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TREENET: AN INNOVATIVE TYPE OF ROCKFALL PROTECTION FENCE ON FORESTED SLOPES SPECIALLY DESIGNED FOR LOW ENERGY EVENTS

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ABSTRACT

This paper deals with a type of fence specifically developed for low energy events. The fence is composed of a wire mesh, three cables and two rigid rods. This fence is tightened between existing trees. The experiments successively impacted the fence in its centre with rocks of varying mass (from 30 kg to 500 kg) with the aim of evaluating its capacities. The system allowed reaching a maximal rock velocity before impact of 17m/s. This velocity was calculated thanks to image analysis obtained with a video camera and a high speed camera. A total of 17 impact experiments were performed for different fences. The first results showed that (i) angular blocks can cut wires even for low mass rocks, (ii) the wire rupture hardly propagates in the mesh during another impact, (iii) supporting cables can be cut during the impact, (iv) the fence is not perforated by the direct impact even for rocks 500 kg in mass, and (v) a reparation of a perforated mesh consisting in placing a patch is perfectly efficient. In parallel to these experiments, numerical simulations were performed based on the discrete element model developed by [Bertrand *et al.* \(2008\)](#).

Key words: rockfall fence, tree root anchorage, eco-engineering, low energy event, modelling.

INTRODUCTION

Forest management in mountainous regions implies silvicultural interventions on slopes submitted by natural hazards such as rockfall. Moreover, in such forested areas, engines, workers or falling trees can initiate rockfall and the site can temporarily turn to a potentially dangerous site. To react against this risk, we have designed a type of protection fence, called Treenet, using trees as support. The principle of this fence is ease to put in use; it is temporary and is less expensive than civil engineering work. Fence protection request a lot of work realized generally by professionals of civil engineering. This cost is cheap and it is not necessary to construct an anchorage with reinforced concrete in the soils. Moreover, these structures are often oversized for confronting the real risk of rockfall. Our fence can be put everywhere without restraint caused by broken ground, but it is sometimes necessary to adapt the procedure of installation functions for different fields.

Treenet is a structure principally developed for low energy events not exceeding 200 kN which is considered as a low value for rockfall protection structures ([Descœudres *et al.* 1997](#)). Many structures are currently installed and are oversized for the real risk. The life time

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prediction is 10 years. This can be the case where the forest previously offered an efficient protection against rockfalls.

Treenet is an intermediate and rapid solution for efficient protection in forest area. This paper presents the first results obtained during the preliminary experiments.

MATERIALS AND METHODS

Fence composition

The structure has been simplified in order to adapt to the field. Thus, we have one fence composed by a wire mesh, two rigid steel rods to keep the fence tightened vertically and two support trees. The connection between the fence and the trees is realized by three cables, see [Fig. 1](#). The fence used has a total length of 25 m and a height of 3 m. The total weight of one fence is 132 kg.

The upper cable and the bottom cable have a diameter of 12 cm and are fixed at the fence by cable clips. The intermediate cable has a diameter of eight centimetres and its objective is to bring elasticity to the system. This cable is only knit in the fence without cable clips. The three cables are fixed at the tree protected by wooden poles. It is possible to add some truss rod to correctly tighten the fence, because we can have distension of the upper and bottom cable during the time.



Fig. 1. Fence installed for real size experiments in Vaujany, France (2008)

Rockfall experiments

Our study area is located in the Forest Communal de Vaujany in France (lat 45.8120 long 6.83) and has an altitude ranging from 1200 to 1400 m above sea level. It covers a forested, northwest facing Alpine slope, which has a mean gradient of 38°. The main tree species in the study area are Silver fir (*Abies alba*, 50%), Norway spruce (*Picea abies*, 25%), European beech (*Fagus sylvatica*, 17%) and Sycamore (*Acer pseudoplatanus*, 4%) ([Dorren et al. 2004](#)).

For the fence experiments, see [Fig. 2.](#), we have used two support trees. One is a spruce with a diameter of 82 cm and one is a maple with a diameter of 60 cm. The length of the fence used for experiment is 16 m.

The experiments consisted of impacting successively the fence in its centre with rock of varying mass with the aim of evaluating its capacities. To throw the rock, we have used a trolley on a cable anchorage between two trees. Velocity was determined function of the height and the angle of the cable. We have obtained a velocity from 14 to 17 m/s corresponding to a maximum energy of 50 kJ.

To drop the rock before the impact with the fence, we started an automatic snap clap, which it was generally used in sails.



Fig. 2. Experimental procedure for rocks throwing

Data acquisition

Two types of measurements have been used. First, the velocity was calculated with image analysis of two cameras and a high speed camera (500 frames/s). Knowing the rock mass and the travel distance of the rock, these cameras could calculate the energy and visualize the trajectory of the rock during the impact.

Secondly, we used one force sensor with a capacity of 200 kN to calculate the tension in the upper cable and two accelerometers. One was placed in the centre of the fence and one was placed on one support tree. This accelerometer was a 200 g capacitive accelerometer with a 0-2.5 kHz frequency response. This accelerometer has been used to determine the tree displacement during the dynamic loading of the fence. However, the accelerometer placed at the centre of the fence has received one impact and it was over.

RESULTS

Experimental results

The first results showed that (i) angular blocks can cut wires even for low mass rocks, (ii) the wire rupture hardly propagates in the mesh during another impact, (iii) supporting cables can be cut during the impact, (iv) the fence is not perforated by the direct impact even for rocks 500 kg in mass, and (v) a reparation of a perforated mesh consisting in placing a patch is perfectly efficient.

The same rock of 200 kg and angular in shape was launched at a 17 m/s velocity for both tests. In terms of energy, this corresponds to a 30 kJ impacts.

To illustrate the results, [Fig. 3](#) and [Fig. 4](#) present the tension in the cable and the acceleration of the tree in both cases. Initially, the tension in the cable is about 20 kN. During the first impact ([fig.3](#)), the maximum tension is about 38 kN. Sudden tension drops are also observed. After 60 m/s, the tensions fluctuate slightly around a value of about 4.3 kN. This value corresponds to the tension at rest after impact. The value of the impact duration is evaluated to 500 ms. During the second impact without tightening the fence, the maximum tension is about 35 kN. Before 0,45 s, the curve is smoother due to the cable clips which already slid on the cable. The second peak corresponds to the rebound in the fence by the rock until tension value returns to about 4.3 kN.

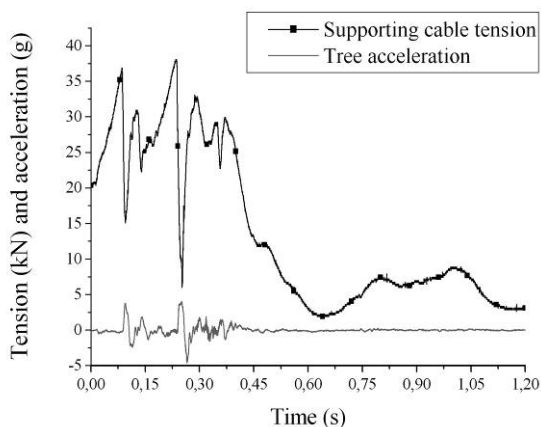


Fig. 3. Tension in a cable and acceleration of the tree measured during the first impact

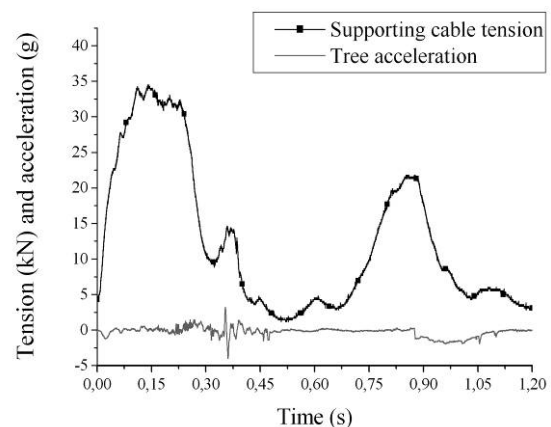


Fig. 4. Tension in a cable and acceleration of the tree measured during the second impact

During these experiments, we have not observed damage on either tree. After the experiments, the fence was completely destroyed but it was very easy to repair.

Numerical simulations

In parallel to these experiments, numerical simulations were performed based on the discrete element model developed by [Bertrand et al. \(2008\)](#). It has allowed the estimation of the relevance of some technical options.

[Bertrand et al. \(2008\)](#) have previously developed a numerical model based on the discrete element method (DEM) to simulate the behaviour of double-twisted wire meshes used in various fields of civil engineering. These authors also investigated the behaviour of rockfall protection fences made of such meshes. The fence considered was vertical and was hung between two poles. The model developed was used as a base of the numerical simulations. It was necessary to adapt or to take into account for the specifications of the considered fence.

The incident velocity (V_i) of the block before impact was varied from 5 to 25 m/s. [Figure 5](#) shows the trajectory of the block during the impact, in a vertical plane. The 25 m/s velocity block perforates the mesh.

The maximum force applied on the boulder during the 20 m/s impact is of about 17 kN. The corresponding tension in the upper cable was of about 10 kN ([Fig. 6](#)).

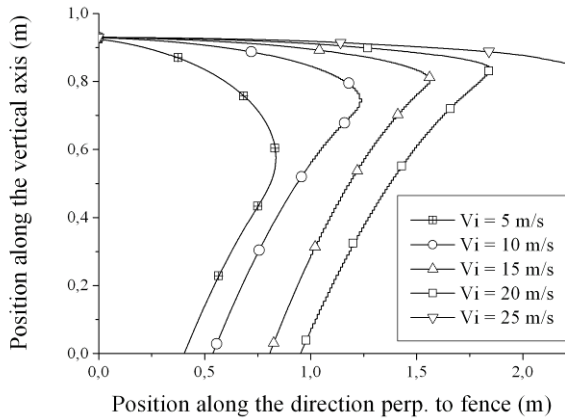


Fig. 5. Trajectory of the rock after contact with the fence for different incident velocities.

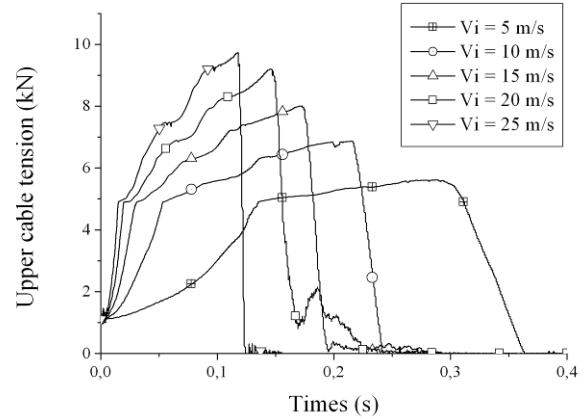


Fig. 6. Tension in the upper cable during the impact for different incident velocities.

The conclusion is that the centred impact is the most critical for the upper cable and that the fence behaves satisfactorily whatever the impact point in case of a 50 kg boulder with an incident velocity of 20 m/s.

Practical application

One pilot site has been set up at Chamonix Mont Blanc in 2009 ([fig.7](#)). The site has an altitude ranging from 1800 to 1900 m. this site was often subject at rockfall activities. Workers of ONF (National Forest Office) have decided to install two fences in the forest above the railway that climbs to Chamonix city at the “Mer de Glace”. The objective of this pilot site is to protect the future clear cut.



Fig. 7. Fence installed in a pilot forest. Chamonix, France (2009)

One fence has a length of 38 m and second fence has a length of 20 m. The both fence have a high of 2 m and a flap of 1 m to avoid that the block across until the fence. The truss rod using during the experiments have been substituted by snow poles.

Some blocks are already trapping in the fences without damages. These constitute the first and encouraging step towards the putting into practice for this structure.

CONCLUSION

Experimental results are always efficient for low energy events until 50 kN. The numerical results are the first modelling approach for a method to calculate the maximum efficiency of this fence in the same condition with the real site. The pilot site contributes a real enthusiasm for foresters in terms of easy to put in use, cheap, and it fits better into the landscape.

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