Rock Fall Risk – Modular Risk Management Process

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ABSTRACT: Rockfall is an alpine phenomenon and must be understood as a risk. Due to the large number of events, detailed geotechnical investigations are not possible in many cases. In this article, a processing workflow is presented that enables an evaluation of a natural rockfall trigger risk. The trigger risk as well as the extent of damage are categorized in a risk matrix. The study of 485 outcrops at several rock slopes shows that without groundwater influence, predominantly stable conditions exist; with groundwater, the stability drops by around 20 %. In the case of a risk value of the "high" class, individual case assessments are necessary; in the case of the "medium" classification, organizational measures are required to minimize liability.

Keywords: Rockfall, risk management, trigger risk, liability.

1 INTRODUCTION

The study deals with rockfall from natural slopes next to municipal paths with blocks up to a size of approx. 50 m³ or a fall mass up to 100 m³ (Dorren et al. 2012). While large infrastructure operators install monitoring systems and rockfall protection structures, this is neither financially affordable nor acceptable in the landscape of municipal environment. The article aims at private owners of municipal paths (e.g., for hiking or biking), tourist or agricultural and forestry enterprises, and municipalities. Usually, these organizations react to rockfall risk by requiring path users to take responsibility for themselves, by signposting, and even by closing areas entirely for users (Kienreich et al. 2022).

Because of the lack of assessment criteria that are easy to apply, consulting experts often determine an "unacceptable risk" and close the area. Reopening, however, is difficult because of the same reason: the absence of such criteria. In this paper, a process is presented to classify the rockfall risk and to identify an unacceptable risk at best.

2 METHOD

The working hypothesis is to understand rockfall as a risk (Mölk 2022). This makes it possible to characterize the potential of a possible rockfall event by means of risk values.

2.1 Risk Management

Following the risk management guidelines (UNISDR 2014), risk (R) is the product of the probability of occurrence (Hazard H) and the extent of damage (Vulnerability V):

$$R = H \times V. \quad (1)$$

In this study, H is defined by the rockfall trigger risk, which reflects the probability of a rockfall event being triggered, and V is the visitor or user frequency. Figure 1 shows the classification and the resulting risk matrix.

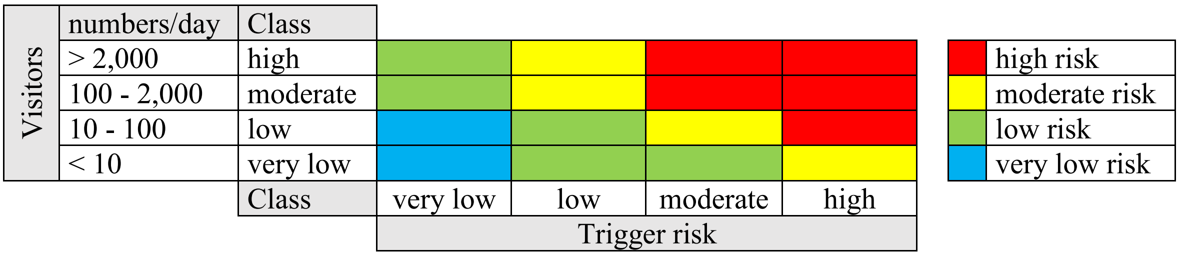

Figure 1. Risk Matrix - The combination of visitor frequency and trigger risk indicates the risk of injury.

According to the recommendations for the protection goal for gravitational natural hazards in Austria (ÖGG 2014), the trigger risk "high" is to be understood as a “concrete risk” and "moderate" as an “abstract risk”. While organizational measures are sufficient for "moderate risk", constructive protective structures are necessary in the "high risk" category (Greinix et al. 2022).

2.2 Trigger risk

The determination of the trigger risk follows the guideline for the geotechnical design of underground structures (ÖGG 2021). The determination process is schematically illustrated in Figure 2 and described in the following sections.

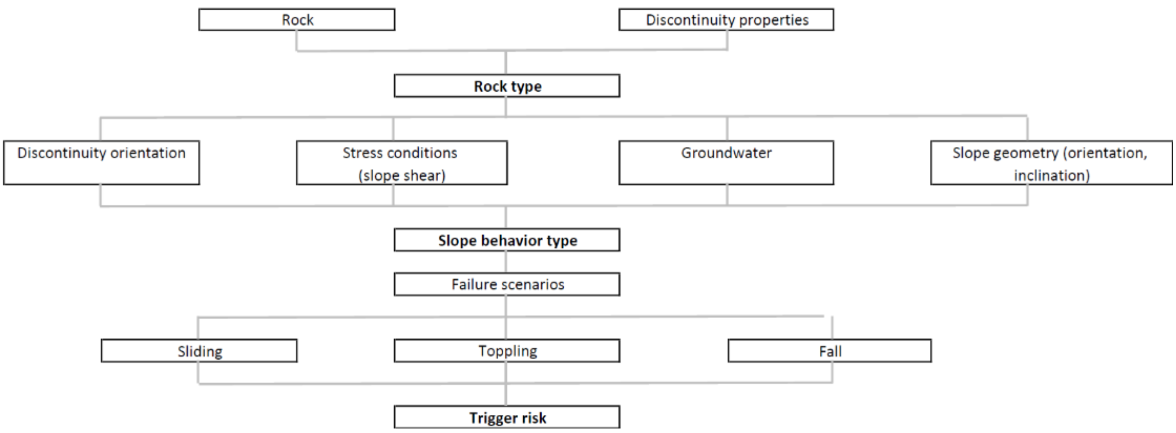

Figure 2. Process for determining the trigger risk.

2.2.1 *Rock type*

Geological processing identifies and defines different rock types. Relevant geological-rock mechanical trigger factors, lithological parameters, and the orientation and properties of discontinuities need to be described (Poisel 1997). Figure 3 shows a categorization example of surveyed rock types.

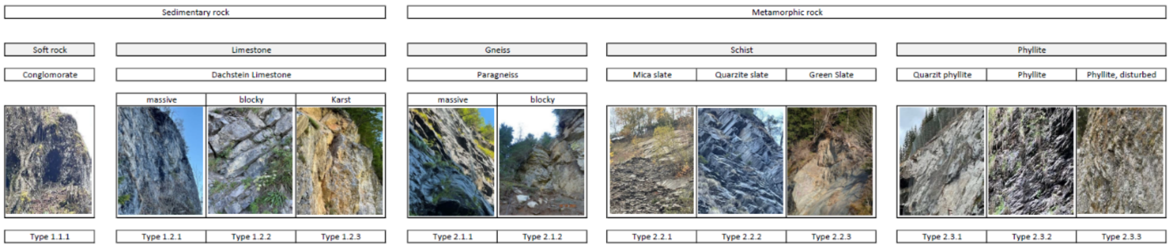

Figure 3. Example of categorized rock types. Left: sedimentary rock (soft rock, limestone); right: metamorphic rock (gneiss, schist, phyllite).

2.2.2 *Slope behavior type*

To form slope behavior types, specific analyses are carried out, namely the spatial position of the discontinuities relative to the surface, joint surface conditions, the joint persistence, possible additional loads from slope pressure or groundwater, and topographical terrain conditions. Figure 4 shows the classification method applied for the determination of slope behavior types.

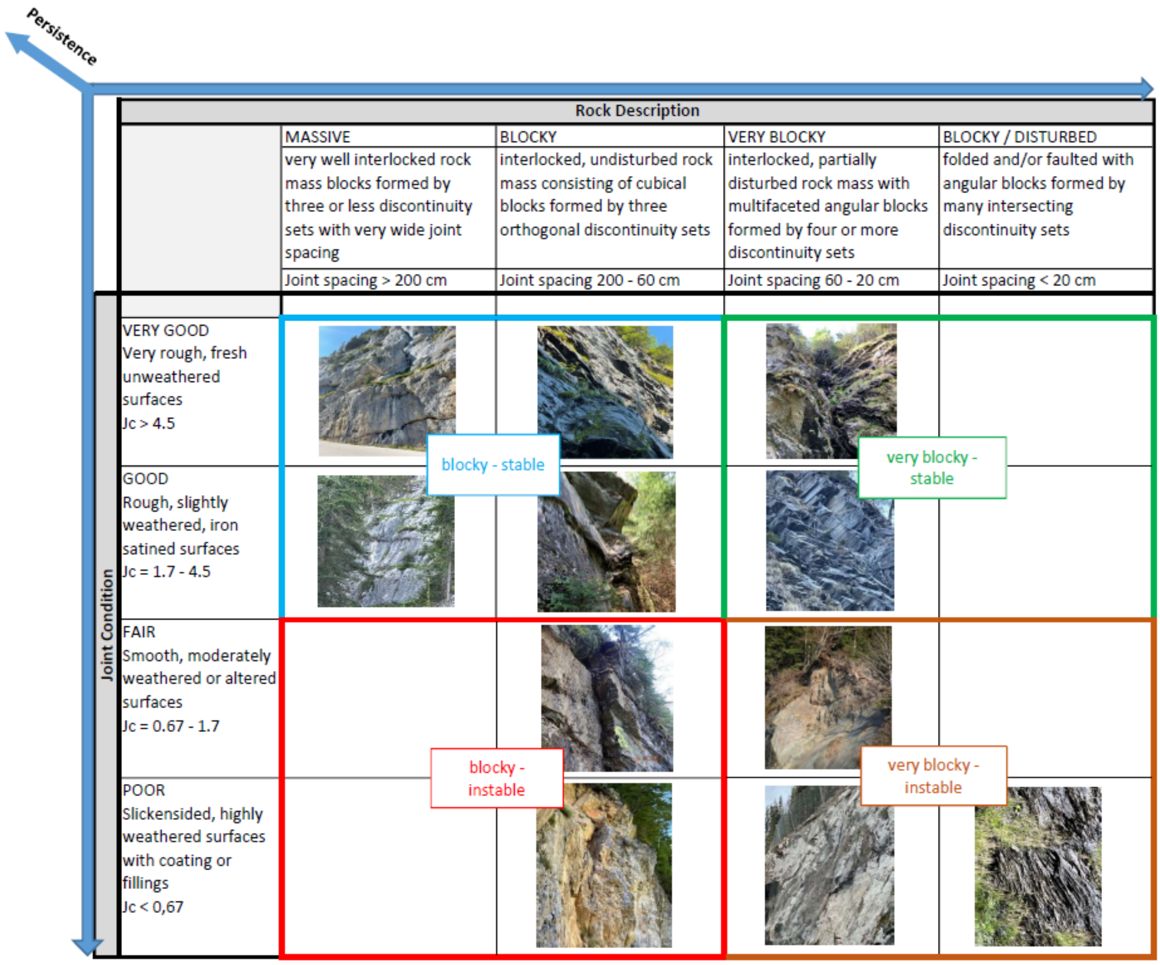

Figure 4. Modified Geological Strength Index (GSI) upgraded by the joint persistence.

The modified Geological Strength Index (GSI; Cai et al. 2004) was used. Along the z-axis, the diagram was supplemented by the degree of persistence of the discontinuities to form a cube. The gradation was chosen as 0-25 %, 25-50 %, 50-75 %, and 75-100 %. The working titles for the types of slope behavior are "blocky-stable", "very blocky-stable", "blocky-instable", and "very blocky-instable".

2.2.3 *Failure scenarios*

Performing sensitivity analyses considering geometric intersections of relevant discontinuities with the surface (Figure 5), a failure scenario (sliding, toppling, and falling) is assigned to each investigated case.

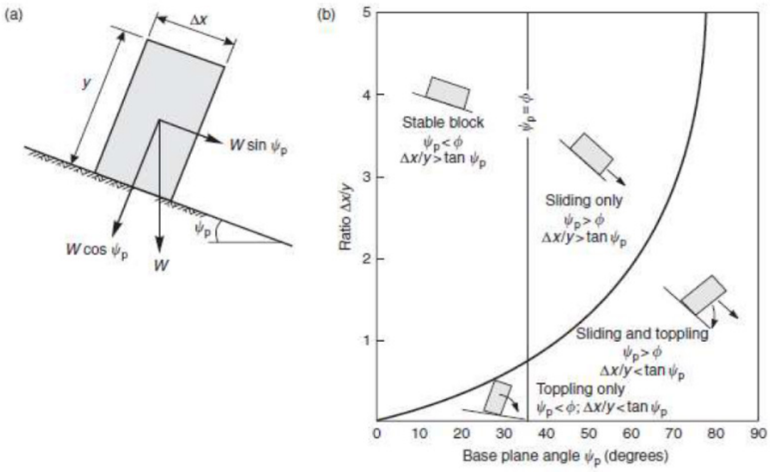

Figure 5. Kinematic analysis based on geometric conditions (Wyllie & Mah 1981).

3 RESULTS

The methodology described above was applied in a field study in the *Liezen* area, Styria (Austria). A total of 485 natural rock outcrops were surveyed, documented, and evaluated. Table 1 lists some statistics on the outcrop properties (left) and the risk categorization (right).

Table 1. Results for Rock type, Slope behavior type and Trigger risk.

Lithology		unit	Limestone	Metamorphic rock
Rock Type		numbers [n]	213	272
movement possible		numbers [n]	136	171
Persistence	< 25 %	[%]	0,5	0,4
	25 % - 50 %	[%]	8,5	10,3
	50 % - 75 %	[%]	27,7	28,3
	75 % - 100 %	[%]	63,4	61,0
Block volume	< 0.008 m^3	[%]	0,9	3,3
	0.008 m^3 - 2.16 m^3	[%]	77,9	78,3
	2.16 m^3 - 8 m^3	[%]	16,4	13,2
	> 8 m^3	[%]	4,7	5,1

Lithology		unit	Limestone	Metamorphic rock
Slope Behaviour type				
blocky-stable		numbers [n]	58	67
very blocky-stable		numbers [n]	134	156
blocky-instable		numbers [n]	-	17
very blocky-instable		numbers [n]	-	4
Failure type				
Sliding		numbers [n]	108	145
Toppling		numbers [n]	39	39
Trigger Risk	Sliding & Toppling mode			
without ground water				
very low/low		numbers [n]	192	223
moderate		numbers [n]	-	17
high		numbers [n]	-	4
with ground water				
very low/low		numbers [n]	168	198
moderate		numbers [n]	14	21
high		numbers [n]	10	25

Approximately 40 % of the rock slopes investigated could be ruled out as stable due to the favorable discontinuity orientation relative to the surface. In the remaining cases, movements are kinematically possible; about 2/3 tends to block sliding and 1/3 to toppling.

Among the identified slope behavior types, over 90 % are classified as blocky/very blocky-stable. Around 5-10 % are "unstable" with the combination of larger block volumes and poor discontinuity shear parameters being unfavorable.

The following graphs (Figure 6a, 6b) show the classification of the individual case studies as an overview, separated according to rock type and persistence. (Empty fields: no case study.) For degrees of persistence below 50 % (not shown), no increased risk (“high risk”) can be determined; for limestone even up to 75 %. For degrees of persistence above 75 %, a moderate or high risk of triggering can already be determined for metamorphic rocks under dry conditions and for large block volumes. Under groundwater influence, a moderate risk of triggering is to be expected for limestone with block volumes of more than 0.4 m³ and for metamorphic rocks with block volumes of over 0.2 m³ with even good joint surface conditions. The influence of groundwater decreases the stability; in about 20 % sliding occurs (Figure 6a, 6b – second row).

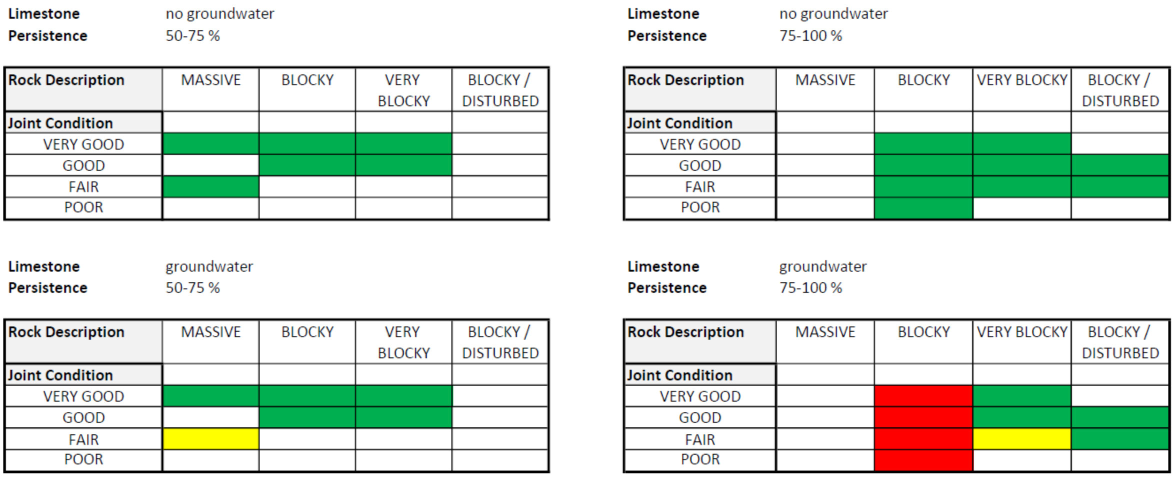

Figure 6a. Results Limestone – left: persistence 50 - 75 %; right: 75 - 100 %; first row: without groundwater; second row with groundwater; green: very low/low risk; yellow: moderate risk; red: high risk.

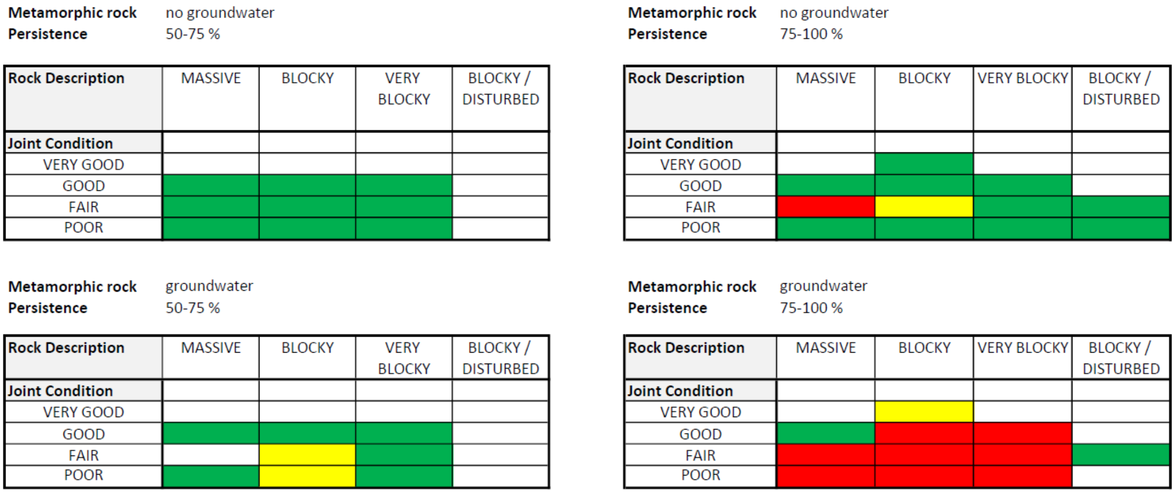

Figure 6b. Results Metamorphic rock – left: persistence 50-75 %; right: 75-100 %; first row: without groundwater; second row: with groundwater; green: very low/low risk; yellow: moderate risk; red: high risk.

4 DISCUSSION OF THE RESULTS

Rockfall events are rock block problems. The methodology illustrates a way to combine rock types with rock-mechanical variables to determine a qualitative trigger risk.

The quality of the results depends on a careful field survey. Since rockfall areas are usually difficult to access, working with bandwidths is recommended. The orientation of the relevant discontinuity set relative to the surface is important. Natural rock slopes are usually highly structured and different intersections may give different results. The combination of block volume and degree of persistence controls the stability.

The rockfall risk of the natural slopes in the investigated areas is generally low. For metamorphic rocks with a persistence of > 0.75, discontinuity surface properties of $J_c < 1.7$, and block lengths of > 60 cm, the risk of triggering is relatively high. Groundwater leads to a significant increase of rockfall risk by about 20 %.

Using the risk matrix (cf. Chapter 2.2), a comprehensible risk assessment can be made.

5 CONCLUSION

The presented method provides a simplified, standardized method for the initial assessment of rockfall risk. The method can be used in municipal road and path networks as a transparent process for preventive assessment of natural rockfall risk.

Periodic inspection in conjunction with necessary measures and documentation has a liability-reducing effect.

In ongoing research (Kienreich 2023), the determination of the trigger risk, a simplification with artificial intelligence (image recognition) will be examined. Furthermore, the inclusion of additional external factors (climate, vegetation, etc.) in the processing procedure will be investigated.

6 LITERATURE

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