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A design procedure for high energy rockfall barriers

Conception des écrans pare-blocs à haute énergie

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ABSTRACT: The design of high energy rockfall barriers is traditionally carried out through trajectory simulations along the slope. The simplest way of designing these structures is comparing the energy level derived from these simulations with the results of the real scale tests according to the European Guideline Document 340059-00-0106 (which substitutes the previous ETAG 27-2008). This EAD is the harmonized document that defines how to test dynamic rockfall barriers and obtain their features (energy, residual height, deformation) in Maximum Energy Level (MEL) and Service Energy Level (SEL). Even though this guideline allows to compare in a reliable way the different barriers, this design procedure has limitations and doesn't consider how the real impact and installation conditions affect the barrier performance. In this paper, we give an overview of the contents of the EAD, and we show a design approach based on the Italian norm UNI 11211:2012, the mentioned EAD and the extensive experience of Maccaferri. Lastly, we will highlight the state of the art related to the foundation design.

RÉSUMÉ: La conception des écrans pare-blocs à haute énergie est traditionnellement réalisée par des simulations de trajectoire le long du talus. La manière la plus simple de dimensionner ces structures consiste à comparer le niveau d'énergie dérivé de ces simulations avec les résultats des essais en vraie grandeur conformément au Document d'Évaluation Européen 340059-00-0106 (qui remplace l'ancien ETAG 27-2008). Ce DDE est le document harmonisé qui définit comment tester les écrans pare-blocs dynamiques et obtenir leurs caractéristiques (capacité d'absorption d'énergie, hauteur résiduelle, déformation) au niveau d'énergie maximal (MEL) et au niveau d'énergie de service (SEL). Bien que ce guide permette de comparer de manière fiable les différentes barrières, cette procédure de conception présente des limitations et ne tient pas compte de la manière dont les conditions réelles d'impact et d'installation affectent la performance de la barrière. Dans cet article, nous donnons un aperçu du contenu du DDE, et nous présentons une approche de conception basée sur la norme italienne UNI 11211 :2012, le DDE mentionné et l'expérience approfondie de Maccaferri. Enfin, nous mettrons en lumière l'état de l'art lié à la conception des fondations.

Keywords: Rockfall protection systems; rockfall barrier; EAD 340059; new design approach.

1 INTRODUCTION

Rockfall dynamic barriers are kits designed to catch rock blocks that can fall from a slope. They are installed far from the detachment area; thus, they are classified as passive protection systems.

These systems can cover large surfaces that could not otherwise be protected with an active system (pinned drapery), they can absorb large impact energies, and they have been tested and certified by a recognised Technical Assessment Body.

1.1 EAD 340059-00-0106

The EAD 340059-00-0106 (hereinafter referred to as EAD) defines a dynamic rockfall barrier as a kit able to stop moving rock blocks on a slope with an energy level greater or equal to 100 kJ.

The kit is made up of:

- Interception structure: made of a principal net, and an optional additional layer usually with a finer mesh.
- A support structure: composed of metallic posts (minimum 4), with a separation distance between 8 and 12 meters.
- Connection components: consisting of metallic ropes, wire rope grips, and/or energy dissipating devices.

The foundation is not considered part of the kit.

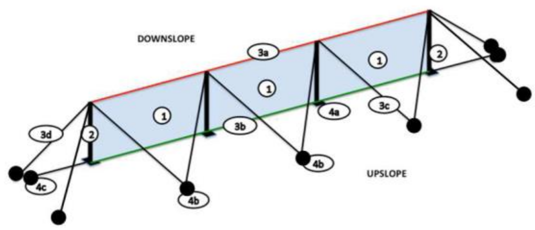

Figure 1. View of rockfall barrier components.

2 ROCKFALL SIMULATIONS

2.1 Input data

The first step to carry out the rockfall simulations in a reliable manner is to obtain the following:

- Geomechanical data: Type and dimensions of the rock blocks.
- Geological data: Type of ground in the hillside to obtain the restitution coefficients.
- Topographic data: To define the most unfavourable section, locate the rockfall detachment area, and choose the optimal location for the bar.

These parameters can be obtained with different degrees of accuracy, which will influence the Safety Factors for the calculations later.

2.2 Rockfall simulations

The rockfall simulations are done through several commercial softwares that rely upon different algorithms. These tools allow the designer to identify the block route and the parameters (velocity, energy, bounce height) at each point. For the numerical analysis, designers should take into account the following (Giachetti & Zotti, 2012):

- It is not advisable to directly use the kinetic energy given by the software, but to calculate it through the mass and translational velocity of the block ($E=1/2\ m \cdot v^2$), to avoid using abnormal data and to apply the corresponding safety factors.
- The rotational kinetic energy accounts for 10-15% of the total energy. Therefore, it can normally be disregarded.
- The statistical analysis allows for a 5% risk. Thus, the trajectories to consider should include the 95% confidence interval.

To validate the simulation, it is recommended to do back testing to check the results and the in-situ evidence, adjusting the restitution coefficients.

3 ROCKFALL BARRIER DESIGN

3.1 Design and safety factors

The EAD 340059 introduces the concepts of Maximum Energy Level (MEL) and Service Energy Level (SEL).

Generally, the MEL design is adopted if the frequency of the rockfalls is low, if individual blocks are expected, if the allowed risk is relatively high or if the maintenance tasks can be done with ease.

SEL design is adopted to reduce maintenance costs, when the allowed risk is low, or when multiple blocks are expected to impact. This criterion is more costly, as it implies the barrier must have a capacity three times higher (SEL = 1/3 MEL), but it enhances the safety of the site, and can be adequate in some cases (i.e. at the entrance of tunnel portals).

3.2 Energy of the barrier

The most important design parameter to determine is the energy level of the barrier, obtained with the following formula:

$$E_{sd} = \frac{E_b}{\gamma_E} \tag{1}$$

where E_{sd} = Block energy.
E_b = Nominal energy of the barrier, according to the EAD 340059.
γ_E = safety factor depending on the design criteria. 1.20 for MEL; 1.00 for SEL; 2.00 if the barrier is shorter than 30 m.

E_{sd} is defined with the classical formula of kinetic energy increased by a safety coefficient ($\gamma_R \geq 1.0$) which considers the human risk.

$$E_{sd} = \left(\frac{1}{2} M_d * {v_d}^2\right) \gamma_R \tag{2}$$

where M_d = Design mass of the block.
v_d = Design velocity of the block.
γ_R = 1.00 for a location of low economic value and easy repair; 1.20 for a location of high economic value and without possibility of repairing.

As per equation number (2); designers must define the design mass and velocity, which are obtained as following:

$$M_d = (Vol_B * \gamma)\gamma_{VOL} * \gamma_\gamma \tag{3}$$

$$v_d = (v_t * \gamma)\gamma_{Tr} * \gamma_{Dp} \tag{4}$$

where Vol_b = volume of the design block.
γ = Unit weight of the block.
γ_{vol} = safety coefficient related to the precision of the design block survey.
γ_γ = safety coefficient related to the evaluation of the unit weight of the rock of the block.
v_t = velocity calculated with the rockfall simulation and considering the 95th percentile of the velocities.

γ_{tr} = safety coefficient related to the reliability of the rockfall simulation.
γ_{Dp} = safety coefficient related to the quality of the topographic survey.

3.3 Height of the barrier

The minimum height of the barrier has to be defined considering the design height, a free zone, and the size of the block:

$$H_b > H_t * \gamma_{Tr} * \gamma_{Dp} + R * \gamma_R + f_{min} \quad (5)$$

where H_b = minimum height of the barrier.
H_t = Impact height of the block simulations, including the 95% confidence interval.
γ_{tr} = safety coefficient related to the reliability of the rockfall simulation.
γ_{Dp} = safety coefficient related to the quality of the topographic survey.
R = radius of the block.
γ_R = safety coefficient on the radius of the block (γ_R> 1.0)
f_{min} = safety zone that cannot be impacted (usually f_{min} ≥ 1.0)

3.4 Separation distance of the barrier

The minimum distance between the barrier and the structure to be protected is determined as follows:

$$D_A \geq D_b * \gamma_d \quad (6)$$

where D_A = minimum distance between the barrier and the protected zone.
D_b = maximum dynamic deformation of the barrier, measured in accordance with the EAD.
γ_d = safety coefficient related to the energy level adopted during the design (γ_d>1.0 for MEL approach; γ_d=1.0 for SEL approach), the length of the barrier (γ_d>1.0 if the barrier is shorter than 30m) and to barrier-span impacted by the boulder (γ_d>1.0 if the lateral span of the barrier may be impacted)

4 FOUNDATION DESIGN

Even if the EAD does not define the foundations of the barrier as a component of the rockfall kit, these must be appropriately designed, regarding the type of barrier and the type of ground observed at the job site.

This implies that every barrier should have its proper anchoring system.

4.1 Load analysis

During the real scale tests, the suppliers must measure the forces transmitted to the anchors during the impact. Usually, the systems to measure the forces are a data logger connected to different load cells placed on the main foundations of the barrier.

The foundations are divided in 3 categories taking into consideration the worst load for each anchor:

- Post foundations: compression and shear stresses
- Upslope foundations: tensile stress (pull-out)
- Lateral foundations: tensile stress (pull-out)

Table 1 describes an example of the maximum loads in the anchors of the barrier RB 1500, obtained during the MEL crash test. These are the reference values for the design of the anchors, taking into account that this is the worst case scenario and the loads for the SEL test are lower.

Table 1. Forces in barrier RB 1500 during MEL.

Foundation	Type of force	Value
Posts	Compression	226,26 kN
	Shear	157,36 kN
Upslope foundations	Tensile	163,10 kN
Lateral foundations	Tensile	252,60 kN

4.2 Types of anchors

Foundations have to be able to transmit the load to the ground. Deep foundations are normally used in order to guarantee the best performance with a minimum cost. Generally, the anchoring systems are designed as follows:

- Post foundations: steel bars (for rock) or micropiles (usually for loose soil).
- Upslope and lateral foundations: flexible cable anchors (steel bars are not recommended due to the dynamic loads, which can pull the bar in different directions)

All the anchoring systems are considered passive because they start to work only if they are stressed by the impact. They are installed in drilled holes, and they are fully grouted along their entire length in order to develop the maximum anchor-grout and grout-ground friction.

The length and the diameter of the anchors as well as the drilling diameter depends on the design requirements. If the barrier is installed in an uneven terrain, a little concrete plinth can be foreseen to give a flat base for the posts of the fence.

5 CONCLUSIONS

The EOTA published in 2018 the EAD 340059, that replaces ETAG 27-2008 and defines standard procedures to evaluate the rockfall barriers in real scale tests, which allows to obtain the behaviour of the barriers and obtain the ETA and CE marking. Unfortunately, it describes the performance of the barrier in ideal conditions that differ from reality.

We have seen several cases where the consequences of the real installation conditions influence the behaviour of the rockfall barrier when impacted.

To design a rockfall barrier taking into account these factors, a new design approach based on the Italian norm UNI 11211:4-2012 has been defined to design the barriers in Ultimate Limit State and Service Limit State.

Even if the foundations are not considered part of the kit as per the EAD, these elements are crucial in the behaviour of the rockfall barrier. These foundations can dissipate the energy of the impact to prevent problems in other parts of the barrier and to reduce the maintenance costs.

The efforts of the main rockfall barrier suppliers are focused on delivering barriers with the following characteristics:

- Easy to install, through lesser anchors in the plate posts.
- Quick assembly, thanks to premounted elements such as the ring net.
- Effective, through their capability to absorb further impacts in Service Energy Level (SEL).

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