ASSESSMENT OF RISKS IN A ROAD TUNNEL CONSTRUCTION USING TREE ANALYSIS

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Nowadays, new technologies, materials and machines enable the application of tunnel solutions even in the most difficult construction conditions. However, even with the great progress in tunneling, uncertainties and risks are always present in this field. In this direction, risks in tunnel construction should be appropriately analyzed and managed. This paper shows a methodology for risk assessment of road tunnels using combination of fault and event tree analysis. The fault tree is used for determination of the probabilities of previously estimated hazards and the event tree defines the consequences and the risks during a road tunnel construction in a quantitative form. The use of such approach can contribute to more successful tunneling project.

Keywords: tunnels, construction uncertainties and hazards, risk assessment, tree analysis

1. INTRODUCTION

Tunneling is a specific area of civil engineering that is associated with dangers during project execution. Dangers impose hazards on all parties involved not only on those directly engaged with the task [1]. Therefore worldwide exists an increasing trend for the application of risk-based approaches to increase awareness of this issue. In that sense risk assessment is a structured process that identifies the probability and degree of negative consequences resulting from certain natural events or human activities (hazard) [2].

In R. N. Macedonia according to the current and future project solutions for the road and railway corridors, the construction of a significant number of tunnels is in sight. These tunnels have different characteristics and conditions, which means that various risks can occur during construction [3]. Neglecting the risk during construction can lead to increased costs and delays in the project [4]. In some cases, negative impact to the environment and people can arear. Thus, risk analysis and management is becoming mandatory part of tunnel engineering, contributing to better design and safer construction.

2. RISKS IN TUNNELING

Generally, risks in tunneling construction can be associated with economic losses and less often with human, environmental and other consequences. The data from the most significant tunnel losses in the past few decades shows that the most frequent causes are [5]:

- Insufficient ground investigation and/or interpretation;
- Faulty design and/or workmanship (construction);
- Lack of appropriate measures or procedures on site which would enable the timely recognition of imminent problems.

This shows that tunnel risks should be assessed and managed in every project phase [6]. For a long time tunnel accidents during construction have been connected with a significant number of human victims. A drastic reduction in fatal injuries comes with the emergence and application of newer tunneling methods and technologies [7,8]. But even nowadays there are still human fatalites and injuries. In may 2022 during the construction of the Khooni Nallah tunnel in India, 10 workers died after a collapse [9].

1.1 TYPES OF RISK ASSESSMENT

There are different types of risk assessment that can be used in various project phases. The first and simpler one is the qualitative risk assessment. This type is mostly used in earlier project stages while major changes in the design part are still possible [10]. Usually this is done in a form of a risk register [4].

In later project phases, when more information and data is available, the quantitative approach is adequate for risk assessment. This type of assessment can be used during the making of the final (main) design, before or after construction start. The quantification of uncertainties, hazards and risks represents a combination of graphical and mathematical approaches or models such as analysis, artificial networks, studies and processes. Some of the used quantitative approaches are: fault, event and decision tree analysis, neural and Bayesian networks, failure mode and effects analysis, multicriteria decision analysis, Markov Analysis, etc [2,11,12].

2.1.1 Fault tree analysis

This approach serves to analyze a particular hazard and different ways and reasons that cause it. The fault tree itself is a graphical model that shows a combination of observable events or uncertainties (preceding the potential hazard). The nature of the particular graphical model is qualitative, but due to its particular suitability for quantification, it is often used in combination with probabilistic models (figure 1). From the top (main) event, the tree is logically branched to the basic events that contribute to the probability of failure or occurrence of the top event [5,13].

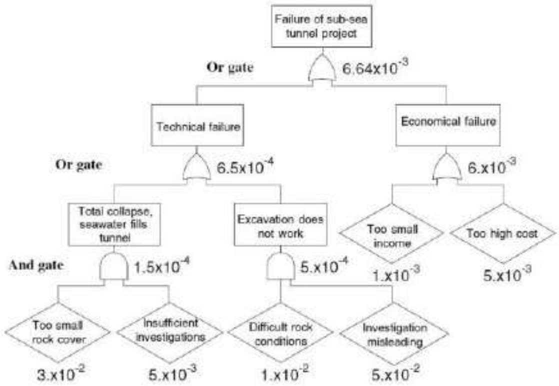

Figure 1. Example of a fault tree for a failure of a sub-sea tunnel project [10]

2.1.2 Event tree analysis

The description of the development from an initial event through possible sequences to a defined final state can be carried out through event tree analysis. This technique identifies and analyses possible scenarios that follow a certain initial event (hazard). The tree of events allows, through a logical and overview order, to determine the consequences that may occur in the project (figure 2) [14].

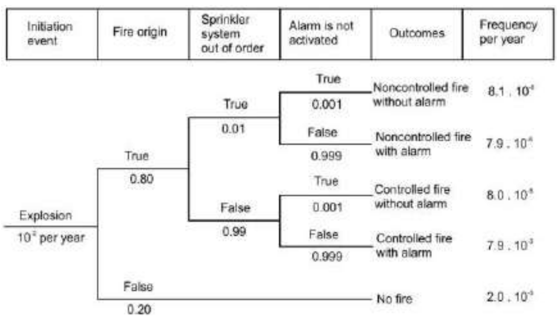

Figure 2. Example of an event tree analysis for an explosion in tunnel [15]

3. ROAD TUNNEL RISK ASSESSMENT

With a combination of the fault and event tree, we can assess previously defined hazards and the consequences they cause regarding the success or failure of some construction measures. After the definition of the structure of the trees, probabilities are assigned for each event, after which the probability of the top event (hazard) is calculated. This top event with its probability represents the initiating event in the event tree. The event tree is then branched using three main measures that mostly affect the outcome. In this paper, this type of combination is shown for a road tunnel.

The tunnel is part of the future highway line in the west part of North Macedonia (Gostivar-Kicevo) on the European transport corridor VIII. It's a standard highway tunnel solution with two tunnel pipes (L_1=622,0m; L_2=705,8m). The risk assessment is done for the construction phase (which is not started) using all the data and information from the design phase. The available data consist of studies, reports and project documentation (main design) regarding tunnel positon, geometry and support, geology, ground investigations and classification.

With previously conducted qualitative risk assessment, three hazards where chosen for the quantitative approach. The results from the fault tree are shown in table 1 for each hazard different fault and event trees where constructed with different probabilities for the basic events. Additionally for the highest probability hazard, using the lognormal distribution and advanced Monte Carlo simulation with 1000 samples, results were obtained in the form of a cumulative probability distribution.

Table 1. Results from the fault tree analysis

Hazard	Probability of occurrence
Unpredicted groundwater inflow (flooding)	0,0420 (4,20 %);
Instability of the excavation face (face collapse)	0,0874 (8,74 %)
Instability of rock blocks (rock fall)	0,1626 (16,26 %)

By applying these hazard occurrence probabilities and assigning failure probabilities to preventive measures (risk reduction measures) in the event tree, the risk results where obtained (table 2). For each hazard there are three types of preventive measures: grouting (forepoling), primary support (timely adequate installation) and cavity filling (concrete or cement). Their success or failure represented by a probability, determinates the risk outcome.

Table 2. Results from the event tree analysis

Risk	Probability of occurrence
Unpredicted groundwater inflow (flooding)	0,0000210 (0,00210 %)
Instability of the excavation face (face collapse)	0,0000874 (0,00874 %)
Instability of rock blocks (rock fall)	0,0001626 (0,01626 %)

For the instability of rock blocks, the additional probabilistic analysis was conducted. The results are shown in table 3 and 4.

Table 3. Results from the probabilistic fault tree analysis

Primary value	0,1626
Mean value	0,1624
Standard deviation	0,0509
5 %	0,0962
50 %	0,1518
95 %	0,2571

Table 4. Results from the probabilistic event tree analysis

Primary value	0,0001626
Mean value	0,0001573
Standard deviation	0,0001516
5 %	0,0000256
50 %	0,0001081
95 %	0,0007240

Figure 3 shows the fault tree for the instability of rock blocks (rock fall) with the logical branching and the probabilities of all the events. There are three main groups bellow the top event: previous data, construction technology, instruments and monitoring. Figure 4 shows the event for the instability of rock blocks with the preventive measures and the probabilities of all the events. The top branching represent the worst scenario where all the measures fail and we have severe consequences.

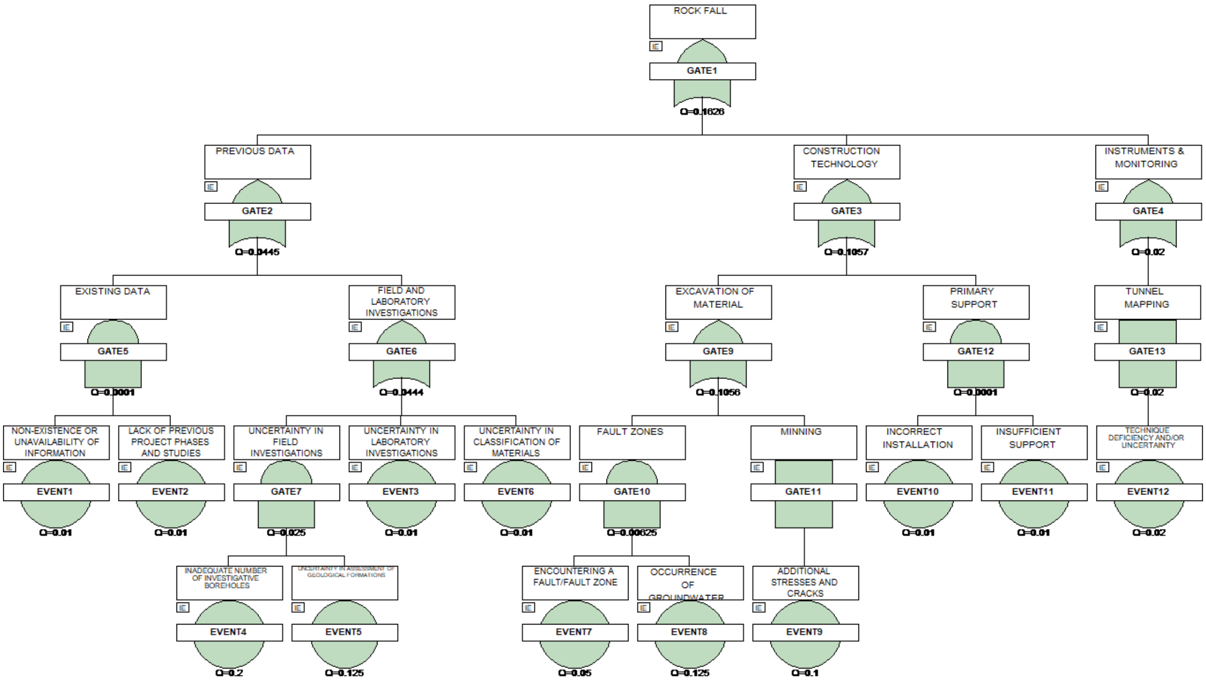

Figure 3. Fault tree for instability of rock blocks (rock fall)

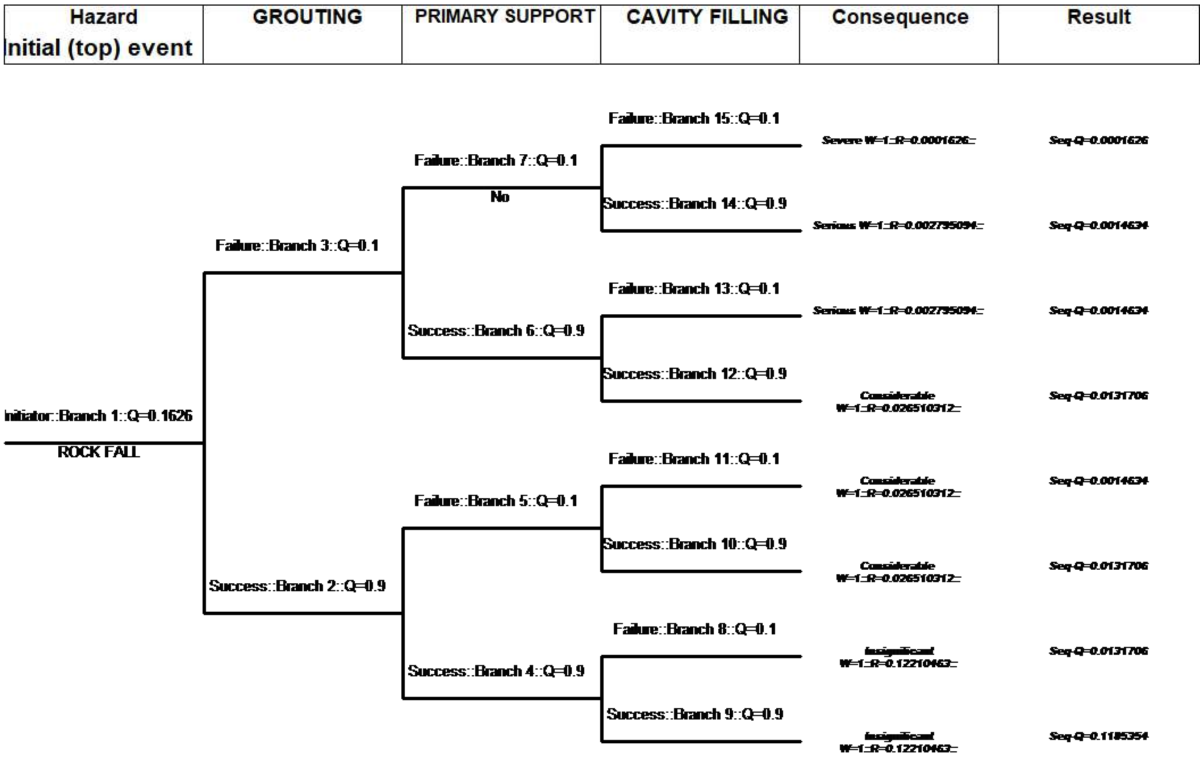

Figure4. Event tree for instability of rock blocks (rock fall)

4. CONCLUSIONS

Risks are always present in tunnel engineering. From planning, through design and finally in the construction phase risks can have a major influence for the project. Neglecting this problem can only lead to unpredicted consequences that usually have negative impact. This paper shows a combination of tree analysis models that can be used for quantitative risk assessment. First with the fault tree, the hazards can be analyzed, resulting in probability of occurrence or failure for each event. Afterwards in the event tree we can analyze different scenarios and consequences that follow every hazard. The shown assessment refers to a road tunnel, where the data from the design phase is used for the determination of risks that can occur during construction. Three main hazards are analyzed with to combination of the fault and event tree. Additionally for the highest risk, a cumulative probability distribution was implemented. The fault tree for this risk shows that the construction technology has the biggest influence in the hazard occurrence. The event tree presents the effectiveness of the preventive (remedial) measures and in the end the consequences i.e. the risks from each scenario. The determination and classification of the assessed risks should be made in the management phase. This next step should define the acceptable levels of risk and different actions to be carried out based on the classification. This kind of approach to risk throughout assessment and management can benefit all the project participants and cause safe and reliable working environment.

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