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Dynamic Barriers for Protection against Rocks Falls

Las barreras dinámicas como elemento de protección frente a la caída de rocas

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Abstract

In this paper the most important aspects for designing dynamic barriers for protection against rockfalls are presented. Technological advances in fabrication of metallic materials are increasingly enabling the use of barriers with greater ability to absorb energy. However, in order to establish what type of barrier is needed to solve a given problem (location, height and energy), it is necessary to know the basic principles of the way these elements function, as well as the design methodology to be applied. In the following paragraphs of the paper the basic concepts that should be taken into account by the engineer responsible for the design of a barrier are described, and, by applying a commercial software, a real example of the design of a rockfall protection system on a hillside is finally illustrated.

Keywords: Rockfall; rockfall protection; dynamic barrier; energy absorbtion, protection barrier design.

Resumen

En el presente artículo se pretenden mostrar los aspectos más destacados en el diseño de las barreras dinámicas de protección frente a caídas de rocas. La tecnología y avances en la industrialización de los materiales metálicos están permitiendo disponer cada vez de barreras con una mayor capacidad de absorción de energía. Sin embargo para poder establecer qué tipo de barrera es necesaria para resolver un problema determinado (posición, altura y energía) es necesario conocer la forma elemental de funcionamiento de estos elementos, así como la metodología de diseño de las mismas. En los siguientes apartados del artículo se describen los conceptos básicos que debe tener el ingeniero responsable del diseño de una barrera, ilustrándose finalmente con un ejemplo de diseño real de un sistema de protección de caída de rocas en una ladera, mediante la aplicación de un software comercial.

Palabras claves: Caída de rocas, protección contra la caída de rocas, barreras dinámicas, absorción de energía, diseño de barreras de protección.

Introduction

When in a rocky slope, natural or dug by men, stone elements are found (fragments and/or more or less rounded blocks), a triple elimination alternative can be used to fixing them to prevent loosenings or avoiding to reach the proceted good if loosen (Ministerio de Fomento, 2005). The first of these options (blocks withdrawal) is often used when there is a certain and reduced number of elements, and are easily removable due to its size and location. In either cases, very important sizes and complex withdraws, or if it is difficult to quantify if the upper fragments will destabilize, usually is more advantageous resort to its punctual bolt fixing, cable net or gunited, which would correspond to the second option. Finally, as third option, in the case blocks may come from a larger and inaccessible area, and if were a greater number, the use of barriers may be preferable to prevent them from reaching the good to be protected (communication channels, buildings, industrial areas, etc.) if the loosening takes place.

According to the barrier physical behavior to stop the rock, can be established three different typologies (Bourrier & Hungr, 2013): the first one consists of static barriers, which are composed by rigid elements that employ their high inertia to stop the stones. The most common solutions are walls (of concrete or gabions), formed by metal profiles and earth ridges; the second type corresponds to dymac barriers of static deformation, having a reduced capacity of energy absorption (below 150-200 kJ), which are mainly used as energy dissipators elements in docks with shock absorbers, which are not useless after impact; finally, can be found dynamic barriers of plastic deformation characterized by current absorption capacity of 8.000 kJ, using special elements that deform and tear for dissipating this high energy, so that they must be replaced after an impact. Of these three typologies, the latter is the most often used nowadays, and is the one that takes place in the following sections.

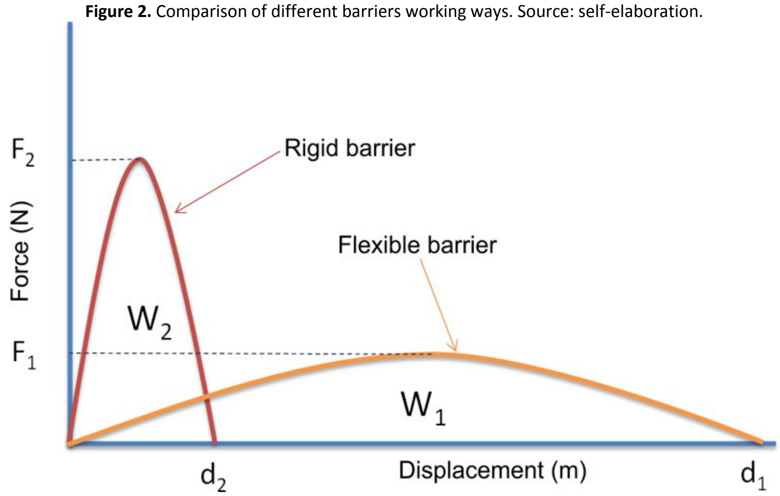
Figure 1. Example of dynamic barrier use for road protection. Source: R.L. Fonseca & Gonzalez-Gallego, 2007.

Barriers stiffness

When a rock fragment is moving (rotates, slips or flies) accumulates energy which is the responsible for the damages caused when impacts an object. The principle of energy conservation is well known, it says that in a system energy can neither be created nor destroyed, it is only transformed. Therefore, the devices used to intercept rocks should not attempt to remove the energy of these, it would not be possible, but to transform it in other type of energy that do not cause physical damage to the elements to be protected

Applying the virtual works principles (Fonseca, 2010), the available rock energy E can be transformed into work W, which will be the product of a force by a displacement (W = F·d). In the Figure below can be seen two different design phylosofies. Both aims to dissipate the energy W which has an identical value W1 = W2, represented as the area below each curve.

Figure 2. Comparison of different barriers working ways. Source: self-elaboration.

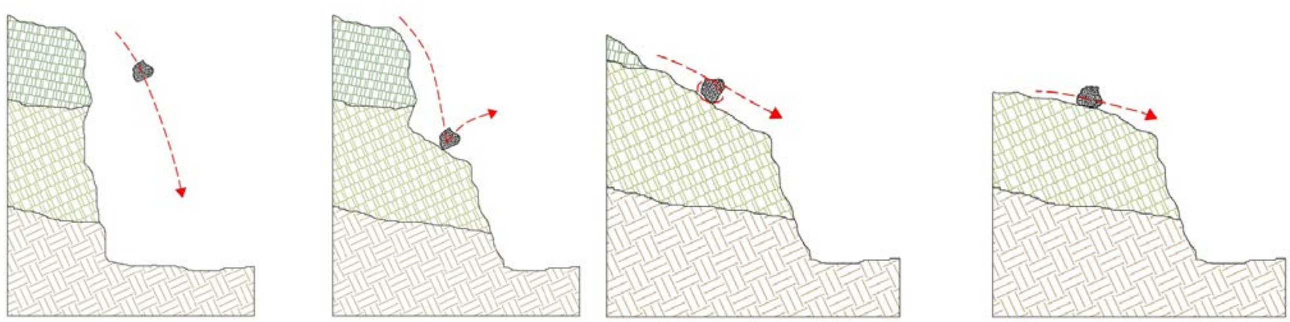


In the rigid barrier case, its displacement is very limited (d2) so the maximum developed force (F2) is very high, thus demanding very resistant and expensive structural elements for its materialization. In the other hand, in a flexible barrier design, the force is reduced (F1), but the displacement is very high (d1). By way of illustration, to quantify the magnitude of the energy to be dissipated, as graphic example can be taken two different vehicles. Thereby, the energy of a touring of 1 t when travelling at 120 km/h (33,3 m/s) is of 555 kJ, while a truck of 40 t at 50 km/h (13,9 m/s) is of 3.860 kJ. In the case of a rocky block of approximated cubic dimensions of 2 m of edge, weight would be about 21 t. If a free fall of 25 m is considered (without initial speed) its energy would be about 5.150 kJ, noticeably higher than the truck of the example.

Types of movements

During its descent path, blocks can only have four types of movement: free fall, rebound, rolling and slipping (Geobrugg, 2009).

Figure 3 Type of blocks movements: a) free fall, b) rebound, c) rolling and d) slipping. Source: self-elaboration.



Free fall movement

In this case, the stone trajectory is often represented assuming that it's mass is concentrated in one point and air resistance is not considered. The curves that describe are those corresponding to a solid under gravity, which are known as parabolic movement. Thus, as it is assumed that the horizontal acceleration is zero, and the vertical is the gravity g, horizontal and vertical speeds are $v_x = v_{0x}$ and $v_y = v_{0y} + gt$ being v_{0x} and v_{0y} the initial speeds of the stone in both directions. Integrating again the speeds, displacement laws are obtained $d_x = v_{0x} + x_0$ y $d_y = v_{0y}t + 1/2gt^2 + y_0$, where x_0 and y_0 are the initial coordinates of the stone position. As the stone trajectory is completely defined, the impact point can be obtained through the intersection of it with the land's surface, producing a rebound.

Rebound movement

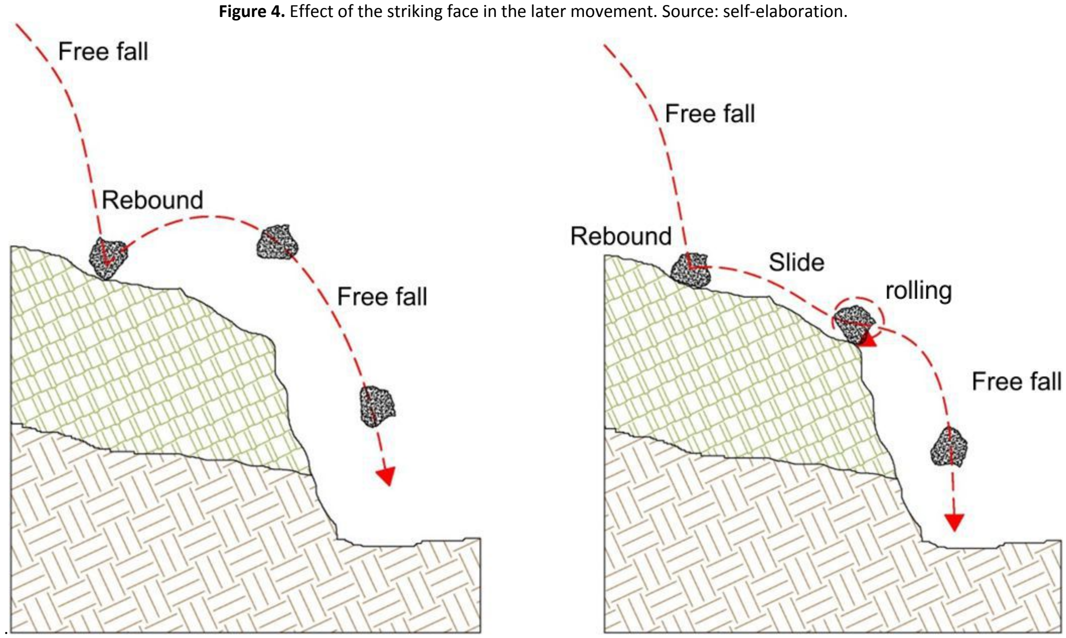
Physically the rebound movement can be analyzed with the theory of shocks. In this case, the shock usually can be considered as inelastic collision (the amount of movement is conserved, but not the kinetic energy), reaching in borderline cases the energy full damping (highly absorbent materials type gravel beds) in a completely inelastic collision. In general, to estimate the effect of the stone speed modification before (v_i) and after (v_f) the impact are used restitution coefficients, which are defined as $K = v_i/v_f$ (Fonseca & Gonzalez-Gallego, 2007). For a further detail analysis of the effect of the surface, it is differentiated between the normal (K_n) and tangential (K_t) restitution coefficients at the slope surface hitting point. In Table 1 can be seen approximated values according to the types of slope surfaces.

Table 1. normal (K_n) and tangential (K_t) restitution coefficients according to types of surfaces. Source: self-elaboration.

K_t	K_n	Type of surface
0,87-0,95	0,37-0,50	Solid rock
0,83-0,87	0,33-0,37	Solid rock covered by great sized blocks
0,68-0,75	0,30-0,33	Uniformly distributed bedrock
0,50-0,60	0,25-0,30	Vegetation covered soils

Nevertheless, previous values should be considered for pre-design phase, as in the rebounds many different factors are involved such as relative dimensions between the impacting block and those existing in the terrain; the block material resistance and its possible disaggregation as well as edges breakage and the hitting point in the block's surface. This latter aspect can noticeably modify the followed trajectory, as depicted in the following figure. In the situation on the left can be seen how the block hits firm ground with a corner, so a rebound with little energy loss occurs and a later flight. In the situation on the right the block hits firm ground with an almost flat surface, so it absorbs a large amount of energy, to later slip and roll down the slope. Finally, when the stone reach an edge, it falls back into free fall.

Figure 4. Effect of the striking face in the later movement. Source: self-elaboration.



Slipping and rolling movement

In a first approximation, the speed with which a block slip or roll over an inclined plane is

$$v = 2\sqrt{g(sen\alpha - tan\theta cos\alpha)l} \tag{1}$$

Being α the angle with the horizontal slipping surface; θ the friction angle for slipping or turnover and l the distance traveled by the block along the inclined plane.

The intial slipping and rolling speed after a impact can be obtained according to the restitution coefficients previously mentioned, obtaining a total kinetic energy (rotation and displacement) per mass unit according to the following expression:

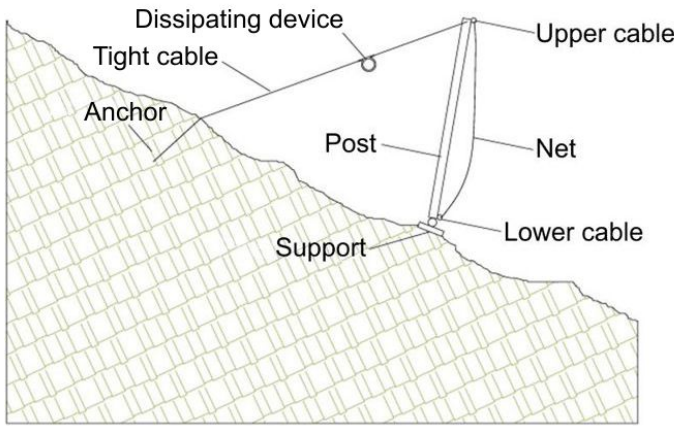
$$E_c = \frac{1}{2(I\varpi^2 + v_x^2 + v_y^2)} \tag{2}$$

where, I is the moment of inertia of the rock, ω the rock rotation speed, and v_x, v_y the travel speeds according to x and y axes. From these basic expressions more complex expressions are developed, for which resolution is required to use softwares designed for the rockfall study.

Dynamic barriers elements composition: Operating principle

The general operation principle of this type of barrier is to interpose rocks falling trajectory with an element of consireable extension, type metal mesh, able to become deformed, transmitting the cinectic energy of the falling rock to the terrain throughout a system of cables, anchores and energy dissipators (Franklin & Senior, 1997). To achieve this behavior, the different parts and components of the barrier are a net, a post, connection cables, tie rods and support plates, which are depicted in Figure 5.

Figure 5. Diagram of dynamic barrier parts. Source: self-elaboration.



A short definition of each of these parties is presented as follows: net, element which intercepts the rock trajectory and is composed of a metal mesh of rings or cables; usually, a further net of lower opening is overlapped in order to hold smaller items; the post corresponds to a metallic profile, often articulated in its support, which is used to keep up the net, both are directly connected; the connection cables are metal wires that connect different net stretches to the posts, being able to be arranged inside the stretches to reinforce the net and avoid exessive deformation of the same; the tie rods are metal wires that connect the heads of the posts to the ground anchors in order to transmit the stone's energy to the same. They are arranged with energy dissipators elements responsibles for absorbing the major part of the kinetik energy of the rocks, after a rock impact over the barrier these must be replaced because become useless; finally, the support plates are metal plates for the post foundation.

Figure 6. General view of the different elements of dynamic barriers (a), and detail of the energy dissipators (b). Source: R.L. Fonseca & Gonzalez-Gallego, 2007.

Basic description of barrier operation
When a rock falls and rolls, fly or rebound downslope, is taking variable energy that must be absorved by the barrier. The barrier brings a metalic element, net type, that deforms accompanying for some centimeters the rock path (sometimes decimeters), transmitting to the nearest posts the rock load through the connection cables. This tensile load over the cables brings a strength over the posts head, which is resisted by the tie rods connected to the ground; tie rods count with dissipators elements. Occasionally, when the load is too high, the tie rods and dissipators elements get broken because its structural strength is surpassed, producing the collapse of the involved post. In this case, the adjacent posts collaborate to a greater extent. Finally, the tensile load over the tie rods is transmitted to the ground through anchors, usually of reduced length. The joint collaboration of all these components allow to absorb and dissipate the kinetic energy of the rock, although some of them breakage occurs, the effect of stopping the rock has been achieved, thus it can not be said that the barrier has failed. By simply replacing the damaged parts and restoring the intial barrier geometry, it returns to be operational.

Barrier selection parameters
Dynamic barriers are composed by the combination of metallic industrialized elements, with their respective manufacturing processes and control tests. In this sense, the engineer responsible for the barrier design must follow the information provided by the manufacturer. Nevertheless, is the engineer resposability to set correctly three aspects of the barrier, such as: a) Situation in the profile of the slope. Aspects such as accessibility, number of intercepted stones, instalation costs, etc. should be taken into account. b) Barrier height and tilt. Barriers can be arranged in a wide range of angles, from horizontal to vertical. Regarding height, maximum commercial height is about 5 m. c) Energy able to be absorbed by the barrier. The industrial design of metallic elements (wires diameter, tie rods and anchors section, type of dissipator´s elements, posts metallic profiles, etc.), and its cost is directly related to the energy of design of the barrier.

International standards for the homologation of dynamic barriers
In order to certificate that dynamic barrier’s energy absorption capacity corresponds to the one indicated in the manufacturer’s catalog, full-size testing in test fields must be performed. These tests are regulated by two standars that in broad terms are similar, although they have differentiating nuances that exceeds this article scope: The Guideline for the approval of rock protection kits of the Federal Environment Office of Switzerland (Gerber, 2001) and the Guideline for European technical approval of falling rock protection kits. ETAG-27 of the European Standardisation Organisation (EOTA, 2008).

In these documents is defined in detail how homologation tests must be performed, indicating the moving mass shape, the geometry of the barrier before and after the impact as well as the fulfillment requirements to consider the test has been passed successfully. In this regard, in the guide ETAG-27 are defined two levels of energy for the barriers, so-called SEL and MEL. The Service Energy Level (SEL) is the energy that the barrier, after the impact and having held the rock, almost remains without noticeable signs of damage. The Maximum Energy Level (MEL) is the maximum energy at which the barrier suffered an impact to its limit of strenght, having held the rock, and some of its structural elements (such as energy dissipators, tie rods, nets, etc.) have suffered deformations and must be replaced. This is the energy understood as energy of design and is the one referred by the manufacturers when specified the energy that the barrier “holds”. The MEL energy level is three times higher regarding the SEL energy level. In the following section it is included a real example of dynamic barrier design, where all abovementioned aspects are involved.

Example of application

Problem description

The slope on which rockfalls may occur, which is subject of this dynamic barrier design example, is dug in its lower 10 m, while the rest of it is natural slope which origin is due the size of its cliffs close to the river network. The studied zone reaches a maximum height of about 45 m. The lithology belongs to the formation of orthogneisses, schists and quartzites. A panoramic view of the area is illustrated in the following figure, where is detailed the location of the buildings and facilities to be protected (hydroelectric power plant) regarding the slope location.

The study area comprises 70 m length in plant and 45 m of the slope maximum height. Over the slope edge, the hillside continues less steep and there are some buildings of a former nearby village. A geologist with extensive experience performed an estimation of the rock mass quiality index, to estimate its global stability as well as to get an approximation of the maximum block size which might be loose according to the joints' continuity and spacings. As result of this analysis, was deducted a good global quality of the rock mass with a RMR index of about 70-80. According to the lithological and geomorphological characteristics of the slope was performed a zoning of the same in order to address the rockfalls study as well as to locate the possible corrective measures to be implemented.

Basis of calculation methodology

To define the location and the energy of the dynamic barriers that could be implemented to protect the buildings and the road in front of possible rockfalls, several computer simulation calculations were performed according to the lithological and geomorphological characteristic of the affected zone. From the point of view of the rockfalls' energy and trajectory, was considered there are two clearly differentiated zones.

The presence of a horizontal area in the left zone facilitates rockfalls control since rocks impact this zone and lose energy. In the zone of the right, of more vertical uniform slope and without vegetation, rocks impact the slope without losing energy and its trajectory moves away from the slope. In order to perform a more detailed analysis of the rockfalls and to determine the optimum location, level and energy of the dynamic barriers that could be implemented to reach a suitable control of unstable rocky blocks, a study of rockfalls based on computer simulations was conducted.

Figure 7. Studied slope and location detail of the 3 calculated profiles. Source: self-elaboration.

To perform this analysis, first of all were developed previous field studies, which allowed to analyse and define the lithological and geomorphological characteristics of the area. Among these previous studies, possible historic rockfalls that may have occurred are considered as a valuable information source regarding the trajectories, rockfall typology, areas of blocks source, etc. Furthermore, were performed detailed topographic profiles of the most particular points of the area, in which, for calculation process, were included lithological and geomorphological characteristics of detail of the falling trajectory.

Computer softwares for rockfall simulation and analysis are based in elementary laws of motion of a rigid body, and allow to calculate blocks trajectory, speed, kinetic energy, height and other parameters of interest. Furthermore, these softwares include statistical analysis of obtained data, which makes them fundamental tools for the rockfall study. In this case was used the rockfall simulation software, ROCFALL 4.054, (Rocscience, 2004) widely contrasted with field studies as well as retrospective analysis of known rockfall. There is a wide range of parameters and factors that influence the rocky block trajectory along the fall. The consideration of all the parameters as independent variables would lead to an unfeasible analysis. In this way, in order to reduce the number of variables and simplify the problem, the rockfall simulation softwares assume the following hypothesis: 1) It is no need to consider the slope lateral variability if the selected profile layout follows the most probable trajectory according to field studies, performing in this way a bidimensional analysis of the rock path. 2) There is no rock fragmentation along the path, which usually happens, focusing the calculation on the safety due the rock mass remains constant. 3) The rock geometry is assimilated to a sphere, which is the most unfavourable form regarding both the trajectory and its final energy. 4) It is not considered the possible interaction between two or more blocks that could fall at the same time. The utilized software contemplates the four most common modes or movement mechanisms, previously mentioned: free fall, rebound, rolling and slipping, in such way there is a transition between one and other movement along the falling path. The calculation algorithm includes the angular velocity of the falling rocks along the slope getting in this way a better approximation to reality. The interaction calculation between the rock and the land surface is based on characteristic parameters of both. The topographic profile is divided into many segments in which the characteristic parameters of the slope surface are entered, which change randomly during the calculation, according to the software and margins preset by the user. In the same way, initial movement parameters can be varied randomly improving the obtained results accuracy.

In addition, unlike other similar simulation softwares, the Rocfall 4.054 program includes the chance of varying randomly the position of the segments' vertices amongst preset margins. In this way, the analisys takes into account not only the preset profile, but also existing small lateral variations of its surroundings. When calculating a block falling trajectory, the characteristic parameters are: the normal restitution coefficient (Kn), the tangential restitution coefficient (Kt), the slope roughness and the friction angle. These parameters are defined according to the geometrical as well as lithological characteristics of the slope and the type of loosened block. Furthermore, the mentioned software incorporates tables with coefficients for a multitude of different slopes and lithologies, for either known rockfall retrospective analysis and field studies developed for this purpose.

The software calculates and draws the falling trajectory of each rock, but also performs an statictical analysis of: a) Total energy, translational and rotational, b) Velocity, translational and rotational y c) Trajectory height regarding the calculation point. The software allows to insert dynamic protection barriers, representing the trajectories as well as statistical distributions of height, velocity and energy in its interaction with the protection structures, being able to develop in this way an optimum design of the needed rockfall control measures.

Performed calculations

Rockfall simulation calculations were performed for different zones of the slope, being calculated a total of 3 different profiles in the study area and 5 possible locations of dynamic barriers. With the field studies of both visual assessment as well as the spacing and continuity of the joints was determined the maximum rocky block that may become detached would be of approximately 4 m3.

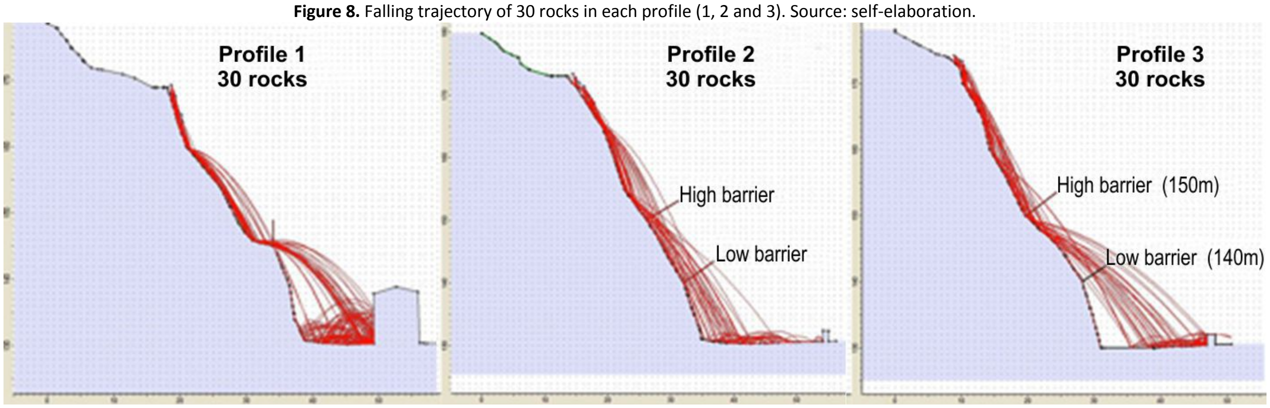
As the software simulates spheric rocks (focusing the calculation on the safety), trajectories were calculated for rocks of 2 m of diameter, which supposed a mass of 11.3 t. In all the profiles, rockfall simulations were performed taking into account as source area or rockfall origin the highest slope level for each zone. In order to define the optimum location to install the barrier, prior to definitive calculations preliminary calculations were performed analyzing which is the profile point where the relation between the trajectory height and the total reached energy is more favourable for the protection structure installation.

In this case, there was a great difference regarding the suitability to install a dynamic barrier in the left zone and in the right: In the left there is a horizontal area with vegetation, where rocks tended to impact losing a lot of energy, what makes it a very favorable point to install a dynamic barrier; in the other hand, since the right zone is a more vertical and uniform slope the rocks almost did not lose velocity when impacting the slope, thus energies to be retained by the protection structure were too much higher, also the rebound were far more unpredictable regarding its trajectory.

On each of the 3 analyzed profiles (see figure 9), 500 different falling rocks simulations were performed and the situation of 3 different barriers locations were analysed, one in the profile 1 (corresponding to the left zone) and two in the profiles 2 and 3 (corresponding to the right zone). In the profiles 2 and 3 two dynamic barriers locations were calculated. Initially, from its installation point of view, the most favorable position was called low barrier, setting the barrier at 140 m height. In this case, the use of a crane from a lower road was possible (approximately at 130 m height).

Nevertheless, another proven aspect through the preliminary calculations is that the rocks trajectory at 140 m height passed too far from the wall. For this reason, further calculations were performed setting the barrier higher (150 m height), which was called higher barrier. On each of the three profiles, restitution coefficients values (Kn and Kt) were assigned to each segment according to its tipology. In accordance with these coefficients, the software recalculates the rock trajectory whenever it impacts the ground. In total were used 5 types of different surfaces, from the outcropping solid rock to zones of vegetation covered soils. The figure 8 shows the falling rocks trajectories calculations of each profile with the statistical distribution of the energy values reached in the contact point with the dynamic barrier.

Figure 8. Falling trajectory of 30 rocks in each profile (1, 2 and 3). Source: self-elaboration.



Results

Once performed the previously mentioned calculations, and as summary, in Figure 9 are shown, for each profile and studied barrier location, the following values: the maximum energy, the mean energy and the energy with which 90% of the blocks would stop. It is important to expressly indicate that this type of study assumes a statistical analysis obtained from the results of the rockfalls simulation calculations. In profiles 2 and 3, as the falling rock almost did not lose energy when impacting the hillside (due the slope and the outcropping rock), it can be appreciated that at low height it arrives with more energy.

This distinction was also noticed with the trajectories heights of the stones (logically, measured in the direction of the logical barrier placement), and as can be appreciated in figure 10 in the barriers located at the lowest heigh the trajectory height is much greater since when rocks impact zones with great slope tend to move away of its surface.

Figure 9. Energies reached in the dynamic barrier. Source: self-elaboration.

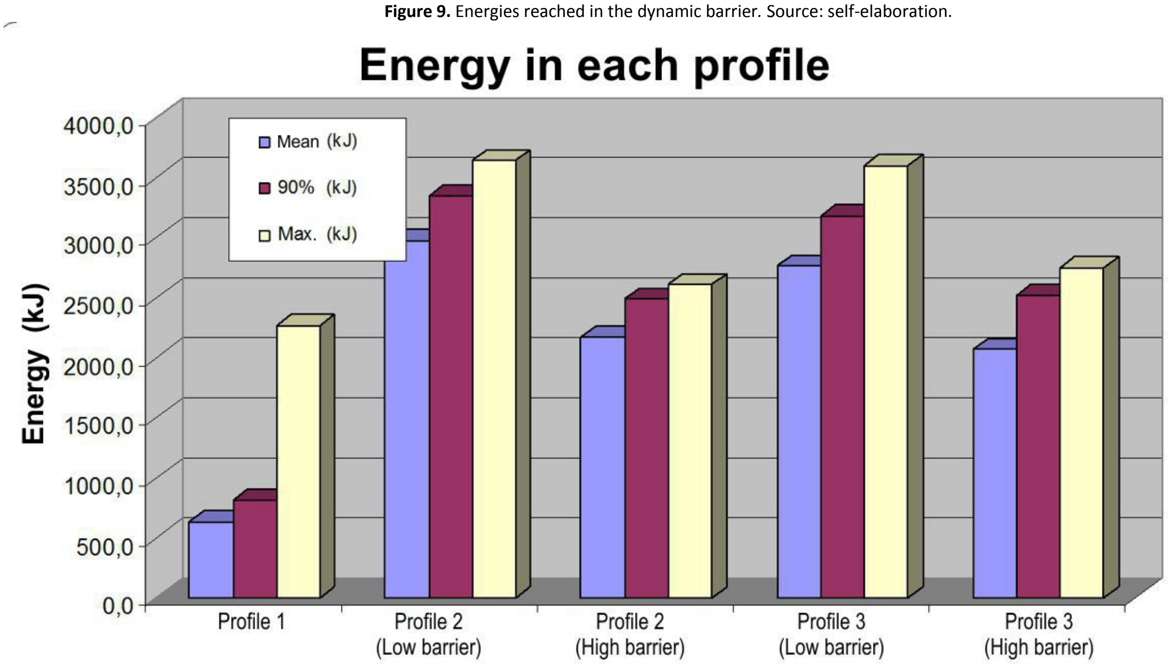


Figure 10. Maximum blocks heights along its fall when reach the dynamic barrier location. Source: self-elaboration.

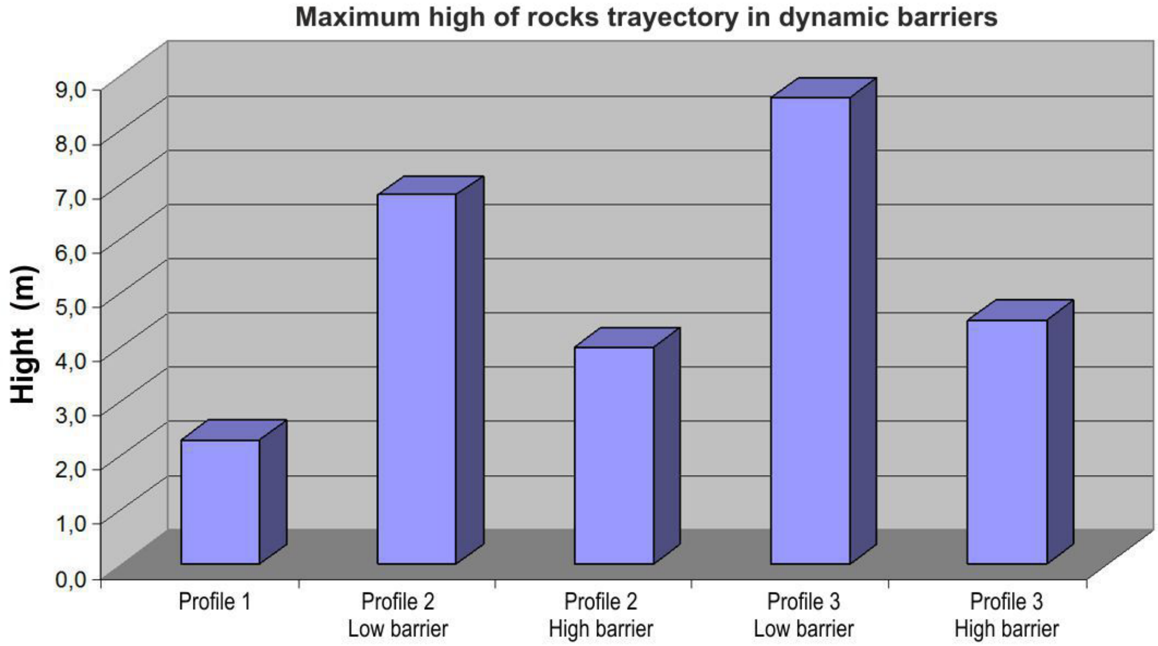


Table 2. Summary of needed energies and trajectories heights for the different profiles. Source: self-elaboration.

	Mean (kJ)	90% (kJ)	Maximum (kJ)	Trajectory height (m)
Profile 1	637	817	2266	2,3
Profile 2 (barrier at low elevation)	2967	3339	3638	6,9
Profile 2 (barrier at high elevation)	2167	2486	2606	4,0
Profile 3 (barrier at low elevation)	2761	3173	3591	8,7
Profile 3 (barrier at high elevation)	2065	2517	2740	4,6

Profile 1

Based on the analysis of the obtained results was deducted that for the left zone, a dynamic barrier installation in the horizontal area would be quite favourable for the rockfall control in that side of the slope. By the fact of existing a covered of vegetation semi horizontal area, the majority of the rocks impact on it first losing velocity and trajectory height. In the barrier installation point the maximum trajectory height is 2.3 m and the maximum reached energy 2,266 kJ. According to the simulations results it is highlighted that only some rocks would directly impact the barrier without losing energy, what makes the maximum energy get up to 2,266 kJ. Nevertheless, blocks that impact the horizontal area first reach the barrier with a maximum energy of 1,400 kJ. Taking into account the block size and the usual practice of barrier's designing with an energy lower than the maximum (maximum energies usually respond to quite singular and unrealistic trajectories), the recommendable barrier to install would be of 4 m height with an energy of design of at least 2,000 kJ (MEL energy).

Profiles 2 and 3

Both profiles 2 and 3 have a very similar conFiguretion, thus results analysis was performed together. In these profiles, falling rocks by a steep hillside and without vegetation, reached energy is quite high. The dynamic barrier installation at low height (140 m) was easier to execute and had the advantage of covering a greater slope height. Nevertheless, at this point height trajectories were quite high (6.8 m for profile 2 and 8.6 m for profile 3). It means that some rocks or fragments could overpass the barrier reaching the existent road next to the foot of the slope. The energies in this level were of 3,638 kJ for profile 2 and 3,591 kJ for profile 3. In case of installing barriers in this point, its energy of design would be at least 3,500 kJ (MEL energy) and its height 6 m (currently, this corresponds to the greater standard barrier height commercialized)

In the other hand, in case of installing barriers at the higher height (150 m), at this point height trajectories are 4.0 m for profile 2 and 4.6 m for profile 3. While maximum reached energies are 2,606 kJ y 2,740 kJ, respectively. In this way, in case of installing a barrier at this height (150 m) it should be of 5.0 m height and 3,000 kJ of minimum energy of design (MEL energy).

Conclusions

When in a slope there are unstable fragments and/or rocks a triple elimination alternative could be taken, fixing them to prevent loosenings or avoiding to reach the proceted good if loosen. In the case blocks may come from a larger and inaccessible area, and if were a greater number, the use of barriers may be preferable to prevent them from reaching the good to be protected (communication channels, buildings, industrial areas, etc.) if the loosening takes place.

According to the barrier physical behavior to stop the rock, different tipologies can be established, being the most usual the dynamic barriers of plastic deformation. These, to dissipate the high energy of the rocks (at present up to 8,000 kJ), use special elements able to suffer deformations and break up, which after the impact must be replaced.

Dynamic barriers are composed by the combination of metallic industrialized elements, with their respective manufacturing processes and control tests. In this sense, the engineer responsible for the barrier design must follow the information provided by the manufacturer. Nevertheless, is the engineer resposability to set correctly three aspects of the barrier, such as the situation in the profile of the slope, barrier height and tilt and the energy able to be absorbed by the barrier. A real example of dynamic barrier design has been included, where all abovementioned aspects are involved.

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