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AN APPROACH FOR TUNNEL RISK MANAGEMENT

Modern tunnel construction is a very complex and intense process. In this process different uncertainties and risk can occur and they should be adequately managed. This paper explains the systematic approach of the tunnel risk management as a general concept that should include all the available information and preliminary data in order to obtain a quality solution.

Keywords: Tunneling, construction uncertainties, risk management, acceptable risk, decision making

1. INTRODUCTION

The importance and value of construction projects, especially in the area of tunnels require the necessity for different approaches for assessing and dealing with risks. Therefore, there is a wide application of analyzes and methods for risk assessment, as well as their management. Globally, there is an increasing trend for the application of risk-based approaches, which idea is to increase awareness of this issue in various branches of society.

Once the risks are assessed and their intensity is determined, the management follows. This process is crucial in all design and construction issues, as it should define ways to deal with unwanted events, and it is desirable to perform it in an environment of good cooperation between stakeholders.

2. TUNNEL RISK MANAGEMENT

Tunnel risk management usually includes the following:

- Analysis of the results from the hazard and risk assessment;
- Decision making for risk treatment;
- Implementation of the proposed treatment measures;
- Monitoring.

In certain literatures the hazard and risk assesement is also stated in the risk management.

2.1 ANALYSIS OF THE ASSESSED HAZARDS AND RISKS

Once the hazards and risks have been assessed, the results obtained should be analyzed in order to suggest appropriate measures for their treatment. The analysis generally consists of classifying, ranking and comparing the assessed risks in relation to predefined parameters. Classifications or ranking systems can be defined specifically for the project itself, but most often their origin is based on more detailed research on previous and current problems and experiences in this area (Table 1). One of the main goals of these analysis is to define the so-called acceptable (tolerable) level of risk. In relation to this level, the other levels (classes) can be determined and the necessary measures can be determined accordingly. The type of results has a great influence on the classification, more precisely whether it is a qualitative description or a quantitative value. Several organizations and agencies dealing with this problem have issued detailed classifications according to which the assessed risks can be analyzed.

Table 1. Example of risk classification and actions (measures), Eskesen et al (2004)

Risk classification	**Example of actions that should be carried out for each class**
Unacceptable	The risk shall be reduced at least to Unwanted regardless of the cost.
Unwanted	Risk mitigation measures shall be identified. The measures shall be implemented as long as the costs of the measures are not disproportionate with the risk reduction obtained (ALARP principle – As Low As Reasonably Practicable) .
Acceptable	The hazards shall be managed throughout the project. Consideration of risk mitigation is not required.
Negligible	No further consideration of risks or hazards is needed.

The most critical risks in society are those with the greatest consequences, and that represents human victims. Most often, these analyses first consider these risks and therefore in the literature there is a large number of data and values presented in relation to the number of victims for a certain period of time.

In the case of tunnel construction, the values for the occurrence of a risk are usually in relation to the entire period of construction. Depending on the parameters considered, the risks and hazards can also be interpreted in terms of the length of the tunnels or the number of tunnels if multiple cases are considered.

Acceptance limits for tunnels and construction in general range from 10^{-2} to 10^{-4}, often referred to as the ALARP zone or acceptable area. These values refer to the probability of occurrence of a human victim in a certain period which is usually taken as one year. Acceptance limits can also be used to analyse other critical risks, such as those with large economic and time losses or large environmental impacts.

In our country there are no rules and guidelines that define the acceptable level of risk in tunnels. For this purpose, limits of acceptable level of risk are proposed that could be used for any type of tunnels (Figure 1).

For the probability (frequency) of occurrence of victims, the adopted limits are based on criteria and guidelines of few European countries. They are expressed through the following equations:

- Upper limit:

$$F_1 = 10^{-2} * N^{-1} \text{ for } 1 \leq N \leq 1000 \text{ victims} \quad (1)$$

- Lower limit:

$$F_2 = 10^{-4} * N^{-1} \text{ for } 1 \leq N \leq 1000 \text{ victims} \quad (2)$$

F – probability of occurence

N – number of victims

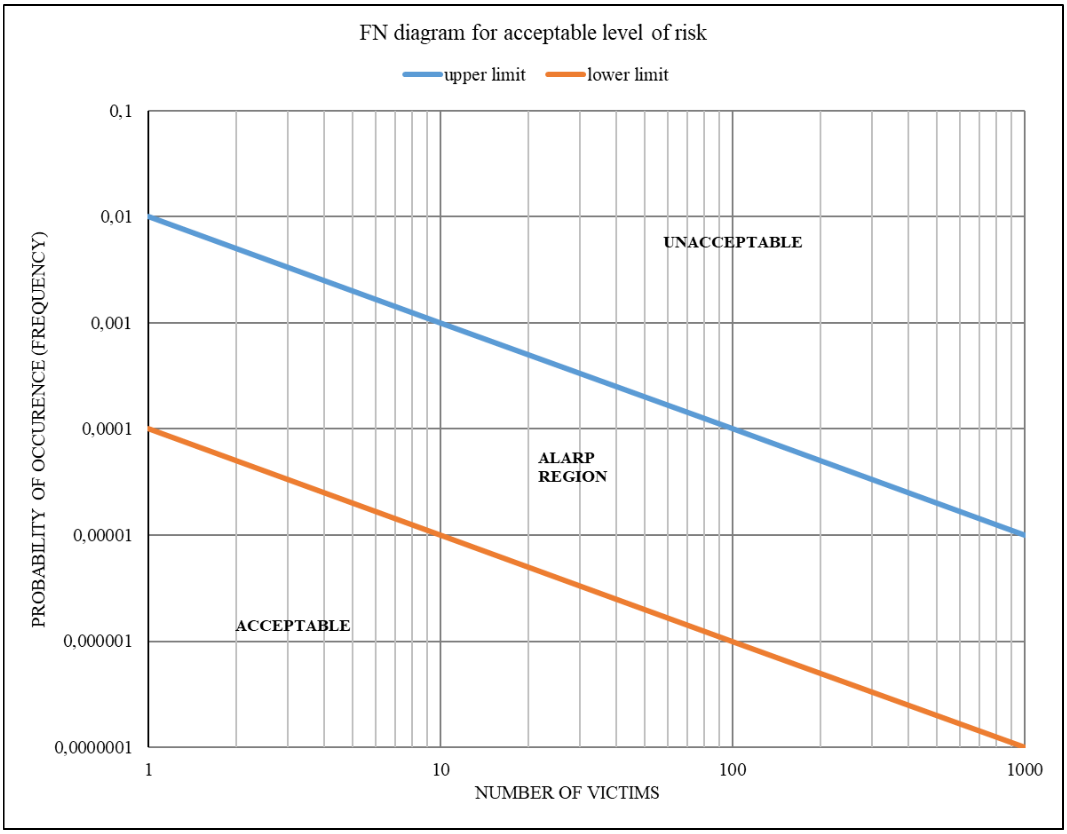

Figure 1. Proposed diagram for acceptable level of risk in relation to human victims in tunnels

The more common and frequent risks are associated with economic loss and time loss (delay). The classifications and acceptable levels for these kind of risks are usually different than the ones with human and environment consequences.

This paper presents an approach for tunnel risk management with proposed classifications and acceptable risk levels for analyzing of the assessed risk in tunnel construction.

The probability of occurrence of risks is the final value, i.e. the result of the quantitative assessment. A five-class system is proposed for ranking, which refers to the potential for risk occurrence in the entire construction period (Table 2).

Based on more detailed research, a classification is proposed that takes into account economic and time losses, which are often closely related (Table 3). The classification does not express the consequences through direct (fixed) values, but as a percentage increase of the initially defined values of the project.

Table 2. Proposed classification for the probability of occurrence of risks in tunnels

Probability of occurrence	Interval	
Very High	> 1/2	> 0,5
High	1/10 - 1/2	0,1 - 0,5
Moderate	1/100 - 1/10	0,01 - 0,1
Low	1/500 - 1/100	0,002 - 0,01
Very Low	< 1/500	< 0,002

Table 3. Proposed classification for economic and time consequences in tunnels

Impact on project costs and time	
Disastrous	> 80 %
Severe	10 - 80 %
Serious	1 - 10 %
Considerable	0,1 - 1 %
Insignificant	< 0,1 %

The final classification or ranking is done using a risk matrix (table 4) which is listed in the guidelines of the ITA International Tunneling and Underground Space Association). It contains 5 columns and 5 rows that correspond to frequencies (probabilities) and consequences. With this matrix there are 25 combinations between the frequencies and consequences and 4 possible outcomes. Based on those outcomes appropriate measures for the risk can be proposed.

Table 4. Risk matrix, Eskesen et al (2004)

	Consequence				
Frequency (probability)	Disastrous	Severe	Serious	Considerable	Insignificant
Very high	Unacceptable	Unacceptable	Unacceptable	Unwanted	Unwanted
High	Unacceptable	Unacceptable	Unwanted	Unwanted	Acceptable
Moderate	Unacceptable	Unwanted	Unwanted	Acceptable	Acceptable
Low	Unwanted	Unwanted	Acceptable	Acceptable	Negligible
Very Low	Unwanted	Acceptable	Acceptable	Negligible	Negligible

2.2 ANALYSIS OF RAILWAY TUNNELS

Using this approach for risk classification and ranking, an analysis of the assessed risk was made for railway tunnels. Four railway tunnels on the future railway line on the corridor 8 in Macedonia (section Kriva Palanka – border pass Deve Bair) were previously assessed in terms of hazards and risk (table 5). The assessment covers the three most critical hazards and risks that threaten the construction of these railway tunnels.

Using these quantitative results, a classification was made according to the risk matrix (table 4). For a serious and severe consequence and a very low and low probability of occurrence (< 0,002; 0,002 – 0,01) the risks are classified as acceptable. This means that the hazards shall be managed throughout the project. Consideration of risk mitigation is not required.

In terms of the diagram for probability of occurrence of human victims (figure 1), the values belong to the ALARP region, which means that the measures shall be implemented as long as the costs of the measures are not disproportionate with the risk reduction obtained.

In general, the analysis and the results can help in the management process during the construction of the tunnels, which can start after a very longer period than planned.

Table 5. Results from previous quantitative risk analysis for the railway tunnels

Hazards	**RISK (probability of occurrence)**	
	Severe	**Serious**
Ground water inflow	0,0000779 (very low)	0,0007011(very low)
Excessive deformation (swelling)	0,0001990(very low)	0,0017915 (low)
Instability of the excavation face	0,0003130 (very low)	0,001252 (low)

2.3 DECISION MAKING

The treatment of unacceptable risks can be done in many ways. Risks can be avoided, reduced (mitigated) or transferred. Some risks can be avoided by adapting to a more robust method of construction or changing the tunnel alignment. Other risks may be transferred to insurance companies. However, most of the risks must be reduced to an acceptable level.

Risk mitigation can be seen as part of quality assurance work.

The optimal methods for risk mitigation are aimed at the epistemic nature of uncertainties, which implies that risks can be reduced by obtaining additional information.

The selection of appropriate measures should be made in an environment of good cooperation between stakeholders. The following parameters usually have the largest influence on the decision making process:

- The results from the analysis of assessed hazards and risks;
- Type of project;
- The size of the project;
- Budget size;
- Design phase;
- Stakeholders and third parties;
- Possibility to implement and folow the effects of the proposed measures.

2.4 RISK MONITORING

One of the least discussed components of risk management is monitoring (figure 2). The main objectives of the monitoring are:

- Predicting future events;
- Validation of the modeled asumptions;
- Improving of the overall accuracy of the risk-related decisions;
- Beter communication between the stakeholders.

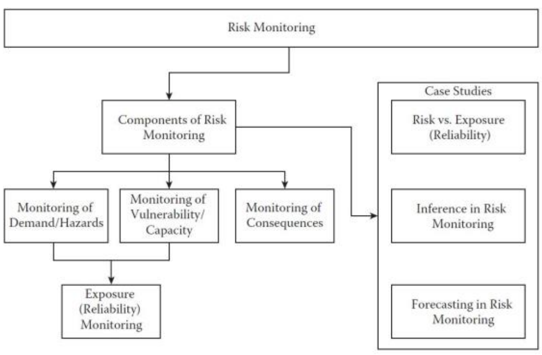

Figure 2. Risk monitoring diagram, Ettouney et al (2017)

The methods of monitoring (observation) and the location of the instruments depend on the field conditions, methods and technologies for construction and the nature of the risk events.

Risk monitoring is esspecialy important in structures such as tunnels or bridges.

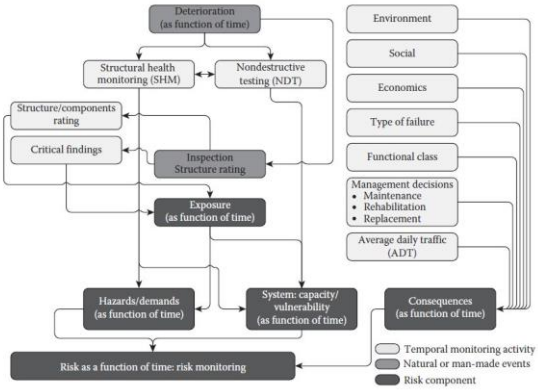

Figure 3. Risk monitoring components, Ettouney et al (2017)

3. CONCLUSIONS

Tunnel risk management is an important part in the construction phase. The success and benefits of implementing an effective risk management depend on the quality of identified risk reduction measures and the active involvement, experience and general opinion of the participants (Investor, Designers, Contractors and Supervisors). Risk management is not achieved by implementing systems and procedures individually, but through meetings where there is an understanding and appreciation of this issue.

The approach showed in this paper is based on a quantitative risk assessment which in the end gives results that can be classified or ranked. The proposed values for probabilities of occurrence and consequences may be used not only for tunneling but in other large civil engineering projects also.

The results from the railway tunnels analysis show that the three most critical risks for the projects are acceptable in terms of economic and time consequences, but in relation to human victims the risks belong in the ALARP region. This means that before (or during) the constructions of the tunnels appropriate measures should be proposed and considered.

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