CETRA[2020*] 20-21 May 2021, Zagreb, Croatia
6th International Conferenceon Road and Rail Infrastructure

METHODOLOGY FOR TUNNEL RISK ASSESSMENT USING FAULT AND EVENT TREE ANALYSIS

Zlatko Zafirovski, Vasko Gacevski, Zoran Krakutovski, Slobodan Ognjenovic, Ivona Nedevska
University "Ss. Cyril and Methodius", Faculty of Civil Engineering – Skopje, North Macedonia

Abstract

The intense demand and construction of tunnels is accompanied by uncertainties. The reason for appearance of uncertainties are the complex solutions and conditions for these structures. Location and dimensions are becoming more challenging, and the construction is predicted in complexed geological conditions, leading to application of new approaches, methodologies and technologies by the engineers. Most of the uncertainties and unwanted events in tunnelling occur in the construction phase, which generally leads to economic consequences and time losses. For easier handling of the uncertainties, they should be anticipated and studied within a separate part of each project. One of the newer approaches to dealing with uncertainties is hazard and risk assessment and defining ways to deal with them i.e. management. Hazards and risks can be analysed qualitatively and quantitatively. The quantitative analysis, examines the causes and consequences in more detail way and gives explanation of the dependencies. With the quantitative approach, a more valuable information for decision-making can be provided. There are various models and methods used for the quantification of hazards and risks. This paper presents a methodology in which the fault tree analysis and event tree analysis are used in combination to obtain quantitative results. The fault tree analysis is used for assessment of various hazards and the different ways and reasons that cause them. The event tree analysis is a method for assessing the possible scenarios, which follow after a certain hazard i.e. the consequences that may occur in the project. These trees represent graphic models combined with a mathematical (probabilistic) model, which give the probability of occurrence of the risks.

Keywords: tunnels, risk assessment, fault tree analysis, event tree analysis

1 Introduction

The transport infrastructure has a great importance for the society. Project optimization and infrastructure construction can bring great benefits to any state and the wider region. In order to be successful, projects must meet certain technical, economic, safety and time requirements.
Tunnels as underground structures are an integral part of the transport infrastructure. They allow overcoming of complex obstacles and the fulfilment of technical parameters for the construction of modern roads and railways, where high speeds are developed. Tunnels minimize the impact of infrastructure on the environment, and in cities, their placement improves the quality of life. As urbanization continues and demands for quality and safety of life increase, the importance of underground structures is expected to increase even more.

DOI: https://doi.org/10.5592/CO/CETRA.2020.1051

The nature of these underground structures indicates uncertainties. Because of the uncertainties, there is no project without a certain level of risk. The risk in its most basic form is defined as a potential for unwanted consequence due to an event or occurrence i.e. hazard.
Risk assessment is an essential part for making the right decisions. Very often solutions that look cheaper and faster based on deterministic estimates are associated with greater uncertainties and risks. Tunnels can pose significant risks associated with cost overruns, delays in construction and environmental impacts. Also, as demonstrated in several historical records, tunnels have great potential for accidents involving people in the construction process.

2 Hazards and risks in tunnelling

Risk is associated with certain events that cause consequences, which are often negative. There are a great number of definitions for risk in the literature, but the main terms use in this area are usually the same (hazard, consequences and vulnerability).
In recent times, tunnelling hazards are mainly followed by economic and time consequences, and rarely with human consequences. In terms of environmental impacts, underground structures have many positive characteristics and in many cases are the best solutions to problems in this area.
The data collected from different sources, indicates various types of hazard and risks occurring in tunnel construction around the world. Tunnel collapse is one of the most often recorded event because of the major consequences it has on the construction process, workers safety and the environment. The collapse can be manifested in different ways such as: crown (roof) fall, daylight collapse, instability of the tunnel face, instability to the walls, etc. Most of the time this is caused by several factors, some of which are other types of hazards: excessive deformation, flooding (large inflow of water), rockfall, rockburst and other. According to the location, most of hazards and risk happen near the tunnel (excavation) face.

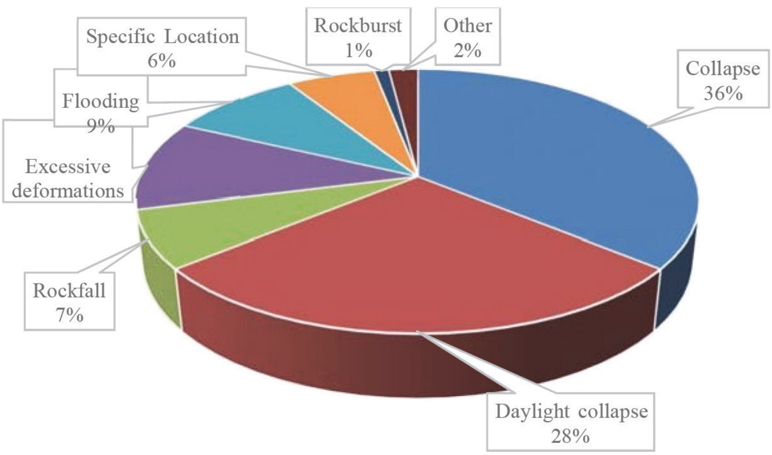

Figure 1 Distribution of hazards during construction of 132 tunnels around the world [1]

The exploitation phase of tunnels includes other types of hazards such as: fires, vehicle collisions, explosions, leaks of aggressive or toxic materials, natural disasters (earthquakes and floods) and specific events (characteristic for submerged tunnels). The largest number of hazards and risks occur in traffic tunnels, because usually people cause unwanted events during tunnel exploitation.

3 Methodologies for tunnel hazards and risks assessment

There are generally two approaches to assessing hazards and risks: qualitative and quantitative approach.

3.1 Qualitative analysis

In the initial project stages for the identification of potential hazards that pose a threat to construction activities, a qualitative risk analysis could be performed. The main goal of this analysis is to raise the awareness of all participants about the risks involved in the construction process and to provide a structural basis for decision making in the early stages of the project. This analysis should contain the following:

- Identification of hazards;
- Classification of hazards;
- Identification of adequate protection or preventive measures;
- Details of the risks in a so-called risk register.

3.2 Quantitative analysis

For more detailed analysis of hazards and risks, a numerical or quantitative approach is applied, which can be deterministic or probabilistic. The quantitative approach needs a detailed analysis of the causes and consequences and an explanation of the dependencies between the considered events and phenomena. This analysis provides valuable information for decision making in the case of uncertainty and unforeseen events, such as the selection of an appropriate project or construction technology, possible protection measures, impacts on third parties and the environment. It also allows the determination of prices and construction time.
The approach to quantifying uncertainties, hazards, and risks is often a combination of mathematical and graphical models or methods. In the literature, they can also be found as graphic networks or as risk management tools. Some of these methods are the Fault and Event tree analysis, Markov process, Bayesian networks, Failure Mode and Effects Analysis (FMEA), Hazard Operability Study (HAZOP), Hazard Analysis and Critical Control Points (HACCP), etc.

4 Tunnel risk assessment using fault and event tree analysis

The combination of fault and event tree with their probabilistic models is a methodology, which as a final product gives the risk in quantitative form. This approach can be used to assess hazards and risks in different types of tunnels under construction and exploitation.
The principle of this methodology begins with the formation of the fault tree, where an expected hazard in the tunnel, which is defined based on the available data, is presented as a top event. The branching of the tree is done in a logical order where the primary events are grouped into several main groups that represent them. Probabilities are given for each primary event describing the uncertainty of the occurrence or the impact on the top event. This gives the likelihood of a hazard (top event) occurring during the tunnel construction period.
The top event from the fault tree with its probability is then presented as the initial event in the event tree. In the event tree, the nodes indicate the adopted and proposed measures that affect the occurrence of the hazard, i.e. their success or failure determines the consequences.
In the fault tree probabilistic analysis, standard deviations are assigned to all primary events separately. With the use of logarithmic distribution and advanced Monte Carlo simulation

with 1000 samples, the results are obtained in the form of cumulative probability distribution. The same concept of assigning standard deviations to preventive measures and the initial event is implemented in the event tree. The results of this analysis give the most critical direction (path) in the event tree, which is actually a sequence of failure of all preventive measures.

4.1 Railway tunnels

This process of combining the two trees has been used for risk assessment of several tunnels designed on the future railway line, which is part of the Pan- European transport corridor VIII in North Macedonia. Specifically, the section Kriva Palanka - border with R. Bulgaria, with length of 23,40 km is the most complexed part of the railway line from Skopje to the border with Bulgaria. Along the route, 24
tunnels with a total length of about 9,00 km have been designed. In this paper the results from the two longest tunnels (1,4 and 1,3 km) along the section are shown. The tunnels are placed in a horizontal curve where the railway slope is near the maximum (23,50 and 19,00 ‰). The excavation of the tunnels is predicted to be mostly with the Drill & Blast method.
For the risk analysis, different information have been used such as:
• number and length of investigative boreholes;
• classification, types and quality of ground materials;
• number and types of fault zones;
• level and quantity of groundwater;
• tunnel support.

Four hazard have been analyzed for these tunnels: unpredicted inflow of ground water, excessive deformation (swelling and squeezing) and instability of the excavation face (collapse). The results from the fault tree show that the unpredicted inflow of ground water (figure 2) is the hazard with the most probability of occurrence, QH = 0,2195 (21,95 %), but the biggest risk in the event tree comes from the instability of the excavation face (figure 3) QR = 0,0002530 (0,02530%).

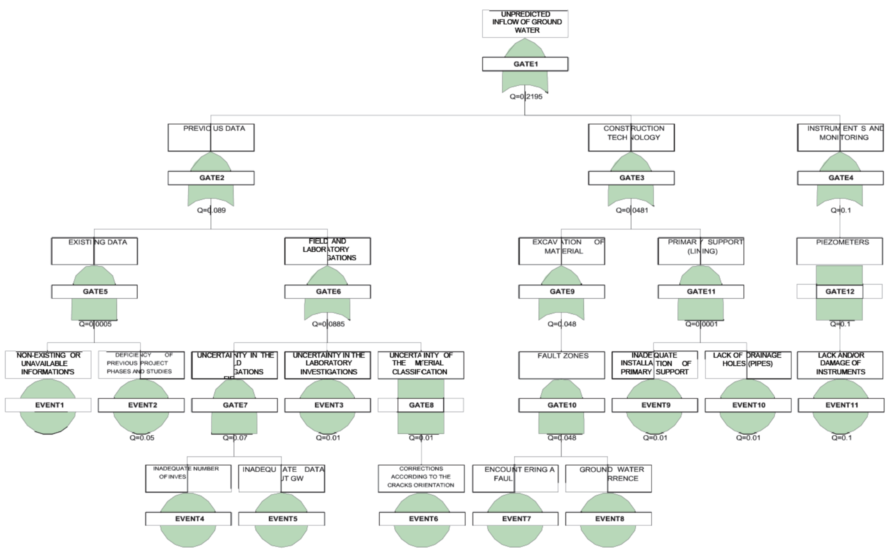

Figure 2 Figure 2. Fault tree analysis for unpredicted inflow of ground water

Table 1 Probabilistic analysis results in the fault tree for inflow of ground water

Parameter (probability)	Primary value	Mean value	Standard deviation	5%	50%	95%
QH	0,2195	0,2189	0,0671	0,1287	0,2090	0,3445

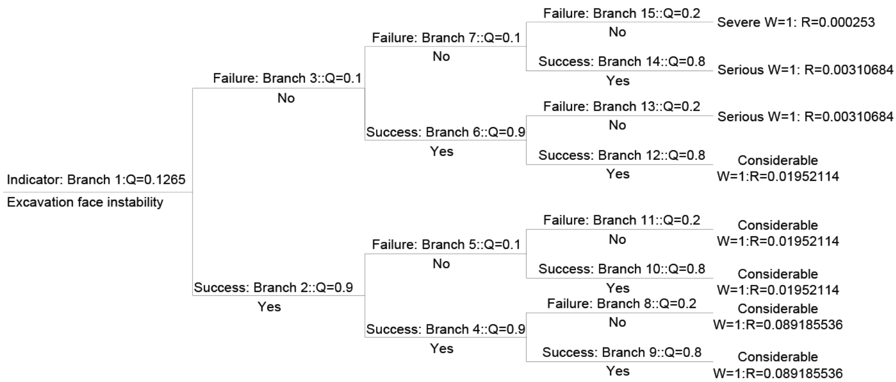

Figure 3 Event tree analysis for instability of the excavation face

5 Conclusion

In the current practice, the risks in the projects were mainly analysed on a qualitative basis. For greater effectiveness, certain changes are needed that focus on the application of quantitative methods.

The methodology shown in this paper a combination of fault tree, event tree and probabilistic model resulting in cumulative function distribution. The fault tree serves to define and asses the hazards and the event tree analyses the critical scenarios aSSnd the consequences that can occur from a defined hazard.

The results in this paper show that the hazards with highest probability of occurrence not always represent the highest risk. Further, the results from this methodology can be used for classification and definition of acceptable risk levels and the appropriate measures i.e. the management of risks.

References

[1] Sousa, L.R.: Risk Analysis for Tunneling Projects, Massachusetts Institute of Technology, Department of Civil and Environmental Engineering, PhD Thesis, 2010.

[2] Eskesen, D.S., Tengborg, P., Kampmann, J., Veicherts, H.T.: Guidelines for tunnelling risk management: International Tunnelling Association, Working Group No. 2, Tunnelling and Underground Space Technology 19, pp. 217-237, 2004.

[3] Hyun, C.K., Min, S., Choi, H., Park, J., Lee, M.I.: Risk analysis using fault-tree analysis (FTA) and analytic hierarchy process (AHP) applicable to shield TBM tunnels, Tunnelling and Underground Space Technology, 49 (2015), pp. 121-129

[4] Stille, H.E.: Geological Uncertainties in Tunnelling – Risk Assessment and Quality Assurance, International Tunnelling and Underground Space Association (ITA), Sir Muir Wood Lecture, 2017.

[5] Kikkawa, N., Itoh, K., Hori, T., Toyosawa, Y., Orense, P.R.: Analysis of labour accidents in tunnel construction and introduction of prevention measures, Industrial Health, 53 (2015), pp. 517-521

[6] Seidenfus, T.: Collapses in Tunnelling, Stuttgart University of Applied Sciences, MSc Thesis, 2006.

[7] Špačková, O.: Risk management in tunnel construction projects, Czech Technical University in Prague, Faculty of Civil Engineering, PhD Thesis, 2012.

[8] Yoe, C: Principles of Risk Analysis – Decision Making Under Uncertainty, Second Edition, CRC Press, 2019.