NEW SUSTAINABLE MODULAR AND CERTIFIED ROCKFALL PROTECTION SYSTEMS

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Abstract: *The transition to modular, certified rockfall protection systems represents a natural evolution in flexible barrier engineering. Rather than refining isolated parts, the approach reframes how systems are designed, manufactured, and installed to satisfy current technical, logistical, and environmental requirements. Through modularization, Geobrugg consolidates structural elements that previously evolved separately—post heads, post bases, brake elements, and base plates—thereby simplifying engineering, reducing part diversity, and streamlining logistics without compromising dynamic performance. From an environmental perspective, component standardization reduces embodied carbon, transport-related emissions, and waste, which is material given that Scope 3 accounts for more than 97% of the Group's footprint. Field deployment (e.g., Genestoso, Asturias) shows faster installation and fewer on-site errors, while full compatibility with EOTA-ETA, CE Marking, FOEN, and the Geobrugg 2025 test protocol has been kept. Overall, the modular strategy strengthens sustainability, manufacturing efficiency, and safety, and supports circular-economy aims.*

Keywords: *rockfall protection, modular systems, European Certification according to EAD, CE Marking*

NOVI ODRŽIVI MODULARNI I CERTIFICIRANI SUSTAVI ZAŠTITE OD ODRONA

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Sažetak: *Prijelaz na modularne, certificirane sustave zaštite od odrona stijena predstavlja prirodnu evoluciju u području fleksibilnih zaštitnih barijera. Umjesto usavršavanja pojedinačnih komponenti, ovakav pristup redefinira način projektiranja, proizvodnje i ugradnje sustava kako bi se zadovoljili suvremeni tehnički, logistički i okolišni zahtjevi. Modularizacijom Geobrugg objedinjuje konstrukcijske elemente koji su se prethodno razvijali zasebno — glave stupova, baze stupova, kočne elemente i temeljne ploče — čime se pojednostavljuje projektiranje, smanjuje broj različitih dijelova te optimizira logistika, bez kompromisa u pogledu dinamičkih performansi sustava. S aspekta zaštite okoliša, standardizacija komponenti smanjuje ugrađeni ugljik, emisije povezane s transportom te količinu otpada, što je posebno značajno s obzirom na to da Scope 3 emisije čine više od 97 % ukupnog ugljičnog otiska Grupe. Primjeri iz prakse (npr. Genestoso, Asturija) pokazuju bržu ugradnju i manji broj pogrešaka na gradilištu, uz potpuno zadržavanje kompatibilnosti s EOTA ETA smjernicama, CE oznakom, FOEN zahtjevima i Geobruggovim protokolom ispitivanja iz 2025. godine. Sveukupno, modularna strategija doprinosi održivosti, učinkovitosti proizvodnje i sigurnosti te podupire ciljeve kružnog gospodarstva.*

Ključne riječi: *zaštita od odrona stijena, modularni sustavi, europska certifikacija prema EAD smjernicama, CE oznaka*

1. INTRODUCTION

Responsible management of the corporate carbon footprint is now a business imperative under increasing regulatory and societal pressure. Cutting greenhouse-gas (GHG) emissions mitigates climate risk and reinforces leadership, credibility, and trust among clients and stakeholders. Within this context, systematic management follows four stages -calculation, reduction, compensation, and certification- supported by transparent measurement, reporting, and verification (Fig. 1).

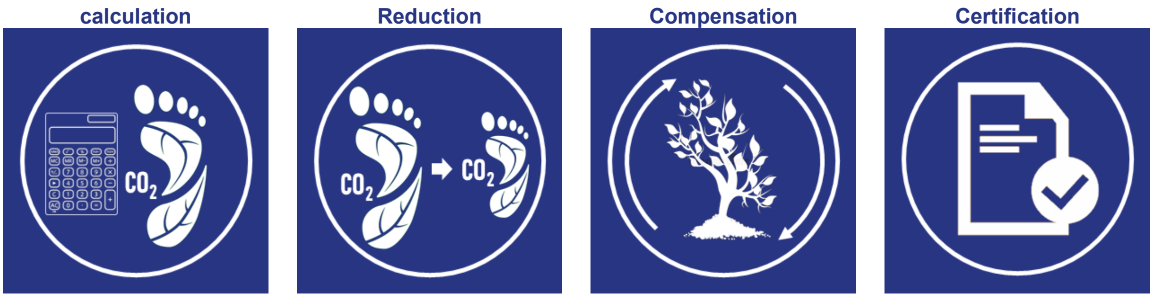


Figure 1. *Stages of corporate management of the CO_2 footprint.[modified from 11]*

The **Corporate Carbon Footprint** (CCF) quantifies all emissions from organizational activities by converting activity data (e.g., kWh, fuels, kilometres, materials) to tCO_2e under accepted standards such as the GHG Protocol. Identifying hotspots enables target setting and effective mitigation. At Geobrugg, modular flexible barriers contribute to emission reductions through streamlined logistics, easier part reuse, improved traceability, and more efficient installations. Residual emissions are compensated via verified projects aligned with erosion control and community benefits, complementing engineering solutions such as high-tensile TECCO® meshes [6].

2. CORPORATE CARBON FOOTPRINT, CCF

A carbon footprint is the total greenhouse gases emitted directly or indirectly by an activity, person, or organization. These emissions include both natural gases such as CO_2, CH_4, N_2O, and O_3, as well as human-made gases like HFC[1]s and PFC[2]s. Carbon footprints can be assessed at three levels:

1. Product footprint, covering emissions from raw material extraction to end-of-life.
2. Event footprint, accounting for transport, energy use, materials, and waste.
3. Organizational footprint, reflecting all emissions associated with a company's operations.

To classify emissions, the GHG Protocol defines direct emissions (from sources owned or controlled by the organization) and indirect emissions (generated by third parties due to the organization's activities) [11]. These are grouped into three scopes: direct emissions from owned equipment, vehicles, or processes; indirect emissions from purchased electricity and all other indirect emissions, such as supply chain impacts, business travel, and third-party logistics. Understanding and calculating these scopes enables companies to identify their environmental impact, strengthen sustainability strategies, and prove commitment to climate action. The Figure 2 shows graphically the scopes and the main emission elements that compose them. In the case of scope 3, where the effects are indirect, they are divided into two: those caused by activities and those resulting from activities derived from manufacturing. They are called in that order: upstream (suppliers) and downstream (distribution to customers) [8, 1].

[1] Hydrofluorocarbons
[2] Perfluorocarbons

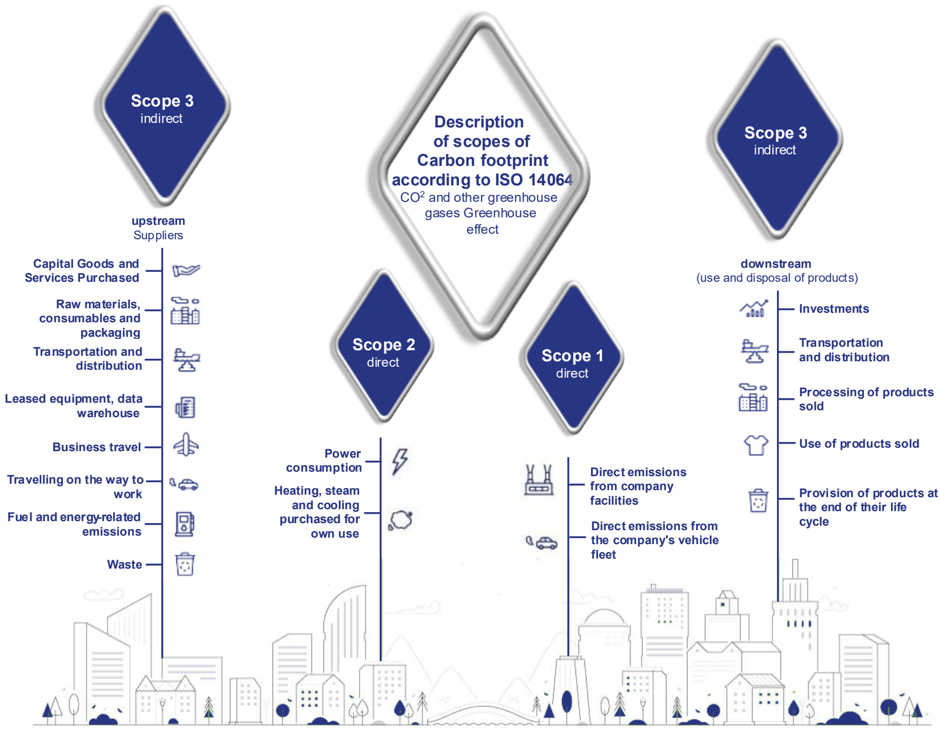


Figure 2. *Carbon footprint in the value chain, description of direct and indirect scopes [8,1]*

Calculating an organization's carbon footprint requires analysing all activities that generate greenhouse gas emissions, with complexity increasing as more emission sources are included [1]. In the Brugg Group's inventory, the distribution has been stable: Scope 1 ~1.5%, Scope 2 ~0.7%, and Scope 3 ~97.8% of total emissions (Fig. 3). The largest Scope 3 categories are purchased materials and consumables (~78%), followed by capital goods (~6%), supplier logistics (~5%), and customer logistics and provisioning (~3% each), with the rest collectively ~6%. This profile makes materials and supply-chain activities the dominant decarbonization levers.

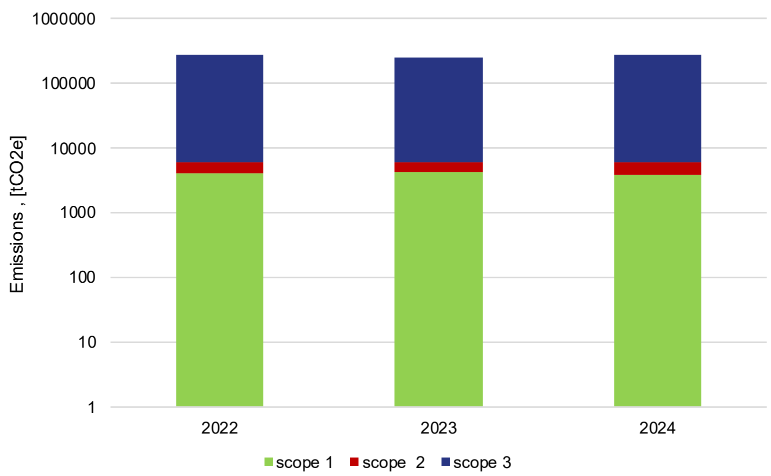


Figure 3. *Evolution of the carbon footprint in [tCO_2e] in the Brugg Group [1]*

Figure 4 shows that Scope 3 emissions at Geobrugg are overwhelmingly dominated by raw materials and consumables, which account for about 78% of the total. Capital goods contribute around 6%, supplier logistics roughly 5%, and both customer logistics and provisioning add about 3% each. All remaining Scope 3 categories together make up only about 6%. This distribution clearly shows that material use and supply-chain activities are the primary sources of Scope 3 emissions [1].

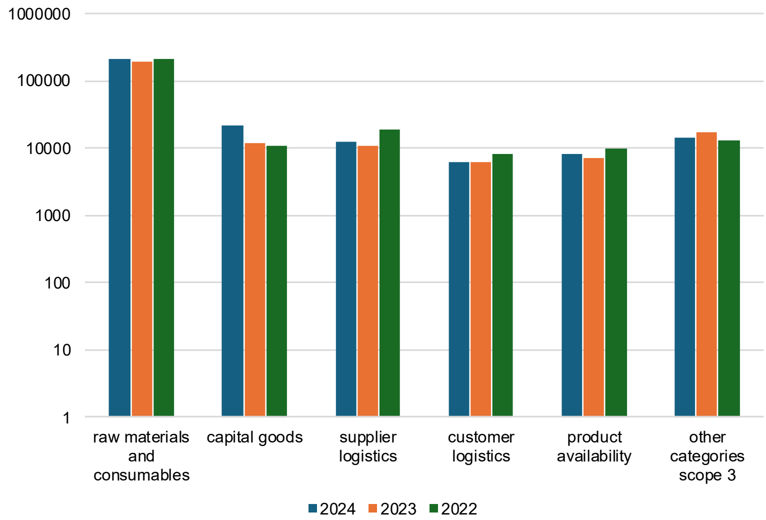


Figure 4. *Composition of emissions by category in scope 3 for Brugg [1]*

The data shows where efforts must be focused to achieve effective emission reductions: product and system manufacturing, which represents nearly 85% of Scope 3 emissions, followed by logistics—from both suppliers and customers—at around 8%. To address these hotspots, Geobrugg pursues [6]:

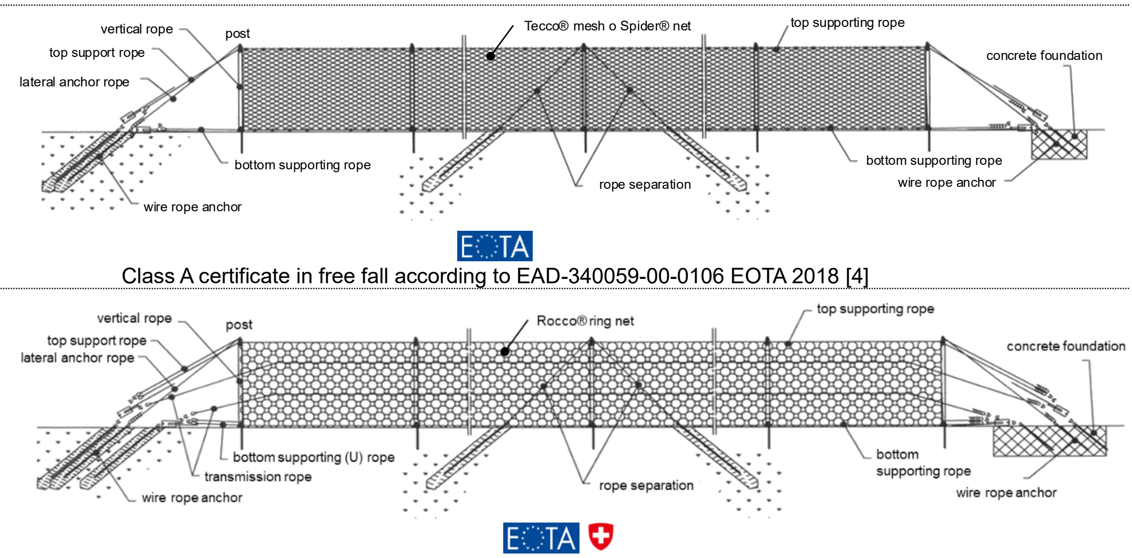
- expanded local manufacturing to reduce logistics emissions
- R&D for lighter, robust, longer-life systems that use fewer materials
- modularization to avoid shipping basic components globally
- faster, error-resistant installations that support emergency works

Core activities—monitoring, warning, prevention, and protection—target risks worsened by climate change (rockfalls, debris flows, avalanches, erosion). High-tensile steel meshes reduce material usage and extend service life through superior corrosion protection; recent initiatives include increasing slag content in steel production and developing damping systems combining meshes with reused tires (e.g., Rockfall X).

3. MODULAR BARRIER SYSTEMS

Driven by the company's sustainability commitments and the technical need to rationalize system components, the idea appeared to modularize flexible rockfall protection systems by creating interchangeable common parts. Geobrugg operate three barrier families—GBE, RXE, and ROCCO—each certified to different performance levels and component sets [4, 6, 7, 2, 5]. Figure 5 provides an overview of each of these barrier series, illustrating the starting point from which the modularization initiative was developed.

GBE

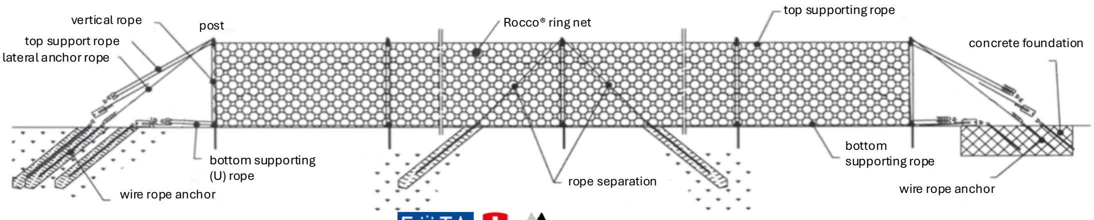


Class A certificate in free fall according to EAD-340059-00-0106 EOTA 2018 [4]

RXE

Class A certificate according to EAD -340059-00-0106 EOTA 2018 [4] and FOEN 2006 [7], 2018 [5]

ROCCO



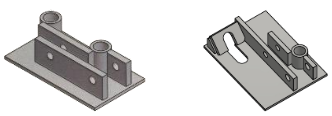
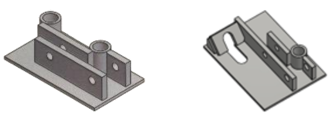
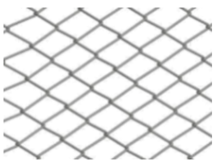
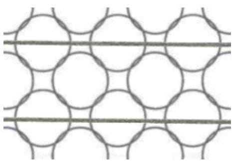
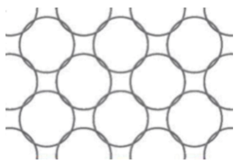
Class A certificate according to EAD -340059-00-0106 EOTA 2018[4], FOEN 2006 [7], 2018 [5], 2022 [2] and GB 2025 [6]

Figure 5. *Geobrugg barrier series and safety level*

Rockfall barriers are traditionally certified using impact tests performed only at the central span of a three-module system, as required by standards such as the European EAD 340059-00-0106 [4]. However, actual rockfall events rarely strike this idealized point and often involve off-centre impacts, edge hits, or fragmented blocks. Geobrugg new testing methodology accounts for these real-world conditions, ensuring protection across the entire interception area. Because conventional tests encourage over-dimensioning, designers typically add modules or increase barrier height. The ROCCO® series, validated under the Geobrugg 2025 protocol [6], avoids unnecessary over dimensioning and reduces material use, fully supporting circular-economy principles. In addition to the safety levels established by the different test procedures (Fig. 5), the three-barrier series also differ in some key structural components [6,3,10]. These include the base plates, posts, braking elements, and the interposition membranes, as summarized in Table 1:

1. base plates and posts: the GBE and RXE series share these components, whereas both elements differ in the ROCCO® series.
2. braking elements: The GBE and RXE brake elements are very similar, both manufactured from stainless steel; however, the GBE series uses plates-shaped devices, while the RXE series employs double-bar configurations. In contrast, the ROCCO® series uses plate-shaped brake elements made from hot-dip galvanized structural steel (S355).
3. the interposition membrane: in the GBE series, the interposition membrane consists of either a high-strength diamond-shaped wire mesh or a rhomboidal-shape spiral net. In contrast, both the RXE and ROCCO® series use high-tensile steel ring-net panels in a 4:1 configuration. These two series can be distinguished visually: the RXE ring-net panels include horizontal transmission or reinforcement ropes that control deformation, whereas the ROCCO® series employs an unreinforced ring-net configuration. In all cases, high-tensile steel is used.

Table 1. *Components of the three series of GBE, RXE and ROCCO® barriers [6, 3, 10]*

Element	GBE	RXE	ROCCO®
Base plate			
Posts			
Brakes			
Membrane			

The **modularity** of a system refers to the capacity to be subdivided into independent but interconnected subassemblies (pieces), which fulfil specific functions and can be assembled to form the complete system. A detailed component analysis showed opportunities to rationalize parts and create standardized, interchangeable sub-assemblies without sacrificing performance. The post and base-plate interface became the centre of the modular concept [7, 8]. A small set of interchangeable parts (screwed, not welded to the post) was designed to achieve, using the minimum number of components, post-head components now cover all standard positions. Figure 6 shows, three screwed pieces (❶, ❷ and ❸ in two sizes) are enough [6, 3,10].

piece ❶ for <u>intermediate post</u>, connections for retaining ropes, to the valley and pulleys

piece ❶ combined with ❷ part [Y], valid for <u>side post</u>, connections for retaining ropes, lateral, vertical and pulleys

piece ❶ combined with part ❸ [H], valid for <u>rope separation post</u>, connections for retaining ropes, support, and transmission.

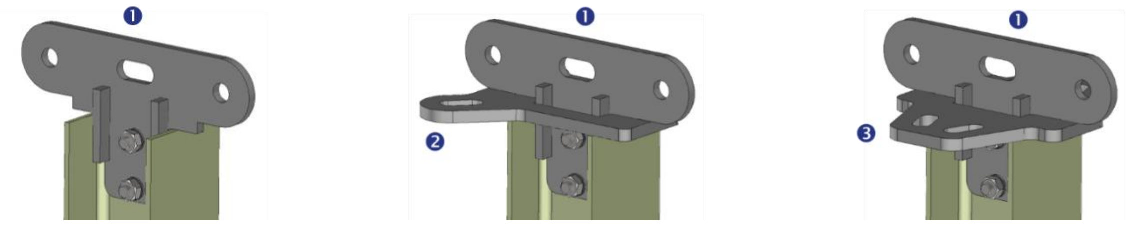


Figure 6. *Post heads for modular system [GBE-RXE] parts ❶, ❷ and ❸ they are available in two sizes, one for HEA 120-160 profiles and one for HEA 180-240 profiles [6, 3,10]*

The ROCCO family (Fig. 7) uses two sizes as well, with four screwed parts, (❶, ❷, ❶ and ❸) two of which are shared with GBE-RXE series (❶ and ❸).

Piece ❶ for <u>intermediate post</u>, connections for retaining, to the valley and integrated cable guide

Piece ❶ with [❷ Y] piece, valid for <u>side post</u>, connections for retaining ropes, lateral. vertical and integrated rope guide

Piece ❶ combined with ❸ [H], valid for <u>rope separation</u>, connections for retaining ropes and support (Ditto GBE-RXE).

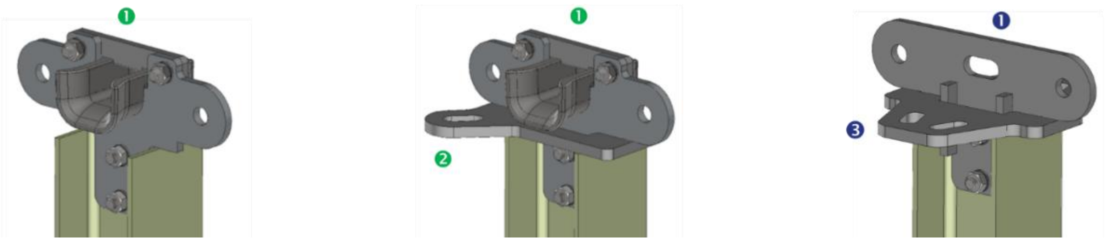


Figure 7. *Post heads for modular system [ROCCO], the parts ❶, ❷ and ❸ are available in two sizes, one for HEA 120-160 profiles and one for HEA 180-240 profiles [6,3,10]*

For the **post feet** connection to the base plate, the modular solution implemented a single bolted component that is compatible across all three series (GBE, RXE and ROCCO®), in two sizes (Fig. 8). This piece has a larger diameter hole that houses a screw, where the articulation with the base plate occurs, which rationalizes installation procedures.

Piece ❹ HEA 120-160 profile

Piece ❺ profile HEA 180-240

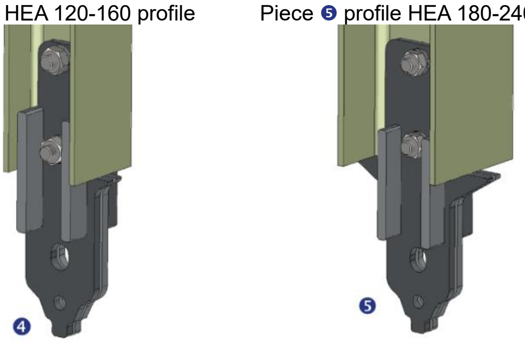


Figure 8. *Post feet for modular system. The pieces ❹ are ❺ available in two sizes, one for HEA 120-160 profiles and one for HEA 180-240 profiles [6,3,10]*

The optimization eliminates the need for different profile types at the boundary modules, simplifying installation and reducing errors. The cross-section of the post profile will be a function of the height of the barrier. The **base plate** concentrates a significant part of the innovation. Front and rear anchors are aligned; plates and bolted adapters (including a replaceable prism element) allow either twin vertical piles or a 45° rear traction anchor with minimal effort (Fig. 9). The post can be set at different angles with a simple bolt adjustment, which speeds on-site work. ROCCO® features a specific base plate with integrated cable guide; GBE-RXE employ a double-pulley foundation option for vertical micropiles with a 45° anchor.

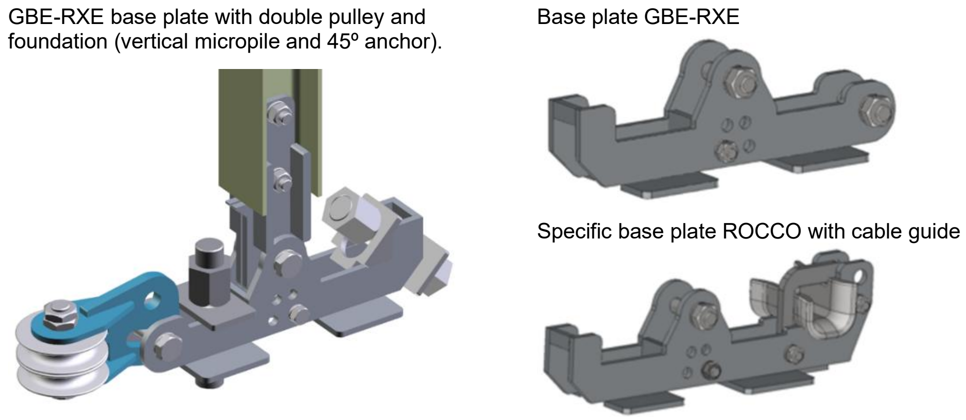


Figure 9. *Modular series base plates (GBE-RXE) and (ROCCO) [6,3,10]*

Standardized **U-shaped brake elements** (energy-dissipation devices) now cover all series with geometries A, B or C[3] and length variants (150, 400, 500 cm). Manufactured in hot-dip galvanized structural steel S355 (Fig. 10), they provide an optimal strength–deformation response and durable performance fig. 11).

Figure 10. *Standardized U-shaped braking device diagram (geometries A, B or C) [6,3,10]*

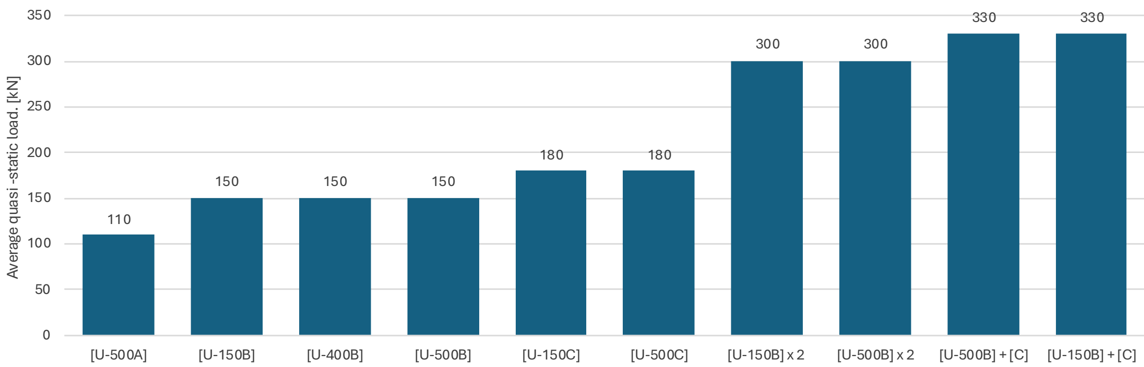


Figure 11. *Average quasi-static load according to geometry and length of the brake*

In parallel, pulley housings were optimized, reducing weight by approximately 2.9 kg (two-unit sets) and 3.4 kg (three-unit sets), while improving functionality and appearance (Fig. 12).

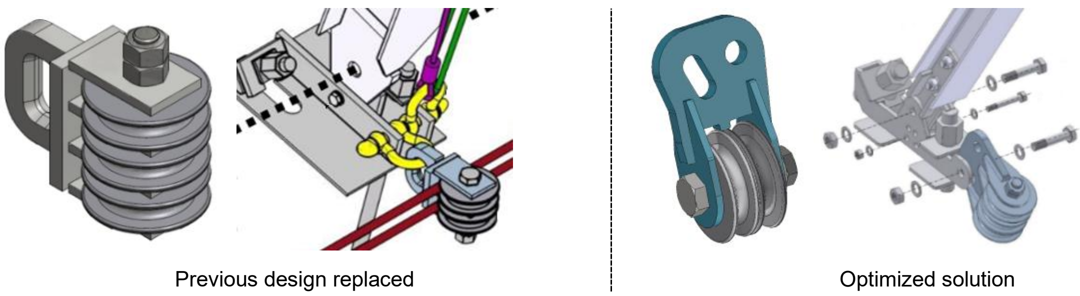


Figure 12. *Evolution of the pulley system for the transmission of loads between one functional module and another [6,3,10].*

[3] cross-sectional dimensions of the platform A [70x8], B [70x10] and C [65x12]) in mm

4. CERTIFICATION

All current evaluations for the three barrier families remain valid following modularization, with the new components fully integrated into existing certifications. For example, the GBE-1000A barrier keeps European Technical Assessment (ETA 09/0262; version 02 dated 10/06/2024) and Constancy of Performance for CE Marking (1301-CPR-0573; version 02 dated 30/09/2024) (Tables 2 and 3).

Table 2. *European certification for a GBE-1000A barrier (TSÜS[4]) [4,3,10]*

ETA 09/ 0262 [16/08/2014]	**ETA 09/ 0262** version 02 [10/06/2024]

TSUS
Technický a skúšobný ústav stavebný, n. o.
Building Testing and Research Institute
Studená 3
821 04 Bratislava
Slovak Republic
Phone: +421 2 49228101
E-mail: sternova@tsus.sk
Website: www.tsus.sk

Designated according to Article 29 of Regulation (EU) No 305/2011

Member of EOTA
www.eota.eu

European Technical Assessment — **ETA 09/0262 of 16/09/2014**

General Part

Technical Assessment Body issuing the ETA and designated according to Article 29 of the Regulation (EU) No 305/2011: Technický a skúšobný ústav stavebný, n. o.

Trade name of the construction product	Rockfall Protection Barrier GBE – 1000A
Product family to which the construction product belongs	Product area code: 34 Building Kits, Units and Prefabricated elements
Manufacturer	Geobrugg AG Geohazard Solutions Aachstrasse 11 CH–8590 Romanshorn Switzerland http://www.geobrugg.com
Manufacturing plant	Geobrugg AG Geohazard Solutions Aachstrasse 11 CH–8590 Romanshorn Switzerland
This European Technical Assessment contains	27 pages including 16 annexes which form an integral part of this assessment. Annexes 5/8/9 contain confidential information and are not included in the European Technical Assessment when that assessment is publicly available.
This European Technical Assessment is issued in accordance with regulation (EU) No 305/2011, on the basis of	ETAG 027, edition September 2012 amended April 2013, used as European Assessment Document (EAD).
This version replaces	ETA-09/0262 with validity from 28.09.2009 to 27.09.2014

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European Technical Assessment — **ETA 09/0262 – version 02 of 10/06/2024**

General Part

Technical Assessment Body issuing the ETA and designated according to Article 29 of the Regulation (EU) No 305/2011: Technický a skúšobný ústav stavebný, n. o.

Trade name of the construction product	Falling Rock Protection Barrier GBE-1000A
Product family to which the construction product belongs	Product area code: 34 Building Kits, Units and Prefabricated elements
Manufacturer	Geobrugg AG Geohazard Solutions Aachstrasse 11 CH–8590 Romanshorn Switzerland http://www.geobrugg.com
Manufacturing plant	Geobrugg AG Geohazard Solutions Aachstrasse 11 CH–8590 Romanshorn Switzerland
This European Technical Assessment contains	31 pages including 25 annexes which form an integral part of this assessment. Annexes 6/7/8/9/17/18/19 contain confidential information and are not included in the European Technical Assessment when that assessment is publicly available.
This European Technical Assessment is issued in accordance with regulation (EU) No 305/2011, on the basis of	EAD 340059-00-0106
This version replaces	ETA 09/0262, issued on 16/09/2014

Table 3. *Constancy of Performance (CE marking) for a GBE-1000A barrier (TSÜS) [4,3,10]*

CE 1301-CPR-0573 [26/09/2014]	**CE 1301-CPR-0573** version 02 [30/09/2024]

Notifikovaná osoba č. 1301
TECHNICKÝ A SKÚŠOBNÝ ÚSTAV STAVEBNÝ, n. o.
BUILDING TESTING AND RESEARCH INSTITUTE
Studená 3, 821 04 Bratislava, Slovenská republika

Certificate of constancy of performance

1301 – CPR – 0573

In compliance with Regulation 305/2011/EU of the European Parliament and of the Council of 9 March 2011 (the Construction Products Regulation or CPR), this certificate applies to the construction product

Rockfall Protection Barrier GBE – 1000A
Energy level classification
3
Classification for residual height for MEL
Category A

with the intended use to stop moving rock blocks on a slope with the Service Energy Level 330 kJ and with the Maximum Energy Level 1000 kJ and covers a range of ambient temperatures from - 20 °C to + 50 °C.

Produced by manufacturer

Geobrugg AG
Geohazard Solutions
Aachstrasse 11, CH-8590 Romanshorn
Switzerland

and produced in the manufacturing plant

Geobrugg AG
Geohazard Solutions
Aachstrasse 11, CH-8590 Romanshorn
Switzerland

This certificate attests that all provisions concerning the assessment and verification of constancy of performance described in the ETA

ETA 09/0262

under system 1 for the performances set out in this certificate are applied and that

the construction product fulfils all the prescribed requirements for these performances.

This certificate was first issued on 21 January 2010 (under the CPD) and will remain valid as long as the ETA remains valid and the manufacturing conditions in the plant or the factory production control itself are not modified significantly, unless suspended or withdrawn by the product certification body.

Bratislava, 26 September 2014

Technický a skúšobný ústav stavebný, n. o. TSUS -1- Notifikovaná osoba 1301

Dipl. Ing. Daša Kozáková
Head of Notified Body 1301

066236

Notifikovaná osoba č. 1301
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BUILDING TESTING AND RESEARCH INSTITUTE
Studená 3, 821 04 Bratislava, Slovenská republika

Certificate of constancy of performance

1301 – CPR – 0573

In compliance with Regulation (EU) 305/2011 of the European Parliament and of the Council of 9 March 2011 (the Construction Products Regulation or CPR), this certificate applies to the construction product

Falling Rock Protection Barrier GBE-1000A
Energy level
Category 3
Residual height for MEL
Category A

is used to stop moving rock blocks on a slope. The barrier is able to stop a block impacting the interception structure with a Service Energy Level (SEL) of 330 kJ and Maximum Energy Level (MEL) of 1000 kJ covering a range of ambient temperature of -20 °C up to +50 °C.

Produced by manufacturer

Geobrugg AG
Geohazard Solutions
Aachstrasse 11, CH-8590 Romanshorn
Switzerland

and produced in the manufacturing plant

Geobrugg AG
Geohazard Solutions
Aachstrasse 11, CH-8590 Romanshorn
Switzerland

This certificate attests that all provisions concerning the assessment and verification of constancy of performance described in the ETA

ETA 09/0262 – version 02, issued on 10/06/2024
and
EAD 340059-00-0106

under system 1 for the performance set out in the ETA are applied and that the factory production control conducted by the manufacturer is assessed to ensure the

constancy of performance of the construction product.

This certificate was first issued on 21 January 2010 (under the CPD) and will remain valid as long as neither the ETA, the EAD, the construction product, the AVCP methods nor the manufacturing conditions in the plant are modified significantly, unless suspended or withdrawn by the notified product certification body.

Bratislava, 30 September 2024

Technický a skúšobný ústav stavebný, n. o. TSUS -1- Notifikovaná osoba 1301

Dipl. Ing. Daša Kozáková
Head of Notified Body 1301

169800

In addition, certified climbing-aid anchor points have been added along the posts. These anchor interfaces are weld-free and certified as work equipment, improving contractor safety during installation (see Table 4).

[4] TAB: Technical Assessment Body, EOTA member

Table 4. *Anchor Point Certification (TÜV [9])*

Anchors point for certified installation

Report number:
PSA24-062E

TÜV AUSTRIA

Test Report PSA24-062E

Manufacturer: Geobrugg AG, Aachstrasse 11, 8590 Romanshorn, Switzerland

Client: (if different) REPAPRESS AG, Palmensteg 4, 8580 Amriswil TG, Switzerland

Test Object: Personal fall protection equipment – Anchor device EN 795:2012 type A

Model: The anchor device 'Climbing Aid' is used to secure a maximum of two people against falls from a height and is intended for installation on steel structures with sufficient load-bearing capacity. It consists of a folded sheet metal bracket (t = 5 mm) made of galvanised steel (S355). The hole (Ø 12 mm) is used to accommodate the corresponding fastening elements. The PPE is attached via the round opening (Ø 40 mm). The anchorage device can be loaded horizontally or downwards.

Picture:

Figure 1: anchor device 'Climbing Aid' "

Test Basis: (EN ISO/IEC 17025) EN 795:2012, CEN/TS 16415:2013

Additional set of rules: --

Test results and conformity statement:

Test requirements	Remarks	Result
5.1 General	–	PASS
5.2 Materials	–	PASS
5.3 Design and ergonomics	–	PASS
5.4 Deflection and deformation	–	PASS
5.5 Specific requirements	–	PASS

Summary: The above-mentioned product fulfils the requirements of the cited sections of the standards (see section 1) if it is used in accordance with the manufacturer's information. Chapter 6 contains a detailed summary of the results. This test report consists of 13 pages.

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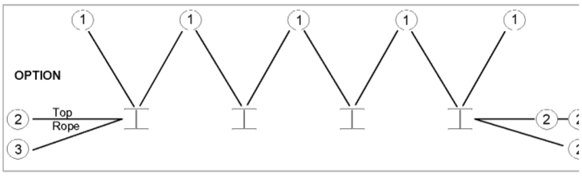
5. LOADS ON FOUNDATIONS AND ANCHORS

A key question for designers and owners is whether the new modular configuration affects load transfer to foundations and anchors. Testing confirms that characteristic loads at critical nodes are maintained, with improvements at specific points [4,6]. Below is an example based on the 2000 kJ barrier of the RXE series, illustrating how the transition from Version 1 to Version 2 affects the characteristic loads transmitted to the foundations at the post bases (Table 5).

Table 5. *Loads on the foundations of the bases of the posts [6]*

Loads on foundations RXE-2000 (V1)

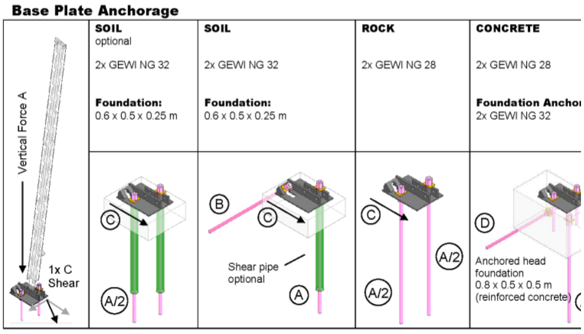
Rope Anchorage



No.	Anchorage Type	Anchor Type	Characteristic Load
1	Upslope Anchor (Retaining Ropes)	Type III 18.5 mm	315 kN
2 (3)	Lateral Anchors (Support Ropes, Lateral Ropes)	(2) Type III 18.5 mm (3) ---	(2) 285 kN OPTION: (3) 535 kN
A B C D	Vertical Force Normal Force in Anchor Shear Force, parallel to base plate Anchored Head Foundation (>0.1m³)		310 kN 115 kN 160 kN 115 kN

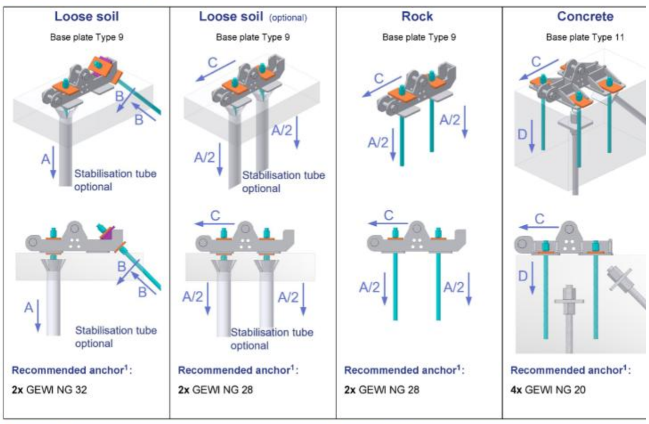
IMPORTANT: When using rod anchors with flexheads, it is necessary to have reinforced head foundations to bear the shear forces.

Base Plate Anchorage



Loads on foundations RXE-2000 (V2 modular)

Base plate anchorage



	Characteristic Force F_k		Characteristic Force F_k
A	310 kN	C	160 kN
B	115 kN	D	80 kN

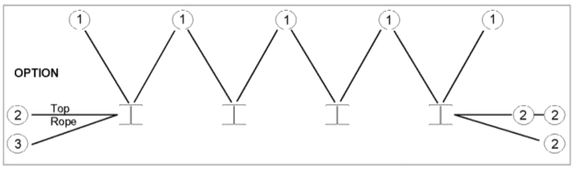
Note that characteristic tensile demand on the 45° downslope anchor (point D) decreases from 115 kN to 80 kN—approximately a 30% reduction—while other characteristic values remain consistent with earlier versions. Updated technical sheets for the modular barriers also provide more information on anchor forces (Tables 5 and 6) for upslope retention and valley ropes under different configurations (angles and rope counts).

Table 6. *Anchors forces [6]*

Loads on anchors RXE-2000 (V1)	Loads on anchors RXE-2000 (V2 modular)

Loads on anchors RXE-2000 (V1)

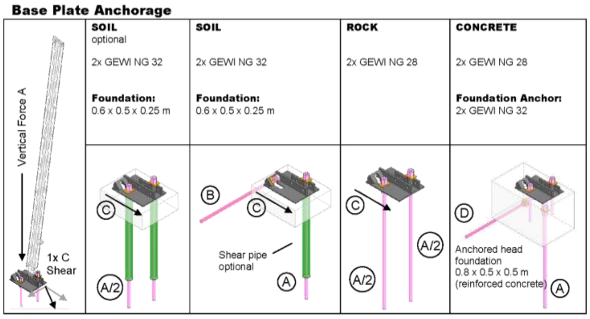
Rope Anchorage



No.	Anchorage Type	Anchor Type	Characteristic Load
1	Upslope Anchor (Retaining Ropes)	Type III 18.5 mm	**315 kN**
2 (3)	Lateral Anchors (Support Ropes, Lateral Ropes)	(2) Type III 18.5 mm (3) ---	**(2) 285 kN OPTION: (3) 535 kN**
A B C D	Vertical Force Normal Force in Anchor Shear Force, parallel to base plate Anchored Head Foundation (>0.1m³)		**310 kN 115 kN 160 kN 115 kN**

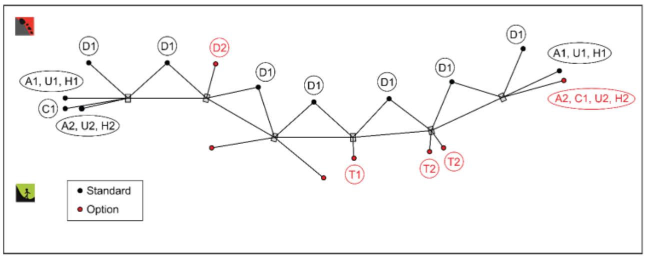
<u>**IMPORTANT:**</u> When using rod anchors with flexheads, it is necessary to have reinforced head foundations to bear the shear forces.

Base Plate Anchorage



Loads on anchors RXE-2000 (V2 modular)

Rope Anchorage



	Anchorage Type	Characteristic Force F_k	Recommended Anchorage Type[1]
D1	Upslope rope	**315 kN**	Spiral rope anchor 18.5 mm
A1, U1, H1	Support rope, U-rope, Transmission rope	**285 kN**	Spiral rope anchor 18.5 mm
C1	Lateral rope	**285 kN**	Spiral rope anchor 18.5 mm
A2, U2, H2	Support rope, U-rope, Transmission rope	**285 kN**	Spiral rope anchor 18.5 mm
T1	Downslope rope with one rope, 5-15°	**205 kN**	Spiral rope anchor 14.5 mm
T2	Downslope rope with two ropes, 15-25°	**170 kN**	Spiral rope anchor 14.5 mm
D2	Upslope rope (change towards downslope < 40°)	**130 kN**	Spiral rope anchor 14.5 mm
A2, C1, U2, H2	Support rope, Lateral rope, U-rope, Transmission rope	**535 kN**	Spiral rope anchor 22.5 mm

[1] According to Load bearing proof $[E_d = F_k \times 1.15] \leq [R_d = R_k / 1.1]$

6. CASE STUDY: MERAG FERRY TERMINAL, ISLAND OF CRES – CROATIA

The rockfall protection project on Cres Island represents a practical application of next-generation modular barrier systems in a real infrastructure setting (Fig. 13 – 16). The primary objective was to improve safety along the access road to the Merag ferry terminal, an area exposed to rockfall hazards and increased seasonal traffic loads. This project was interesting not only because it was supplied with the well-known and proven active slope stabilisation solution TECCO® G45/2 but also because it showcased the new modular GBE-2000A barrier system (Fig. 17) and the first regional installation of a ROCCO 2000 system (Fig. 18.), and it was the actual demonstration on how modular technology enhances both performance and efficiency.

As it was stated, a key advantage of the modular barrier concept is the reduction in component diversity through standardized, interchangeable parts. In the Cres project, this translated into simplified logistics and more efficient material handling. Fewer unique components meant easier transport, reduced risk of missing elements on site, and improved coordination between delivery and installation teams as well as easier installation learning curve since the parts are repeatedly the same. This type of optimization typically contributes to a noticeable reduction in transport-related emissions, supporting lower overall carbon footprint, particularly important given that material production and logistics account for most emissions in such systems.

Installation efficiency was another major benefit. The modular design, based on bolted (rather than welded) connections and adaptable base plate configurations with self-standing mounted posts, enabled the contractor to use less manpower and brought overall faster assembly under challenging terrain conditions with reduction of installation time in the range of 15–30% (depends on the level of contractor experience). This is especially relevant for infrastructure projects like Cres, where it was imperative to finish the installation before touristic season starts to minimize road disruption during peak hours. Installation error reduction also played a significant role. The use of standardized components and simplified connections reduces the likelihood of incorrect assembly, which is common in complex barrier systems with many unique parts. On Cres, this contributed to smoother installation workflows, fewer on-site adjustments, and improved overall quality control.

From a materials perspective, the modular system avoids unnecessary over-dimensioning by aligning design more closely with real impact scenarios. In combination with optimized component geometry and high-tensile materials, this results in estimated material savings of approximately 15 – 20% compared to conventional systems, which was the case on the Cres Project, where it was not only visible cost reduction but also direct impact on lowered embodied carbon.

Finally, the ROCCO barrier installed on Cres highlights the structural and testing advancements of the modular approach. Its certification for multiple real-world impact scenarios allows engineers to achieve required safety levels with fewer system extensions, further contributing to material efficiency and installation simplicity.

Overall, the Cres project illustrates how modular rockfall protection systems deliver tangible benefits: faster installation, reduced error rates, optimized logistics, and lower environmental impact, all while maintaining the highest safety standards.

Figure 13. *Detail of the head of a GBE-2000A intermediate post (piece ❶)*

Figure 14. *Detail of the foot ❹ and base plate of a GBE-2000A*

Figure 15. *Detail of the approved anchor points on the back of the GBE-2000A post (Table 4.)*

Figure 16. *Detail of modular posts with pre-assembled mesh for easier installation*

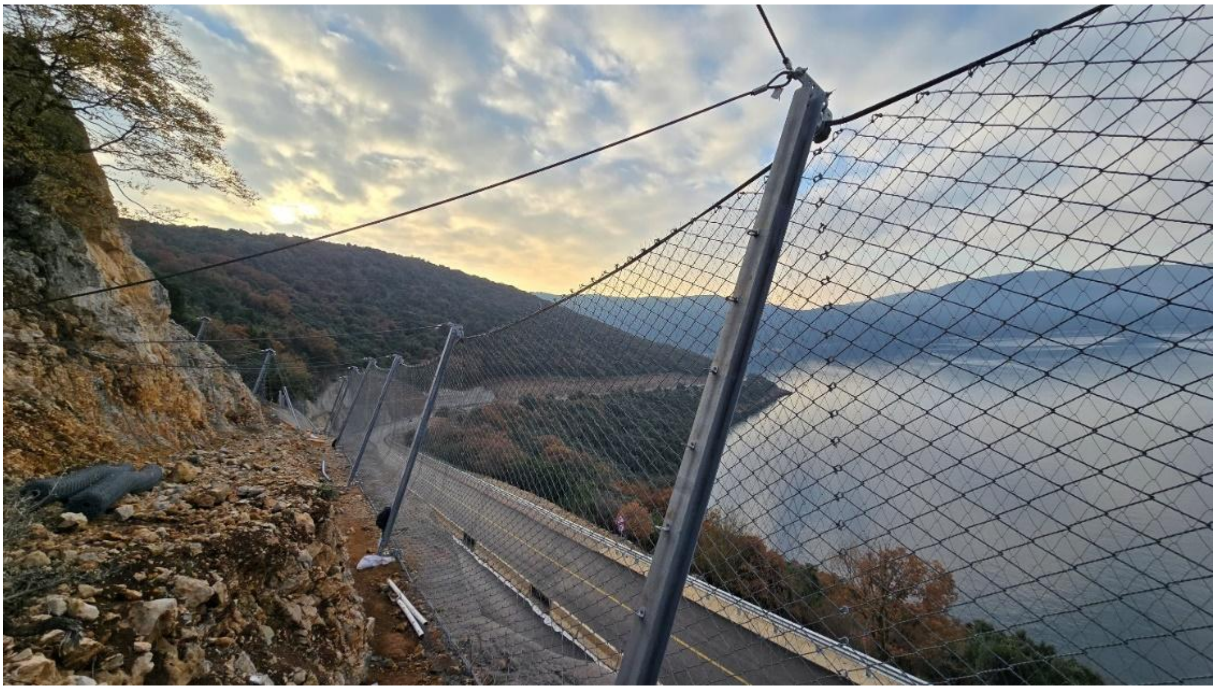


Figure 17. *Finished product, GBE-2000A modular barrier system*

Figure 18. *Finished product, ROCCO 2000 one-field barrier system*

7. CONCLUSIONS

Modular Design Optimization. Consolidating heads, post-to-base interfaces, base plates, and brake elements reduces part diversity, simplifies logistics and maintenance, and enhances long-term serviceability.

Sustainability and Emissions Reduction. Standardization and optimized manufacturing reduce raw-material use and transport, directly lowering Scope 3 emissions that currently dominate the Group's footprint; increased reuse potential supports circular-economy goals.

Regulatory compliance and security. Modularization preserves ETA and CE compliance, while enhanced certified anchor points improve installer safety; Geobrugg expanded testing protocol addresses real-world impact scenarios beyond conventional standards.

Operational Efficiency. Field experience shows faster, more consistent installation with fewer errors, particularly in complex terrain or emergency works requiring rapid deployment.

Applied Innovation. Standardized brake elements (S355), optimized pulley assemblies, and interchangeable post-head and base interfaces deliver functional gains and weight reductions without compromising strength or safety.

Strategic Industry Benefits. Modularity strengthens competitiveness in markets that demand rapid, safe, and sustainable solutions, while enabling local manufacturing, shortening supply chains, and creating skilled employment.

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