Rockfor$^{\cdot NET}$: A New Efficient Tool for Quantifying the Residual Rockfall Hazard of a Forested Slope

Frédéric Berger[1] and Luuk Dorren[2]
1) Cemagref Grenoble, 38402 St. Martin d'Hères, France (frederic.berger@cemagref.fr)
2) Cemagref Grenoble, 38402 St. Martin d'Hères, France (luuk.dorren@cemagref.fr)

Abstract

To provide a tool that quantifies rapidly the protective capacity of a forest stand against rockfall, which takes into account general characteristics of the slope, the forest stand and the dominating falling rock, we developed Rockfor$^{\cdot NET}$ (http://www.rockfor.net). The underlying calculation is formalised in a user-friendly tool and uses only a small amount of input data. These data give a global representation of reality and are easy to acquire at the scale of a slope or a forest stand. Presently, there are no clear quantitative rules for determining the optimal combination of stand density and mean stem diameter for a protection forest, depending on the dominating rock size, its kinetic energy and the tree species present. Rockfor$^{\cdot NET}$ fills this gap. This paper explains the underlying principles of the tool.

Keywords: it rapid assessment tool, rockfall, residual hazard, protection forest

Introduction

Rockfall occurs at all steep rock faces due to weathering and mechanical influences and it can pose serious risks to people and infrastructure. In our work, we define rockfall as the fall of individual rocks ($< 5\text{m}^3$) from a cliff face (Berger et al., 2002). Although civil engineering techniques developed rapidly during recent years, the possibilities for technical protection are still relatively restricted and, above all, very costly. Rocks that are stopped on forested slopes show that forests offer an ecologically friendly and cost efficient alternative for technical protective measures against rockfall as confirmed by, for example, Couvreur (1982), Jahn (1988), Gsteiger (1993), Schwitter (1998), Perret et al. (2004), Dorren et al. (2005), Stokes et al. (2005), Dorren and Berger (2006), Stoffel et al (2006). The forester, who is responsible for the protection provided by forests, has to be able quantify rapidly the state of affairs regarding the protective function in a forest stand. A rapid assessment implies the calculation of the protective capacity of a forest stand using a small dataset, formalised in a user-friendly tool. The input data should give a global representation of reality and should be easy to acquire, for example, at the scale of the slope or the forest stand. Until now, an adequate tool that meets these requirements does not exist. Moreover, there are presently no clear quantitative rules for determining the required combination of stand density and DBH, depending on the dominating rock size, its kinetic energy and the tree species present in a forest stand. To provide a tool that quantifies rapidly the protective capacity of a forest stand against rockfall, which takes into account general characteristics of the slope, the forest stand and the dominating falling rock, we developed Rockfor$^{\cdot NET}$ using knowledge obtained from real size rockfall experiments (see Dorren et al., 2005). In this paper we aim to explain the underlying principles of Rockfor$^{\cdot NET}$.

Real size experiments

We carried out more than 350 real size rockfall experiments in the French Alps to obtain quantitative data on rockfall on forested and non-forested slopes. The experimental site ranges from 1200 m to 1400 m a.s.l. The mean slope gradient is 38°.

The forested site covers 1.7 ha on a northwest facing slope (Fig. 1). In total, we measured and mapped 395 trees with a diameter larger than 5 cm at the site, which gives a stand density of 232 trees ha^{-1} (planimetric). The measured total basal area was 39.2 m^2. The mean stem diameter at breast height (DBH) calculated from the total basal area is 36.4 cm. The main tree species in the study area are Silver fir (*Abies alba* — 50%), Norway spruce (*Picea abies* — 25%), and European beech (*Fagus sylvatica* — 17%).

We released individual rocks with a mean diameter of 0.95 m (Fig. 2) by a Caterpillar digger. Rockfall velocities and energies were calculated from the estimated rock mass and digital films recorded by high-speed cameras (25 images per second). Velocities observed between 30 and 140 m from the release point are well represented by the energy line principle (Heim, 1932; Gerber, 1998), using an angle of 31° (cf. Fig. 3).

pp. 229–235

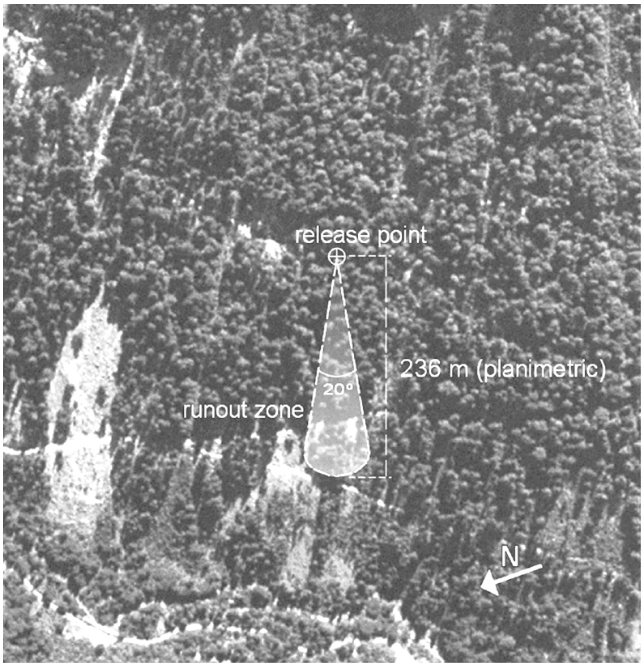

Fig. 1. Map of the forested site and the envelope of the runout zone of the released rocks.

Fig. 2. Example of a released rock (nr. 27) that was stopped by a tree stump after several impacts against trees.

We surveyed the trajectory of each rock from the release to the stopping point. If they occurred, we measured impact damages on trees and the basal area (the area of a cross-section of a tree, including bark, at breast height. Basal area of a forest stand is the sum of the basal areas of all individual trees in the stand, usually reported as m^2 ha^{-1}) of the impacted tree. The longest distance covered by a rock was 236 m. Additional details on the experiments and obtained results are given by Dorren et al. (2005). Figure 4 shows the measured basal area that was intercepted by the released rocks versus their planimetric travel distance. This figure shows that the predicted basal area that will be intercepted corresponds to reality. The theoretical line is constructed using the total basal area (in m^2 ha^{-1}) of the forest stand and the mean rock diameter. With those two a linear estimate can be made of the intercepted basal areas versus the planimetric travel distance (theoretically intercepted basal area = rock diameter * distance from source * total basal area / 10000).

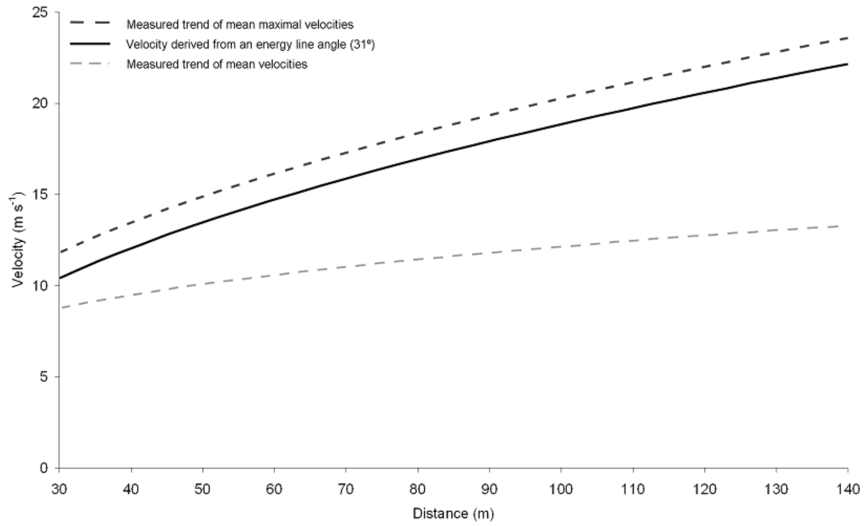

Fig. 3. The observed velocities between 30 and 140 m from the release point and the velocity derived from the energy line angle principle.

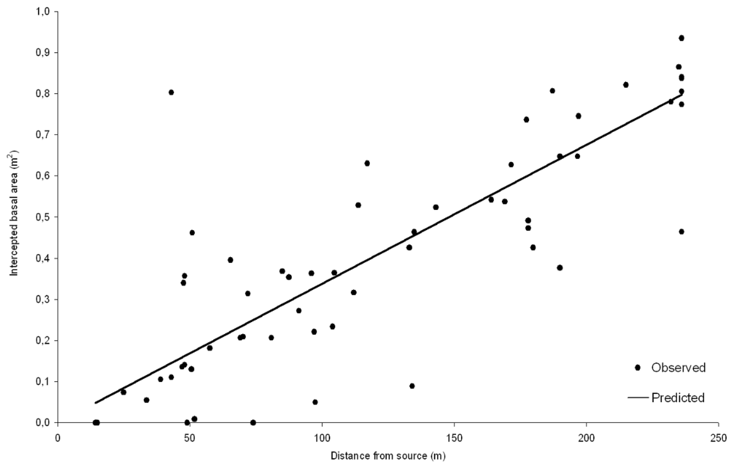

Fig. 4. Basal area intercepted by the rock versus the planimetric travel distance.

Basic principle

Rockfor$^{.NET}$ considers the existing forest as a spatially distributed rockfall net. It converts the existing forest structure into virtual rows (curtains) of trees as shown in Fig. 5. The opening between two trees in a curtain is equal to 90% of the mean diameter of the dominant rock size that falls on a site. This approach ensures that the rock cannot virtually pass a curtain without impacting a tree.

The slope length determines the total curtain length, as a lateral deviation of 10° from the straight downslope line to both sides is taken into account. Knowing the lengths of the curtains, the required number of trees can be calculated, which is the curtain length divided by 0.9*rock diameter + 2/3*DBH. We only take 2/3 of the DBH of each tree as Dorren and Berger (2006) showed that the outer parts of the tree stem hardly absorb energy during a rockfall impact. So about 1/3 of all the accumulated surface of tree stems in a forest can be virtually neglected. In reality it logically contributes to the barrier effect of the forest, resulting in an increased number of impacts and a reduction of the kinetic energy of the falling rock. The distance between two curtains along the slope is equal to the Mean Tree Free Distance after Gsteiger (1993) at our test site. We

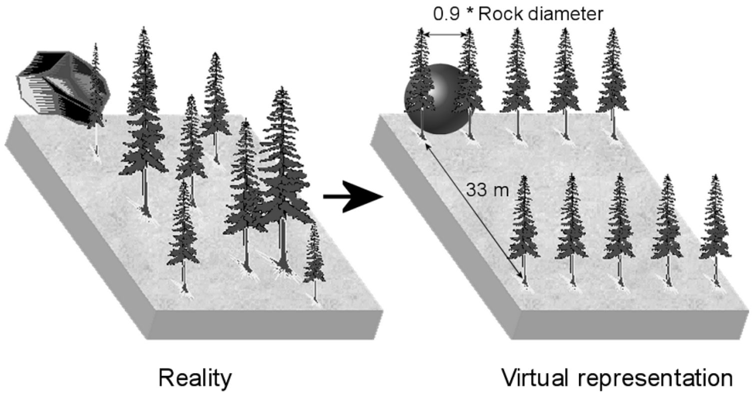

Fig. 5. Scheme explaining the basic idea of Rockfor$^{\cdot \mathrm{NET}}$.

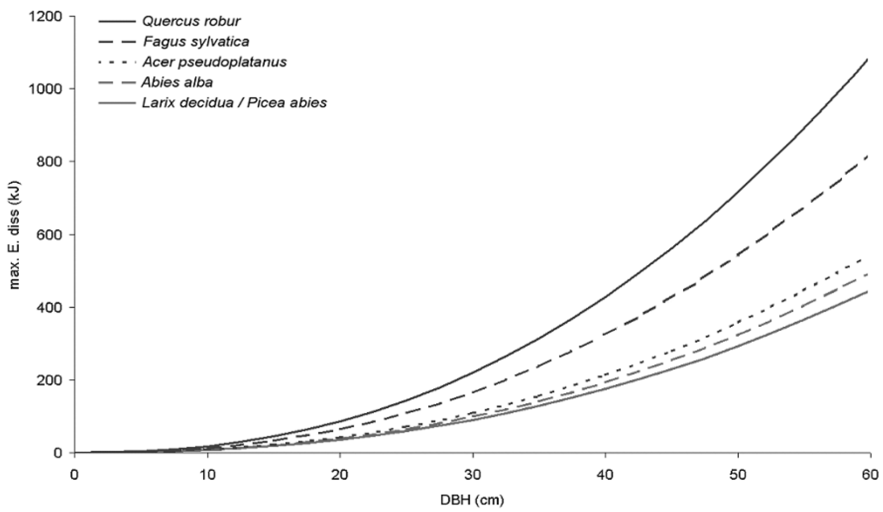

Fig. 6. Relationship between the tree species, the DBH and the maximum amount of energy that can be dissipated by a tree.

calculate MTFD following,

$$MTFD = \frac{Area}{Nrstems * \left(Rock_{diam} + \sqrt{\frac{4*BasalArea_{tot}}{\pi * Nrstems}} \right)}$$

where, Area is the size of the analysed area (m^2), Nrstems is the number of trees in the Area, $\mathrm{Rock}_{\mathrm{diam}}$ is he mean rock diameter (m) and $\mathrm{BasalArea}_{\mathrm{tot}}$ is the total basal area in the Area. All the trees in a curtain have a diameter equal to the mean DBH in the forest stand, which determines, in combination with the tree species, the efficacy regarding energy dissipation during an impact as shown in Fig. 6. More information is given in Dorren and Berger (2006).

The tool Rockfor$^{\cdot \mathrm{NET}}$

A wide range of factors influence the energy loss during rebounds, such as the shape of the rock, the properties of the material covering the slope surface, etc. Rockfor$^{\cdot \mathrm{NET}}$ is a tool that only takes into account: * the energy line after Heim (1932), Toppe, (1987), Gerber (1998) and Meißl (1998), (the energy line angle used is 31°)

- the total length of the slope (m)
- the cliff height (m)

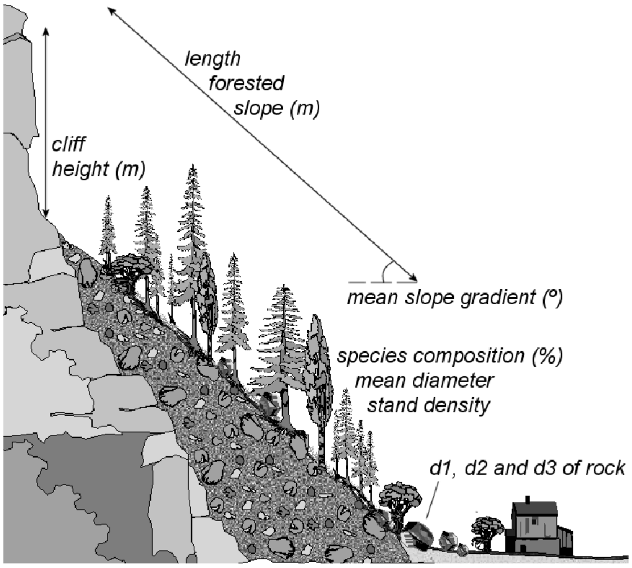

Fig. 7. Scheme showing the topography that is assumed in Rockfor$^{\cdot NET}$ and the principle variables that are taken into account.

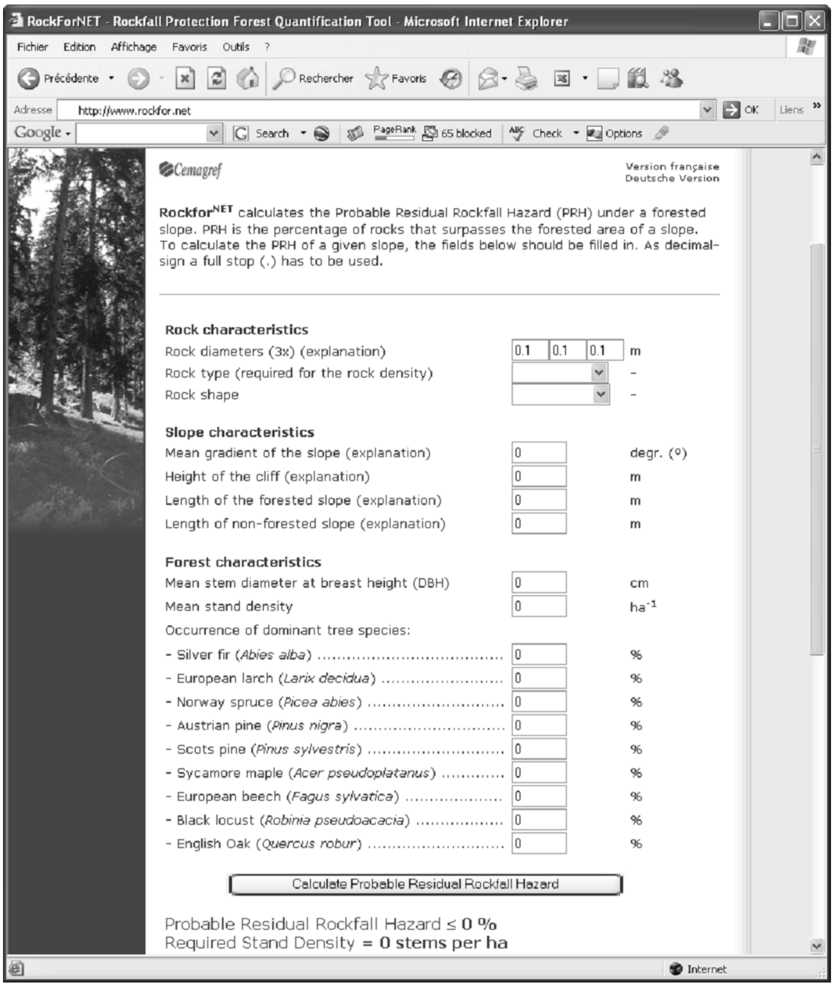

Fig. 8. Web interface of the tool Rockfor$^{\cdot NET}$.

- the mean slope gradient (°)
- the rock size and the rock density, which provides the rock mass (kg)

The energy line angle used in Rockfor$^{\cdot NET}$ is 31°, which is the average between the angle observed during the real size rockfall experiments on a non-forested slope of 38° described by Dorren et al. (2005), which is 31.9° and the energy line angle that fits best to the observed velocities in the forested part, which is 31°. By knowing the amount of energy that needs to be dissipated and the energy that can be dissipated by one curtain, the number of curtains required for protecting the foot of the slope for 100% can be calculated. In order to calculate the probable rockfall hazard, Rockfor$^{\cdot NET}$ subsequently compares the required number of curtains translated in a number of trees with the number of trees present in the forest covering the area of interest. Again, the size of this area is determined by the length of the slope and a 20° lateral deviation angle from the central downslope line as shown in Fig. 1. The outcome of the comparison is the probable residual rockfall hazard expressed in a percentage.

Conclusion

Points that need improvement are the sensitivity to regarding parameter values, especially the mean stem diameter, which is difficult to assess in a forest stand and can be highly variable. Further, additional data for calibration and validation would be very useful. For now, the tool is only calibrated with the data obtained from our rockfall experiments at one single site.

Stopping reasons other than tree impacts, for example, due to surface roughness, are not included in the tool, which could be problematic for small rocks as they tend to stop due to terrain features as well. It would be great if we could develop a Rockfor$^{\cdot NET}$ that was able to account for different rockfall zones with different forest types and differing topography.

The strong point of Rockfor$^{\cdot NET}$ is that it is a free of charge and publicly accessible tool (http://www.rockfor$^{\cdot NET}$, see Fig. 8.) that is widely used by practitioners. As such, it has been tested at many sites throughout Europe. It is simple, robust and scientifically sound, which is appreciated by the users.

References

Berger, F., Quetel, C. and Dorren, L.K.A. (2002) Forest: a natural protection mean against rockfalls, but with which efficiency? *International Congress Interpraevent 2002 in the Pacific Rim*, Matsumoto, Japan. Congress publication, volume 2, p.815–826.

Couvreur, S. (1982) *Les forêts de protection contre les risques naturels.* École Nationale du Génie Rural des Eaux et Forêts (ENGREF), 89 p.

Dorren, L.K.A., Berger, F., LeHir, C., Mermin, E., Tardif, P. (2005) Mechanisms, effects and management implications of rockfall in forests. *For. Ecol. Manage.* 215 (1-3), 183–195.

Dorren, L.K.A. and Berger, F. 2006. Stem breakage of trees and energy dissipation at rockfall impacts. *Tree Phys.* 26, 63–71.

Gerber, W. (1998) *Waldwirkung und Steinschlag.* In: R., Schwitter (Ed.), Dokumentation der 14. Arbeitstagung der Schweizerischen Gebirgswaldpflegegruppe mit der FAN 1998. Grafenort/Engelberg, p. 1–15.

Gsteiger, P. (1993). Steinschlagschutzwald. Ein Beitrag zur Abgrenzung, Beurteilung und Bewirtschaftung. *Schweiz. Zeit. Forstw.* 144, 115–132.

Heim, A. (1932) Bergsturz und Menschenleben. *Beiblatt zur Vierteljahrschrift der Naturforschenden Gesellschaft in Zürich* 77, 218.

Jahn, J. (1988) Entwaldung und Steinschlag, *International Congress Interpraevent*, Graz. Conf. Proc. Vol. 1, pp. 185–198.

Meißl, G. (1998). *Modellierung der Reichweite von Felsstürzen. Fallbeispeile zur GIS-gestützten Gefahrenbeurteilung aus dem Beierischen und Tiroler Alpenraum.* Ph.D. Thesis, Universität Innsbruck, Innsbruck, 249 pp.

Perret, S., Dolf, F. and Kienholz, H. (2004) Rockfalls into forests: analysis and simulation of rockfall trajectories — considerations with respect to mountainous forests in Switzerland. *Landslides* 1, 123–130.

Schwitter, R. (2001) Zusammenfassung und Schlussfolgerungen, In: R. Schwitter (Editor), *Dokumentation der 14. Arbeitstagung der Schweizerischen Gebirgswaldpflegegruppe mit der FAN 1998*, Grafenort / Engelberg, 1–5.

Stoffel, M., Wehrli, A., Kühne, R., Dorren, L.K.A., Perret, S., Kienholz, H. (2006) Assessing the protective effect of mountain forests against rockfall using a 3D simulation model. *For. Ecol. Manage.* 225(1-3), 113–122.

Stokes, A., Salin, F., Kokutse, A.D., Berthier, S., Jeannin, H., Mochan, S., Dorren, L.K.A., Kokutse, N., Ghani, M.A. and Fourcaud, T. (2005) Mechanical resistance of different tree species to rockfall in the French Alps. *Plant and Soil* 278(1-2), 107–117.

Toppe, R. (1987). *Terrain models — A tool for natural hazard mapping.* In: B. Salm and H. Gubler (Eds.), Avalanche formation, movement and effects, IAHS Publication nr. 162: pp. 629–638.