Sensitivity analysis of rockfall trajectory simulations to material properties

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Many tools have been developed to manage rockfall risk. In particular, many softwares are designed to simulate rockfall trajectories. These softwares require the definition of many parameters, especially those describing the mechanical properties of soils (rigidity, roughness, etc.). Choosing appropriate values for these parameters remains a difficult task and will depend on the expert know-how. Here, we propose a simple method that can be used routinely to evaluate the relative influence of these parameters (about 50 parameters for the examples below) on the simulation results. The objective is 1) to identify the parameters that are playing a key or predominant role in the simulations and that require additional characterization efforts, 2) to estimate the uncertainty that exists on the simulation results. The application cases for this sensitivity analysis are two busy roads on Reunion island (France) when considering the residual rockfall risk after a major rockfall event.

1 SIMULATION OF THE RESIDUAL ROCKFALL RISK AT TWO SITES ON REUNION ISLAND

The residual rockfall risk after a major rockfall event is studied for two busy roads on Reunion island (France): the national roads RN1 and RN5 (upper part of Figure 1). A probable residual rockfall volume of $0.2m^3$ is considered for RN1 and of $6.4m^3$ for RN5. Both slopes are mostly constituted of volcanic rocks. However, their topographies are very different: the slope at RN1 (landmark PR12+800) is almost vertical while the slope at RN5 (landmark PR10+960) is of moderate declivity. Thus, rockfall trajectory simulations at these two slopes show typical characteristics: mostly free flight for RN1 and mostly rolling/sliding for RN5 (upper part of Figure 1).
Rockfall trajectory simulations are carried out using the 2D Pierre-98 stochastic rock fall dynamics simulation program (co-developed by BRGM and university of british Columbia, Mellal et al., 1998). The materials along the profiles are described using mechanical parameters (Table 1) that we consider variable. Thus, a simulation corresponds to 1000 realizations of trajectories for which these properties are randomly drawn in the parameter space (according to predefined probability distributions), while the size of the falling blocks remains constant.

Table 1: List of parameters defined for each material to perform rockfall trajectory simulations

Parameter	Description
Rf	dynamic friction coefficient for rolling/sliding
Rd (m)	maximum rolling/sliding distance before rebound
S (m)	roughness
Cf	static friction coefficient
En, Et	normal and tangential restitution coefficients
F0 (kN)	limit beyond which there is reduction of the restitution coefficients under impact
C1 (kN/m)	soil stiffness for impacts where F <F0
Rn, Rt	coefficient of reduction of normal and lateral rigidity under strong impact

2 SENSITIVITY ANALYSIS ON THE SIMULATION RESULTS

The probability of the road to be damaged by a falling block correspond to the percentage of simulated blocks that reached it and which can be deduced from the Cumulated Distribution Function (CDF) of the maximum runout distances. In order to estimate the relative influence of each parameter on the simulation results, we will thus quantify the changes of the maximum runout CDF when removing the uncertainty about one material property following the approach named PAWN developed by Pianosi and Wagener (2015) (e.g. the targeted material property remains constant while all others vary). The central insert of Figure 1 shows the evolution of the maximum runout CDF when the parameter S of the parent rock is successively fixed at $0+n\times0.1$ m with $n=[0,1,2,3,4]$.

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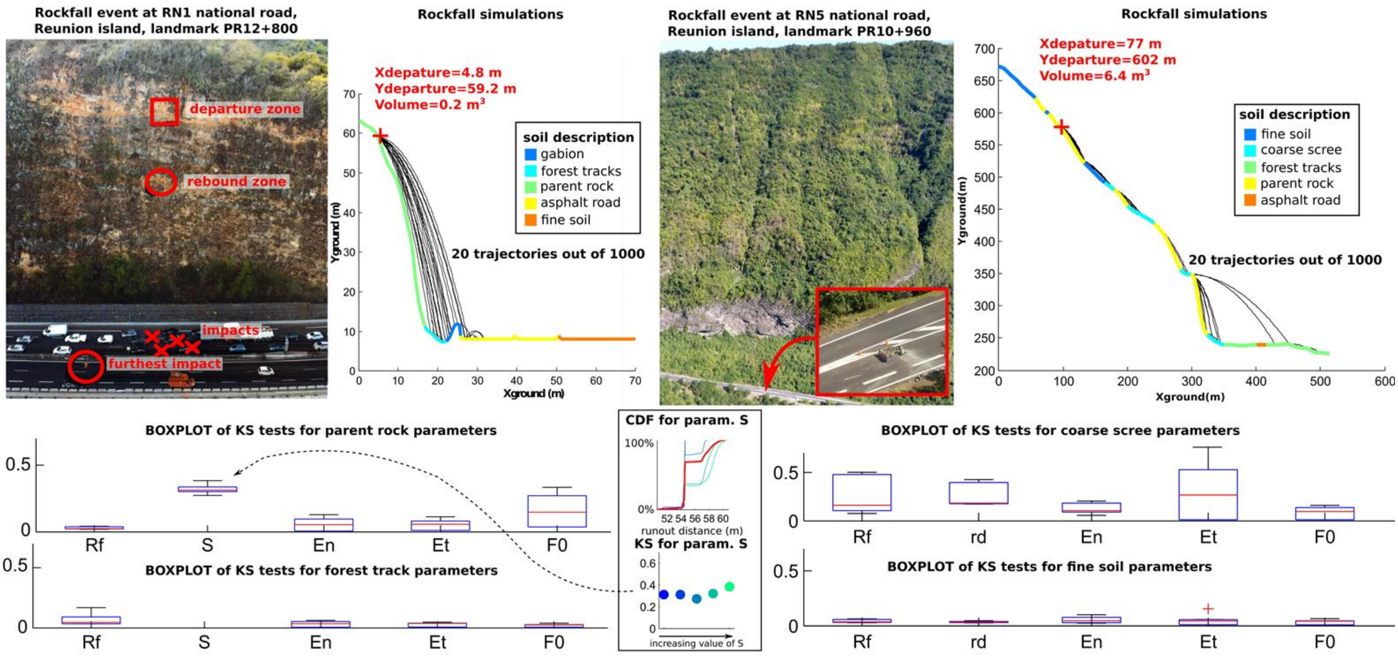

Figure 1: Photographs of two sites exposed to rockfall risk at Reunion island together with corresponding 2D simulations (upper part). Boxplots of the Kolmogorov Smirnov (KS) statistics on several parameters used in the simulations summarizing their relative influence on the distribution of runout distances (lower part). Bottom and top of the boxplots are the 25th and 75th percentile of the obtained KS values, red line is the median and the whiskers are the minimum and maximum KS values. The central insert illustrates how KS values are obtained from Cumulative Distribution Functions (CDF) of the maximum runout distances: the upper plot shows the CDF of the reference simulation in red (e.g. 1000 random realizations of trajectories where all inputs vary simultaneously) together with 5 CDFs corresponding to simulations where all inputs vary except S, which successively takes 5 fixed values (blue lines), the lower plot shows the obtained values for the KS statistics that quantifies the distance between the reference (or unconditional) CDF and each of the other CDFs.

Figure 2 shows the roughness of the parent rock (basalt) at the RN1 site, translated by the expert by a variation of parameter S between 0 and 0.1 m. The variation of the maximum runout CDF compared to a simulation for which all the parameters vary simultaneously is estimated using the Kolmogorov smirnov statistic (denoted KS distance), which can vary between 0 and 1. The larger the KS distance, the larger the importance of the studied parameter on the simulation results (central insert of Figure 1). For all parameters, we study the variation of the maximum runout CDF using 5 different fixed values of the parameter and by calculating the corresponding KS distances. The distribution of the obtained KS distances is represented using boxplots in Figure 1 (lower part). For the RN1 site, we observe that parameters S and F0 of the parent rock play a dominant role on the simulation results when compared to other parameters (whether they are other parameters describing the parent rock or parameters describing the forest tracks). This result is very consistent with the characteristics of the trajectories on this profile (free flight). Indeed, these two parameters play a key role on the characteristics of the initial collision and the following rebound. On the other hand, we observe that it is parameters Rf, rd and Et of the coarse scree (see Table 1) that play a dominant role on the simulation results at RN5 site. This result is also consistent with the characteristics of the trajectories on this profile (rolling/sliding), because these parameters are involved in the modelling of rolling/sliding. Interestingly, coarse screes constitute only a small proportion of the RN5-profile where rolling/sliding occurs, nonetheless this material is by far the most heterogeneous material of the profile and it plays a major influence on the block trajectories.

Figure 2: Detail of the outcrop at RN1 site, showing the roughness of the parent rock (basalt).

CONCLUSION

We propose a simple method that can be used routinely to evaluate the relative influence of parameters used in simulations of rockfall trajectories. The above examples show that out of a large number of initial parameters (about 50), only 2 or 3 influence considerably the results. This information can be quickly integrated by the expert to estimate the uncertainty of the probability of the road to be damaged by a falling block.

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