Using the Discrete Element Method for rockfall protection forests efficiency assessment

D. TOE[a], F. BOURRIER[a], I. OLMEDO-MANICH[a,b], D. BERTRAND[b], F. BERGER[a]

a. Irstea - UR EMGR, 38402 Saint Martin d'Hères, France – franck.bourrier@irstea.fr
b. LGCIE, INSA-Lyon, 69000 Villeurbanne, France

Résumé :

L'évaluation de l'efficacité de la forêt pour la protection contre les chutes de blocs n'est possible que suite à l'étude détaillée de l'impact d'un bloc sur un arbre. Dans cette optique, un modèle basé sur la Méthode des Eléments Discrets a été développé et utilisé pour identifier les paramètres principaux contrôlant la cinématique du bloc après impact sur l'arbre. L'objectif final de ce travail est de construire un méta-modèle de l'interaction entre un bloc et un arbre utilisable en pratique dans les modèles de simulation de la propagation des blocs.

Abstract:

The assessment of forest protection efficiency against rockfall hazard requires a detailed analysis of the impact of rocks on standing trees. A model based on the Discrete Element Method was developed for that purpose. This model is used to identify the key parameters controlling the kinematic response of a block after an impact on a tree. The final objective of this approach is to build a rock-tree interaction meta-model usable in practice for rockfall simulations.

Keywords : Discrete Element Method, rockfall, forest

1 Introduction

In the field of rockfall hazard assessment, the integration of forest effect on blocks propagation and the assessment of forest protection function are increasingly being studied. The integration of forest effects in rockfall propagation models is challenging because of the complexity of the mechanical processes involved into the interaction between the blocks and the trees.
The integration into process based lumped-mass rockfall models was extensively investigated [4], [8]. Although these modelling approaches present efficient computational times and global accounting of forest effects, they do not allow integrating all the physical processes occurring during the interaction between the blocks and the tree [8]. In particular, they do not account for the respective contributions of the different tree components - stem, root system and crown - on the impacting block velocity changes and energy reduction.
Integrating all these contributions requires developing simulation tools based on mechanical approaches [1], [6]. The calibration of such models is complex and is classically done using in situ impacts on standing trees [4] or laboratory experiments [1].
The main difficulty related with the practical use of these models remains the in-situ characterization of the numerous parameters involved. In addition, the integration of the results from these approaches

into either empirical or process based rockfall models is challenging. The results can be transformed into meta-models of the impacting block velocity reduction depending on the block properties and tree characteristics. Another solution could consist in the direct coupling between the rockfall model and the mechanical model of impact on the trees. In both cases, the main parameters of the mechanical models managing the interaction with the block have to be identified to limit the amount of parameters to be estimated in the field.

This paper aims at presenting a mechanical model of the interaction between a block and a tree and at identifying key parameters controlling the kinematic response of a block after impact.
A model simulating the impact of blocks on trees based on a Discrete Element Method (DEM) is developed. Simulations of impact on trees are held using this model and a meta-model of the simulations is used to identify the key parameters controlling the block kinematic parameters from a sensitivity analysis.

2 DEM model

The DEM model of impacts of blocks on trees (Fig. 1) was developed to account for the relative contributions of the different tree components using the open source code Yade-DEM [9]. The interaction between the block and the tree is modelled as one of a rigid spherical body - the block - with a deformable beam - the tree. The contact between the two bodies is accounted for by applying forces to the two bodies depending on their overlap and relative velocities. The tree stem is represented by a flexible cone subjected to normal, shear, bending, and twist loadings [2]. The crown of the tree is modelled as an additional mass distributed uniformly on the upper part of the stem. Finally, the contribution of the root-system is integrated by means of a rotational non-linear spring acting at the bottom of the tree [7].
The interaction forces between the impacting sphere and the cylindrical connections were calculated in the normal and tangential directions to the contact surface as exposed in [2]. Energy dissipation at the contact between the tree and the block was neglected. The normal interaction was related to the overlap between the sphere and the cylinder associated with the connection using a linear relationship. The normal stiffness coefficient characterizing this linear relationship was related to the radial elasticity modulus of fresh wood. The interaction force in the tangential direction was calculated using an elasto-frictional contact model. The tangential stiffness coefficient was set at the same value as the normal one. The threshold tangential force for which sliding occurs was determined from the normal interaction force following Coulomb's friction model.

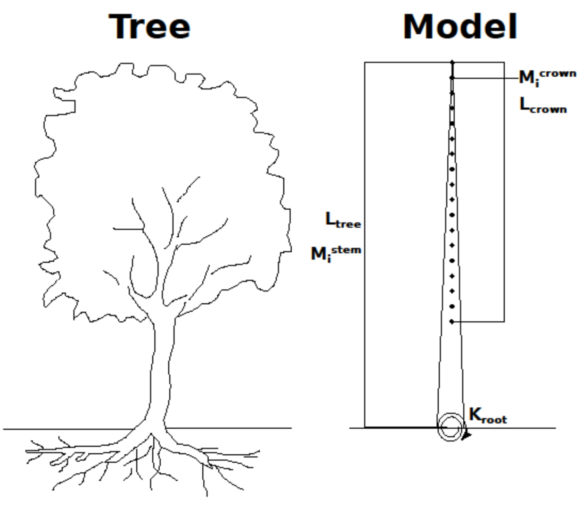

Figure 1: Schema of the DEM model. K_{root} represents the rotational stiffness modelling the root system contribution, M^i_{crown} and L_{crown} correspond to the crown modelled as a distributed mass

3 Key parameters controlling the block kinematics

In total, 19 input parameters of the DEM model have been identified. Among the 19 parameters, 11 parameters were related with the tree properties, the other being related with the rock or rock/tree interface. In addition, 5 output variables of interest have been investigated: the reflected velocity, the reflected rotational velocity, the energy dissipated during the impact and the two rock deviation angles were saved.
The study consisted in using the meta-modelling approach and the sensitivity analyses to identify the key parameters controlling the kinematic response of a block after an impact on a tree. 1300 DEM simulations were done technique based on a Latin Hypercube sampling to build a meta-model which could accurately reproduce the DEM response for the 19 input parameters.

Using the DEM results, a PCE meta-model was built with the Least Angle Regression technique. Comparisons between results predicted by the DEM model and the PCE meta-model have shown acceptable error for the estimation of the 5 output variables.
The comparison of the relative influence of the 19 input parameters was done by post-processing the PCE meta model to calculate total Sobol indices.
The sensitivity analysis based on Sobol indices (Fig. 2) shows that the rock velocity after impact was highly influenced by the rock velocity before impact (V^{in}) with a low influence of the tree diameter (*TDiam*) and of the impact eccentricity (*Ecc*). The rock rotational velocity after impact (V_{rot}^{out}) was almost fully influenced by the rock rotational velocity before impact V_{rot}^{in}.
Finally, the rock kinetic energy decrease due to impact (*Ediss*) was mainly influenced by the tree diameter (*TDiam*) and the eccentricity (*Ecc*) with a lower influence of rock impact velocity (V^{in}).

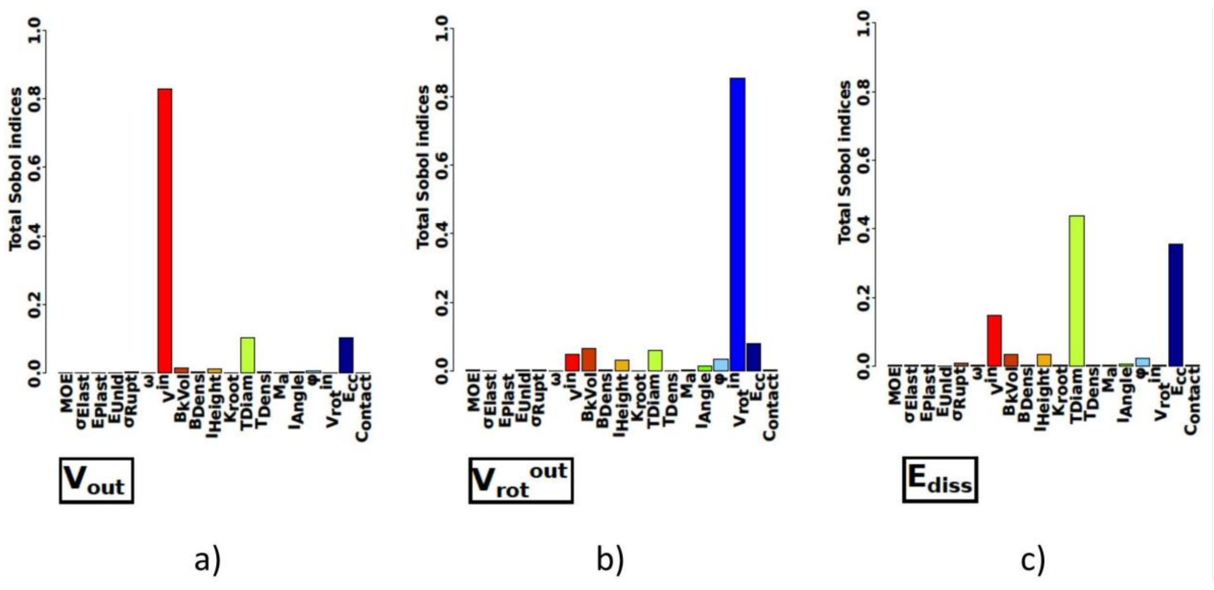

Figure 2: Values of the total Sobol indices for the rock velocity after impact (V_{out}), rock rotational velocity after impact (V_{rot}^{out}), and rock energy reduction (E_{diss}). The relative influence of the different input parameters (horizontal axis) is proportional to the values of the associated total Sobol indice.

5 Conclusions and perspectives

The research work presented allowed identifying the key parameters for an accurate modeling of the rock kinematic changes after interaction with a tree. The results obtained constitute a basis for the building of a meta-model that can be integrated into classical rockfall propagation models. Such a model has to be depending only on a reduced amount of parameters that can be limited to those identified in this study.

Preliminary results for the building of such a meta-model have been obtained concerning the rock kinetic energy reduction. Indeed, this quantity is classically used in the literature to assess forest efficiency. Similar results as in the literature [3], [5] are found concerning the obtained evolution of the rock energy reduction (Fig. 3).

Detailed analysis of the rock energy reduction, rock rotational changes and rock deviation, depending on the influent parameters identified from the sensitivity analysis are still required for obtaining relevant information for the building of a meta-model usable in practice for rockfall simulations.

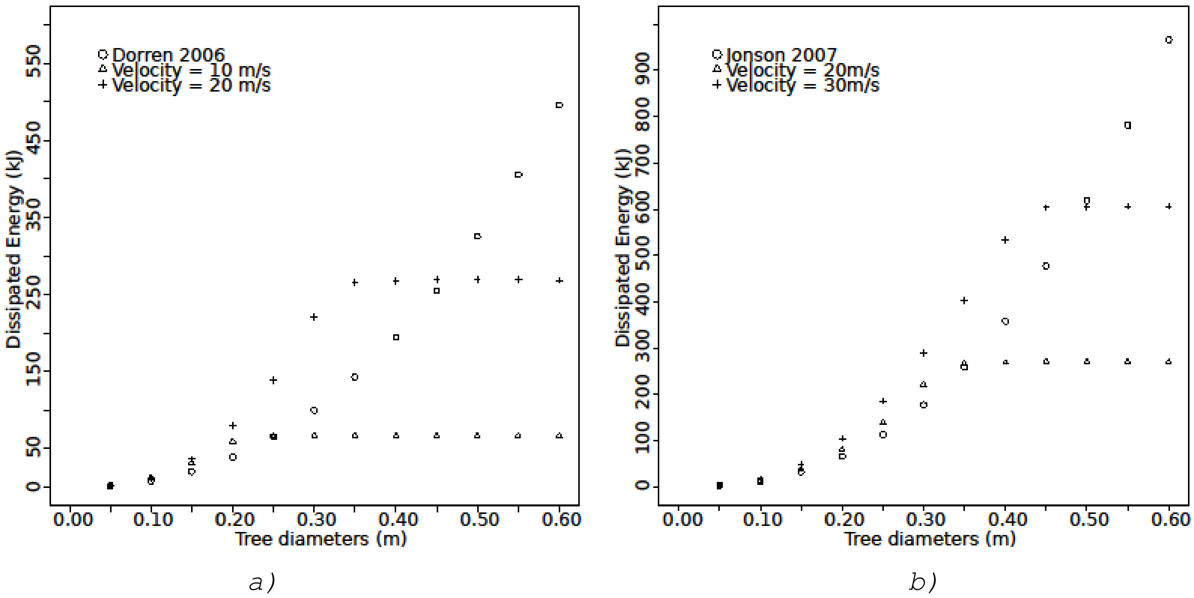

Figure 3: Evolution of the rock energy reduction due to impact (dissipated energy) for different impact velocities and compared with [3] (a) and [5] (b).

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