REMOTE MONITORING OF FLEXIBLE PROTECTION SYSTEMS

Geobrugg GUARD
Practical guide

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Geobrugg GUARD

Practical guide

Remote monitoring of flexible protection systems

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1. Introduction

The Geobrugg GUARD monitoring system is designed to permanently monitor flexible protection systems against natural hazards such as rockfall, avalanche and debris flow. Measurement devices (GUARDs) installed on the protection system monitor different parameters on-site. Data is regularly transferred to a central server by mobile signal and displayed in an online monitoring platform. The primary use is the automated 24/7 monitoring of the barrier. The GUARD system also supports inspection and maintenance units in decision-making and planning the on-site inspections.

This practical guide presents the GUARD measurement devices and the online platform, discusses the use of the monitoring system, and shows how GUARD supports managers and natural experts in decision-making, inspection and maintenance. The practical guide further explains how the system is installed and by whom it is managed and cared for. Available manuals and inspection and corrosion protection standards for flexible protection systems are discussed. Differences from other monitoring systems such as warning and alarm systems are highlighted, too. The reader finds different use cases on installations with Geobrugg GUARD in the appendices.

2. GUARD measurement devices and data monitoring platform

The GUARD monitoring system is a combination of measurement devices and a specially developed online monitoring platform (dashboard).

2.1 GUARD measurement device

A GUARD is a small measurement device installed on the rope of flexible protection system (see also Figure 1 below). It contains different sensors which transmit environmental and physical data over a mobile network:

- Rope force measurement (0kg - 30’000 kg (294kN))
- Acceleration measurement (0g - 200g)
- Sample wires with electric sensors to measure corrosion rates
- Temperature measurement (-50°C to 80°C)
- Humidity measurement [0% - 100%]

Figure 1: Geobrugg GUARD measurement device installed on a flexible ring net barrier

Please refer to Appendix A for a detailed technical product description [1]. The relatively simple installation process of Geobrugg GUARD on a protection barrier is shown in the Geobrugg GUARD Product Manual [2] and in chapter 5 of this practical guide.

2.2 GUARD online monitoring platform

The data is displayed in an online monitoring platform (dashboard). The monitoring platform displays rope forces, acceleration measurements and corrosion rates and may generate warning message (text, e-mail) if predefined limit values are exceeded.

Figure 2 shows a screenshot of a project in the GUARD online monitoring platform.

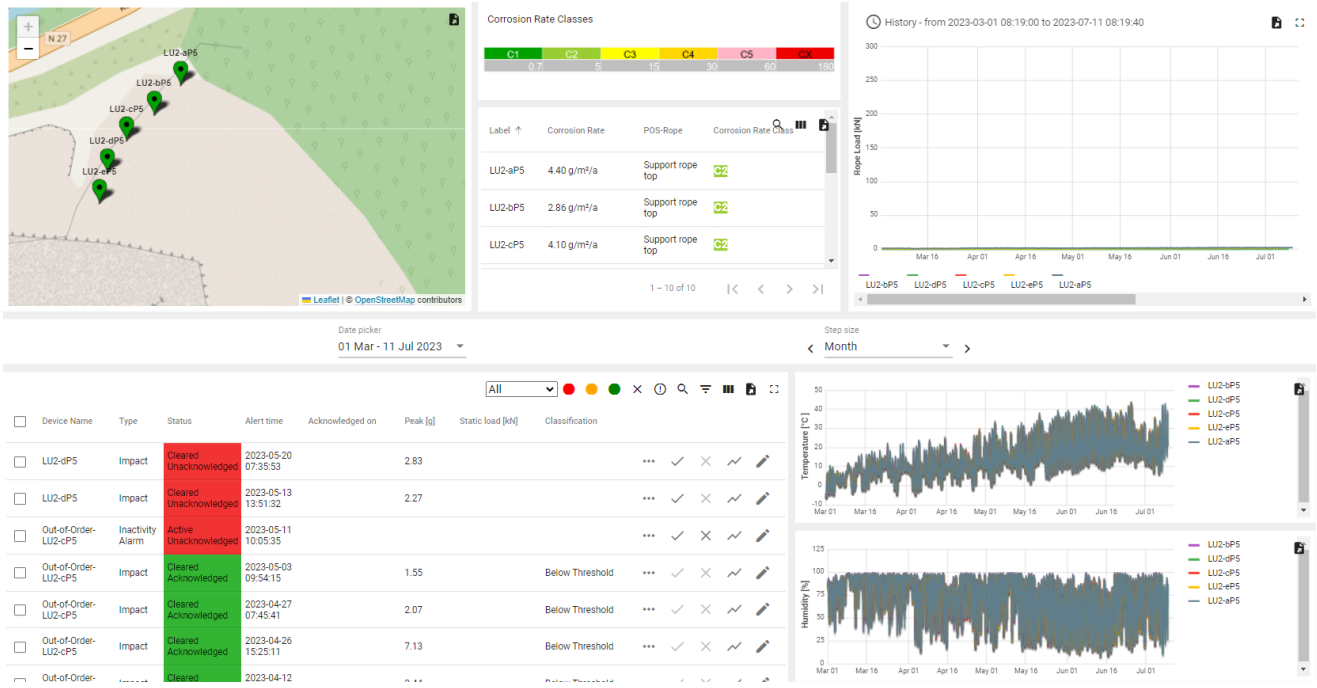


Figure 2: Screenshot of the GUARD online monitoring platform

The online platform is designed to visualize relevant monitoring data and make it easily accessible to stakeholders of the protection system (owners, inspection and maintenance crew, natural hazard experts etc.). Access to the online monitoring platform for different stakeholder may be defined individually by the protection structure owner.

Integration of the data into the platform is project specific. The data can be presented in both desktop and mobile devices and support decision making both inhouse and on-site.

3. Data interpretation and use of the GUARD monitoring system

The gathered information is supporting protection system managers and inspection crews in decision-making and the planning of on-site inspections:

- Permanent surveillance of protection systems may reduce on-site inspections
- Rapid intervention on-site in case the barrier is predicted to be filled
- Reliable planning of inspection intervals according to measured data over the last years

Figure 3 below summarizes the functioning of the GUARD monitoring system

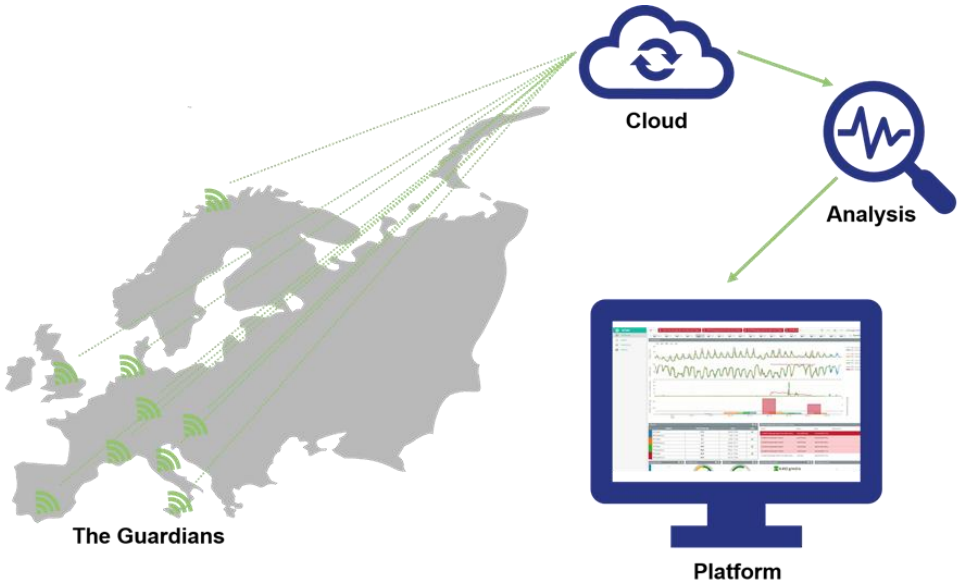


Figure 3: Functioning of the GUARD monitoring system

4. Sensor concept and decision support with GUARD monitoring system

Three main sensors built into the GUARD device support identifying dynamic and static load cases as well as corrosion rates. Notifications and recommended actions can be defined within the online monitoring platform depending on the urgency of different pre-defined problems.

Table 1 below gives an overview on relevant sensors, levels of urgency and possible notifications and actions for both load cases and the corrosion rate measurements.

Table 1: Relevant sensors, levels of urgency and possible notifications and actions with Geobrugg GUARD

Problem	Dynamic load cases	Static load cases	Corrosion / Zinc reduction
	• Rockfall • Impact through trees • Debris flow • and more...	• Snow pressure • Slow debris flow • Rubble • and more...	• Humidity • Salt • Air pollution • other location factors…
Problem identification	**Acceleration sensor**	**Rope force sensor**	**Corrosion sensor**
Urgency	High impact → Immediately Low impact → Weeks	Day / Weeks	Months / Years
Notification	SMS and/or E-Mail	E-Mail, Dashboard or Report	Dashboard or Report
Measures to maintain the level of safety	Replacing elements such as brake elements, net, support ropes, ...	Replacing elements such as brake elements, net, support ropes, ...	Replace parts or add corrosion protection

5. Installation and commissioning of the GUARD monitoring system

The GUARD product manual [2] shows the tools needed and the steps to take to correctly install a GUARD system. A summary is given below.

The required tools are:

- Socket wrench
- Long-Nut / Size 32 needed are
- Torque wrench, range 25 – 100Nm
- Mobile phone
- GUARD product manual

The GUARD needs to be mounted on a rope of the protections system using a torque wrench (only 50Nm are required) as shown in Figure 4:

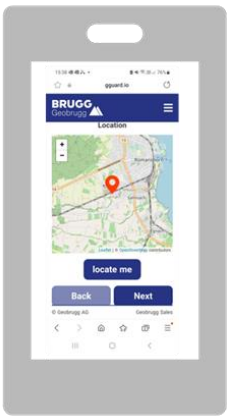


Figure 4: Correct installation of a Geobrugg GUARD device on a flexible protection system using a torque wrench. Integration of the GUARD into the platform (dashboard) using a mobile phone on-site.

The GUARD device is ready to be set into operation immediately. It may be integrated on-site into the online platform using a mobile phone.

The measurement device is designed to operate fully autonomously up to 10 years without recharge of the battery. Measurement signals are transmitted by mobile network to the online monitoring platform. If mobile network coverage is given, there is no need for any additional external signal transmitter.

6. Life cycle of GUARD monitoring system and responsibilities

Important life cycle steps of the GUARD monitoring system are setup, monitoring and update of the monitoring software. For each step, trained staff is necessary to ensure the system's proper functioning.

Figure 5 shows life cycle steps and corresponding responsible staff:

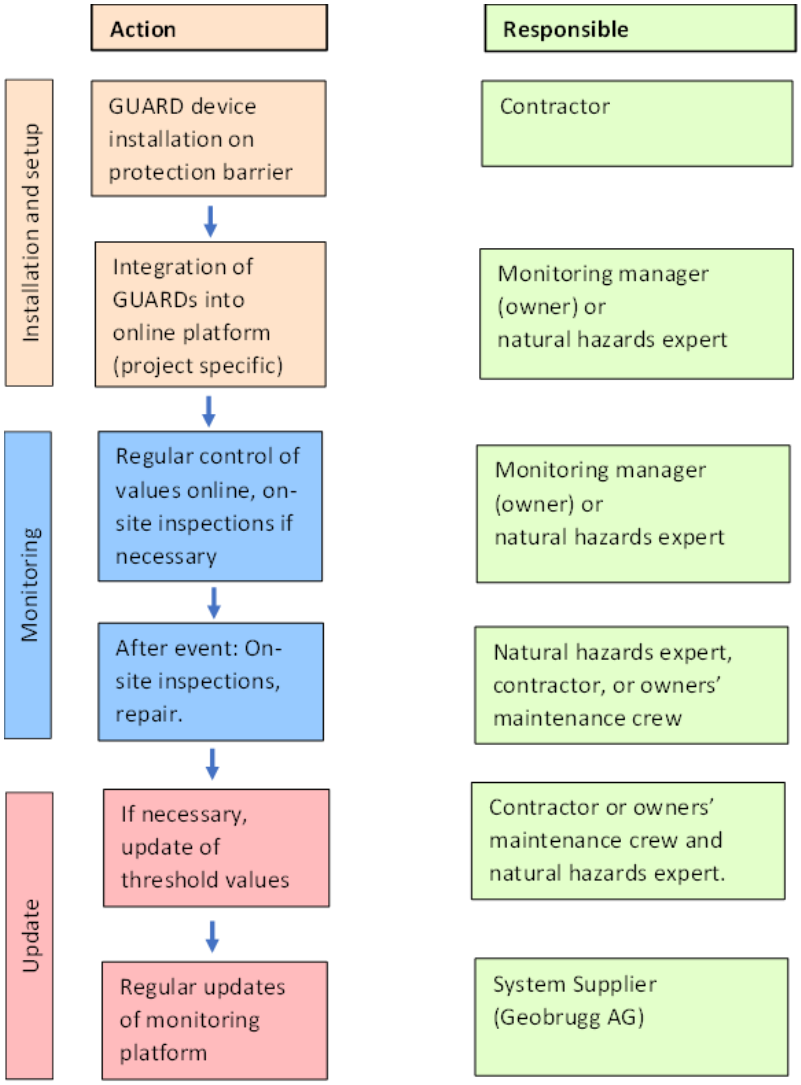


Figure 5: Life cycle steps of GUARD monitoring system and responsible persons / bodies

One person may cover different tasks in this scheme. E.g., the monitoring manager is a natural hazard expert or is trained in on-site inspection and maintenance. We recommend defining responsible staff members from the beginning of every GUARD monitoring project.

Table 2 describes different tasks of the responsible body/staff:

Table 2: Responsibilities and task description for the GUARD monitoring system

Responsible	Task description
Monitoring manager (owner)	The monitoring manager, usually within the structure owner's organization, is a trained person who is responsible for the functioning of the GUARDs and for regular check of status in the online tool. He orders on-site inspection and maintenance if necessary.
Natural hazards expert	A natural hazards expert (local engineer, geologist etc.) may support the monitoring manager or take over monitoring tasks from him.
Maintenance crew	Owners define internal or external maintenance staff trained to maintain protection systems and replace GUARDs if necessary.
Contractor	Local contractors familiar with flexible protection systems may support the owner to install Geobrugg GUARD.
GUARD system supplier (Geobrugg AG)	The system supplier is regularly updating the monitoring online platform and is informing the monitoring manager

7. Monitoring concept and reporting

It is important to regularly check the dashboard and report all events. For that, we recommend setting up a site-specific monitoring concept and reporting routine that fits the organizations needs and the legal context of the country. It is advised to report any impact incident on a short note to assure the best overview on the site-specific impact conditions.

If needed, a local engineering consultancy or Geobrugg may assist in defining relevant conceptual parameters for the internal monitoring concept.

Figure 6 shows, as an example, how a short note on an impact measurement and the following inspection may look like.

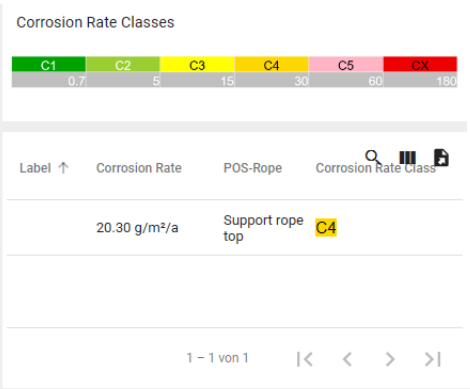
Short note on impact measurements and inspections

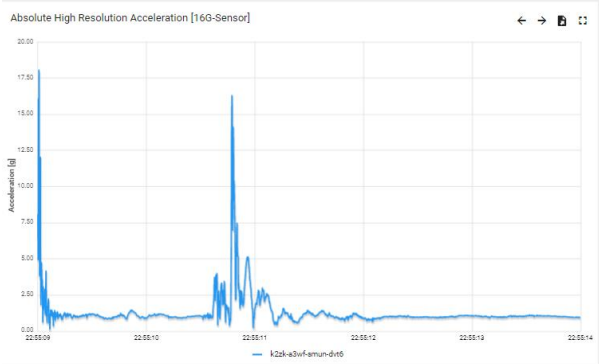
Organization Entilini Concession (RF) (Pty) Ltd

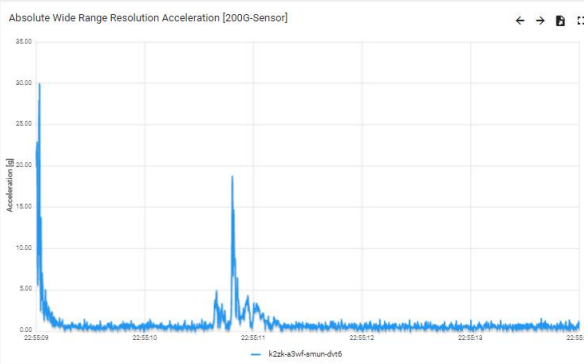
Impact

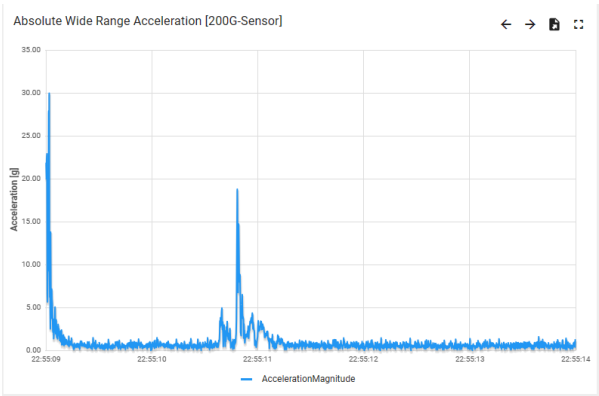
Barrier location	Chapmans Peak Drive, South Africa
Impact location	CH 30 - Field 3 (Post 4)
Alert time	2023/06/06, 22:55:09

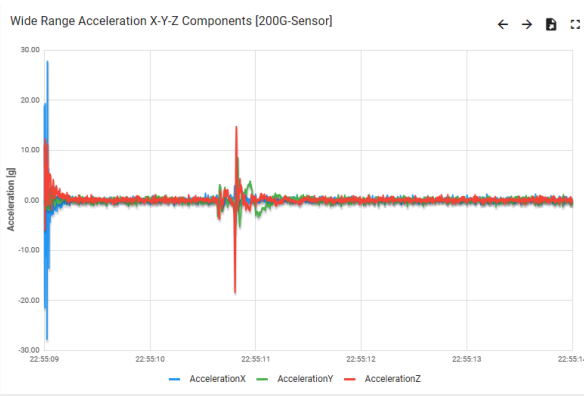
Measurements GUARD











Results

Corrosion Rate class	C4
Peak load	29.96 g
Acceleration Magnitude	27.89 g

Inspections

Date of inspection 2023-06-12, 08:10:00

Comments on inspection

a. The team checked the fence this morning.
b. We suspect there was one block that released from the cliffs above, and then broke into multiple blocks, hitting CF 30 in Field 2 and 3
c. Several boulders in Field 2 - largest boulder being 410 x 350 x 200mm
d. Several boulders in Field 3, but most passed beneath the spill through tail – largest boulder 1000 x 700 x 500mm
e. No damage or activation in Field 2 or 3

Pictures

Field 2 – rocks

Field 2 impact on rear slope

Field 3

Field 3 debris at base of spill through tail

Figure 6: Example short note on impact measurements and inspection of rockfall barriers (Inspection comments and images courtesy of Entilini Concession (RF) (PTY) Ltd)

8. Guidelines and best practices on inspection and maintenance

Manuals and standards defining inspection and maintenance of protection systems against gravitational natural hazards are for example available for Switzerland [3],[4] and Austria [5]. Excerpts from those guidelines are shown in Appendix B.

The guidelines define responsible bodies for operation, monitoring and maintenance and the necessary means for those tasks (e.g., inspection intervals).

Other countries may have defined their own rules and regulations, or best practice cases for the inspection of civil engineering works are available.

We recommend checking with national standard organizations, environmental and natural hazard protection agencies whether local manuals, guidelines or recommendations for inspection and maintenance need to be respected for the area of the GUARD installation.

8.1 Responsible bodies for inspection and maintenance of protection systems

Generally, owners or operators of the protection structures (road authorities, railway authorities, forestry etc.) are responsible to ensure that the function of the system is permanently given and are responsible for the inspection and maintenance of said protection structures. They are also responsible for compliance with local standards and guidelines [3], [4], [5].

8.2 Typical inspection and maintenance schemes

Typically, inspection is divided into regular inspection and inspection after extraordinary meteorological events that increase the risk of impacts on the protection structure.

- Generally speaking, guidelines recommend regular inspection once or twice a year, e.g., in spring and before winter for alpine countries
- Most of the guidelines recommend inspection after heavy precipitation and storms (to check whether a protection system is filled and needs maintenance)

Figure 7 shows a typical inspection and maintenance scheme based on manuals and standards [3],[4] and [5].

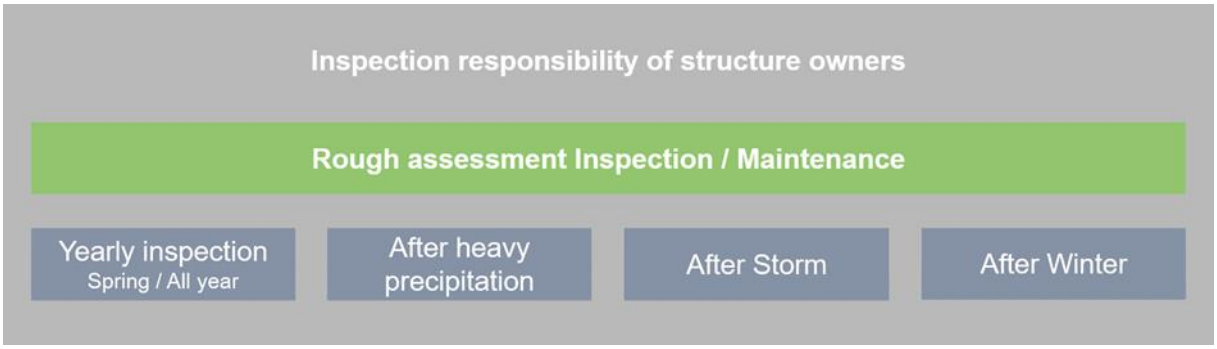


Figure 7: Typical inspection and maintenance scheme based on manuals and standards [3],[4] and [5]

Comments on inspection and maintenance schemes:

- Heavy rainfall and thunderstorms are not clearly defined by the guidelines. It is recommended to discuss with local experts in meteorology which limit values shall be chosen for the area.
- The Austrian guideline ONR specifically states that regular inspection can be omitted in case of a permanent monitoring system of the protection structure (see also excerpt from ONR standard in Appendix B).

8.3 Typical lifetime assessment of steel wire structures (corrosion rate)

Apart from gravitational natural events, corrosion is the most important factor for a reduced service life of installations [8]. Nowadays, the corrosiveness of the environment is defined according to ISO 12944-2 [9]. This environment definition leaves a great deal of scope for interpretation.

Figure 8 shows a typical calculation for the theoretical service life prediction of zinc wire coatings (applied according to DIN EN 10244-2 [10]):

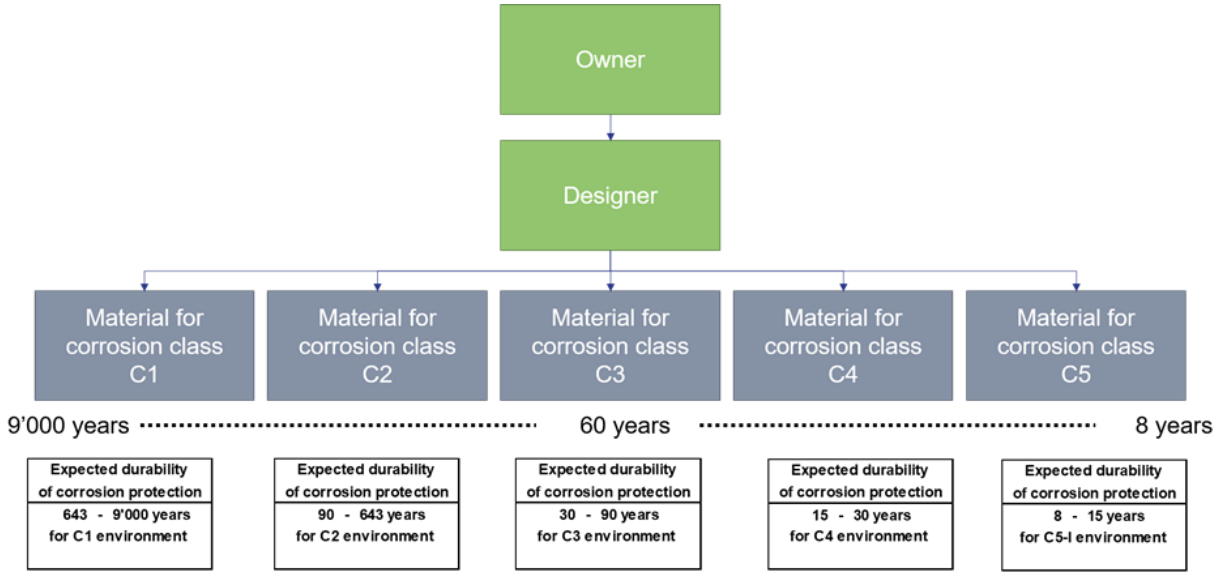


Figure 8: Typical calculation for the service life prediction of zinc wire coating according to ISO 12944-2 [9]

Using ISO 12944-2 [9] for the service life-time calculations, the results in the example give a span of factor 3 (between 30 and 90 years) for an average corrosion class C3.

For designers, it is often hard to choose the appropriate corrosion class correctly and effective lifetime of coatings is difficult to assess.

9. Benefits of the GUARD monitoring system for the surveillance and service life assessment of protection systems

As a specially designed monitoring system for flexible protection systems, the GUARD monitoring system answers the need for the monitoring of protection systems with the following assets:

- Automated site-specific measurement of vital parameters of the protections system such as rope forces, acceleration, and actual corrosion rates
- Ongoing surveillance of protection barriers (24/7, all year round)
- Automated messages in case of exceeded pre-defined limit values
- Shared access to the online platform for all stakeholders (owners, managers, inspection and maintenance crew, natural hazard experts)
- Learning from the past data

Using these technological assets wisely in combination with trained staff, ongoing learning about the reaction of protection systems allows for more predictable on reliable protection structure management. On-site inspection may be reduced to the necessary minimum.

10. Difference between warning systems, alarm systems and monitoring systems for protection structures (GUARD)

Practical guides and manuals published by both the Swiss Federal Office for the Environment and for Civil Protection distinguish between early warning systems, alarm systems and combined systems to monitor gravitational natural hazards [3], [11]. Table 3 below then classifies the different types of systems.

- **Warning systems** measure a slow process (i.e., crack measuring in a rock face) and indicate when a process is more likely to occur.
- **Alarm systems** measure natural hazard processes once they have happened and induce an action required (e.g., closing of the roads, evacuation of people)
- **Protection structure monitoring systems** such as the GUARD are mapping the structure's life cycle. This means giving information on the frequency and magnitude of impacts on a flexible protection structure, information on the loading of the wire ropes of the structure as well as information about the ongoing on-site corrosion of the steel wires.

Table 3: Definitions of warning and alarm systems for gravitational natural hazards according to [3] and comparison with protection system monitoring such as GUARD (in yellow)

Function	Warning system	Alarm system	Protection structure monitoring (Geobrugg GUARD)
Reaction time	Hours and weeks	Seconds and minutes	Months and years for corrosion rates. Days and weeks for static loading. Immediate for full dynamic loading.
Actions	Interpretation of results by experts. Possible actions are started “manually” (e.g., evacuation of people)	Immediate and automated actions, e.g., closing of roads, railways on evacuation of people	Interpretation of results by experts. Possible actions are started “manually” (e.g., inspection and maintenance of protection systems).
Area of use	Monitoring of slow and continuously developing natural hazard processes (e.g., movement of rockfaces, spread of cracks, landslides)	Monitoring of fast and spontaneously occurring natural hazard processes (e.g., avalanches, rockfall)	Management of maintenance intervals for protection structures.
Measured parameters	Deformation, precipitation, snow height, water level, temperature, activity (number of rockfalls, avalanches), seismic activity	Deformation, velocity, pressure, water level, flow height, seismic activity	Corrosion rate of single wires, static rope forces, acceleration of a dynamic impact.
Technologies	• Interferometric Georadar • Deformation detection camera • Crack measuring devices • Pressure gauges • Inclinometers • Displacement measurements • GPS • Weather stations	• Avalanche detection radar • Rockfall detection radar • People detection radar • Water level gauges • Cables with predetermined breaking loads.	Pre-defined combined measurement: • Rope force measurement • accelerometer • electric sensors to measure corrosion rates • temperature measurement • humidity measurement

11. Frequently asked question (FAQ)

How many GUARDs are needed for a 25 m long protection barrier?

It is recommended that GUARD devices be installed on the lateral suspension (left and right) of the top support rope. For longer structures, it is recommended to install a GUARD every 25 meters on the upslode anchor rope. To ensure redundancy of the sensor system, it is recommended to install at least 2 GUARD devices.

Are GUARDs measuring parameters 24/7 and all year round?

Yes. GUARD devices collect relevant data on an hourly basis in a “sleep-mode”. Data is saved and transferred to the monitoring platform on a weekly basis (7 days). In case of a dynamic impact, the GUARD is activated, (i.e. removed from “sleep mode”) and is sending all data to the platform immediately.

At the planned installation site of the GUARDs, there is poor or no mobile signal coverage at all. Is it possible use another type of signal / frequency?

Regularly, GUARD devices are equipped to send signal over 2G/3G or 4G. The signal of GUARD devices may be transferred by installing additional antennas. Please contact Geobrugg for further information on this case.

May GUARD devices be installed on barriers of other manufacturers?

Yes, it is possible to install GUARD devices on barriers of both Geobrugg and other manufacturers. Geobrugg’s GUARD devices can be installed on any type of protection barrier, for rope diameters between 12 and 24 mm.

Is it mandatory to use Geobrugg’s online platform for the integration of the signal of the GUARD devices?

Geobrugg’s online platform is specially designed and regularly updated for the best use of Geobrugg GUARD devices. It is however possible to extract automated data from GUARD devices and send it to other monitoring platforms over a data interface (Rest-API). Please contact Geobrugg for further information.

May Geobrugg GUARD monitoring system be used as an alarm system, e.g. for closing roads etc.?

Geobrugg GUARD is designed as monitoring and management system for protection systems. It is not designed to replace an alarming system for immediate intervention, e.g., to close roads, inform police and fire brigades etc.

The dynamic impact measurements of Geobrugg GUARD however may be used as a prioritization information for an intervention in case of large-scale events with several impacts in several protection structures.

What is the expected lifetime of a Geobrugg GUARD?

The measurement device is designed to operate fully autonomously up to 10 years without recharge of the battery. If the battery is down, this will be detected in the online platform. The GUARDs are designed to last 10 years. The service life depends on

various factors. However, it has already been proven worldwide that the GUARD works without problems for at least 5 years in various locations. In 2018 the first GUARDs were installed and so far, all of them are still working. Even in very hot, corrosive locations and places with temperatures as low as -20°C for longer periods.

12. Summary

Geobrugg GUARD addresses the need for permanent surveillance of protection barriers for owners, managers and inspection and maintenance crew. GUARD devices mounted on ropes of the protection system measure completely autonomously vital parameters such as rope forces, accelerations and corrosion rates. The data is sent regularly over the mobile phone network to a server and displayed in a specially designed online monitoring platform. This allows for 24/7 surveillance of the structure and the notification of expert staff in case of an impact. The corrosion rate measurement may assess on-site corrosion conditions, and realistic lifetime determination is possible.

The GUARD monitoring system supports protection system owners and decision-makers in their daily work. It helps to make inspection and maintenance more reliable and predictable.

References

[1] Geobrugg AG (2023): Geobrugg GUARD Technical Product Description. Version 2023 EEA Countries
[2] Geobrugg AG (2023): Geobrugg GUARD Product Manual. Version 2023 EEA Countries
[3] FOEN (2020): Überwachungssysteme für gravitative Naturgefahren - Handbuch (Monitoring systems for gravitational natural hazards - Manual). Swiss Federal Office for the Environment (in German).
[4] Cantons GR, BE, VS (Editors), (2018): Handbuch Schutzbautenkontrolle (Manual for Inspection and Maintenance of Protection Systems). Office for Forests and Natural Hazards of the Canton of Grisons, Natural Hazards Division of the Office for Forests of the Canton of Bern and Service for Forests and Landscape of the Canton of Valais. (in German).
[5] ONR 24803:2008: Protection works for torrent control – operation, monitoring, maintenance. Austrian Standards.
[6] ONR 24810:2021: Technical protection against rockfall — Terms and definitions, effects of actions, design, monitoring and maintenance. Austrian Standards.
[7] Sorg, M.; Eicher M (2020): Überwachung der Korrosion von Schutzverbauungen (Monitoring of corrosion on protective systems) in: Journal Technik. Journal N° 8 December 2020
[8] Hoffmann, H. (2021): Remote monitoring of flexible protection systems against natural hazards in: Georesources 1/2021
[9] ISO 12944-2:2017-11: Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 2: Classification of environments. International Organization of Standardization.
[10] DIN EN 10244-2:2009-0: Steel wire and wire products - Non-ferrous metallic coatings on steel wire - Part 2: Zinc or zinc alloy coating. Deutsches Institut für Normung DIN e.V.
[11] Sättele M., Bründl M. (2015) Praxishilfe für den Einsatz von Frühwarnsystemen für gravitative Naturgefahren. (Practical Guide for the Use of Early Warning Systems for Gravitational Natural Hazards). WSL-Institute for Snow and Avalanche Research SLF, Federal Office for Civil Protection FOFP (ed.). (In German)
[12] Koe, A., Murphy, W., & Nicholson, R. (2018): Rock netting systems – design, installation and whole-life management. CIRIA, publication C775

Appendix A Technical Product Description Geobrugg GUARD

TECHNICAL PRODUCT DESCRIPTION

Geobrugg GUARD

Version 2023 EEA countries / creation date 15.05.2023

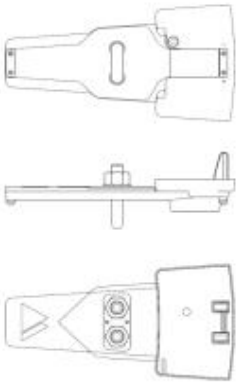
General	
Dimensions:	l=325mm / w=170mm / h=85mm
Weight:	2.2 kg
Assembly:	Wire rope Ø12mm - Ø24mm
Battery lifetime:	7-10 years
Security:	Independent operating system
Durability:	Outdoor approved (waterproof, UV-resistant, cold and heat resistant)

Sensors	
Rope force measurement:	up to 30'000kg (294kN)
Impact acceleration:	XYZ-axis / 0g - 200g
Orientation:	XYZ-axis [g]
Corrosion:	Current [µA]
Temperature:	- 50°C up to 80°C
Humidity:	0% - 100%
Device status:	Battery voltage and signal strength (RSSI)

Connectivity	
Type of Connectivity:	GSM / UMTS / LTE
Module:	2G / 3G or 4G
Protocol:	MQTT
Security:	Multiple encrypted

Function

Geobrugg GUARD / Version 2023 EEA countries / creation date 15.05.2023



The Geobrugg GUARD is an independent electronic device which sends data. It can be used either with the Geobrugg GUARD platform or with an own portal (data interface available against additional charge). Depending on your needs Geobrugg offers to sell the GUARD as a product or the service which includes access to the platform and your data.

Appendix B Excerpts from manuals, reports and standards for inspection, maintenance and corrosion protection

Example: cantonal / regional guidelines in Switzerland

Cantons GR; BE, VS (Editors), 2018: Handbuch Schutzbautenkontrolle (Manual for Inspection and Maintenance fo Protection Systems)

Inspection cycle

The following applies in general:

- A visual inspection in the sense of an observation is carried out annually, whereby this is also possible from a distance (optimally by means of a telescope, binoculars). These observations are defined as a minimum requirement.
- The actual cycle for protection system inspections is determined by the responsible protection construction specialist (in cooperation with the territorially responsible engineer). The cycle can vary between one and max. 5 years.
- Additional inspections outside the regular cycle after special events (heavy rainfall, snowy winters, etc.) are ordered by the responsible person (protection structure specialist).

Example: Austria / ONR standard

ONR 24803:2008/2017: Protection works for torrent control – operation, monitoring, maintenance. Austrian Standards (formerly Ö-Norm).

Inspection:

The following applies in general:

- Ongoing monitoring (OM) / Special inspection (SI)
- Control (C)
- Audit (A)

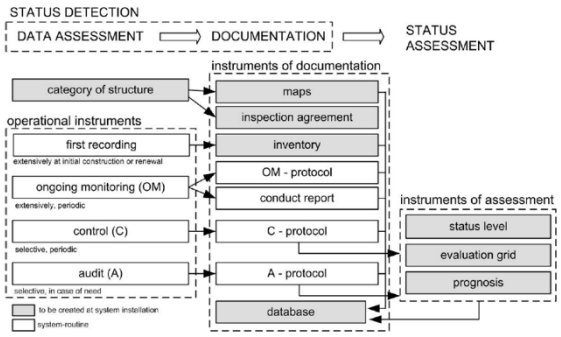


Figure 15 — Inspection tools

Example: Austria / ONR standard

ONR 24810 (2021): Technical protection against rockfall. Terms and definitions, effects of actions, design, monitoring and maintenance. Austrian Standard, Vienna

7.3.3 Ongoing monitoring (OM)

Ongoing monitoring of technical rockfall protection measures shall be performed annually. If continuous monitoring of protection measures occurs via suitable methods, Ongoing monitoring may be omitted. For protection measures with low sensitivity (e.g. rockfall protection dams and galleries) in consequence class CC 1, the Ongoing monitoring may be omitted according to Table 22. Functionality of the structure is inspected within the framework of the 10-year inspection.

7.3.5 Special inspection

Independent of the routine intervals, special inspections (SI) shall be performed when required as a result of Ongoing Monitoring or after exceptional events (e.g. storm, avalanche, mass movements, accidents) acting on the protection measures.

Example: Austria / ONR standard

ONR 24803 (2008): Protection works for torrent control – Operation, monitoring, maintenance. Austrian Standard, Vienna

5.3.2 Ongoing Monitoring

Ongoing monitoring (OM) is used to determine the serviceability (functional efficiency) of the barrier structures.

Responsible for the implementation are the owners of the structure (e.g., holders of the water right, public adminstrations) or the parties interested in publicly funded protective structures (municipalities, waterco-operatives and others). The inspections for the continuous monitoring are to be carried out by trained staff (forest wardens, torrent wardens, watercourse wardens).

Example: UK, CIRIA

Rock netting systems – design, installation and whole-life management

Koe, A., Murphy, W., & Nicholson, R. (2018). Rock netting systems – design, installation and whole-life management. CIRIA.

6.8 CORROSION

6.8.1 Introduction

Estimation of corrosion is an important part of design and a management aspect of the rock netting system. The strength of some parts of the system (eg the mesh component) can be dramatically affected by corrosion and this should be taken into account in the design for each of the components. Phear *et al* (2005) and BS 8006-2:2011+A1:2017 both give detailed guidance on the levels of corrosion protection available. This section provides further details for the components of rock netting systems and an overall approach to assessing the level of corrosion protection available, which depends on several stages (see Figure 6.12). It is important that each of the stages in Figure 6.12 be considered when estimating the design life of various components, and also the required maintenance of various components of the rock netting system.

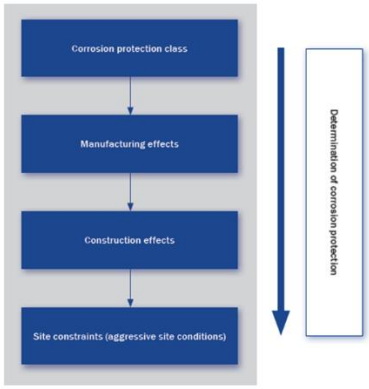


Figure 6.12 Effect of processes to assist in determination of corrosion class

Example: UK, CIRIA

Rock netting systems – design, installation and whole-life management

Koe, A., Murphy, W., & Nicholson, R. (2018). Rock netting systems – design, installation and whole-life management. CIRIA.

6.9 SUMMARY

The components of a rock netting system need to be adequately considered and specified correctly for the system to work as desired.

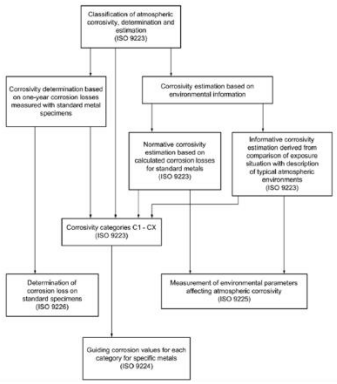
For appropriate whole-life management, the long-term performance of these systems demands that adequate corrosion resistance be considered.

Good practice considerations
Rock netting system components

- Rock netting systems are often designed to be used with specified components. So it is important to follow the manufacturer's specifications as it will maximise the whole-life performance of a system.
- It is no longer considered good practice to use turnbuckles as a component of a rock netting system. Older installations may have these components and care should be taken when removing debris as a wire rope may have become overloaded.
- Ensure that corrosion protection is appropriate to the site where a rock netting system is used. All components should have corrosion protection consistent to the whole system.
- Certificates of conformity for materials supplied should include the level of galvanisation class for the materials used for rock netting components.
- Site conditions may exert additional corrosion stresses on rock netting components. Particular attention should be given to galvanisation classes for coastal zones, areas affected by road salt, or where there is heavy atmospheric pollution and sulphur/sulphate rich geological materials (eg some mudstones, evaporites and mineralised zones).

ISO 9223:2012

Figure 1 –Classification of atmospheric corrosivity



Appendix C.1 Use case SØRØYA, Norway

Sørøya II

Monitoring

Projekt	Sørøya II
Ort	Sørøya
Land/Region	Norwegen
Installationsjahr	2020
Kunde	Troms og Finnmark fylkeskommune
Ausführende Firma	Fjerby AS

Ausgangslage

On the north Norwegian island Sørøya, above the main road from Hasvik to Sørvær, SPIDER Avalanche® Barriers were installed in 2019 to protect this remote - and touristic - road from rockfall and avalanches.

The island of Sørøya is situated north of Tromsø, north of the arctic polar circle. Though touristic in summer, it takes many hours to get there. The barriers of high-tensile steel are not only exposed to rockfall in summer and avalanches in winter, they are also close to the sea. This means corrosion is a permanent threat.

The Norwegian authorities requested a solution to monitor and report impacts or slow filling of the barriers. They also are interested in knowing about any corrosive effects the nearby Barents Sea is having on the barriers - not an average calculation, but reality time measurements at on these barriers.

Massnahme

In the first phase, three GUARD monitoring devices were placed in different locations within the barrier field. An early finding was that corrosion is significantly higher at the barriers close to the sea than those further up the slope. These, are more frequently and more severely affected by rockfall, for example the barrier shown on the top-left edge of the picture below where one of the GUARDs is on duty.

Today authorities can use data to decide when measures at the barriers are to be taken. In this way inspection trips can be reduced and maintenance works can be bundled. More importantly, safety increases since assessments can be taken when an event is reported by the GUARD.

Geschützte Objekte	Strasse, Touristische Infrastruktur, Infrastruktur
Systeme	Geobrugg GUARD
Weitere verbaute Anwendungen	Lawinenprävention

The Geobrugg GUARD on a barrier on the island of Sørøya north of the arctic polar circle.

Sørøya is hard to access: Journeys for controls inspections or maintenance are time consuming and expensive.

In the first phase, three monitoring devices were placed in different locations within the field. This site is affected by rockfall, snow loads and also a high corrosion rate.

The installation of the monitoring device requires no special knowledge. Only two nuts must be tightened.

Appendix C.2 Use case CARRIÈRE DE MICHELAU N27 (II), Luxembourg

Carrière de Michelau N27 (II)

Monitoring

Project	Carrière de Michelau N27 (II)
Location	Erpeldange-Michelau
Country/Region	Luxembourg
Year of installation	2020
Customer	Ministère du développement durable et des infrastructures, Adm. des Ponts et Chaussées, Division de la Voirie de Diekirch
Engineering	GEO BENELUX, Geobrugg Partner&Supplier Benelux countries
Initial situation	The road has been protected for years by two rockfall barriers RXI-500. At this location exists a very high rockfall activity. For these reasons, the fence's material must be removed regularly, which requires regular inspections of the fence. Not only small events can fill the barrier over time. Also, large rockfall events can occur. The rockfall barriers must then be emptied immediately.
Description	To guarantee constant monitoring, nine Geobrugg GUARD devices were installed on the two fences. With an acceleration sensor, larger rock impacts can be detected. The force measurement measures the slow filling of the fence. Furthermore, a corrosion sensor records the corrosion at this specific location, classifies it, and calculates the material service life. Installation and initial start-up were carried out independently by the customer. Credit for pictures: Administration des ponts et chaussées Division de la voirie de Diekirch - GEO Benelux. Merci!
Protected object	Road, Touristic infrastructure
Systems	Geobrugg GUARD
Other installed applications	Rockfall Protection, Slope Stability

The GUARD monitoring device continuously reports the state of the barriers, here placed on a retaining rope

Rockfall barrier with four GUARD devices installed on the retaining ropes

GUARD installed on a top support rope of a rockfall barrier

The GUARD monitoring device is placed on the top support rope

Detail of the expert dashboard with the corrosion calculation, which is C2 at this location

This rockfall event from March 4th, 2021, 11.51 h, was immediately reported via an alert to the mobile phone.

As mentioned before «At this location exists a very high rockfall activity.» Impact from beginning of June 2021.

The rockfall barrier did its job. But our new hero is the Geobrugg GUARD - our monitoring device reported the impact without delay.

Appendix C.3 Use case MELLITZ, Austria

Mellitz

Monitoring

Projekt	Mellitz
Ort	Mellitz
Installationsjahr	2021
Kunde	BBA Lienz
Ausführende Firma	Felbermayr
Ausgangslage	The road has been protected for years by rockfall barriers RXI-200. Due to the high snowfall in this region, the Geobrugg GUARDs were installed for test purposes. The aim was to confirm that the Geobrugg GUARD also measures the slowly increasing snow load.
Massnahme	To guarantee constant monitoring, three Geobrugg GUARD devices were installed: • With an acceleration sensor, larger rock impacts can be detected. • The force measurement measures the slow filling of the fence. This enables measuring the snow load in the winter months. • Furthermore, a corrosion sensor records the corrosion at this specific location, classifies it, and calculates the material service life.
Geschützte Objekte	Strasse
Systeme	Geobrugg GUARD
Weitere verbaute Anwendungen	Steinschlagschutz

Installation of Geobrugg GUARD on the top support rope with a torque wrench

Rockfall barrier, view from behind

Snowloads measured during winter 2020/ 2021