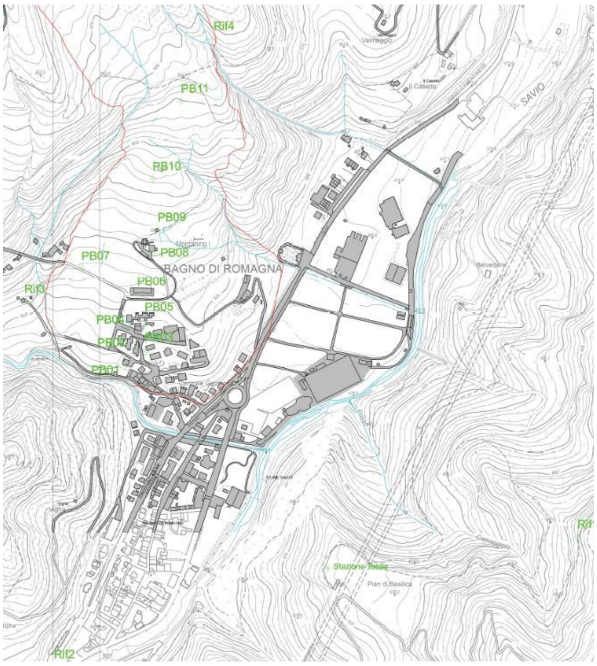

Figure 6. Location of the total station, references and targets at Bagno di Romagna landslide (Italy)

From a geotechnical point of view, however, the characteristics of the soils of Bagno di Romagna present several critical issues:

• Low Cut Strength**:** Marl and pelite, once altered and saturated with water, have a low-cut resistance, i.e. a limited ability to resist the forces that tend to make them slip.

• High Plasticity: The clays present are characterized by high plasticity, which makes them easily deformable even under modest loads.

• Erosion at the foot of the slopes: The erosive action of the Savio river and its tributaries destabilizes the foot of the slopes, favoring the detachment of soil masses and the retrogression of landslides.

Considering these geological and geotechnical characteristics, the monitoring of the landslide in Bagno di Romagna assumes crucial importance for several reasons:

• Complexity of Landslide Phenomena: The complex geological stratigraphy and the variety of landslide movements make it difficult to predict the behavior of landslides. Continuous monitoring is necessary to understand its evolution and predict any critical scenarios (Figures 6 and 7).

• Presence of Population Centers and Infrastructures: Landslides threaten homes, infrastructures (roads, bridges) and local economic activities, making a monitoring system essential for the safety of people and the protection of property.

• Identification of Warning Signals: Monitoring allows you to detect ground deformations, variations in the speed of movements and other warning signs of instability, allowing you to promptly activate civil protection measures.

The combination of complex and fragile geology, unfavorable geotechnical conditions and active hydrological dynamics, makes Bagno di Romagna a particularly vulnerable area to landslides. In this context, monitoring, understood as a continuous process of observation, measurement and interpretation of phenomena, is an irreplaceable tool for understanding, managing and mitigating hydrogeological risk, ensuring the safety of people and the sustainability of the territory.

3.2 Landslide monitoring

In this case, the monitoring system consists of a long-range total station which, at set times, performs measurement cycles on prisms placed at strategic points of the landslide.

Figure 7. Trimble S9 Long Range total station at Bagno di Romagna landslide (Italy)

As illustrated on Figure 8, time series of targets are plotted during a period in 2024.

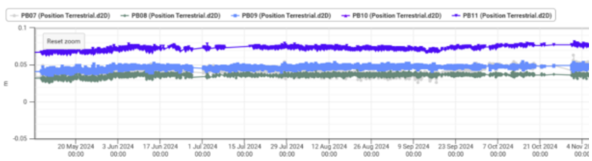

Figure 8. Example of time series of position of targets at the Bagno di Romana landslide (Italy)

4 Bagno di Romagna landslide, Italy

4.1 Geological and geotechnical settings

The site of the Dovadola and Vigna landslides, located in the Apennine hills of Emilia Romagna, has a territory characterized by steep slopes and a geological substrate that makes the area particularly susceptible to landslides (Figure 5). Significant slopes, which can exceed 30°, increase the likelihood of ground instability, especially in adverse weather conditions.

The geological features of the site include a variable soil composition, which mainly includes clays, marls and limestones. These soils are notoriously prone to slippage phenomena, especially clays, which are expansive and react strongly to changes in moisture. The presence of unstable rock layers and geological discontinuities, such as fractures and faults, further increases the vulnerability of the area to rotational or translational landslides. These phenomena are more likely in soils characterized by a low cohesive stratification and a poor drainage capacity.

From a geotechnical point of view, the site is particularly sensitive to the surface water table. The presence of water in the subsoil, combined with the low permeability of some layers, causes an increase in interstitial pressure that can reduce cohesion between soil particles, facilitating the detachment of portions of soil during heavy rainfall. The circulation of water in the soil also makes the site prone to rapid liquefaction or slipping, which is facilitated by excessive humidity.

4.2 Dovadola and Vigna monitoring systems

Monitoring in this area is essential for several reasons. Heavy seasonal rainfall, which occurs mainly in autumn and winter, increases the risk of surface erosion and promotes ground movement, bringing out signs of landslides that could involve homes, farmland and infrastructure. Ground deformations, such as cracks or displacements, could anticipate landslide events, requiring accurate geotechnical monitoring to detect these signals and assess the extent of the risk by controlling the degree of soil saturation (using soil moisture sensors) in correlation with rainfall data.

In addition, moderate seismic activity in the region could trigger further ground movements, accentuating the risk of landslides in already unstable terrain.

Continuous monitoring allows you to collect crucial data on the behavior of soil and rock over time, such as the speed of movement of slopes, changes in groundwater level and ground deformations. This information is crucial for taking preventive measures and protecting the safety of people and infrastructure, such as building drains, reinforcing slopes, and adopting soil stabilization techniques Figure 9, 10, 11 and 12).

Figure 9. Monitoring system, geotechnical sensors, at Dovadola site (Italy)

Figure 10. Locations of reflectors at Dovadola site (Italy)

Figure 11. Dovadola site, Trimble S9 total station (Italy)

Figure 12. Poles equipped with reflectors at Dovadola site (Italy).

5 Ancona landslide, Italy

5.1 Geological and geotechnical settings

The Ancona landslide, which affected the area of the municipality of Posatora, develops along a coastal slope characterized by a steep and complex morphology (Figure 13). This slope is the result of a combination of tectonic, erosive and gravitational processes, which over time have shaped the territory and made the area particularly vulnerable. The landslide was triggered in an area connecting the hill and the coast, with considerable exposure to the actions of atmospheric agents and the sea.

From a geological point of view, the Ancona area is characterized by limestone and marly-limestone formations with clay and sandy soils, whose lithological composition can influence the stability of the landslide due to the parameters of cohesion and resistance of the soil.

In addition, the presence of faults, fractures or other structural discontinuities in the subsoil creates planes of weakness in the soil, facilitating the detachment and sliding of blocks.

From a geotechnical point of view, the combination of these geological factors determines the following critical issues:

- **Poor shear resistance**: marls, once altered and saturated with water, have a low shear resistance. This means that their ability to resist the forces that tend to cause them to slide is limited, making them easily prone to landslides.
- **Presence of sliding surfaces:** The discontinuity surfaces, both geological and structural, present in the subsoil can act as preferential sliding surfaces, especially in the presence of water that lubricates and weakens the contact areas.

5.2 Ancona site monitoring

Considering these geological and geotechnical characteristics, the monitoring of the Ancona landslide becomes essential for several reasons, such as the identification of pre-landslide deformations, the prevention of risks for people and infrastructures, risk management by allowing the data collected by monitoring to constantly assess the level of risk and to adopt more effective land management strategies.

The Ancona landslide is an emblematic example of how the geological and geotechnical characteristics of an area can make it particularly vulnerable to landslides.

Figure 13. Locations of monitoring pointsat Ancona site (Italy)

For the monitoring system we are using various technologies (inclinometers, total stations, GPS) indispensable tools for understanding and managing hydrogeological risk, allowing us to adopt effective and timely prevention and mitigation measures (Figure 13).

Given the geomorphology and the vastness of the area of interest to be monitored, integrated monitoring was opted for, creating a GPS network with 3 bases outside the landslide and 5 stations in the landslide area.

These stations determine the coordinates of the reference points used by the total station, thus having a network of reference points with dynamic coordinates (Figure 14).

Surface monitoring is supplemented by subsurface monitoring, consisting of multi-parameter columns and piezometers.

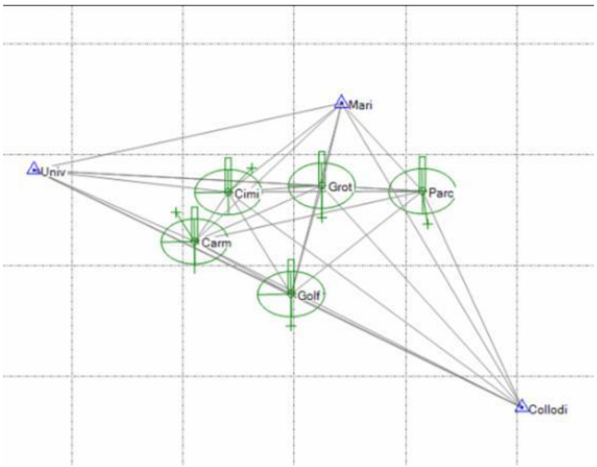

Figure 14. Geodetic network at Ancona site (Italy)

Figure 15. Monitoring system, integrated Trimble S9 total station & Trimble R750 GNSS receiver at Ancona (Italy)

6 Conclusion

This paper illustrates some monitoring systems installed in Europe (France and Italy). The study sites are located in mountainous or coastal areas. On these landslides, geodetic monitoring is carried out by means of an automated tachymeter, which provides regular measurements on targets located on the slide zones and uses several reference targets. GNSS and geophysical measurements are also carried out.

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