THE SECOND WORLD LANDSLIDE FORUM

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Detection and characterization of rock slope instabilities using a portable radar interferometer (GPRI).

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Abstract A portable radar interferomter was used to periodically monitor a rock wall, where millimeter-scale displacements (0.5-0.6 mm/month) on an unstable rock slab were detected. Preliminary interpretation of a radar images acquired over a 5 month period revealed evidence for combined toppling and buckling failure mechanisms on the rock slab. The rock wall of interest has a history of block fall activity, which directly endangers a roadway in Canton Graubünden, Switzerland.

Keywords Portable radar interferometer, ground based radar interferometry, rock fall.

Introduction

The detection of discrete instabilities on rock slopes are often problematic because failure may only be noted when it reaches an easily detectable state, for example when surface morphological features develop, or in the worst case failure occurs unexpectedly with apparently little warning. Traditional methods such as those utilizing laser distance metering (e.g. total stations etc) or *in situ* methods such as tilt meters, extensometers etc, are limited by their capability to measure single points only. Therefore, to attain large area coverage, and to reduce the uncertainties related to the 'geological extrapolation' between measured points, a great deal of instrumentation is required.

Ground-based remote sensing is an increasingly attractive alternative to traditional methods due to its high precision and sensitivity to measuring displacements in a spatial and temporal context. In particular, radar interferometry has been established in recent years as a reliable method for spatial displacement monitoring of rock slopes (e.g. Leva *et al.* 2003, Tarchi *et al.* 2003a Tarchi *et al.* 2003b). Preliminary results from a monitoring campaign on a rock wall are presentedin this study, where a portable radar interferometer (GPRI-I) was used to detect and monitor mm-scale displacments taking place on a large rock slab.

Methods and Results

The portable radar interferometer (GPRI-I)

GPRI-I (Gamma portable radar interferometer, version 1) is a new development in ground-based radar technology for measuring deformation. The GPRI-I is an FMCW radar with a fan-beam antenna array that rotates around a central axis. The system combines great portability, high precision and a rapid sampling rate of up to 10 degrees per second (Werner *et al.* 2008, Wiesmann *et al.* 2008). The system allows for a flexible set-up, which includes a standard geodetic tripod and/or survey monuments that are designed for traditional geodetic survey instruments such as tachymeters and GPS systems etc.

Case study: Block failure at Soazza

Soazza is located in the southern part of Canton Graubünden, Switzerland, adjacent to a state roadway (Fig 1).

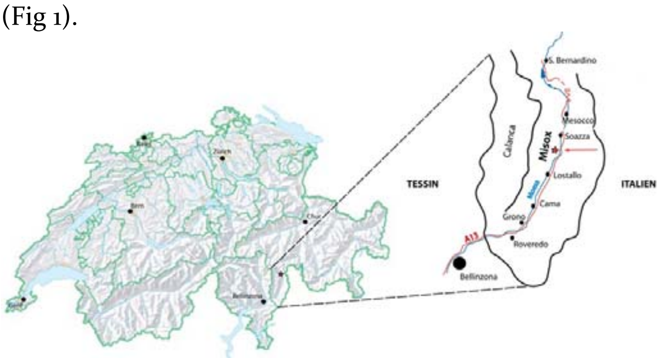

Figure 1 Location of the case study area, Soazza in Switzerland.

The locality consists of a rock wall approx. 600m in length and 300m in height that has been the scene of several block failures, the largest of which occurred in 2007 (~3000m3), followed by two smaller failures in 2008 and 2009 (Fig 2). The rock fall activity directly endangers a roadway running parallel near the foot of the slope in Canton Graubünden, Switzerland.

Figure 2 The rockwall at Soazza showing sites of previous block failure.

In collaboration with the state road authority of Graubünden, radar interferometric measurements were undertaken as part of research project into rock fall release mechanisms in March 2010. Repeat measurements took place in May and August of the same year. Measurements where undertaken with the GPRI-I using a standard geodetic set-up, where the radar was levelled and centred with reference to a fixed survey point (Fig 3). During each campaign, 3-4 hours of continuous data was acquired with the antennae programmed to rotate through a sector of about 70°.

Figure 3 Set-up of the GPRI-I at Soazza using a survey tripod, levelled and centred with respect to a fixed point.

Results of the March – August 2010 campaigns are shown in figure 4 as a 5 month interferogram depicting cumulative displacements for the three measurement campaigns undertaken.

In figure 4, a reflectivity image (e.g. intensity of backscattered energy) is overlain by a filtered interferogram where atmospheric phase noise has been removed. Points, A, B and C have been included to aid the reader's orientation with respect to the rock wall. Clearly visible is the slightly defocused top edge of the rock wall (which is lined with vegetation), areas of backscattering consisting of both strong and weak natural reflectors, and forested areas directly at the foot of the rock wall. Coherent signals are evident on the rock wall, whilst decorrelation is notable in the vegetated areas.

Details of the March to August radar acquisitions are shown as a series of interferograms in figure 5. Interferograms in figure 4 are displayed in radar coordinates (e.g. range and azimuth). "A" demonstrates the relatively good phase stability for the reference measurement taken in March 2010, "B1" is an unfiltered interferogram for the period March-May 2010 showing a linear atmospheric effects on phase, whilst "B2" has atmosphere removed using a low-pass filtering method. A notable feature in "B2" is the emergence of a weak signal corresponding to the rock block adjacent to the failure from 2007 (deformation signal indicated with arrow). "C2" shows the interferogram for the interval May-August 2010, where the previous "weak" signal is stronger and more evident (deformation signal indicated with arrow).

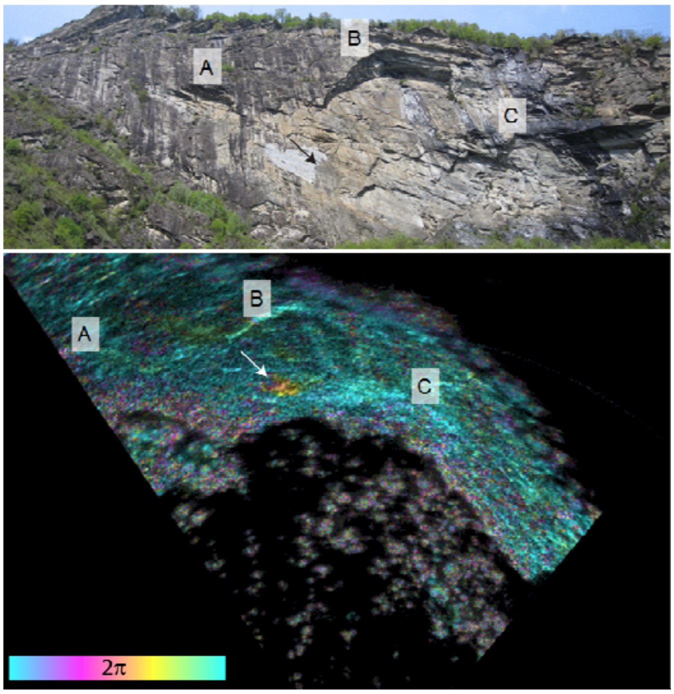

Figure 4 Interferogram showing total displacements for the period March – August 2010.

Discussion

Spatially distributed displacements measured at Soazza show a discrete area of movement corresponding to a large rock slab similar in dimension to the block failure of 2007 (~3000 m^3).

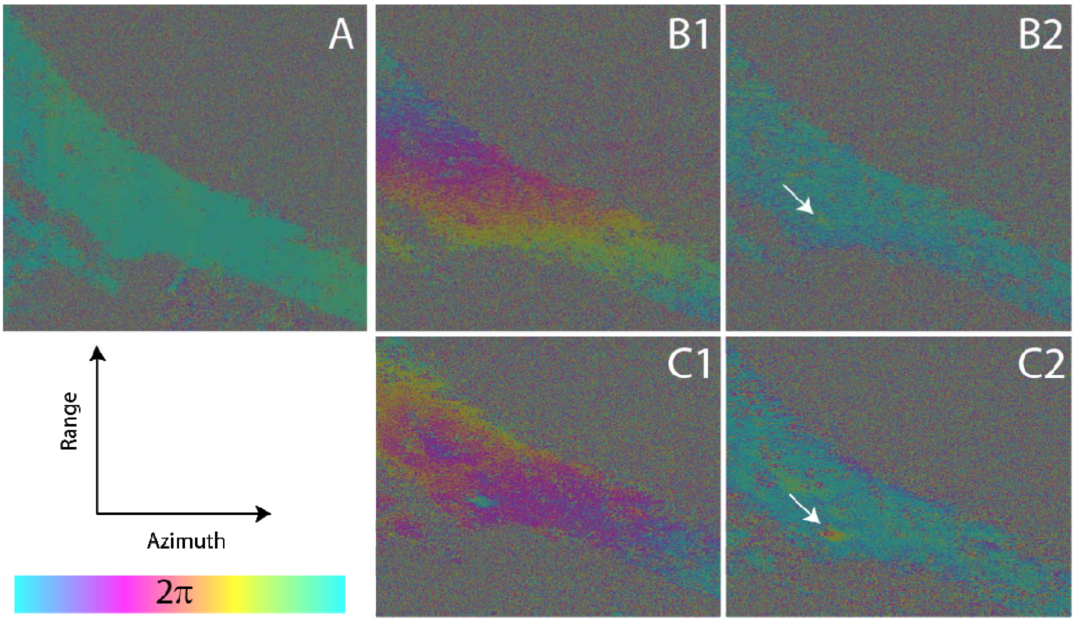

Figure 5 Interferograms for three measurement intervals undertaken at Soazza (see text for details). A: March 2010 reference measurement, B1 & B2: March – May 2010, C1 & C2: May – August 2010.

Qualitatively, the displacement field shows a relatively rapid change in the displacement gradient (i.e. velocity changes over a short distance) towards the lower boundary, whilst toward the right-hand boundary the gradient is apparently more gradual. The upper boundary of the block is also characterized by a relatively gradual displacement gradient.

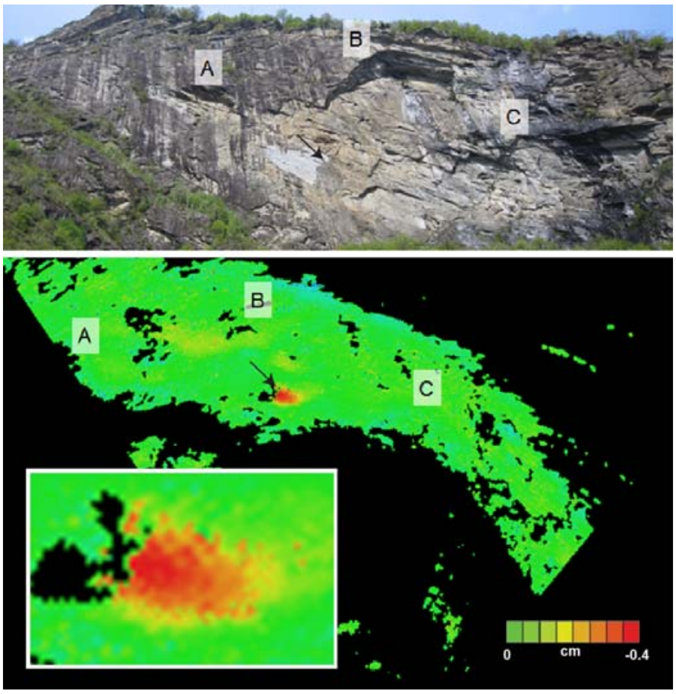

Figure 6 Displacement map (i.e. phase unwrapped) for the period march – August 2010.

Coherent signals show measured average displacements on the order of 0.5-0.6 mm per month (total displacement 3.5 – 4.0 mm). Phase unwrapping revealed a deformation map (fig 6) that clearly delineates the displacements associated with the large rock slab. Although the displacements are relatively small the radar signature depicted in figure 6 shows a greater degree of movement in the middle-left part of the block.

The radar signature appears consistent with a toppling mechanism taking place across the upper portion of the block, whilst in the mid-region, particularly toward the left margin, an outward buckling mechanism is observed. The toppling/buckling mechanism is consistent with field observation (fig 7).

In addition, preliminary analysis of three *in situ* crack meters located on the left margin of the rock slab; (EXT 1-3 in fig 7) show a greater degree of displacement occurring on the middle section (EXT 2 & 3) of the block compared to the upper part (fig 8).

Conclusions and outlook

A rock slab approximately 3000 m^3 characterized by average displacements of 0.5-0.6 mm/month was measured over a five month period (e.g. 3 measurement campaigns) using a portable radar interferometer. The radar signature indicates a combined toppling and bucking failure mechanism.

The goal of ongoing research seeks to elucidate further details of the failure mechanism(s), through the application of periodic high resolution laser scanning, monitoring using *in situ* crack meters and a micro seismic network. Additionally, various environmental parameters are being monitored to understand possible external forcing factors relevant for driving failure processes.

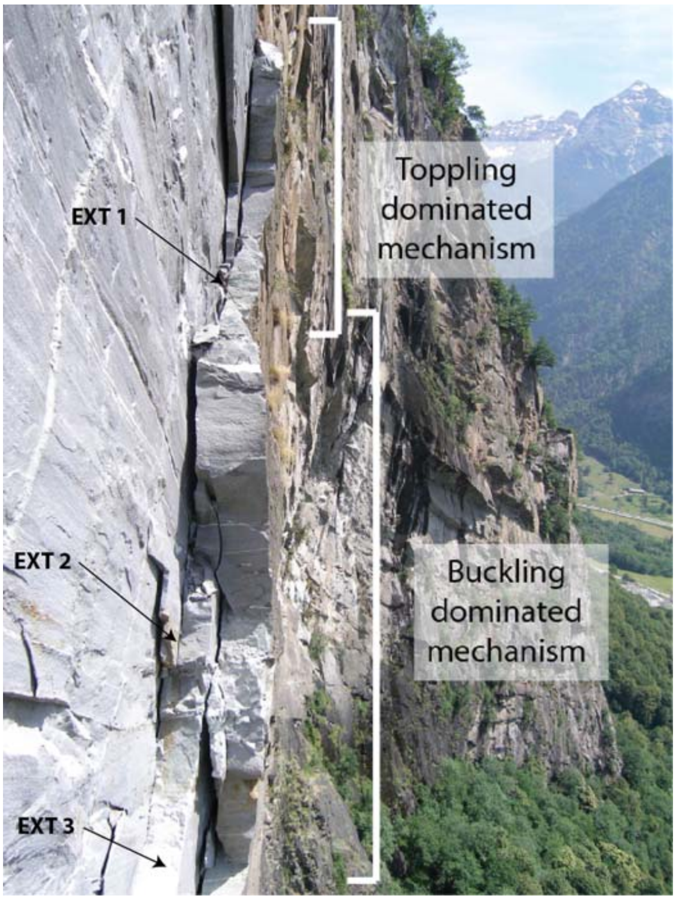

Figure 7 View across the rock slab showing zones of toppling and buckling. The approximate position of *in situ* crack meters labelled EXT 1-3 are shown.

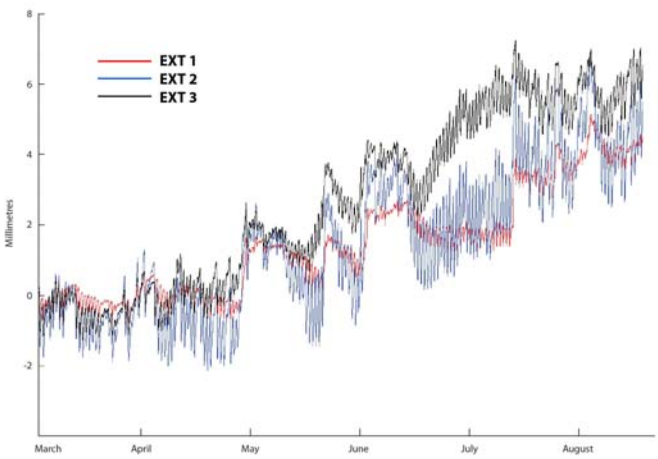

Figure 8 Displacement trends for 3 in situ crack meters located on the left-hand side of the rock slab (see fig 7 for location of crack meters).

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