DESIGN AND VALIDATION OF ROCKFALL PROTECTION SYSTEMS BY NUMERICAL MODELING WITH DISCRETE ELEMENTS

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Rockfall protection systems are installed in order to preserve civil infrastructures against landslides and falling rocks. For the evaluation of these systems, one of the main problems is the difficulty to develop laboratory tests, since landslides and falling rocks are unpredictable events that involve the movement of large masses of material over several meters or even kilometers. For this reason, the use of numerical methods, which allows reproducing full-scale situations without the need of laboratory devices or sliding materials, has become more popular. The study presented in this document shows the application of the Discrete Element Method (DEM) for the analysis of the behavior of one of the most popular rockfall protection systems, flexible metallic fences.
Keywords: Rockfall protection, Flexible metallic fences, Discrete element method, Numerical modeling

INTRODUCTION

Communication and supply needs of an increasing population, all around the world, force the construction of infrastructures in places threatened by natural hazards such as falling rocks. With the purpose of preserving these infrastructures, different containment systems, such as flexible metallic fences [1], drapery systems [7] and granular material embankments [5], are installed.

The difficulty to carry out full-scale laboratory tests, on account of the huge magnitude of the event [3], in addition to the uncertainties in the small-scale testing, due to the distortion in the contours (e.g. anchors of flexible metallic fences), has led to the use of numerical methods.

In this study, the Discrete Element Method (DEM) is used for the analysis of the behavior of flexible metallic fences for rockfall protection. The classic DEM is based on representing the material by rigid particles that interact with each other according to appropriate contact laws, defined by the material properties. It is a suitable numerical method for the problem under consideration, because: (a) it allows large deformations and displacements and (b) the contact detection is more computationally efficient than in other numerical methods, such as the Finite Element Method (FEM).

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The flexible metallic fences are calculated using the bonded DEM, a modification of the classical DEM which assumes that bonds exist between particles, resisting their separation [2]. In this case, the net cables are represented using rigid spheres joined by bond elements that are deformed according to an elasto-plastic law.

Calculations were carried out using the DEMPack program, a specific software developed in CIMNE for modeling with the bonded DEM [4]. This software allows considering the interaction between discrete and finite elements [6], which can be useful to represent the boundaries of the domain, such as the surface of the slope.

Firstly, the code is validated reproducing two benchmark tests available in the literature [1] where the behavior of a small portion of a flexible metallic fence is evaluated. Finally, full-scale tests are reproduced in order to evaluate the energy dissipation capacity of the fence during a rockfall event.

VALIDATION

The validation tests were obtained from the work driven by Bertrand et al. [1] in 2012. Firstly, they performed a simple tensile test on a small portion of the net, composed of five meshes. The lower points of the specimen were fixed and a constant loading velocity of 4 mm/min was imposed to the upper points. The evolution of the force against the displacement was recorded.

Fig. 1 shows the net used in the laboratory test (diameter of the cable is 12 mm) and the corresponding numerical model composed of rigid spherical particles.

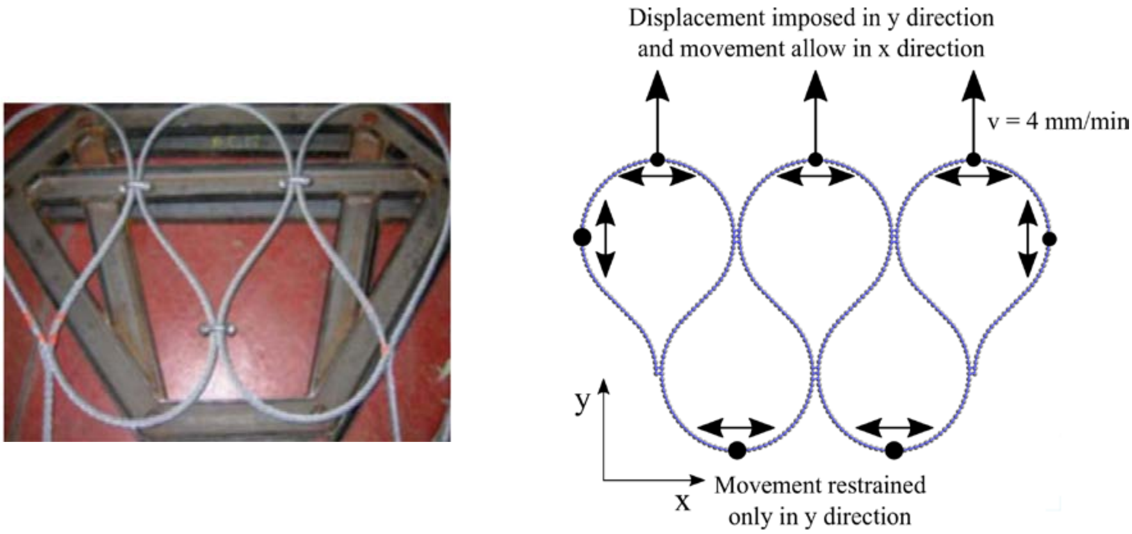

Fig. 1 Laboratory [1] (left) and numerical model (right) of the first validation test.

Fig. 2 exhibits the deformation of the net and the stresses to which it is subjected, during the calculation. It should be noted that this numerical model allows defining different constitutive laws in each bond. In this example, cables and clips are reproduced.

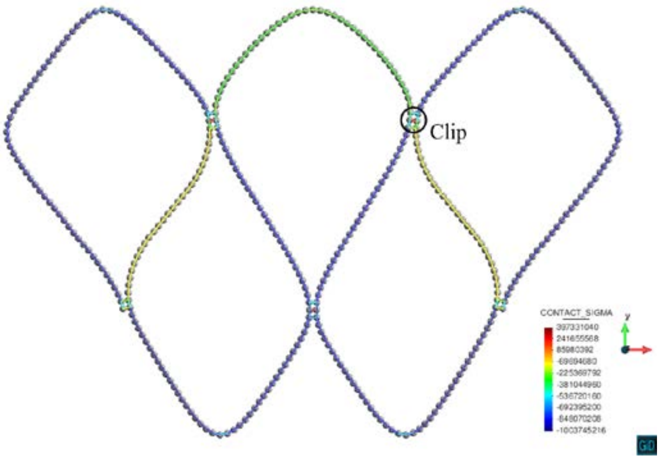

Fig. 2 Deformation of the net and stresses to which it is subjected during the first validation test.

The same authors also developed a punching test (see Fig. 3), aiming to analyze the net response under out-of-plane loading. Due to space restrains in the laboratory a half-scale model was tested, so the cable diameter in this case was 6 mm. A square net with dimensions 2 x 2 m was rigidly fixed to a framework allowing free rotations. A loading rate of 4 mm/min was applied by a cylinder (diameter 330 mm) along the normal direction of the net plane. Reaction forces and penetrations were measured.

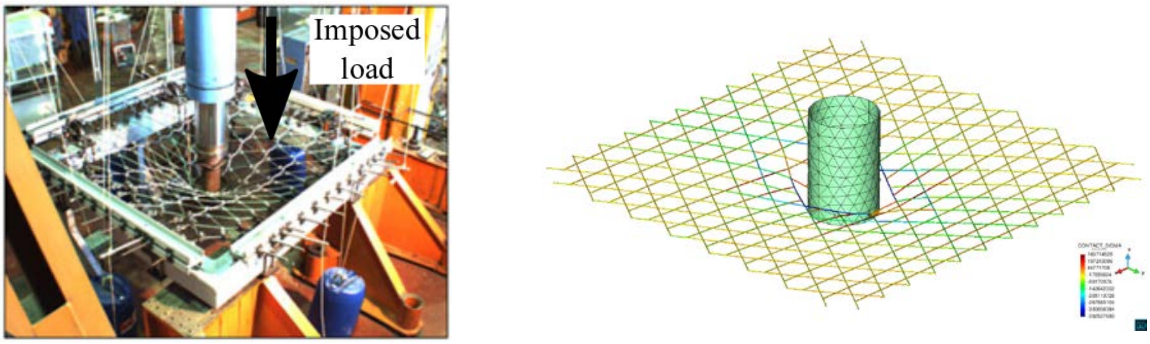

Fig. 3 Laboratory [1] (left) and numerical model (right) of the second validation test.

The two validation tests were calculated with the DEMPack code in order to evaluate its behavior and calibrate the model parameters. These tests allow to properly define the material characteristics of the full-scale test.

In the model presented, each cable is reproduced using several spheres, which increases the computational time of the calculation. However, the deformation of the net is represented in a more realistic way than using discrete elements only in the unions.

FULL-SCALE CALCULATIONS

Regarding full-scale tests, simplified scenarios were analyzed for demonstration purposes. Fig. 4 shows different scenarios, with variable number of falling rocks, shape and kinetic energy. The net geometry has also been modified from one calculation to another.

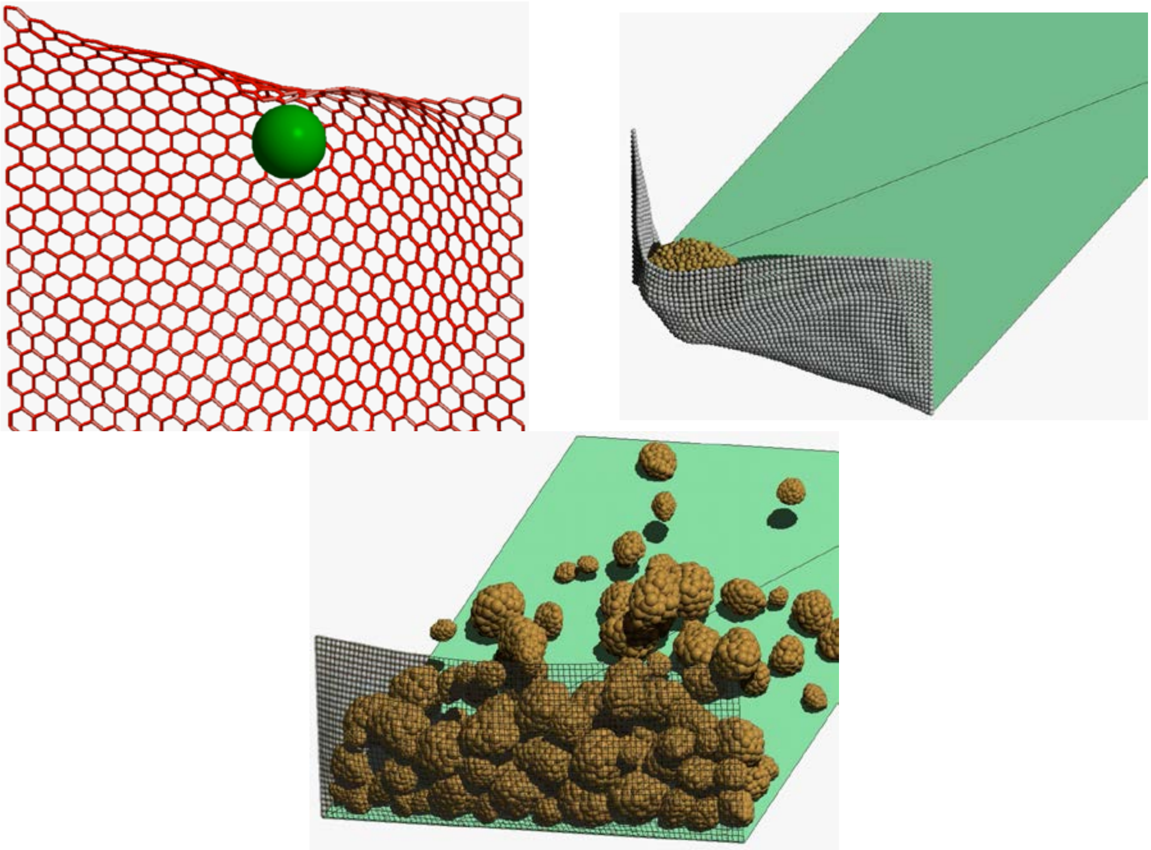

Fig. 4 Full-scale tests with variable nets and arbitrary rock shape.

With this numerical model, the energy and trajectories of the rocks can be accurately tracked. The energy absorbing capability of the net, the effect of the rock shape in the protection system behavior or the response of different net geometries, can be evaluated.

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