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Prototype of a wire-rope rockfall protective fence developed with three-dimensional numerical modeling

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ABSTRACT

This study uses a numerical procedure, previously validated with data from full-scale experiments, to investigate the performance of a modified prototype wire-rope fence to provide protection against rockfall. The cost-reducing modifications are increased post spacing and fewer wire netting layers. The numerical procedure provides the nonlinear response of the prototype under various impact conditions and insights into each component's role in dissipating impact energy. A simple but effective method to increase fence capacity is also developed. Finally, the use of two units of the prototype to protect a wide area is investigated employing the numerical procedure.

1. Introduction

In the last 10 years, several models of fences that provide protection from rockfall and have wide-ranging energy absorption capacities have been constructed in areas with steep slopes and/or mountains. Buzzi et al. [1] introduced rockfall barriers with a relatively low impact energy absorption capacity of 35 kJ, and Gentilini et al. [2–3] reported a series of rockfall protection barriers with energy absorption capacities of 500, 3000, and 5000 kJ.

Ordinarily, the performance of such structures is verified by conducting full-scale tests in which prototypes are subjected to the impact of a block of known mass and velocity [4–7]. However, because of cost and time limitations, full-scale tests cannot be carried out to obtain full knowledge of fence responses under various conditions. Therefore, numerical approaches firmly based on experimental data have been developed that are able to accurately describe the complete response of a fence under dynamic conditions [8–11].

Within this context, we previously developed a new type of rock fence, called the 'wire-rope rockfall protective fence' (abbreviated as WRF) [12]. Two full-scale tests followed by numerical modeling were carried out to thoroughly examine the response of the fence under different impact conditions. Importantly, our numerical approach was thoroughly validated, making it a useful design tool for WRFs. Unfortunately, because of site conditions, the span dimensions (5, 8, and 5 m) of the tested prototype were not fully relevant to practical application. Moreover, wider post spacing would result in appreciable cost benefit because it would reduce post consumption. In this study, we introduce a prototype WRF (referred to hereafter as developed prototype) with a post spacing of up to 10 m in all three modules, as shown in Fig. 1. In addition, our previous work indicated that a second layer of wire netting was largely redundant [12]. Consequently, only one layer of wire netting is used in the newly developed prototype to reduce cost. The effects of these alterations on the response of the fence need to be investigated before the prototype is used.

In this paper, instead of using an expensive experimental approach, we use our previous numerical procedure [12] to examine the properties of the developed prototype WRF. The elongation, energy absorption capacity, post deformation, and effects of impact location and size of the colliding block are investigated. Particular attention is paid to both the middle and side modules of the developed prototype. Detailed comparison and analysis is used to reveal the performance of the fence under various dynamic conditions and the role of each component of the developed prototype. The performance of the energy absorbers is examined, helping to clarify how the average friction force (abbreviated as AFF; refer to [12]

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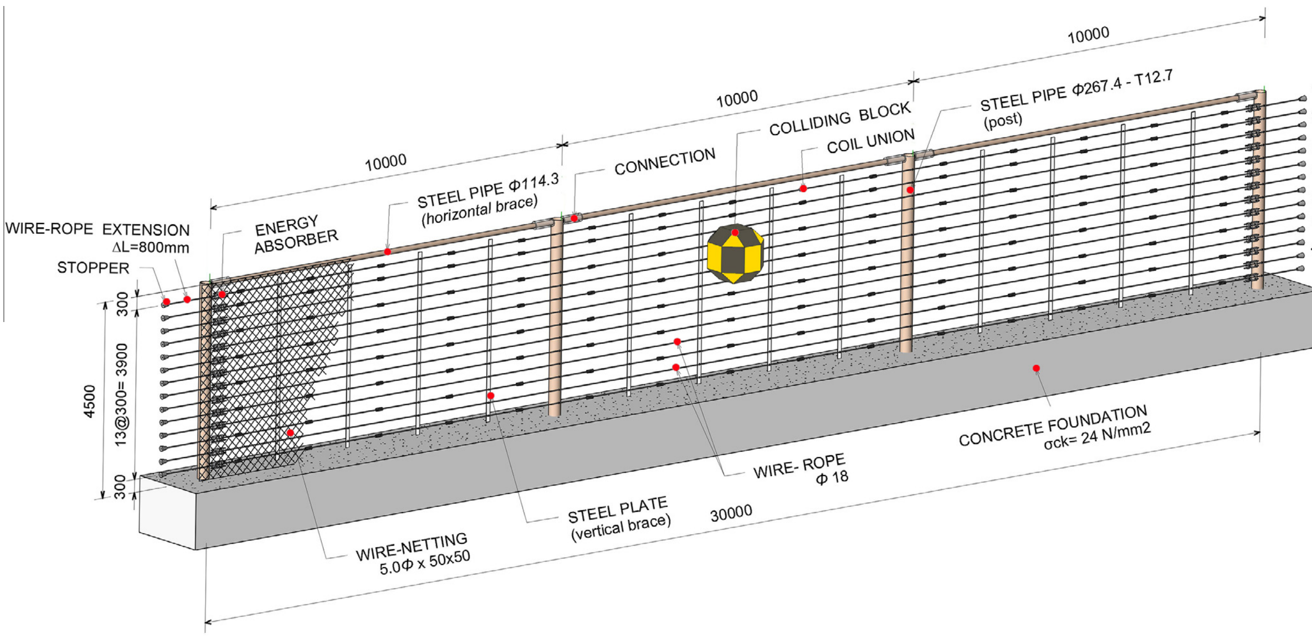

Fig. 1. Schematic drawing of the developed prototype.

for details) between the wire rope and absorber affects fence elongation, which influences fence efficiency. The findings of this numerical study reveal how to improve fence capacity in a simple and efficient manner.

We also consider a practical application in which the site to be protected is wide and requires at least two units of the developed prototype. The performance, particularly the capacity, of a fence composed of two units of the developed prototype is explored. The proposed enhancement method of changing the AFF is verified using iterative numerical models. This is the first time the performance of two units of a rock fence is validated using a numerical procedure, allowing the future practical application of the prototype to be assessed. Furthermore, although the numerical procedure was specifically designed to investigate WRFs, the methodologies and findings derived from this work are likely to help understand the properties of comparable types of rock fence.

A brief description of the developed prototype is given in Section 2, and further details are available in Ref. [12]. Section 3 briefly summarizes the numerical procedure and closely scrutinizes the fence response to impacts targeting the middle and side modules. Section 4 proposes an enhancement of the developed prototype and presents interesting ways to improve the fence. Section 5 investigates the practical application of a WRF consisting of two units of the developed prototype.

2. Description of the developed prototype

The configuration of the developed prototype as depicted in Fig. 1 is the same as that of the previous version of the prototype, except for the post spacing and the number of wire netting layers. The developed prototype WRF has an interception structure, support structure and connecting components (refer to Ref. [12] for additional details). The interception structure is composed of 14 wire ropes, which are primarily responsible for bearing the direct impact of a block, and one layer of wire netting intended to support the wire ropes in arresting the block. The support structure is composed of concrete-filled steel posts, which are rigidly erected on a concrete foundation, and keeps the fence in the vertical plane without requiring lateral cables or anchors. Connecting components include vertical braces, horizontal braces, steel-wire coils, and energy absorbers.

The developed prototype fence has a post spacing of 10 m, nominal height of 4.2 m (defined as the initial vertical distance between the top of the foundation and topmost wire rope), and an interval between wire ropes of 0.3 m.

Fig. 2 shows functional details of the energy absorber, which we previously proved both experimentally and numerically to be effective at dissipating impact energy and preventing wire ropes from breaking [12]. The efficiency of the energy absorber is attributed to: (a) the initial motion of the steel block (2) coming into contact with the steel block (1), which prevents a sudden rise in rope tension at the beginning of impact, and (b) the relevant magnitude of the AFF acting between the rope and blocks (1) and (2), which enables the wire rope to slide through the device during the impact. The AFF can be estimated in a laboratory dynamic test [12] and can be altered simply by controlling the torque applied to the bolts connecting the steel plates in blocks (1) and (2).

3. Numerical analysis of the developed prototype

Although only two features (the post spacing and number of wire netting layers) were altered from our previous WRF [12] to create the developed prototype, we anticipate that these variations

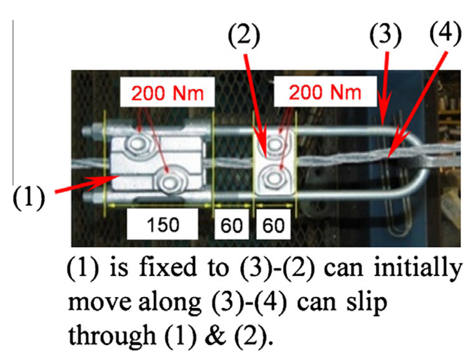

Fig. 2. Energy absorbing device.