ROCKFALL RATING SYSTEMS:

IS THERE A COMPREHENSIVE METHOD FOR HAZARD ZONING IN POPULATED AREAS?

STEINSCHLAG-KLASSIFIZIERUNGSSYSTEME:

GIBT ES EINE FÜR DIE GEFAHRENZONENPLANUNG GEEIGNETE METHODE?

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ABSTRACT

Due to the increasing pressure of spreading residential areas in the sparse space for permanent settlements in alpine regions and due to the limited capacities for hazard zoning, a further development of appropriate tools evaluating rock fall risk is discussed. Most existing rock fall rating systems focus on the evaluation of rock fall risk being relevant for linear structures such as railways, roads or pipelines where often good data regarding the rock fall frequency is available. For land use planning and rather young settlements such data is very often not existent and therefore the evaluation of risk has to be based on a frequency estimation. Such data can be derived from an assessment of the rock faces present on the slope and/or the subsequent accumulations of blocks on the slope. This procedure prescribes state of the art evaluations for land use planning, hazard zoning and design of mitigation measures.

Keywords: Rock fall, hazard zoning, rock fall rating system

ZUSAMMENFASSUNG

Die Ausbreitung von Siedlungsgebieten im alpinen Raum sowie die beschränkten Mittel für die Zonenplanung machten die Entwicklung geeigneter Hilfsmittel für die Bestimmung des Steinschlagrisikos notwendig. Die meisten existierenden Klassifizierungssysteme von Steinschlaggefahren wurden für Eisenbahnlinien, Strassen und Pipelines entwickelt. Für diese Einrichtungen gibt es meist ausreichend genaue Aufzeichnungen über Steinschlagereignisse. Für die Flächenwidmung und junge Siedlungen stehen solche Daten meist nicht zur Verfügung. Daher muss die Risikobeurteilung auf einer Abschätzung der Steinschlaghäufigkeit aufbauen, die von einer Beurteilung der Felsaufschlüsse und/oder der darunter liegenden Blockhalden abgeleitet werden kann. Mit dieser Vorgangsweise werden dem Stand der Technik entsprechende Untersuchungen für die Flächenwidmung, Gefahrenzonen- und Maßnahmenplanung eingeführt.

Keywords: Steinschlag, Gefahrenzonenplanung, Steinschlag-Bewertungs-System

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INTRODUCTION

Rock-fall hazards in alpine regions pose a significant thread to settlements and infrastructure. The current code of practice for the assessment of rock-fall hazards in the hazard zoning of the "Torrent and Avalanche Control Austria" as a public service determines potential run-out zones of rock-falls as an indication zone. Therefore these zones are not determined mandatory and incorporate neither detailed assessment of the potential detachment zone nor a comprehensive evaluation of the rock-fall-process itself.

Due to the increasing pressure of spreading residential areas in the sparse space for permanent settlements in alpine regions, a further development of appropriate evaluation tools is discussed. Due to the extended area that is subject to hazard zoning, a complete evaluation of all the potential rock-fall detachment areas including state of the art rock fall simulations (such as trajectory models, 3-D-modelling etc.) is not feasible with the resources at hand at the service of the "Torrent and Avalanche Control Austria".

Nevertheless the establishment of a standard (best practice) is considered to be important to provide the authorities involved in the land-use planning with specifications for additional investigations to be prescribed.

Fig. 1: Rock fall event in 1998 destroying a building in Zillertal, Tyrol, Austria
Abb. 1:: Steinschlagereignis, das 1998 ein Gebäude im Zillertal, Tirol, Österreich zerstörte

Most existing rock fall rating systems focus on the evaluation of rock fall risk being relevant for linear structures such as railways, roads or pipelines where often good data regarding the rock fall frequency is available (Hungr O. et al. 2003). For land use planning and rather young settlements such data is very often not existent and therefore the evaluation of risk has to be based on a frequency estimation derived from an assessment of the rock faces present on the slope and/or the subsequent accumulations of blocks on the slope. This leads to the necessity to develop a rating system that takes this situation into account. With such a rating system a tool could be provided to evaluate the endangerment of settlements or infrastructure due to potential rock fall events even without a significant history in such events. With this procedure state of the art methods can be established for land use planning, hazard zoning and planning of mitigation measures (Wong H. N. 2007).

The proposed approach aims to an evaluation of existing rock-fall rating systems and their adoption to a comprehensive tool to provide concise information for

- hazard-zoning,
- land-use planning,
- investment decisions regarding risk mitigation measures and
- the assessment of the necessity of further evaluations in case of detected threads.

WHY NOT USE AN EXISTING RATING SYSTEM

For tunnelling, foundations and rock slopes numerous rating systems evaluating the stability are existing. (Bieniawski Z. T. 1988, Barton N. et al. 1974). These systems are designed to quantify necessary support measures in order to maintain the stability of the designed structures. But they do not quantify potential damage and occurrence probability of rock fall events.

Regarding rock fall existing rating systems evaluate hazard or risk for linear infrastructures such as railways, motorways, pipelines etc. (e. g. Pierson L. A. et al. 1990, Wyllie D. et al. 2004, Hungr O. et al. 2003, Pritchard M. et al. 2005...). These systems refer to e. g. sight distance, roadway width and average vehicle risk rather than to the quality of the land use which influences the damage potential of inhabited areas and settlements significantly. Therefore a particular rating system was developed to be applied for rock fall hazard zoning in inhabited areas.

ROCK FALL RISK RATING SYSTEM FOR SETTLEMENTS (R^3S^2)

Due to the significantly higher risk caused by rock fall detachment areas above settlements compared to linear infrastructures a distinct approach was chosen. The discussed method takes into account the higher probability of fatalities in permanently inhabited areas.
The rating results help to:

- plan the land use (hazard zoning)
- priories the areas to be protected
- control financial means for the realisation of mitigation measures

Parameters influencing the rock fall risk
Due to the similarity of the task of identifying risks caused by rock fall several parameters where chosen identically to Pierson L.A. et al. (1990) and to Wyllie D. & Mah C. W. (2005), p281:

- Loosening of rock: described by the width of the joints present in the relevant outcrop.
- Joint strength: is described by the roughness and filling of joints. Each potential detachment area has to be evaluated with respect to its detachment mechanism. The relevant parameter(s) are to be considered for choosing the score (Table 1, e. g. joint strength, rock strength)
- Joints orientation: joint orientation relative to the slope and to each other. Favourable means that the joint orientation does not favour detachments
- Joint continuity: relation between length of joint completely cut through and total length of the joint trace.

- Vertical slope height: Vertical height of the slope measured from the highest point of each particular rock fall source from which rock fall is expected down to the foot of the slope
- Climate and water: existence of water on the slope and probability of freeze-thaw cycles contribute to probability of occurrence of rock falls
- Block size: volume of block most likely to fall derived from scree slope and/or rock fall source
- Roughness and damping characteristics of pathway: influence energy transformation and therefore run out distance
- Proof of historical events: historical events are a proof for rock fall taking place at all and give a good indication of run out distances
- Quality of land use: influences potential damage and number of fatalities possible (Nawar G. & Salter R. 1993)

Risk rating system

The rock fall areas identified are ranked by scoring the parameters as shown in Table 1.

Tab. 1: Rating criteria and score
Tab. 1: Klassifizierungskriterien und Punkteschema

		Parameter	3 Points	9 Points	27 Points	81 Points
Source area	1	**Loosening of rock**	joints closed	joint width mm	joint width cm	joint width dm
	2	**Joint strength**	rough joints	undulated joint-planes	planar joints	slickensides, joint gauge
	3	**Joint discontinuity and orientation**	discontinuous joints, favourable orientation	discontinuous joints, random orientation	discontinuous joints, adverse orientation	continuous joints, adverse orientation
Pathway (transition + immission zone)	4	**Vertical slope-height [m]**	<100	100-300	300-500	>500
	5	**Climate and water**	aspect of slope=north, no water present on slope	slope tends to be dry	water present on slope	aspect of slope=south, permanent water leakage
	6	**Block size $[m^3]$ d_{90}**	< 1	1 - 5	5 - 10	> 10
	7	**Pathway: roughness+damping**	high roughness, good damping	rough, forested slope, good to mean damping (i. e. scree slope)	little vegetation, smooth, mean to poor damping	no vegetation, poor damping (rocky surface)
	8	**Proof of historical events**	no events reported, no silent witnesses	silent witnesses no events reported	1 event/10 years	>1 event/10 years
	9	**Quality of landuse**	agriculture	periodically used buildings	periodically inhabited buildings	permanently inhabited buildings

In order to achieve a risk based evaluation of the land use prone to rock fall, the sum of the scores of the parameters influencing the probability of rock fall and the sum of the scores of the parameters influencing the damage are multiplied (Wyllie D. 2006). The parameters pathway roughness and damping influence both, probability and damage. It is therefore proposed to count vertical slope height, block size, pathway roughness and damping as well as quality of land use to the group of damage influencing parameters and loosening of rock, joint strength, , joint discontinuity and orientation (Wyllie D. C. et al. 2004, Mölk M. 2000, Poisel R. et al. 2004), climate/water and pathway roughness and damping to the group of probability influencing parameters (table 2).

Tab. 2: Calculation of relative risk (example of worst case)
Tab. 2: Berechnung des relativen Risikos (Beispiel mit schlechtestem denkbaren Fall)

		Parameter	Influences	Sum scores damage	Sum scores Frequency/Probability
Source area	1	Loosening of rock	Frequency/Probability		81
	2	Joint strength	'Frequency/Probability		81
	3	Joint discontinuity and orientation	'Frequency/Probability		81
Pathway (transition + immission zone)	4	Vertical slope-height [m]	Damage	81	
	5	Climate and water	'Frequency/Probability		81
	6	Block size [m³] d_{90}	Damage	81	
	7	Pathway: roughness+damping	Damage + Frequency/Probability	81	81
	8	Proof of historical events	'Frequency/Probability		81
	9	Quality of landuse	Damage	81	
				324	486
				'Risiko = 157.464	

PROCEDURE OF ROCK FALL HAZARD ZONING AFTER R³S² (ROCK FALL RISK RATING SYSTEM FOR SETTLEMENTS)

Rock fall hazard zoning should proceed in the following way (Figure 2):

Step 1: Surveillance by aerial photographs, DTMs – identification of scree-slopes and location of detachment areas
Step 2: Investigation of rock fall history (chronicle, interviews)
Step 3: field investigation:
- Identification of outcrops/source area
- Measurement of shadow angle of 26° (as proposed by Wyllie D. 2006, p 26) below the horizontal from the crest of the talus slope of each source area (Figure 3).

Step 4: If land use as defined in Table 1 lies within the pathway bordered by the shadow angle, the rating system has to be applied.

According to "frequency/consequence"-diagrams (e. g. Hungr O. 2006, IMO 2001) risk levels for hazard zoning of rock fall are proposed as shown in Figure 4.

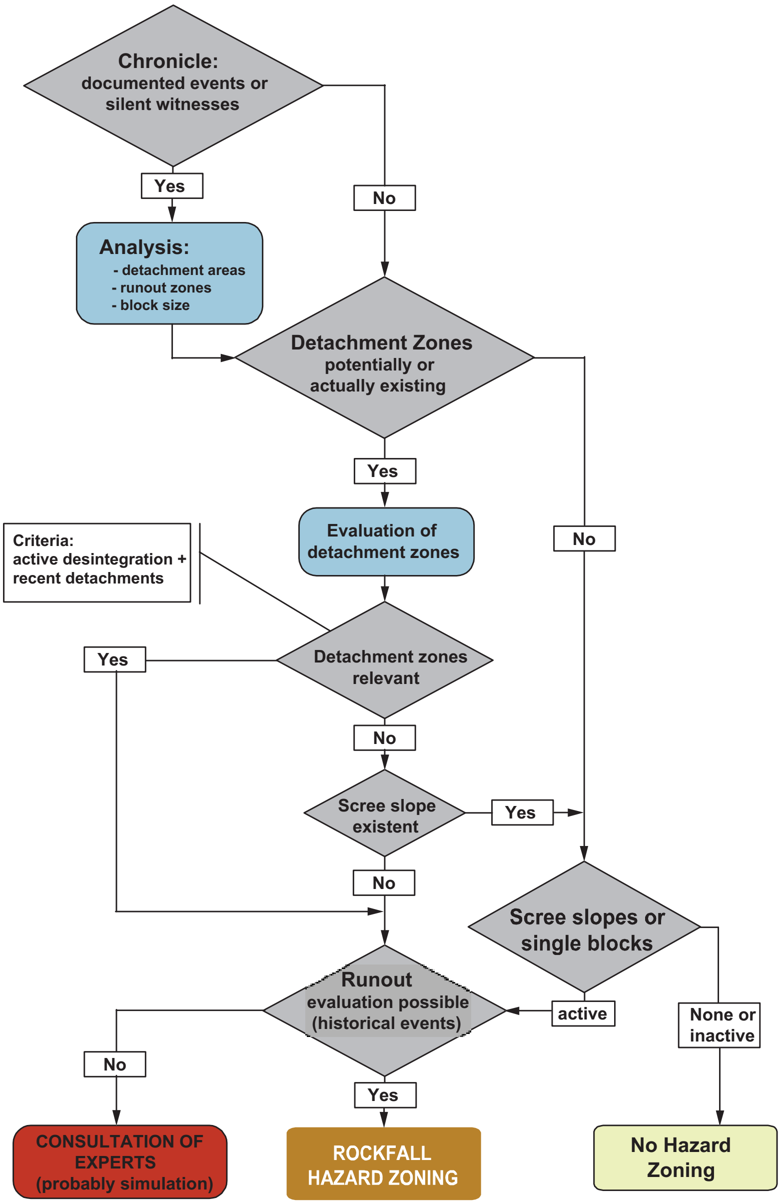

Fig. 2: Draft of a flowchart for a standard procedure in hazard mapping of rock fall processes
Abb. 2: Entwurf eines Flussdiagramms für den Ablauf der Beurteilung von Steinschlaggefährdungen bei der Gefahrenzonenplanung

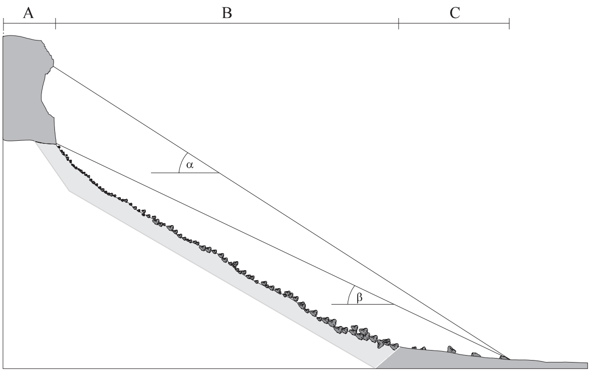

Fig. 3: Geometrical slope angle α and rock fall shadow angle β after Meißl G. (1997)
Abb. 3: Geometrisches Gefälle α und Schattenwinkel β n. Meißl G. (1997)

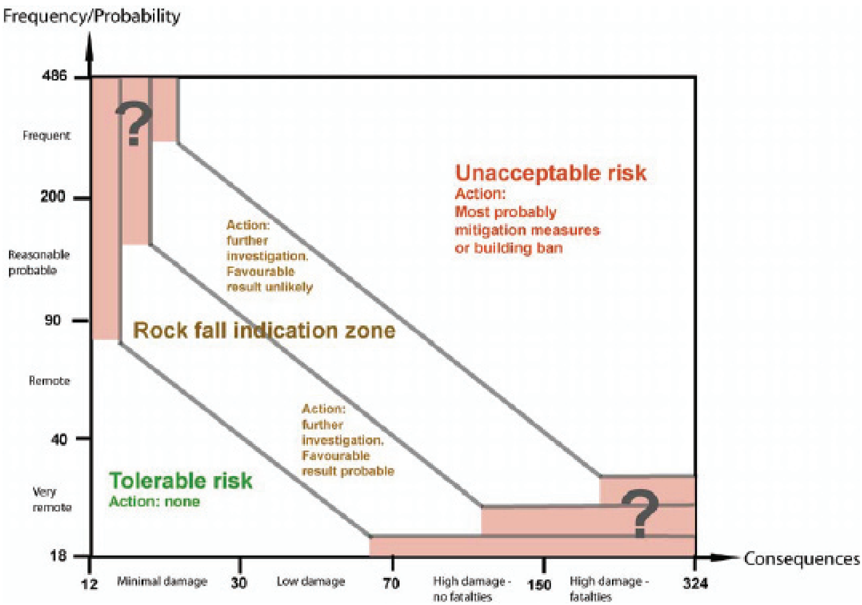

Fig. 4: Frequency/Consequence-diagram
Abb. 4: Wahrscheinlichkeit/Schaden-Diagramm

The application R^3S^2 for inhabited areas having been identified as potentially endangered by rock fall leads to a specific value for each inhabited area. This value represents a semi-quantitative risk for each area. The risk in areas with very remote frequency (probability) and minimal consequences is tolerable (Nielsen N. M. 1994). Areas with a risk higher than tolerable (figure 2) are to be indicated in a plan as "*rock fall indication zone*".

In case of planned construction activity in areas with a risk higher than tolerable (figure 2) more exact investigations such as more detailed mapping, rock fall modelling, etc. (Mölk M. 2002) are necessary in order to find out the actual hazard. It is likely that more exact investigations show a tolerable risk in areas with remote frequency and low consequences. In areas with high risk a building ban is recommended strongly.

FIRST EXPERIENCES AND RESULTS WITH THE RATING SYSTEM

The above described rating system was applied in the rock fall prone community of Ischgl in Tyrol, Austria. The community is situated in a narrow alpine valley with steep slopes and mostly intensive touristic land use – where avalanche and torrent risk allowed development. Due to rock fall events in the last 10 years, mostly with minor damages, a comprehensive study was executed. The study aims to a reproducible evaluation of the rock fall risk for the different settlements being part of the community of Ischgl. Besides a determination of the existence of a rock fall hazard a risk based rating was considered appropriate to produce priorities for the execution of further detailed investigation and consequently the realisation of mitigation measures. Furthermore a classification of the yet undeveloped area of the community was achieved to provide information for a sustainable land use planning.

In the following the rock fall risk rating system is demonstrated at four different examples. Three examples are real detachment areas with settlements being situated at the foot of the slope, one example is theoretical to demonstrate a case where the parameters of detachment, pathway and land use are likely to produce a tolerable risk.

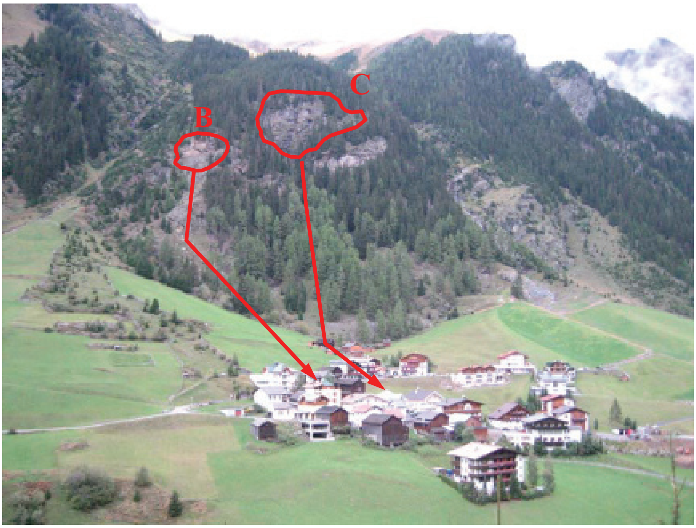

Fig. 5: Overview of investigated area Versahl (B+C) with potential detachment zones and pathway
Abb. 5 Überblick über untersuchten Bereich Versahl (B+C) mit potentiellen Ablösebereichen und Sturzbahn

The detachment zones of the three evaluated areas were investigated in respect of their parameters defining the probability of the detachment of rocks such as loosening of rock, joint strength, joint discontinuity. For example the detachment area B (compare Figure 6) is characterized by joint width of centimetres, rather planar surfaces of the joints and an adverse orientation of these joints. The open joints proof a loose rock mass, planar joints provide a low friction angle when forming gliding planes, which is probable because of the unfavourable orientation of the joints. Below the mostly vertical cliff shown in Figure 6 a steep rocky ramp follows leading to a rough and sparsely vegetated scree slope. Down slope of the block dominated pathway follows a meadow leading to the populated area of the village of Versahl. The slope shows several rather fresh blocks, the block size (d_{90}) reaching 3-5 m³. A rock fall event was reported in march 1999 block sizes ranging from 1,5 to 9 m³, two blocks reached the upper part of the meadow. The scores resulting from the above described characteristics of the detachment, pathway and land use are presented in Table 3, columns *Versahl Area B*.

The rating of the Areas Versahl C and Unterschrofen were executed in analogy to the above described Versahl B.

Fig. 6: Detachment area of Versahl, Area B with orthogneises showing loose rock conditions, low joint strength and unfavourable joint orientation. As the relevant detachment mechanism gliding is considered.
Abb. 6: Ablösebereich Versahl Bereich B mit Orthogneisen mit geringer Verbandsfestigkeit, geringen Kluftfestigkeiten und ungünstiger Kluftorientierung. Als Ablösemechanismus wird Gleiten unterstellt.

Tab. 3: Rating criteria and score for the investigated areas
Tab. 3: Klassifizierungskriterien und Punktevergabe für die untersuchten Bereiche

	Versahl Area B		**Versahl Area C**		**Unterschrofen**		**theoretical tolerable case**	
Parameter	Damage	Frequency/ Probability	Damage	Frequency/ Probability	Damage	Frequency/ Probability	Damage	Frequency/ Probability
Loosening of rock		27		9		9		3
Joint strength		27		3		9		3
Joint discontinuity and orientation		27		9		9		3
Vertical slope-height [m]	9		27		9		9	
Climate and water		9		9		9		3
Block size [m³] d_{90}	9		3		3		3	
Pathway: roughness+damping	9	9	27	27	27	27	3	3
Proof of historical events		27		27		9		9
Quality of landuse	81		81		9		9	
Summary scores for damage and probabiliy	**108**	**126**	**138**	**84**	**48**	**72**	**24**	**24**
Relative Risk	**13.608**		**11.592**		**3.456**		**576**	

The results of the rating of the test areas were plotted in the F/N diagram (Figure 7) designed for the evaluation of the results of the rating. The proposed four categories in Figure 4 and 7 allow for a classification of settlements at risk of being damaged by rock fall processes.

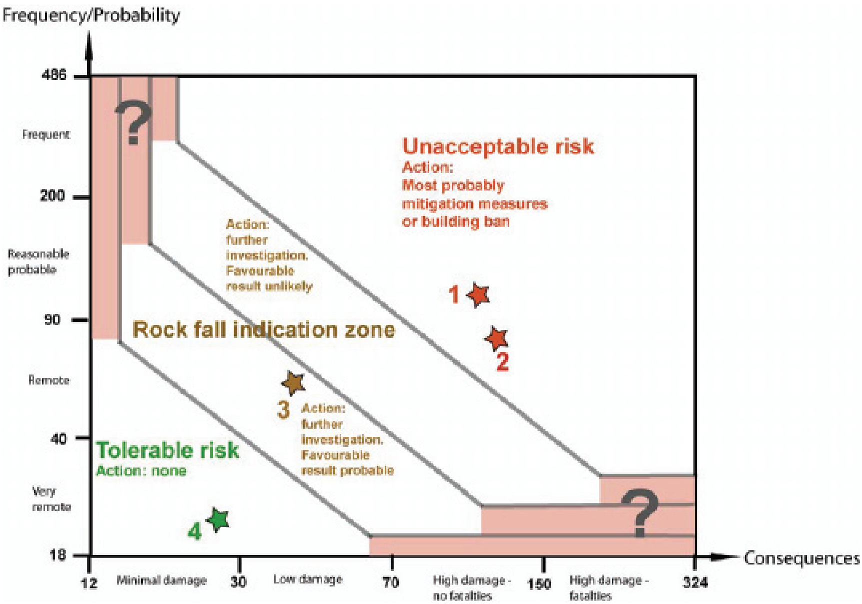

Fig. 7: F/N-Diagramm with four exemplary cases scored after Table 3 and plotted in Figure 4.
1: Versahl/Area B (permanently inhabited buildings) **2**: Versahl/Area C (permanently inhabited buildings)
3: Unterschrofen (sewage treatment plant) **4**: theoretical case at tolerable risk
Abb. 7: F/N-Diagramm mit vier Beispielen gemäß Tabelle 3
1: Versahl/Bereich B (ständig bewohnte Gebäude) **2**: Versahl/Bereich C (ständig bewohnte Gebäude)
3: Unterschrofen (Kläranlage) **4**: Theoretischer Fall mit tolerierbarem Risiko

The proposed categories for the classification (Figure 4 and 7) of the area at risk are:

1. Tolerable risk zone – no action foreseen (e. g. no brown rock fall hazard indication zone). Areas that fall in this category might have a rock fall risk but due to low frequency and/or low damage potential the resulting risk should be rated as acceptable and no further actions are to be taken.
2. Rock fall indication zone (brown rock fall hazard indication zone in Austria) – further investigation necessary, favourable results probable. Areas within this class do have a significant risk to be affected by rock fall, both, the frequency and the damage potential being moderate.
3. Rock fall indication zone (brown rock fall hazard indication zone in Austria) - further investigation necessary, favourable results unlikely. This class contains areas that show a rather high probability of rock fall events taking place and threatening a rather high quality of land-use.
4. Unacceptable risk – necessary action here would be the construction of mitigation measures to protect existing damage potential and further on enact a building ban to avoid further development in an area with high rock fall risk.

In case that a development of an area did not yet take place but is foreseen by land use planning committees, the damage potential should be rated in accordance to the planned quality of the land use. By this procedure a reproducible rock fall risk rating of potential future land development can be provided.

CONCLUSION

Systems such as the method described above are often used for risk rating of rock fall hazard zones at linear infrastructures (Hungr O. et al. 2003, Pierson L. A. et al. 1990). Thus a method is proposed for assessing the rock fall risk of settlements/inhabited areas.

The proposed method helps to identify developed areas subject to a non tolerable rock fall risk making mitigation measures necessary (Angerer et al. 1998, 174). Furthermore areas prone to an eventually tolerable rock fall risk can be found out making, however, further investigations necessary. Areas of equal risk can be connected to rock fall indication zones for land-use planning.

The method allows a hazard zoning of inhabited areas with rather little means (time and effort). However, the scores well document the features important for rock fall hazard. The system includes the assessment of the possible damage thus leading to a reproducible result giving a relative risk (Angerer A. et al. 1998).
The application of this method, however, makes field investigations necessary and cannot be done by remote sensing only. Due to the severe economical consequences (exclusion of further development of land, execution of mitigation measures – both after further, more detailed investigation triggered and located by the risk rating) the rating system can be applied only by rock fall experts. The assessment of the parameters influencing frequency and consequences requires detailed geological and geotechnical knowledge of rock fall processes.

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