Implementation Rather than Deforestation – The Integration of Trees into Rockfall Barriers

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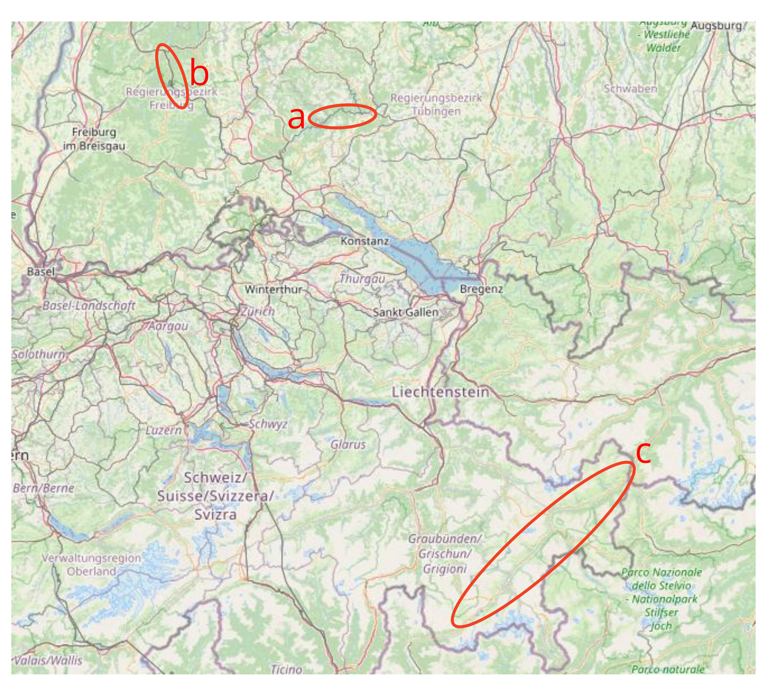
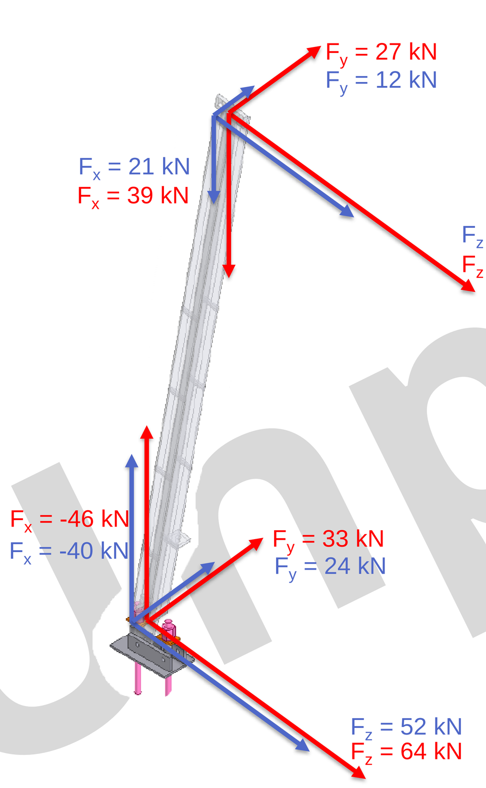
Abstract

This study explores combining natural and technical solutions to mitigate rockfall impacts on civil infrastructure. Protection forests and rockfall barriers are commonly used separately. Here, this study proposes to permanently implement trees into rockfall barriers to increase their protective effect. The energy-absorption potential of eligible trees is assessed, a technical design based on pre-existing **tree-integrated systems (TIS)** is developed and the system is dimensioned according to European guidelines. The resulting proposed tree-integrated rockfall protection system is feasible and structurally sound up to energies of 1000 kJ.

Methodology

Market potential analysis: the potential for rockfall protection nets attached on trees in low-mountain and high-mountain regions is estimated by evaluating sites where such nets are already installed. The study regions chosen for the analysis are in Germany the Danube valley (a) from Beuron to Thiergarten and the valley of the Black Forest railway (b) from Triberg to Wolfach in Baden-Württemberg. In Switzerland, the complete Engadin (c) from Maloja to the border of Austria in Graubünden was chosen. The **proportion of possible tree anchors and posts**, based on the number of linear meters of rockfall barriers installed, is assessed.





TIS method: It involves developing and evaluating different **structural designs** for a rockfall barrier that can be integrated with trees. The figure shows the **maximum impact force** produced on a steel post inside a GBE-500A (blue) and a GBE-1000A (red) barrier by Geobrugg AG, these forces are the basis of all further assessments.
The design also considers the **physiological aspects of trees** and their **energy absorption capacity**. The stability of trees and the breaking strength of their wood is estimated, based on literature research, including tests used for tree inspection in urban areas and forestry work in the mountains.
Finally, the TIS method combines the structural design with the trees' characteristics to determine the dimension of the mitigation measure related to different standards.

Introduction

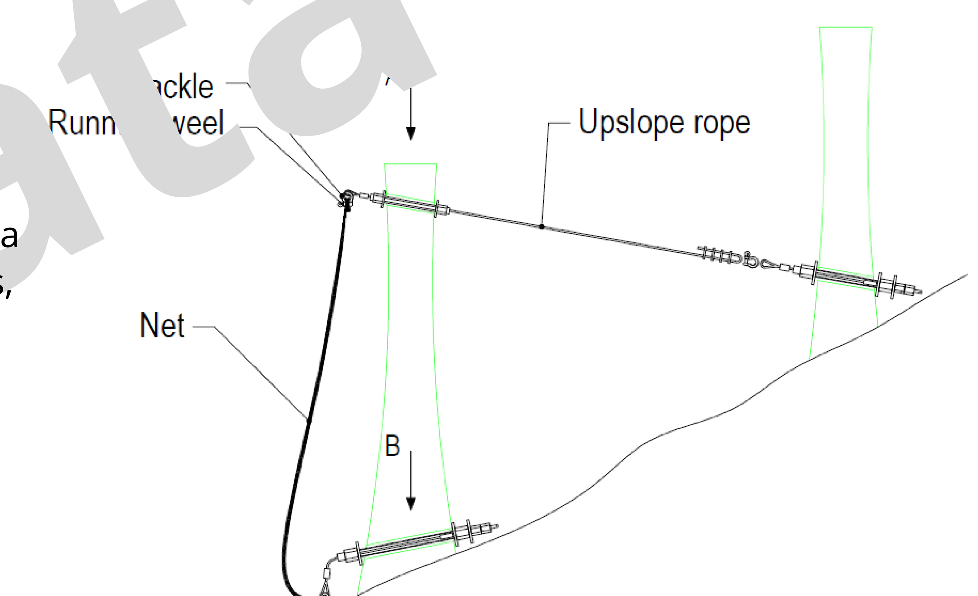
This contribution highlights the need to re-evaluate the use of steel products for **rockfall protection systems** due to rising energy prices, delivery shortages, and carbon footprint concerns.

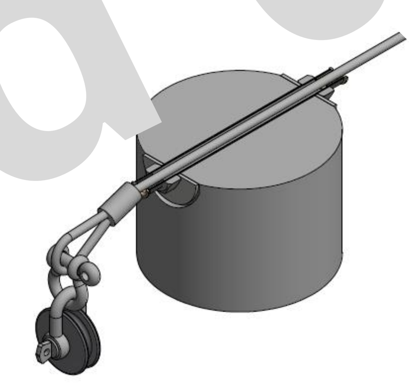
In mountainous areas, flexible rockfall protection systems have traditionally been made of steel and require clearing of trees for construction, which damages the ecosystem as shown in the figure on the left. The idea of using trees as posts for rockfall protection nets has been tested but is not yet permitted in most areas. The feasibility of replacing steel posts with trees for rockfall barriers in densely forested areas and its market potential is analyzed, and existing protection systems with a tree-integrated variant are presented. A novel TIS-structural engineering dimensioning method, compared to EUROCODE 3 and 5, is then proposed.

Results

The **market potential analysis** (Kramer 2023) indicates that nearly 60% of posts and anchors in the low mountain range and 55% in the higher mountain range could have been replaced by trees with similar energy absorption, highlighting the potential for application. A combination of **conventional and TIS solutions** could achieve the maximum market potential.

Structural implementation of the TIS: The figure on the right shows a principle drawing of the barrier attached on trees. The figure below shows a 3D-drawing of the upper attachment, including the drilling of a hole through the tree's center and inserting a thick-walled tube with threads on both sides, secured with a washer and nuts.





Dimensioning: An improved fixation system is proposed that allows an **EUROCODE** conform dimensioning (except the bearing pressure). The different components used in the TIS are CE certified, and verification of their resistance is carried out. The possible impact forces of rockfalls on trees and the results of real-scale rockfall experiments in forests is also discussed in Ringenbach et al. 2022, Dorren & Berger 2006 and Kalberer et al. 2006. The results show that the resistance of the root system is larger than the wood resistance. EUROCODE 5 is used to calculate a minimum diameter at breast height (DBH) for the corresponding impact forces to absorb the required energies. These minimum diameters are shown in the table depending on the type of wood and the energy classification. Overall, the TIS is a promising solution for reducing the negative impact of rockfall in mountainous areas while preserving the environment.

Energy absorption	DBH softwood	DBH hardwood
500 kJ barrier	35 cm	30 cm
1000 kJ barrier	45 cm	40 cm

Discussion

The integration of trees into rockfall barriers is an innovative approach led by **nature-based-solutions** (NBS) to make rockfall protection more sustainable. The high resistance of wood to static loads and even higher resistance to dynamic impacts make it a reliable mitigation measure for natural hazards. Trees' elastic properties result in energy absorption during their deformation, reducing the maximum impact force compared to the conventional system. Furthermore, the self-repairing property of trees makes it unlikely that any impairment from bearing pressure will cause a failure of the system. Real-scale testing of the TIS is recommended to consolidate results and to do further investigation of the trees strength. Of course, the dimensioning concept for the trees can be as well applied for temporary installations during forestry or construction works. Thereby it is important to keep the force and energy transmission in the barrier unchanged to hold the same impact forces on the trees.

TIS example in Montgenèvre (France) to protect a summer toboggan

The **carbon footprint** of TIS is significantly lower than conventional steel and concrete barriers, with short-term (material sourcing), mid-term (burning of the harvested wood), and long-term (no CO_2 accumulation due to cleared-cut) savings. The use of trees instead of steel and concrete elements leads to a total weight savings of approximately 4000 kg for a 100 m barrier. Therefore, changes in conventional concepts and innovative thinking are essential to adapt to changes in society, environment, and the economy.

Conclusion

This study shows, that there is a potential for the use of trees as an alternative to conventional steel posts and concrete anchors in mountainous regions. The technical feasibility analysis has demonstrated that tree-based anchors and posts can provide similar or better performance than metal or concrete equivalents. The literature shows that tree roots have excellent anchoring capabilities, and their ability to absorb and dissipate energy makes them an ideal alternative in forested areas. The economic viability analysis has shown that tree-based posts and anchors are a **cost-effective solution** in the long run compared to conventional alternatives. The initial planning and knowledge may be slightly higher, but the lower costs and environmental benefits make it an attractive option for infrastructure projects in forested mountainous areas. The use of trees as posts and anchors has several environmental benefits, including carbon sequestration, soil stabilization, and biodiversity conservation. Additionally, TIS blend better with the environment and supports local ecosystems. This study is a pioneering approach to dimensioning the use of trees in rockfall barriers and requires further research, modelling, and testing.

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