Geotechnical Safety and Risk V
T. Schweckendiek et al. (Eds.)
© 2015 The authors and IOS Press.
This article is published online with Open Access by IOS Press and distributed under the terms of the Creative Commons Attribution Non-Commercial License.
doi:10.3233/978-1-61499-580-7-803

Reliability of GBInSAR Monitoring in Ingelsberg Landslide Area (Bad Hofgastein, Austria)

Saverio ROMEO [a], Daniel Scott KIEFFER [b], Lucio DI MATTEO[a]
[a] *Department of Physics and Geology, University of Perugia, via A. Pascoli snc, 06123, Perugia, Italy. e-mail: saverioromeo7@gmail.com; lucio.dimatteo@unipg.it*
[b] *Institute of Applied Geosciences, Graz University of Technology, Rechbauerstraße, 12/EG, A-8010, Graz, Austria. e-mail: kieffer@tugraz.at*

Abstract. The present work shows and discusses the GBInSAR measurements for the Ingelsberg area, where one of the most dangerous landslide of Salzburg region is located (Bad Hofgastein – Austria). It is a rockfall developing on an area of about 40000 m^2 which is characterized by the outcropping of anti-dip stratified green and calc-mica schists. The GBInSAR monitoring campaign started on March, 2013 (scan time of about 5 minutes): data acquired by the radar instrument were integrated with those from other traditional monitoring systems consisting in 3 cameras placed near the slope and 5 extensometers placed in the landslide Head Area. In order to evaluate the reliability of GBInSAR monitoring, a comparison with displacement data from extensometers was made. During March-December 2013 at least 5 events were observed, the main of which occurred during April-May-June period (3 events), representing a key period for the landslides occurrence in this region. Taking as reference this period, the comparison of the two monitoring techniques showed a good correlation, indicating that the monitoring system of the Ingelsberg landslide is reliable and useful for further analysis, such as the application and checking of the techniques to predict the time to slope failure (TSF).

Keywords. Landslide, GBInSAR, Monitoring, Reliability, Ingelsberg landslide

1. Introduction

In the last decade, integrated surface displacement monitoring of unstable slopes was widely developed and used (Aloisi et al., 2003; Puglisi et al., 2005; Mattia et al., 2007; Bertacchini et al., 2009). In this framework, the use of GBInSAR technology (Groung-Based Interferometric Synthetic Aperture Radar) for the monitoring of large landslide areas is increased (Tarchi et al., 2003; Bozzano et al., 2010; Mazzanti, 2011).

GBInSAR measurements can be useful to implement an early warning system using deformation parameters like ground displacement or inverse velocity. The great advantage of this technique is that measurements of the surface displacement are carried out remotely, being helpful for the surveillance of the ongoing phenomena as well as for checking the efficiency of consolidation interventions. The acquired data may be also useful to calibrate landslide models. Even if technological development has been improved, studies on the reliability of GBInSAR measurements are of paramount importance and crucial for the evaluation of the overall performance of the monitoring system. In order to analyse the reliability of GBInSAR monitoring, data from the Ingelsberg landslide (Salzburg region, Austria) are analysed and discussed with those from other monitoring techniques, such as extensometers.

2. The Ingelsberg Landslide

2.1. Geological Setting

The Ingelsberg landslide is located in the middle Alpine region at an altitude between 1100-1500 m a.s.l. (Salzburg Bundesland, Austria - 47°10'53.8"N; 13°06'40.0"E). The slope is characterized by anti-dip stratified rocks composed by green and calc-mica schists having and average orientation of 010/25° for the schistosity (Romeo et al., 2014). According to Goodman and Kieffer (2000) - due to several

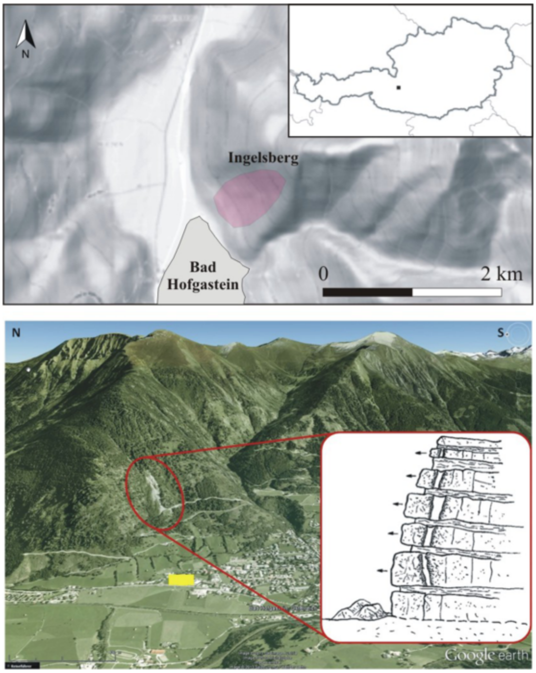

Figure 1. Panoramic view of the Ingelsberg landslide (base map modified from Google Earth, 2014) and rupture mechanism according to Goodman and Kieffer (2000); the yellow rectangle represents the location of GBInSAR (modified from Romeo et al., 2014).

fractures and joints - the main rupture mechanism is the stress relief via “pseudo-sheeting” (Fig. 1). It is a rock fall developing on an area of about 40000 m^2: talus produced by rock falls accumulates along two main channels and is periodically moved as a consequence of heavy rainfalls or melting snow.

The first event recorded dates back to May 1931: due to several heavy rainfall events, in the last decade the intensity of phenomenon seems to be intensified, prompting local authorities to implement a continuous monitoring of the landslide.

2.2. The Survey

Thanks to the collaboration of the Bad Hofgastein municipality, an intense monitoring campaign was carried out between March and December, 2013.

A Ground-Based Interferometric Synthetic Aperture Radar (GBInSAR) was installed. This equipment performs real-time remote monitoring of terrain deformations with sub-millimeter accuracy. GBInSAR is an innovative technique for monitoring movements, and it is based on the same principles of SAR satellite. In other words, GBInSAR provides a remotely sensed measurement of ground displacements: it is an active microwave acquisition sensor that provides its own illumination and measures the reflected signal. It is able to supply a deformation map of the investigated ground portion, without the necessity of positioning targets on the ground and without any physical contact with the slope (Bozzano et al., 2010; Mazzanti, 2011). The radar (Fig. 2) was placed at about 1.2 km away from the slope along NE-SW direction: this location was chosen according to a landslide displacement vectors map produced by Wilhelmstötter (2013).

Figure 2. Photo of installed equipment.

Additionally, 5 extensometers were installed in the main cracks and joints (Fig. 3) located in the upper zone of the landslide: these cracks are up to 10 m deep and up to 2 m wide. Only 4 of the 5 initial instruments have acquired data. These instruments have an accuracy of tenths of millimetres.

Figure 3. Photo of one extensometer within the crack in the *Head Area*.

3. Results

In order to check the reliability of GBInSAR technique, a comparison between data acquired by the radar instrument and those from extensometers was carried out.

Using preliminary GBInSAR data, the Ingelsberg slope was divided into zones with similar characteristics (e.g., lithology, response to rainfall and snow). The slope is composed of a source area in the upper part where rock falls occur (*Head Area*), areas of debris accumulation and stable rock walls. The data from extensometers were compared only with GBInSAR measurements for the landslide *Head Area* because is certainly the part to be monitored most carefully. Moreover, the extensometers are located about 10 m behind the *Head Area*.

It is interesting to point out that the displacement values in the areas of debris accumulation is of one order of magnitude higher than that of the *Head Area*. Although movements registered in *Head Area* are much less than those of debris accumulation areas, the use of extensometers measurements allows to check the quality of radar observations. The extensometers record the opening movement within the main cracks (punctual measurement), while the radar measurements detect the superficial displacement (punctual/areal measurement). Conventionally, in GBInSAR technique, displacement is positive if the pixel moves away from the sensor and it is negative if the pixel moves towards the sensor (Hanssen, 2001).

As shown in Figure 4, trends of the measurements in 3 different main events were

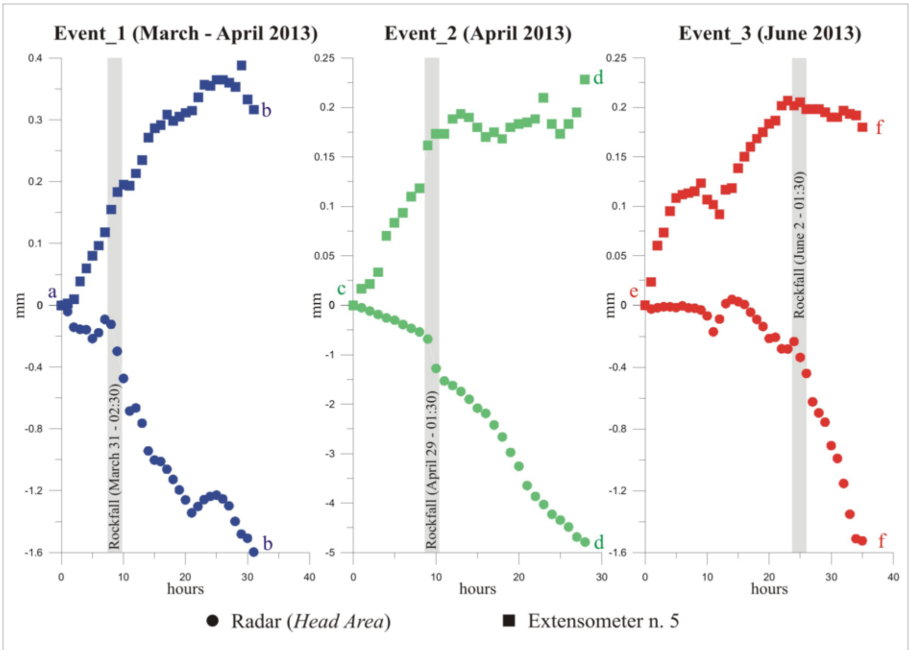

Figure 4. Displacement trends of extensometer and radar data for different events monitored. **a**: March 30th - 20:30; **b**: April 1st – 03:30; **c**: April 28th – 16:30; **d**: April 29th – 20:30; **e**: June 1st – 00:30; **f**: June 2nd – 11:30.

analyzed. It is important to clarify that these measurements refer only to limited periods within extended landslide events. Rockfalls occurred shallow movements with an order of magnitude higher have indeed reached or triggered. Although monitoring instruments used allow a brief scan time (es. GBInSAR scan time of about 5 minutes), for the purpose of this study an hourly average of all measurements recorded was preferred in order to achieve a better and effective comparison.

Displacement trend is well identified in Figure 4 both for extensometers and for radar, even if extensometers show a stepped trend. At the beginning of observations, radar data show an almost stable behavior (movements less than 0.5 mm for the three events) while measures by extensometers clearly increase. This trend is broken by a sudden acceleration of the shallow displacement recorded by radar. After the activation of rock falls (detected also by cameras), a gradual stabilization of the values recorded by extensometers is observed: thus, as expected, the rock falling produces a reduction of rock mass in the *Head Area* causing the drastic reduction of displacements within the fractures and joints. Thereafter, tensions along fractures gradually increase up to the next event.

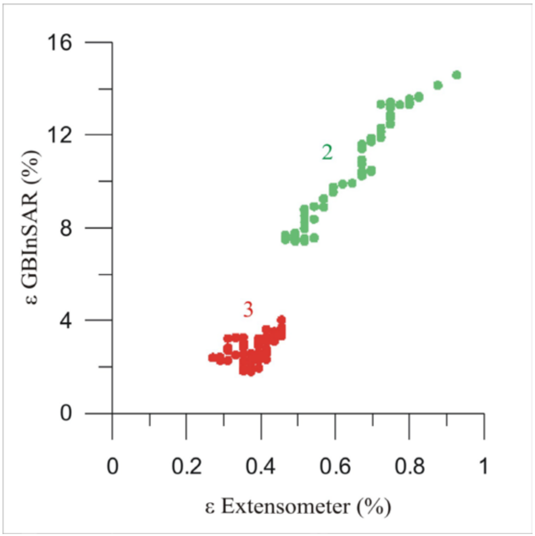

Figure 5. Relationship between percent displacement measured by radar and by extensometers for events n. 2 – 3.

Figure 5 shows the comparison between percent displacement values (ε) recorded each 10 minutes by GBInSAR and extensometer (data are referred to about 10 hours before the occurrence of rockfall events). Analysis has been carried out on Event 2 and 3 (Figure 4) the data of which have been acquired simultaneously and useful for inter-rater reliability analysis: Pearson correlation coefficient values of 0.9 and 0.5 for Event 2 and 3 were obtained respectively, indicating a moderate to substantial inter-rater reliability according to benchmark scales known in the literature (Cohen, 1988).

4. Discussion and Conclusion

The use of innovative technologies for remotely monitoring of shallow movements, are improving knowledge on landslide phenomena. Despite, in the last decade the use of these technologies are increased, depth analyses on the reliability of the GBInSAR measurements are lacking and/or aimed mainly at the comparison with others landslide surface observations (GPS, etc.). The multi-instrumental approach is essential to investigate movements both in surface and in depth. In fact, the use of different monitoring techniques allows to perform a cross analysis of the data and to minimize errors, checking the data quality and improving the monitoring system.

In order to implement early warning systems able to monitor the evolution of landslides in near real-time, the integration of different techniques plays a key role. As shown for the Ingelsberg landslide, GBInSAR measurements are reliable and consistent with those recorded in depth by extensometers, at least for the *Head Area*. The data here presented should be useful to apply and improve some prediction methods such as the well-known Fukuzono (1985). GBInSAR monitoring for early warning system were used to manage some landslides in Italy making successfully results (e.g., Allasia et al., 2013; Casagli et al., 2010; Pratesi et al., 2015). The results here obtained indicate that this remote sensing system could be used to perform an efficient monitoring also in the Ingelsberg landslide, improving the knowledge on landslide behavior and making available data to national authorities for emergency management.

References

Allasia P., Manconi A., Giordan D., Baldo M., Lollino G. (2013). ADVICE: A New Approach for Near-Real-Time Monitoring of Surface Displacements in Landslide Hazard Scenarios. *Sensors,* **13**, 8285-8302.

Aloisi M., Bonaccorso A., Gambino S., Mattia M., Puglisi G. (2003). Etna 2002 eruption imaged from continuous tilt and GPS data. *Geophysical research letters* **30** (23): 2214.

Bertacchini E., Capitani A., Capra A., Castagnetti C., Corsini A. (2009). Integrated surveying system for landslide monitoring, Valoria landslide (Apennines of Modena, Italy). *Proceedings of FIG Working Week 2009*. Eilat, Israel. ISBN 978-87-90907-73-0.

Bozzano F., Mazzanti P., Prestininzi A., Scarascia Mugnozza G. (2010). Research and development of advanced technologies for landslide hazard analysis in Italy. *Landslides*.

Casagli N., Catani F., Del Ventisette C., Luzi G. (2010). Monitoring, prediction, and early warning using ground-based radar interferometry. *Landslides* **7,** 291–301.

Cohen J. (1988). *Statistical Power Analysis for the Behavioral Sciences*, 2nd Edition. Hillsdale, N.J.: Lawrence Erlbaum.

Fukuzono T. (1985). A new method for predicting the failure time of a slope. *Proc. of IV ICFL. Japan Landslide Soc*., 145–150.

Goodman R.E., Kieffer D.S. (2000). Behavior of rock in slopes. *Journal of Geotechnical and Geoenvironmental Engineering* **126** (8), 675–684.

Hanssen R.F. (2001). *Radar Interferometry: Data Interpretation and Error Analysis*. Kluwer Academic Publishers, Dordrecht, pp. 328.

Mattia M., Bonaccorso A., Guglielmino F. (2007). Ground deformations in the Island of Pantelleria (Italy): Insights into the dynamic of the current intereruptive period. *Journal of geophysical research* **112** (B11406).

Mazzanti P., Brunetti A. (2010). Assessing rockfall susceptibility by Terrestrial SAR Interferometry. In: Malet J.P., Glade T., Casagli N. (eds), *Proceedings of the Mountain Risks International Conference*, Firenze, Italy, 24-26 November 2010, pp. 109-114.

Puglisi G., Bonaccorso A., Mattia M., Aloisi M., Bonforte A., Campisi O., Cantarero M., Falzone G., Puglisi B., Rossi M. (2005). New integrated geodetic monitoring system at Stromboli volcano (Italy). *Engineering Geology* **79** (1-2): 13-31.

Pratesi F., Nolesini T., Bianchini S., Leva D., Lombardi L., Fanti R., Casagli N. (2015). Early Warning GBInSAR-Based Method for Monitoring Volterra (Tuscany, Italy) City Walls. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 02/2015.

Romeo S., Kieffer D.S., Di Matteo L. (2014). The Ingelsberg landslide (Bad Hofgastein, Austria): description and first results of monitoring system (GBInSAR technique). *Rend. Online Soc. Geol. It*. **32** (2014), pp. 24-27.

Tarchi D., Casagli N., Fanti R., Leva D., Luzi G., Pasuto A., Pieraccini M., Silvano S. (2003). Landslide monitoring by using ground-based SAR interferometry: an example of application to the Tessina landslide in Italy. *Engineering Geology* **68**, 15–30.

Wilhelmstötter F. (2013). Geotechnisch-Geologische Untersuchung des Felssturzgebietes Ingelsberg/Bad Hofgastein. Unpublished Master's Thesis, Institute of Soil Mechanics and Foundation Engineering, Technical University of Graz.