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Use of explicit FEM models for the structural and parametrical analysis of rockfall protection barriers

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ABSTRACT

This paper illustrates the experimental test procedure and results of two flexible barriers of low and medium energy, the so-called IBT-150 and IBT-500. For this purpose, ETAG 027 European Guideline is used. All the requirements for the tests performance are followed and the two energy-level tests performance requirements have been fulfilled in both rockfall barriers. Numerical modelling helps to understand and predict the behavior of these barriers with different configurations drastically reducing the costs of performing real tests. The results of the real test on IBT-150 and IBT-500 have been taken as references to validate two numerical models using Abaqus Explicit software. Afterwards, a presentation of some alternatives of the barrier IBT-150 are stated, which allow a more economical design removing some components that do not affect the energy level of 150 kJ set by the manufacturer. Also, a parametrical analysis of the IBT-500 numerical model has been performed varying the geometrical characteristics, such as the net grid dimension, the diameter of the perimeter cable, the length of the functional modules and its height. The aim of this analysis is the enhancement of maximum energy capacity of the barrier related with the amount of material used to build it. Following the ETAG recommendation, the maximum energy level (MEL) test is achieved if the barrier is able to retain the block. Thus, the MEL level for each numerical model was determined by increasing the initial speed of the block until it trespasses the barrier.

1. Introduction

Flexible barriers have the function of retaining falling rocks from a slope. They are made of an interception net, posts, perimeter, lateral and upstream cables, and energy dissipating devices, also known as brakes. In the development of these structures, almost all the components have been studied in order to adapt the barrier design to the energy dissipation aim. This is the case of the brakes, which can have a wide range of shapes with different absorption capacities, and can be placed in different number and parts, including side, upstream or perimeter cables [1]. The perimeter cables also have a relevant role. A higher number of perimeter cables in each side allow the placement of more brakes. Moreover, an alternative sewing of the interception structure means a lower damage risk of them around the post ends. Several interception nets have also been developed, using square pattern cable nets, wire ring nets or omega cable wire nets.

In order to numerically reproduce the behavior of barriers, experimental tests of the structure of interest must be done first [2], not only of the full barrier but also each of the components independently [3]. The increasing use of codes based on the Finite Element Method (FEM) in these structures resulted in a vast amount of numerical models able to reproduce its behavir due to an impact. The most simplified models on the literature are 2D [4] representing only the profile of the barrier: one upstream cable, one post and the net represented by two lines linked together in a central point where the block impact takes place. Regarding 3D simplest models [5], they are obtained by reducing the contact interactions between elements of the barrier to the minimum, being the only one located between the block and the barrier, and by generating an equivalent model of the ring net. On the other hand, more complex models [6,7] are aimed to be more realistic: actual connections between perimeter and interception structure and real geometry of the interception structure, which result in a more accurate but also more time consuming model.

The success in the development of a numerical model of these barriers helped in many cases to investigate the influence of several parameters in order to reach a better understanding of the behavior of such complex structures. The size of the impacting mass has been analyzed by Cazzani et al. and Mentani et al. [8,9]. Giving a step forward, Koo et al. [10] compared an impact of a spherical block with a slab-shape block. In addition, Volkwein et al. [11] studied the effect of

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two loads with very different impact areas, being the first a tree trunk with a very sharp head, and the second one a debris flow with a distributed loading area along all the net.

Another parameter that has been studied is the angle between the trajectory of the block and the barrier. Moon et al. [12] used angles of 65°, 60° and 45°, whilst Mentani et al. [13] did a deeper study selecting positive and negative angles of −60°, −30°, 0°, 30° and 60° in order to consider both the descendent trajectory relative to the slope and the ascendant one after a rebound in the slope. Numerous authors considered the influence of the location of the impact. This parameter was evaluated both in a simple net panel [8] and in the context of the full barrier model [13,14,15]. The influence of the speed and hence the bullet effect was a matter of interest for Volkwein et al. [11].

The aforementioned parametrical analysis are related with the block shape, impact location and trajectory. Concerning geometrical parameters of the barrier, Moon et al. [12] takes into account the post spacing using distances of 7, 8, 9 and 10 m. However, his study aims to observe the variations in loads of cables and foundations after applying the same energy impact to the 4 different models, and it is not focused on finding its maximal energy capacity.

A different type of geometrical analysis found in the literature was done by Escallón et al. [16]. It is related to the optimization of several geometrical parameters of a wire net that minimizes the error between an experimental tensile test and its equivalent numerical model. The aim of this study was to find the highest fidelity of the full barrier numerical model by strictly adjusting each component, but, as it happens with the previous geometric study, maximal energy capacity is not explored.

With the purpose of covering this gap, this paper will develop an investigation of barriers IBT-150 and IBT-500 and its parametrical analysis in terms of four geometrical variables: length and height of the functional module, grid size and cable diameter of the net.

To have a reliable model for the geometrical analysis, a numerical model for each barrier is firstly performed and then validated using experimental tests results. Abaqus Explicit package will be used for this aim.

Additionally, the low energy barrier IBT-150 is modified in terms of the number and location of energy dissipating devices to determine the most economical design whilst keeping its energy retention capacity.

2. Experimental tests

IBT150 barrier has three functional modules of 10 m long and 3 m width. The interception structure is a square pattern cable net with a square side size of 200 mm. The perimeter cables have 16 mm diameter and the posts have a pipe profile, with an external diameter of 125 mm and a thickness of 4 mm. The barrier has four upstream cables of 6 m long, one in each post, and four side cables, two in each side, of 4 and 5 m long. Each of the upstream and side cables has an energy dissipation device.

IBT500 barrier has three functional modules of 10 m long and 4 m width. The interception structure is similar than that of the IBT150. The perimeter cables have 22 mm diameter and the posts have a HEB profile. In this configuration, the barrier has eight upstream cables of 8.8 m long and 16 mm diameter, two in each post, and four side cables, two in each side, of 6.8 and 7.8 m long and also 16 mm diameter. Each of the upstream and side cables has an energy dissipation device. A small pretension (22 kN) was induced in side cables in both barriers.

The geometric details of both barriers, as well as the position of the sensors placed in the experimental tests are showed in Fig. 1.

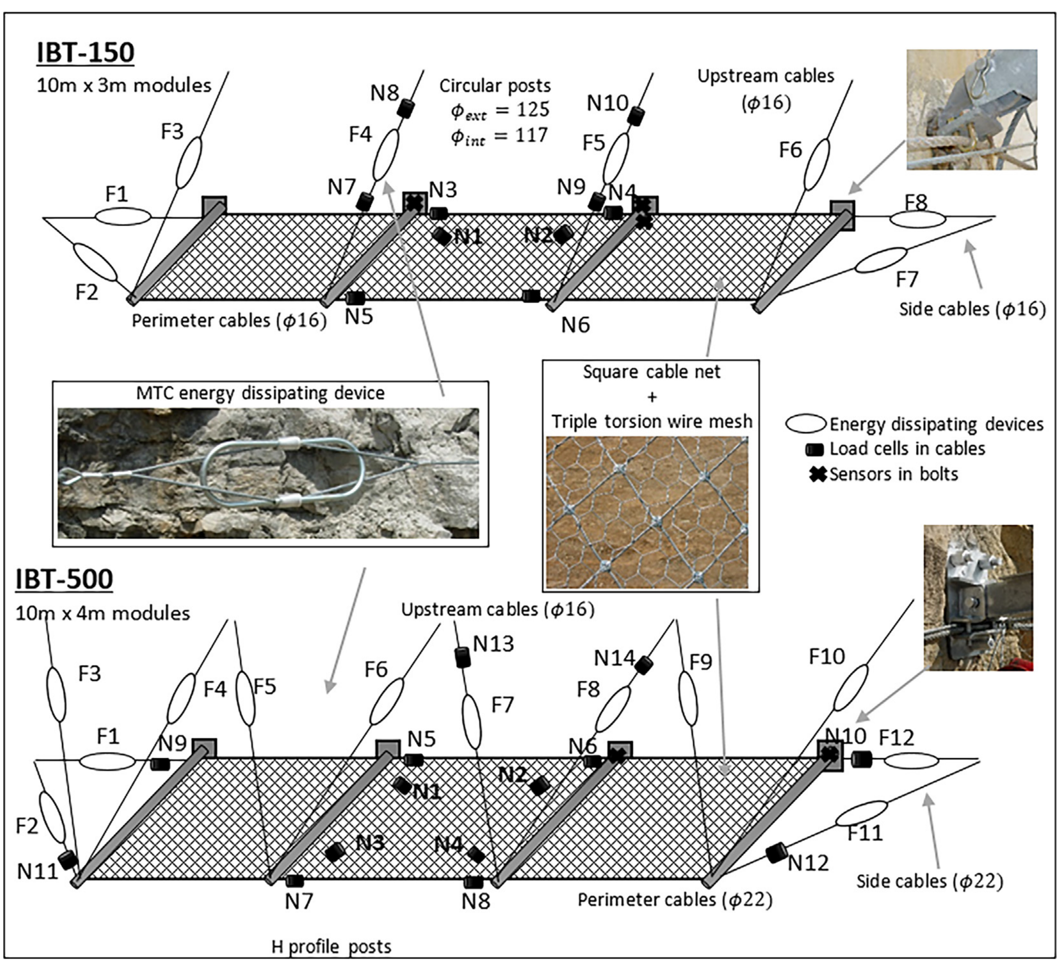

Fig. 1. Specifications and sensor location of flexible barriers IBT-150 and IBT-500.