TORRID - Toolbox for assessing the protective effect of forests against rOckfall and expressing the protective role in a Risk Reduction InDex

Report on:
The state of the art in rockfall protection forests

Alpine space project 462 - RockTheAlps

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1 Background

Mountain forests are a crucial part of different methods for protection against different kinds of natural hazards. This protective function is clearly identified in the first paragraph of the Mountain Forest Protocol of the Alpine Convention of 1996 where it says that mountain forests provide the most effective, the least expensive and the most aesthetic protection against natural hazards. Over the years a lot of research has been conducted and the best practices are gathered in the state of the art recommendations and guidelines for sylvicultural management that primarily protect against rockfall in the Austrian Alps. The techniques for stand stability of protection forests are well exploited by the forest authorities (Dorren et al., 2004). Hence the collection of national and international guidelines and recommendations as well as various articles is performed, from which different point of views of different scientists can be summarized and analyzed.

When risk is hidden behind mature forest, it is a threat and at the end occurrence, is registered only when it reaches settlements and infrastructure. These data serve as information about rockfall occurrence. The original function of the forest, which has been used throughout the history, was suppressed with improvement of engineering infrastructure. Nevertheless, the durability of materials from which protection measures were made was below expected. To utilize forest as best protection measure in cost efficient manner it is important to cover several aspects which are mainly divided into two groups: 1. capability of forest to reduce the rockfall effect and 2. how to improve the existing forests to reduce rockfall effect. Going through historical data it is noticed that research on rockfall mechanics has been carried out sixty years before interactions between forest and rockfall which began 1980. However, nowadays relation between rockfall and forest is much more explored (Dorren et al., 2007).

With respect to fast socio-economic and environmental changes, mountain forests have slow reaction when it comes to the Alps over the last century. These changes call into question how mountain forest should look like and create a dilemma concerning forest management. Therefore, it is important to keep the balance between traditional practices and new technologies and apply them together in the best possible way. Based on earlier beliefs risk was always present in mountain areas. Following these convictions mountain forests were considered ‘holly forests’ where ‘do nothing approach’ was the only management that they had. Since their homes were at the foot of the cliffs, protection forest which serves as direct protection of settlements was not harvested at all, even though they were not directly exposed to risk. Nowadays, contrary to past believes, it crucial to emphasize the importance of management of protection forests with help of recent research tools which assess the proper sylvicultural management to achieve the highest protection that a forest can provide. Basis for balancing tradition and technology must include mixture of experience that was achieved in management in practice and knowledge that was gained from various research (Dorren and Berger, 2006).

Proper management of protection forest results as ecological alternative to civil engineering use, including significantly lower costs. Previous surveys mostly provided qualitative data, while now tools and methods are developed and used and there are more and more qualitative data concerning protection forest. Current protection role and changes over time are studied by forest managers considering stand dynamics. Thanks to experiments in naturalistic quantities, numerical simulation tools have been developed

(https://www.waldwissen.net/technik/naturgefahren/steine/lwf_steinschlagnetz/index_FR, 7th September, 2018)

2 The process

For rockfall events, three different process areas are distinguished. The process of triggering a rockfall event takes place within the source area. Movement of the stone occurs along the transit area whereas
sedimentation of the rockfall event happens within the deposition area. Figure 1 gives an overview of the rockfall domain as stated above (Dorren et al., 2007). It is important to emphasize that boundaries between these areas are not strictly defined.

Fig. 1: Generalization of the three main areas on an active (forested) rockfall slope (Dorren et al., 2007).

2.1 Source area
Triggering of rockfall events depends mainly on the geology, the local climate, weathering, vegetation and the human influence. Concerning the impact of forests within the source area, however, trigger causes are further based on frost-weathering, cleft-water pressure, root pressure and/or wind swinging of trees. However, in general, triggering depends on geology. Following Dorren et al. (2007) the negative effects of a forest stand outweigh the positive ones. Negative impact on the initiation of rockfall caused by forests can be:

- Roots of large trees can promote rockfall activity, because they generally penetrate existing joints and bedding planes in the bedrock and act as wedges.
- Movement of the tree stem due to snow or wind forces can cause rockfall via an additional wedge effect of the roots.
- The presence of roots in the bedrock accelerates chemical weathering.

A positive effect of forest stands within the source areas of potential rockfall events might be:

- Stable standing trees act as barriers and decelerate or stop falling rocks, even in steep source areas

Figure 2 shows some example on how vegetation might influence the trigger process of rockfall events.
2.2 Transit area and deposition area

Transit area is the one where jump heights and velocity of rockfall is maximal. Probable magnitude of rockfall is particularly important considering rockfall protection. Rocks might move by falling, gliding, rolling or jumping. For these reasons a rockfall event is a runout stochastic event although different motion types seem to depend on rock shape and slope gradient. A jumping rock particle gets a high spin (Fig. 3). The form of the rock influences this spin. The runout distance is bigger if cubic or round rocks are jumping.

The total energy of a falling rock particle moving along the transit area is described by its potential energy and kinetic energy – the later can be translational or rotational. Energy dissipation mainly occurs due to collision which reduces the kinetic energy - caused by deformation work on soil surface and/or vegetation structure (including destruction of trees). The loss of kinetic energy depends generally on the rock mass (size of the rock), slope inclination, damping conditions and, important to note regarding protection forest, by collision with structures (e.g. trees) on the surface.

The effect of a forest stand in the transit and deposit area can be described as:

- Energy absorption by single trees, and
- Protective effects at the forest stand level.

In both the transit and the deposit areas, a protection forest stand is generally more effective in reducing the velocity and the rebound heights of falling rocks than in the source area, because the slopes are generally less steep and the forests denser.
Single trees dissipate energy in different ways. Dissemination can occur by rotation and translation of the root system, deformation of the tree stem, oscillation of the tree stem and local penetration of the rock at impact location. For example, Dorren et al. (2007) stated the maximum energy that can be dissipated by a Picea abies tree with a diameter at breast height (DBH) of 0.45 m up to 230 kJ. Figure 4 shows the general relationship between DBH and the range of energy that can be dissipated during a rockfall impact lower than 2 m on the tree stem for broad-leaved and coniferous species.

![Fig. 4: Relationship between dissipated energy and DBH for broadleaved and coniferous trees (Dorren et al., 2007).](image)

Figure 5 shows the influence of trees on the rockfall transit area.

![Fig. 5: Comparison of rock particle paths through a forested area and one without trees (Jahn, 1988).](image)

Based on data from Schneuwly (2009), Table 1 summarizes the protective effects of forests within the transit area.

Table 1: Comparison of traveling velocities and rebound heights between a non-forested and a forested slope (Schneuwly, 2009).

<table>
<thead>
<tr>
<th>Rockfall parameters</th>
<th>Non-forested (N=100)</th>
<th>Forested (N=102)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average transl. velocity (ms⁻¹)</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>Average max. transl. velocity (ms⁻¹)</td>
<td>15.4</td>
<td>11.7</td>
</tr>
<tr>
<td>Max. transl. velocity (ms⁻¹)</td>
<td>30.6</td>
<td>24.2</td>
</tr>
<tr>
<td>Number of rocks stopped after end of forested zone</td>
<td>5</td>
<td>65</td>
</tr>
<tr>
<td>Mean rebound height (m)</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>Max. rebound height (m)</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>
3 The management

The position of forest or even a single tree is extremely important for their further effect in the future. It is noticed that presence of trees in rockfall source can act extremely negative, causing a rockfall itself. The influence of roots in this zone results as wedges with its penetration in between the rocks and existing joints as well as its influence of acceleration of chemical weathering. With the knowledge of these facts it is important that removing trees with large roots from the cliffs is included in forest management. On the other hand, left and managed on the proper place, trees have a function of stopping the rocks acting as strong barriers, reducing the velocity and rebound heights of rockfall, even at areas with high inclination. The major effect is in transit and deposition areas because forest is denser in those areas.

3.1 Forest stand management

Forest management has changed over the past several decades. Focus was timber management, but nowadays ecosystem management and multiple uses are becoming important more and more. This shift also emphasizes the need for proper management and even more important raising people’s awareness of the need for it. The cause of the need for management is certainly a change due to land use change, where settlements are now situated in areas known as strongly unsafe (Berger et al., 2013).

Type of forest management that is most common, concerning protection forest during the past, was coppice with standard system. Traditional coppice management includes clear-cut of small areas that is done every 20-30 years. Deciduous trees have the characteristic of sprouting, which results as bunch of stems from a single tree. Coppice with standard means that standards are the trees that are left for two or more rotation periods, whose role is securing seeds besides vegetative reproduction. Coppice shoots with low diameter can be harvested additionally as firewood. This type of forest includes high densities of stems whereas result trees have small stem diameter. It is usually situated on steep slopes beneath cliffs, which makes them directly exposed to rockfall. Increased protective effect is achieved by their stem density. Coppice stands change their spatial structure over time and their stem diameter become wider, while stem densities decrease. Problem that appears here is that nowadays coppice forests are used less due to socio-economic changes, and as a result they are becoming high forest. From ancient times known rockfall protection, it’s future structure is questioned to properly serve its function. Therefore, studies that were done showed us the quantitative effect of coppice aging considering its protection function against rockfall. Function of coppice forest is represented through several indicators considering their protection function against rockfall. Using these indicators hypothesis as - random stem distribution characteristic for high forests, has the same protective effect as coppice-specific stem distribution in clumps (Radtke et al., 2014).

That period that has passed since last cutting, regarding age of coppice stand, also does not have influence on effect of protection against rockfall. Nevertheless, the present situation that stands out is that coppice forests are with every day more abandoned stand exposed to aging. They are not used as before and harvesting them means work without profit. Therefore, the state of these forests and their function is now questioned. Research results showed that number of rocks that passes through forest is decreased compared with area without forest cover. Rocks have been stopped before a specific distance by the forest. This so called “run-out distance” from deviation in meters with whom 99,5% of all rocks were stopped. With the rise of this distance, the rise of stopped rocks is recorded. Disagreements occur when age of forest was investigated concerning impact of protection, where according to PEd indicator (protective effect of forest), with increase of forest age, protection is also increased. On the other hand, MTFD indicator (mean tree free distance) claims that medium-aged forests have the best protective effect compared with old-aged and young-aged – which showed as “the weakest” competitor. About to basal area and DBH, the bigger value, the bigger protective effect. Relation between stem density and protective effect was not considered because it was unclear. Recommendations for management
consider harvesting at least every 25 years to achieve high stem density for 20 years old forests showed better protection against rockfall. Nevertheless, this research showed that over aging is still does not have so negative impact considering protection function, based on stands younger than 60 years. Small rocks (<0,25 m³) distribution can be stopped by small diameter trees when their density is high, hence it could be maintained as dense. Beside stopping the rocks, coppice forests during young ages serve as soil stabilizer and preventer of erosion. Finally, it is concluded that coppice with standards are preferred because they consist large diameter stems that are left for more rotation periods, which can significantly reduce kinetic energy of rocks. That makes them more favourite in comparison with simple coppice forests, considering their protection function.

Ideal forest properties to protect against rockfall are summarised for instance in Frehner et al. (2005) and revised by Dorren et al. (2015):

- Number of impacts against trees are generally more important, therefore in minimum of > 400 trees/ha with a DBH > 0.24 m is desirable.
- Fast and dense regeneration is important; therefore, coppice stands are preferable forest protection structures because they produce usually dense regeneration from stumps.
- Optimal combination of stand density and mean DBH depends further on the size and energy of the potentially falling rock.
- Maximum distances between trees in the falling direction should be between 20-40 m.
- Special attention should also be given to the slope angle, surface roughness in general and potential surface damping.

By leaving trunks on the slope, preferably diagonally to the slope direction or by leaving so called high tree stumps (>1.3 m), forest management can significantly influence also terrain characteristics. Incidentally, this also applies to the construction of forest roads, which are able to stop large rocks.

3.2 Tree management

Trees manage to stop 10m³ big rocks with high success rate, even though they have expense of their complete destruction, which unfortunately has a higher impact. There are a couple of different ways how energy is dissipated at rock impact occurrence: rotation and translation of the root system, deformation and oscillation of the tree stem, and local penetration of the rock of the impact location (Foetzki et al., 2004). Nevertheless, quantification of the total amount of absorbed energy is very difficult to express since every tree has different way to absorb energy. Depending on the size of a rock, different characteristics are expected from the forest i.e. stand density is important against small rock influence, while DBH has higher influence concerning big size rocks. Next to DBH, tree species is also extremely important since broadleaved trees show stronger resistance than coniferous with respect to protection effect against rockfall. Work by (R. Schwitter, 1998), which was later confirmed Dorren et al. (2005), suggests that the trees in a stand should account for one-third of the size of the falling rocks with the mean DBH. Furthermore, both papers find that the rockfall velocity was reduced by 26% on average and the maximum rebound height by 75% on average. Lateral deviations are caused by impact of tree in the path of the rockfall. Higher length of forested slope allows longer travelling distance of the rock and in that way, tree has the higher probability to stop the rock. The leading conclusion thus is that a lot of hits by more rocks is more significant than effect of a single tree, i.e. coppice stands. Considering tree species Picea abies example in Austria showed that tree with DBH>50cm appears as serious barrier with 10 years duration.

The type of trees concerning protection effect, broadleaves species shown better mechanical resistance than coniferous trees as well as showing faster healing effect. Interesting fact is that smaller trees were more resistant to wounds even though the wounds on them were proportionally bigger. European beech (Fagus sylvatica) was featured in researches as “strongest” considering the rate of uprooting, wounding
or stem breakage. During examinations of root system anchorage important factors were root depth, biomass, topology and number of trees. Studying all the factors, depth of roots and their number were the most important one, where the beech once again emerged. Hence, beech is twice as resistant than fir and tree times more resistant than spruce. It is important that root system has enough space to grow to achieve adequate protective effect (Stokes, 2006).

However, evaluating the protection effect of different tree species, it is important to mention that bark structure and thickness play important role. Mechanical damages done by rocks are in this way recorded on tree barks since they are presented as visible wounds when cambium is mechanically damaged. Following scars at trees stems, we must take into account that multiple scars can probably be the indicator of the same event, and not several single events. Particularly when they are positioned close to each other (Favillier et al., 2015).

4 References


