International Society for Rock Mechanics and Rock Engineering
Macedonian Association for Geotechnics

ISRM Regional Symposium
Eurock 2026
Risk Management in Rock Engineering
Skopje, 15-19 September

DOI: https://doi.org/10.68732/ba65c7345fca6999

ISBN: 978-9989-2053-7-8

Ten Years of Digital Rockfall-Protection Net Operation at Ovella: Cost-Efficient Construction and Maintenance Through Continuous Monitoring and Alarming

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Abstract

Over the past decade, the hydropower construction site at Ovella—located on the Swiss–Austrian border beneath a rockfall-prone slope—was protected with about 1.2 km of rockfall-barrier nets equipped with 120 wireless impact sensors and a real-time alarming system. The system detects rockfall impacts in the nets, strong vibrations and inclination angle changes. Depending on the severity of the detected event, on-site optical–acoustic sirens are triggered within a few seconds. Additionally automated SMS notifications reach the responsible persons within 1-2 minutes. Continuous operation since 2015 has yielded a unique long-term dataset about rockfall activity and sensor performance. This paper documents the architecture and operation of the digital protection-net system (sensors, trigger lines, relays and base station), the alarm logic for graded response during construction and operation, and the supporting online data portal. We discuss operational experience from ten years of service, including how event-based surveillance reduced the need for regular systematic manual inspections, supported focused maintenance planning, and improved worker safety during active construction while enabling efficient surveillance during subsequent operation. We also summarise key limitations (e.g., dependence on radio links, battery power and mechanical trigger integrity) and outline upgrades introduced during the ten years of operation to further enhance robustness and operational awareness.

Keywords

Rockfall protection, Digital monitoring, Impact sensors, Alarm systems, Maintenance planning.

1 Introduction

The Ovella section of the Gemeinschaftskraftwerk Inn (GKI) project (see Figure 1, 2) required reliable protection against frequent rockfall from the steep slope above the site. In 2015 a digital protection-net system was installed that combines flexible rockfall barriers with distributed wireless impact sensors and a site-wide alarming workflow. The primary objective during the active construction phase was to protect personnel through immediate alarms and to document significant impacts into the barriers. During subsequent operation, the same infrastructure continued to provide event-centric supervision of the barrier line and actionable status information for maintenance planning. This contribution synthesises a decade of experience, focusing on system design, alarm logic, data services and lessons learned for cost-efficient construction and maintenance while enhancing safety.



Fig. 1 Ovella section is in the Engiadina Bassa region, in the canton of Graubünden, on the border between Switzerland and Austria. (Source: swisstopo).



Fig. 2 Gemeinschaftskraftwerk Inn power plant (GKI) on the Inn River (GKI) near Ovella (Source: GKI)).

2 System overview and methods

a. Site and protection-net layout

The monitored section consists of fourteen rockfall-barrier nets with a total length of approximately 1.2 km (Figure 3). 120 sensors were mounted across brake elements and selected net fields to achieve wide coverage.

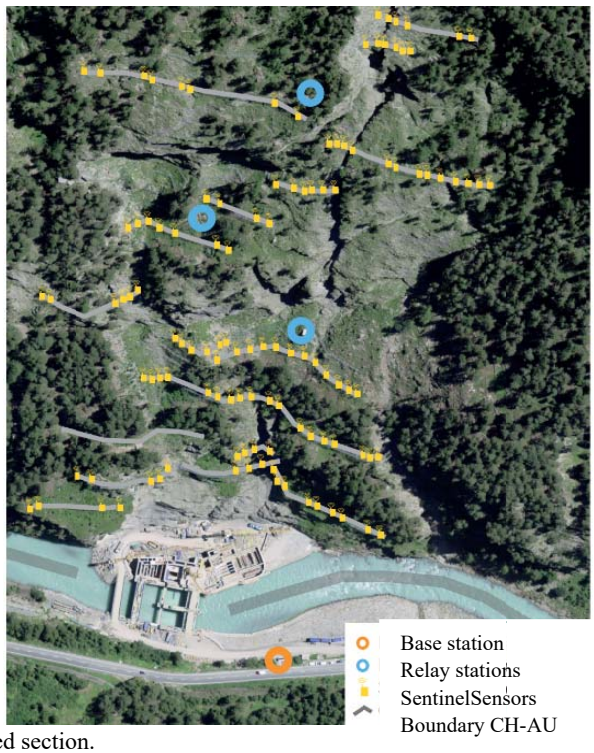


Fig 3. Overview of the monitored section.

b. Sensors and installation

Impact Sentinel sensors are purpose-built for rockfall-barrier supervision. Each sensor integrates one or two pull-out pins coupled to the barrier via 2 mm steel trigger lines that are routed along brake cables or across selected net fields (Figure 4). The pull-out pins are held by calibrated break elements (order of 500 N) so that a relevant deformation or brake activation tears the pin(s) and triggers an event. Sensors are typically mounted at the top of posts to minimise direct impacts and to ensure robust radio links. In addition to pull-out events, the sensors register strong vibrations above a fixed threshold. Alarm activation is possible within 2 – 3 seconds upon event detection. Additionally, these sensors measure inclination angles at regular time intervals (e.g. every three hours) and provide some relevant information about the stability of the structures of the nets.



Fig. 4 Sentinel Sensor above the construction site coupled with trigger lines.

c. Communication, alarming architecture and data portal

Sensor messages are received either directly at the base station or via one of the three solar-powered relay stations distributed along the slope (Figure 5). The base station near the site entrance receives and evaluates sensor messages and transmits notifications to the GEOPREVENT GRAVX online data portal and SMS distribution service. During the construction phase, the status beacon indicated the system state (green: normal operation; yellow: silent alarm; red: acute alarm) (Figure 6). In the case of an acute alarm, an on-site siren with flashing light was additionally activated.

The GRAVX online data portal also provides a comprehensive overview of sensor and system status (Figure 6). All relevant status information can be visualised, including sensor state, communication quality, and battery status. Event histories support targeted site inspections and maintenance planning.





Fig. 5 Left: Base-station with alarming unit (including light and acoustic signals), status light and camera. Right: Solar powered relay station.



Fig. 6 Sensor status overview on GRAVX data portal (green: normal; yellow: minor event; red: major event).

d. Alarm logic and graded response

Two alarm levels are distinguished. A silent alarm is issued for (i) one or two pull-outs on field sensors, (ii) one or two pull-outs on sensors attached to the lower brake, or (iii) a single pull-out on an upper-brake sensor. A major (acute) alarm is issued when both pull-out pins of an upper-brake sensor are torn. In all cases, SMS notifications are sent to the predefined recipient list; major alarms additionally activate the horn with flashing light and switch the information light to red for evacuation.

3 Operational experience and results (2015–2025)

The Ovella installation has been in continuous operation since 2015. During the active construction phase, the system provided immediate, unambiguous on-site cues for evacuation and automated messaging within a few seconds of critical impacts. Over time, the accumulated event records formed a long-term dataset that documents barrier activations and net-field disturbances across seasons.

Event-based monitoring reduced the need for routine ad-hoc on-foot inspections after suspected occurrences, because alarms precisely located affected net segments (upper or lower brake vs. field). This supported focused maintenance and scheduling, particularly after storms or freeze–thaw periods.

In the post-construction phase, the system has continued to deliver value by sustaining situational awareness at low operating effort through the GRAVX data portal and by keeping an auditable record of barrier activity that informs long-term maintenance planning.

4 Discussion

Safety benefits were most evident during construction, when personnel were present below the barriers and rapid response mattered. The graded alarm logic balanced sensitivity and practicality by reserving siren activations for major events (two pull-outs on an upper-brake sensor) while still notifying stakeholders for minor events. For operations, the digital record and remote visibility reduced uncertainty and helped prioritise inspections.

Key limitations stem from (i) operation in an unlicensed radio band, (ii) battery-powered field units, (iii) mechanical dependencies of trigger lines and break elements, (iv) potential damage to sensors, relays or antennas by rockfall, snow or vegetation, and (v) communication relying on cellular modem technology approaching obsolescence or experiencing coverage limitations. These factors motivate periodic maintenance visits, plausibility checks in the receiving software, and design measures such as protected cable routing and sensor placement at the post tops.

Recent upgrades (2023) included replacement of the outdated base station cellular modem with a 4G modem and installation of a volt-free relay module for interfacing with the owner's TIWAG (Tiroler Wasserkraft AG) SCADA (Supervisory Control and Data Acquisition) control system.

5 Conclusions and outlook

A decade of digital supervision of rockfall-protection nets at Ovella demonstrates how flexible barriers, impact sensors and real-time alarming can jointly enhance worker safety during construction while limiting the maintenance effort over the entire life cycle in operation. The approach offers precise localisation of relevant impacts, consistent documentation for asset management, and scalable interfaces to owner systems.

Acknowledgements

The authors thank the Gemeinschaftskraftwerk Inn (GKI), project stakeholders and the field technicians who installed and maintained the Ovella system.

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