A Framework for Risk Management in Rockfall Protection

357

Lovorka Libric, Mario Bacic, and Meho Sasa Kovacevic

Abstract

Rockfalls represent a constant threat to the facilities, infrastructure and inhabitants. Therefore, it is necessary to map the rockfall hazard area and to carry out the risk assessment. In the Republic of Croatia there is no systematic data acquisition of rockfalls. There is also no rockfall classification system adjusted for Croatian Karst. In this paper a Framework for Risk Management in Rockfall Protection in Croatian Karst is presented, which enables a better understanding of the problem and the cooperation of all participants in the project. Decision-making process, necessary for complex decisions, depends on the systematic study of influential factors, the adequacy and quality of information, the number of alternatives, and the use of appropriate models and techniques for selecting optimal alternative. Quantitative risk analysis is carried out if there is a possibility of estimating the probability of a certain event, based on available information about similar events that occurred in the past or on information collected in any other way and also based on personal experience. In the absence of such experience proposed framework allows a qualitative risk analysis with constant control of the consistency of subjective decision-making.

Keywords

Rockfall • Framework • Risk management • Risk assessment • Decision making

357.1 Introduction

Over the last decade, there were several large rockfalls that have occurred in the Republic of Croatia along the Adriatic coast causing serious damage to buildings and transportation infrastructure, personal injury and traffic delays. The main factors that cause rockfalls in limestone slopes are unfavorable climate conditions during heavy rains and influence of the irregular interventions on the slopes during road construction.

Table 357.1 gives a brief overview of significant rockfalls that have occurred in the recent years in the Republic of Croatia whereby the emphasis is given to rockfalls that occurred along the roads and in urban areas (Kovačević et al. 2012).

357.2 Rockfall Risk Assessment

Risk assessment of rockfall hazards along linear infrastructure, such as state roads, highways and railways, is usually based on the results of rating of a certain number of parameters for each chosen location where it is possible for rockfalls to occur. The section that has the largest sum of scores also has the largest risk of rockfalls.

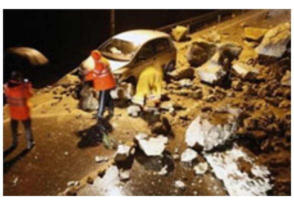
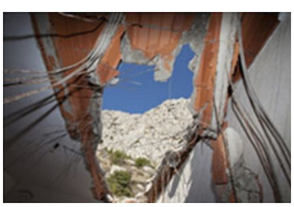
L. Libric (✉) · M. Bacic · M.S. Kovacevic
Faculty of Civil Engineering, University of Zagreb, Zagreb, Croatia
e-mail: llibric@grad.hr

M. Bacic
e-mail: mbacic@grad.hr

M.S. Kovacevic
e-mail: msk@grad.hr

G. Lollino et al. (eds.), *Engineering Geology for Society and Territory – Volume 2*,
DOI: 10.1007/978-3-319-09057-3_357,

Table 358.1 Examples of the rockfalls in Croatia

Location	Volume of the largest blocks Weather conditions	Impact /consequences	Protection measures
 Stupica, D512 Makarska-Vrgorac	Approx 100 and 250 m^3 Rain	The road was closed for traffic for purpose of removing rockfalls and creating design solutions for protecting against possible rockfalls in future in the area concerned	The design for protecting roadway against rockfall was made and it consisted of bypassing the location using the tunnel and protecting approach cutting slopes using rockfall protection barriers
 Brljan, state road Oklaj-Kistanje	No data available Rain and wind	Until blocks were removed, traffic was carried in a single lane	There was no protection measures although minor rockfalls in this area occurred in the past
 Krilo Jesenice, Adriatic coastal road	Approx 8 m^3 Rain	Material damage on the houses People were injured The road was closed for traffic	The location of the rockfall was stabilized by placing steel mesh, Steel cables and anchors
 the city of Omiš	Approx 1 and 0.5 m^3 Storm	Material damage on the houses	There was no protection measures

According to Jaboyedoff and Derron (2005), two types of parameters can be taken into account—rock slope internal parameters which affect the stability of rock slopes or external factors that can cause rockfalls. Internal parameters are: morphology, geology, fracturing, mechanical properties, activity, hydrogeology, etc. External factors are: gravitational effects, water circulation, weathering, erosion, seismicity, active tectonics, microclimate, nearby instabilities, human activities, etc. Apart from internal parameters and external factors, Saroglu et al. (2012) also take into account rockfall history; consequences and associated factors such as the width of the catchment zone, slope accessibility, and potential result of impact and the value of structures.

One of the first and most widely used rating system is Rockfall Hazard Rating System (RHRS) developed for rockfall risk assessment for slopes appeared during highway construction in the state of Oregon in USA in which the rating of nine parameters are summed (Pierson et al. 1990). This was followed by series of modifications of RHRS system and the development of a completely new system in which the number of parameters increases to 20 (Saroglou et al. 2012).

The major disadvantage in the rating system is the fact that a large number of parameters must be qualitatively determined on the basis of subjective evaluations (Budeta 2004). An additional problem is the methodology for determining the relative weight or relative importance of each parameter in the relation to the other. Saroglu et al. (2012) determined the weight of particular parameters empirically on the basis of reasonable engineering estimates and facts. In order to determine the weight of particular parameters, Li et al. (2007) applied the multi criteria decision analysis—Analytic Hierarchy Process method AHP.

357.3 Risk Management in Rockfall Protection

Risk comprises of two independent components: risk probability and risk impact. Both of these components should be quantified in some way in order to be able to analyze various risks, compare with each other and prioritize. This is done by introducing the concept risk exposure which represents the product of risk probability and risk impact: *risk exposure* = *risk probability* × *risk impact* (Cerić et al. 2011).

Proposed framework for risk management in rockfall protection is schematically presented in Fig. 357.1.

Risk management process in rockfall protection for linear infrastructure facilities starts with field inspection and selection of the locations for which the risk assessment will be carried out. It is necessary to determine risk exposure for each selected location and, depending on it risk acceptability.

The absolute value of risk exposure for each location, observed for itself practically has no useful value. It is, therefore, important to determine how much risk exposure of individual locations is lower or greater than the risk exposure of other locations. A risk priority list can be established by determining risk exposure for all locations and placing them in relation to each other. Depending on the position of each location in the list of priorities, in other words depending on the relative value of its exposure with the reference to that of the other locations—there will be engaged adequate resources in the planned risk response.

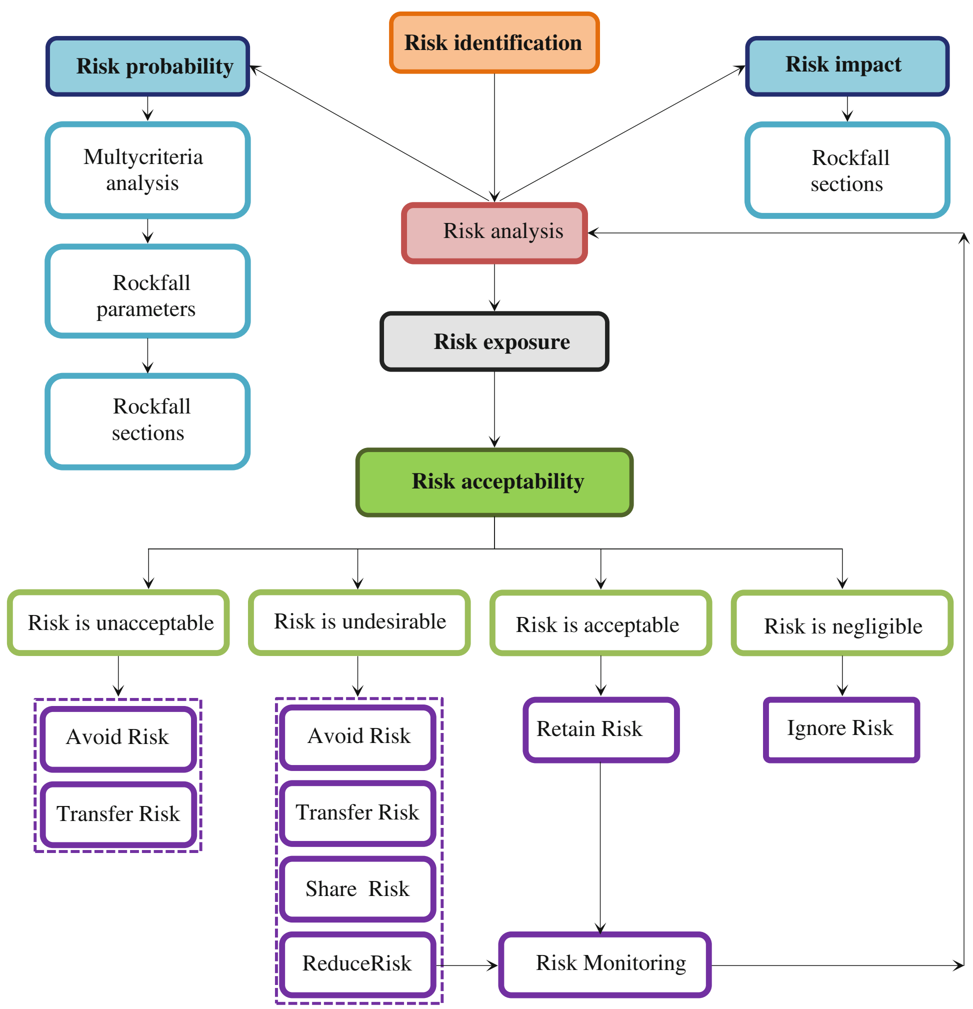


Fig. 357.1 A framework for risk management in rockfall protection

Risk probability or likelihood that the rockfall will occur on particular location—can be determined by quantitative or qualitative approach.

The quantitative approach implies that the risk probability can be calculated if there is a statistically relevant database of experiences of similar events in the past on the basis of which the distribution function is formed for which probability, prediction, variance, confidence interval and all other important statistical parameters can be calculated using statistical methods. An example of such an analysis was given by Chau et al. (2003). In the Republic of Croatia, there is no rockfall inventory neither for any road, about location, size and time period in which the rockfalls have occurred.

The qualitative approach in the suggested framework allows the use of one of the proposed rating systems of a number of parameters or making the rockfall hazard rating system for Croatian Karst. In the lack of experience for determining the weight of particular parameters, it is possible to use three techniques for qualitative risk analysis: Multi-attribute utility theory, Fuzzy analysis and Analytic Hierarchy Process. The analysis of the possibilities of the proposed techniques was given by Cerić and Maric (2011).

After determining risk probability for each location either by using qualitative or quantitative approach, the next is the weighting evaluation of all the probabilities of all the locations to obtain relative relationship between them or in other term to rank the risk according to corresponding probability. The weighting or probability normalization is carried out in a way that the risk probability of a particular location is divided with the sum of all the risk probabilities of all the locations. In this way, the sum of newly created probabilities will be equal to 1 and now the risk probability for the entire section becomes a random variable.

Risk impact represents the influence on the project, in this case the amount of kinetic energy of the fallen rock on the road. For this purpose, framework allows the use of any commercial computer software for 2D and 3D numerical modeling. After calculating the kinetic energy of fallen blocks, weighting evaluation or impact normalization is carried out in the same way as the risk probability normalization.

After risk probability and risk impact are determined for each identified location, risk exposure can be calculated as a product of risk probability and risk impact. Based on the obtained risk exposure, a location risk priority list is formed according to which it can be decided how to respond to it and also predict and distribute resources for response.

Each identified risk, depending on the level of risk exposure, is classed as unacceptable, undesirable, acceptable or negligible. This classification affects the decision about how to respond to it. If a risk is classed as unacceptable, the response to it may be risk avoidance or risk transfer. If a risk is classed as undesirable, the response to it may be risk avoidance, risk transfer, risk reduction or risk sharing with the appropriate risk monitoring. If a risk is classed as acceptable, the response to it may be risk retention with the appropriate risk monitoring. If the risk is classed as negligible, no response to it is necessary.

357.4 Conclusion

In the Republic of Croatia there is no systematic data acquisition of rockfalls which could give useful information about rockfall magnitude and frequency needed for mapping of endangered zones and for designing protection measures in the most endangered areas. Up to now there was no scientific research that would result in the development of rockfall rating system adjusted to Croatian Karst. Due to specificity of Karst in Croatia, there is a need to develop new methods for determining initial parameters, the formation of rockfall inventory on the basis of previous rockfalls and new findings should be based on and verified by in situ tests.

In order to overcome these shortcomings, a Framework for Risk Management in Rockfall Protection is proposed which enables a better understanding of the problem and the cooperation of all participants in the implementation of projects for rockfall protection.

References

Budetta P (2004) Assessment of rockfall risk along roads. Nat Hazards Earth Syst Sci 4:71–81

Chau KT, Wong R, Liu J, Lee C (2003) Rockfall hazard analysis for Hong Kong based on rockfall inventory. Rock Mech Rock Eng 36:383–408

Cerić A, Marić T (2011) Određivanje prvenstva pri upravljanju rizicima građevinskih projekata. Građevinar 63:265–271

Cerić A, Marčić D, Ivandić K (2011) A risk assessment methodology in tunneling. Techn Gazette 18:526–536

Jaboyedoff M, Derron MH (2005) Integrated risk assessment process for landslides, landslide risk management. Taylor and Francis, London

Kovačević MS, Mirčeta A, Librić L (2012) Tunnel Stupica—rockfall protection. In: Proceedings international conference on road and rail infrastructures, CETRA 2012, Dubrovnik, pp 789–796

Li ZH, Huang HV, Yin J (2007) Risk assessment of rockfall hazards on highways. In: Proceedings of first international symposium on geotechnical safety and risk, ISGSR2007, Shanghai, pp 687–696

Pierson LA, Davis SA, Van Vickle R (1990) Rockfall hazard rating system implementation manual. Federal highway administration report FHWA-OR-EG-90-01. FHWA, US department of transportation

Saroglou H, Marinos V, Marinos P, Tsiambaos G (2012) Rockfall hazard and risk assessment: an example from a high promontory at the historical site of Monemvasia, Greece Assessment of rockfall risk along roads. Nat Hazards Earth Syst Sci 12:1823–1836