12 Advanced Debris-Flow Monitoring and Alarm System at Spreitgraben

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Abstract

After a rock avalanche in 2009, the Spreitgraben avalanche course in the Bernese Oberland, Switzerland, has experienced extremely erosive debris flows that pose an increasing threat to infrastructure and residents. Following first events, an extensive alarm and research system was installed that is designed to alert residents and automatically close off the endangered cantonal road. The alarm system is composed of several vertical trigger lines and gauge radars mounted above the channel. Geophones provide a backup detection system in case of trigger line disruption. Early warning data stems from a weather station and several webcams monitoring extended parts of the channel. Repeated terrestrial InSAR measurements provide information about rock instabilities in the starting zone on the northeast face of the Ritzlihorn. To better understand the process chain of the Spreitgraben debris flows, a third subsystem consists of several research components. Two profile scanners constantly sample the channel cross section in order to investigate debris-flow dynamics. Additionally, two different models of Doppler radar systems are being tested at the Spreitgraben site. These are aimed at an early detection of debris flows in order to prolong the warning time provided by the conventional warning system. The entire system is connected to an extensive data transmission and information dissemination system that allows for continuous system monitoring and provides around-the-clock data access to local authorities and decision makers. Though 2012 and 2013 remained uneventful, the alarm system provided successful alerting throughout the debris-flow seasons of 2009 through 2011 and provides valuable insight to debris-flow process understanding.

Keywords

Natural hazards • Debris flow • Monitoring • Alarm system

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12.1 Introduction

The Spreitgraben is located at the Grimsel Pass in the Central Alps, an important connection between northern and southern parts of Switzerland. After several rock avalanches from the northeast face of the Ritzlihorn (3,263 masl) ascribed to thawing permafrost (Gruber 2012; Hasler et al. 2011), debris-flow activity started to increase in 2009, eroding the channel to a width of 50 m and a depth of 30 m up until 2013. Due to the strong erosion, a total amount of 650,000 m^3 of sediment has been deposited in the receiving Aare River since debris-flow activity started. Large debris-flow surges peaking at

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500–600 m^3 were registered when large amounts of sediment, originating from small debris flows triggered in the rock fall depositions, had been retained by the snowpack and released together with large amounts of water. From 2009 to 2011, the transported debris increased from 100,000 m^3 to nearly 300,000 m^3. A detailed discussion of the geomorphological processes is beyond the scope of this paper, but has been thoroughly investigated by local authorities. The channel itself is situated on a large cone that bears witness to debris-flow activities and mass movements lasting throughout the Holocene (Kober et al. 2012). The local geology exhibits mainly highly foliated gneisses of the Aare Massif with intensive shearing due to clusters of steep parallel joints. The main source of debris is the heavily weathered northeast face of the Ritzlihorn. From a hydrological point of view, the Spreitgraben catchment extends across 4.2 km^2 and over an altitudinal range of 2,313 m.

Important infrastructure is increasingly affected: the main road, the international gas pipeline between Germany and Italy, and numerous inhabited houses. The avalanche gallery protecting the cantonal road crossing beneath the graben is not constructed to withstand the impacts of massive debris flows and has been damaged several times. The gas pipeline has been partially relocated to the opposite side of the Aare river bed. Two houses close to the Aare depositions were abandoned and eliminated in 2011. Assuming debris-flow events of similar magnitude to those in 2011, the expected damage potential additionally extends to certain parts of the settlement (Flesch, Leen, Boden) and to the wastewater treatment facility. The alarm system installed at the Spreitgraben is designed to automatically close endangered areas of the cantonal road. Additionally, local authorities are automatically informed of the current situation via SMS, pager or telephone. The system is designed to work redundantly, allowing for a constant monitoring of the situation in case of secondary events and first-instance trigger line disruption. An online data portal provides users around-the-clock data accessibility of all system components.

12.2 Reasoning for Passive Measures

In many places, constructive measures as part of integrated risk management strategies have successfully mitigated debris-flow threats (e.g. Mizuyama 2008; Phillips 2006). At the Spreitgraben site, non-destructive and organizational measures were favored due to several factors: Firstly, the expected erodible volumes and limited space make the construction of retention and deflection dams extremely hard. Secondly, debris-flow, rockfall and avalanche hazards impede extended constructions works, and lastly, the landscape impact of passive measures is significantly lower than that of constructive measures.

12.3 Alarm- and Monitoring System

12.3.1 Alarm System

The components of the alarm system can be assigned to alerting or reacting systems, where the first are designed to detect the debris-flow activity and the latter respond in the form of road closure and information dissemination.

Primary debris-flow detection systems are located at positions 1, 2 and 3 in Fig. 12.1. In contrast to traditional wire sensors that are stretched across the torrent, a vertical setup has been implemented at the Spreitgraben in order to overcome the large distance to the channel bottom. The steel cables, termed trigger lines henceforth, are hung from a cable that is stretched across the graben and have stones attached to their ends, in order to be easily entrained by the debris-flow front. The breaking points of the trigger lines can be precisely defined due to industrially produced pull linkages and the state of the trigger lines can be monitored continuously. Additionally, the simple design of the trigger lines makes them easy and inexpensive to replace after an event. In other setups, the trigger line force is also monitored separately, permitting the detection of false alarms, e.g. due to cable damage.

Two gauge radars with specifically implemented algorithms allow for distance measurements to turbulent surfaces. They provide essential information on flow height in case of debris-flow events. In normal operating mode, the gauge radars trigger flow height warnings, but they are also used as backup alarm triggers in case of secondary events. Two geophones serve as backup alarm systems and data verification, detecting vibrations linked to debris-flow activity.

Signals from any of the sensors are transmitted to the data control station via a remote control cable. From there, traffic lights and LED information panels are automatically activated and alarm SMS are issued to authorities. Four traffic lights ensure the closure of the avalanche gallery as well as the area around Boden, where the Aare River passes beneath the cantonal road. Additionally, an alarm horn and beacon are positioned by an endangered house where hazard assessment and field surveys have revealed a potential threat in case of damming at the avalanche gallery, resulting in a deviation of the debris flow along the road.

12.3.2 Early Warning Systems

Investigations by local authorities have shown that the debris-flow hazard potential depends heavily on medium-term meteorological conditions as well as debris availability. A weather station mounted on the debris-flow cone therefore supplies local meteorological data to authorities and decision

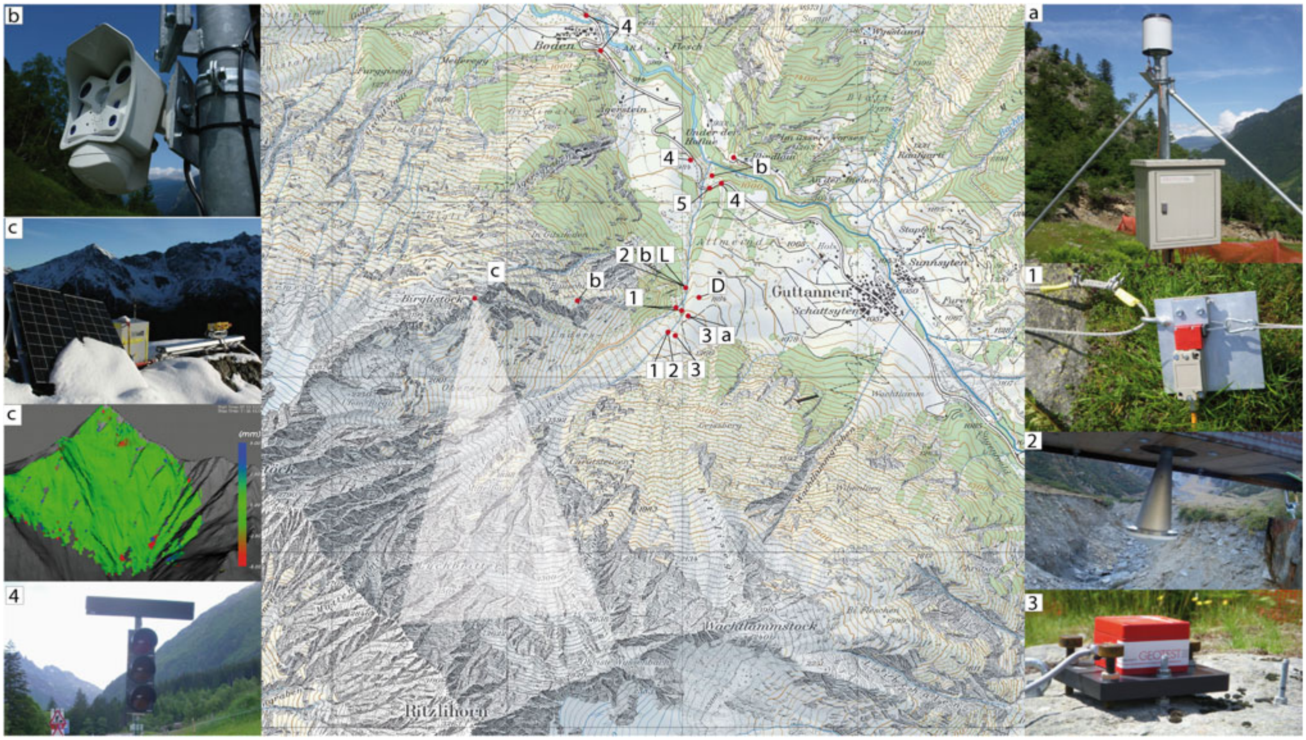

Fig. 12.1 Overview of all alarm and research systems. Arabic numbers represent components of the primary alarm system: Trigger lines (*1*), gauge radars (*2*), geophones (*3*), traffic lights (*4*), data control center (*5*). *Lowercase letters* stand for early warning system components: weather station (**a**), webcams (**b**), InSAR position (**c**). *Capital letters* represent components of the research system: Doppler radar (*D*), laser profile scanners (*L*)

makers at all times. Repeated terrestrial InSAR measurements of the Ritzlihorn northeast face (see Fig. 12.1) procure information on potential rock instability zones. Webcam images from the Ritzlihorn rupture zone, and from cameras mounted above the channel, by the avalanche gallery and the Spreitgraben-Aare confluence provide important information on hazard predisposition and serve as useful organizational tools in case of debris-flow events.

12.3.3 Research and Monitoring System

In cooperation with the Swiss Federal Office for the Environment, laser profile scanners that were originally designed for traffic monitoring are being tested at the Spreitgraben site. These scanners provide high resolution data of the channel cross-section and debris-flow dynamics, supplying essential information for process understanding. The setup of the scanners, mounted at a distance of approximately 1 m from each other, is intended to permit the extraction of flow velocity data based on correlation analysis. Additionally, we will attempt to excerpt information on grain size distribution and hydrographs from the laser data. The extraction of such parameters from debris-flow observations should provide useful model input data. As another part of the research system, a FMCW Doppler radar system is being tested. The Doppler radar is expected to detect debris flows in the rupture zone, thus roughly doubling the warning time provided to date by the trigger lines. It detects debris flows by measuring flow velocities, similar to the way velocities of cars are monitored. Tests with moving targets have yielded promising results, but the system has not yet been tested in an emergency situation. The detectability of a moving debris flow amongst raindrops blown in the direction of the radar constitutes the largest uncertainty hereby.

12.3.4 Data Transmission

Apart from the direct alarm transmission via remote control cable to the control station, all data is transmitted to the data servers via mobile network. Aside from the first-order data such as precipitation or webcam images, system status information is also transmitted at regular intervals. This allows for a constant surveillance of logger temperature, battery voltage, logger response time etc. A secure local wireless alarm transmission has also been successfully tested and will be implemented in summer 2014, providing a redundant alarm transmission in case of cable damage. All issued warnings and alarms are automatically distributed as prioritized SMS to authorities and decision makers, via Swisscom eAlarm service. SMS that are not confirmed by the recipient are automatically forwarded as telephone calls to defined numbers. In case of an event, telephone conferences can be launched by specified users, in order to initiate appropriate measures as soon as possible.

12.4 Discussion and Conclusions

Central to the Spreitgraben alarm system, trigger lines provide a tried and tested approach to debris-flow detection that is low in maintenance and fail-safe, while the gauge radars and geophones provide a reliable backup. This system has proven to be indispensable throughout the debris-flow seasons of 2009 through 2011, despite the fact that the summers of 2012 and 2013 remained without any major events. However, in both years, data from the early warning system confirmed that debris-flow potential remained low. Webcam images from the rupture zone proved that avalanche deposits remained consistent throughout the summer season, and the development of air temperature, soil moisture and precipitation did not favor the release of debris flows.

InSAR measurements were not repeated in 2013. In the case of the Ritzlihorn, where continuous, small scale rock falls dominate over large scale movements of rock faces, InSAR measurements are slightly hampered by the fairly low spatial resolution provided by the radar. Here, high resolution terrestrial laser scanning data could provide more detailed insights thanks to the higher density of measurement points. Data from the profile scanners is scarce due to the lack of events, but data from a very small event in early August 2013 promises an accurate assessment of changes in channel geometry.

The state-of-the-art infrastructure installed at the Spreitgraben, drawing on a variety of technologies, allows for very advanced debris-flow monitoring and alerting, and has provided successful detection and surveillance of past events. Climatic changes have evoked extensive shifts within the Spreitgraben process chain, resulting in increased frequency and magnitude of mass movements. The Spreitgraben catchment has been studied in-depth, but the complex interaction of spatially and temporally varying processes emphasizes the need for continued measurements, especially in order to arrive at conclusions for the surrounding region.

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