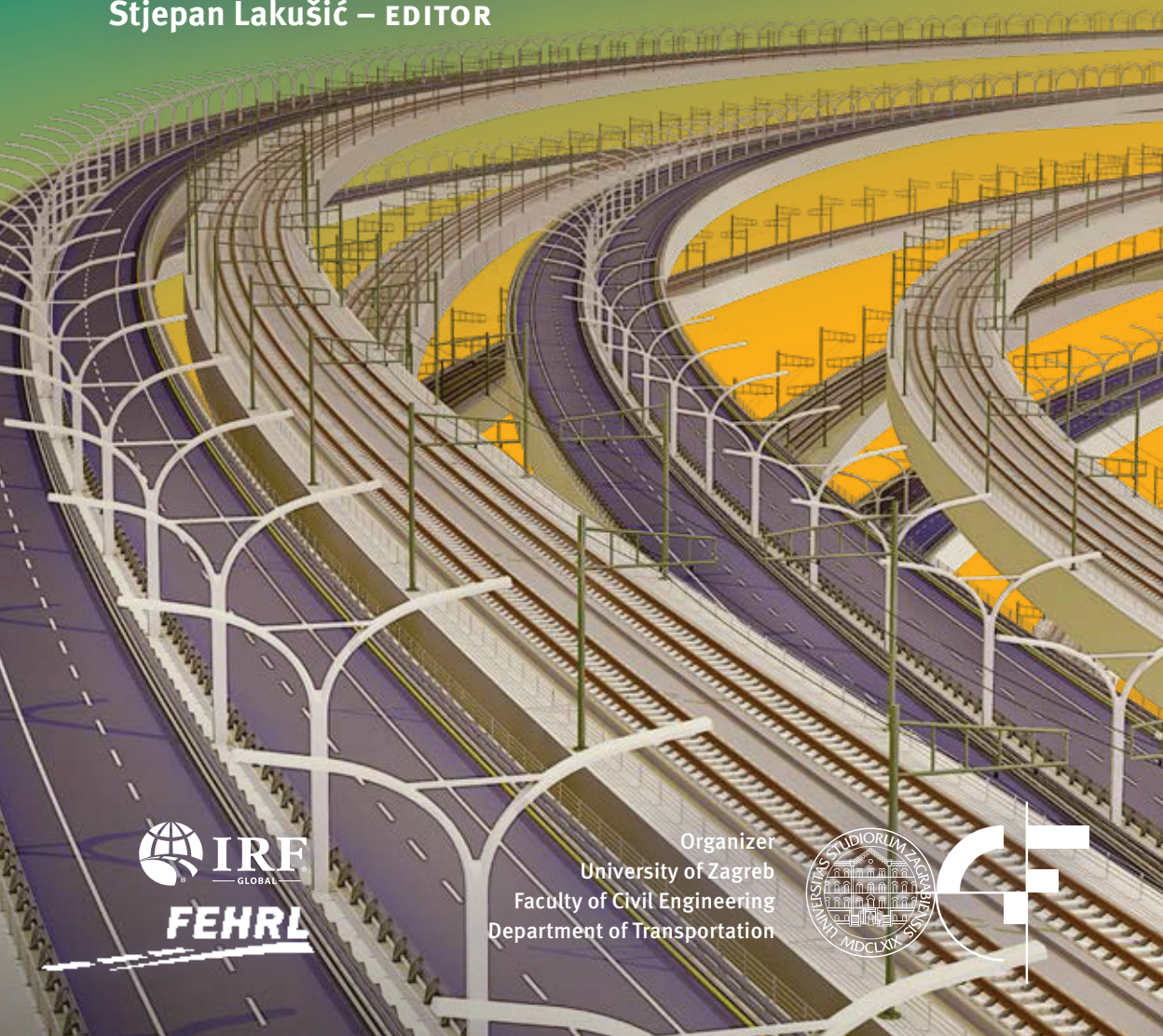


CETRA^{2020*}

6th International Conference on Road and Rail Infrastructure
20–21 May 2021, Zagreb, Croatia

Road and Rail Infrastructure VI

Stjepan Lakušić – EDITOR



Organizer
University of Zagreb
Faculty of Civil Engineering
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20–21 May 2021, Zagreb, Croatia

Road and Rail Infrastructure VI

EDITOR

Stjepan Lakušić

University of Zagreb

Faculty of Civil Engineering

Department of Transportation

Zagreb, Croatia

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FOREWORD

The 6th International Conference on Road and Rail Infrastructure – CETRA 2020* was organized by the University of Zagreb - Faculty of Civil Engineering, Department of Transportation Engineering. The Conference was held in Zagreb, capital of Croatia. Zagreb's history dates back to Roman times when the urban settlement of Andautonia existed at the location of the modern-day Šćitarjevo. In 1945, Zagreb was declared the capital of Croatia and today it is the cultural, scientific, economic, political and administrative centre of the Republic of Croatia, and a home to the Croatian Parliament, Government and President. It is located on the southern foothills of Medvednica Mountain and spreads along the banks of the Sava River. Culturally, it is a European city well worth visiting, with its numerous historical monuments, parks and medieval architecture. Everything is accessible by foot - from your hotel to the theatre, and for wandering around the old Upper Town or through the bustling streets of the more modern Lower Town, which has not lost an ounce of its charm despite the eternal march of time. The streets and monuments of Zagreb proudly testify to its hundreds of years of history.

The 1st International Conference on Road and Rail Infrastructure – CETRA 2010 was held on 17-18 May 2010 in Opatija. The 2nd International Conference on Road and Rail Infrastructure – CETRA 2012 was held on 7-9 May 2012 in Dubrovnik. The 3rd International Conference on Road and Rail Infrastructure – CETRA 2014 was held on 28-30 April 2014 in Split. The 4th International Conference on Road and Rail Infrastructure – CETRA 2016 was held on 23-25 May 2016 in Šibenik. The 5th International Conference on Road and Rail Infrastructure – CETRA 2018 was held on 17-19 May 2018 in Zadar. Great interest of participants in topics from the field of road and rail infrastructure, as expressed during previous CETRA conferences, confirms the adequacy of the Department for Transportation Engineering's decision to keep organising this international event. Positive comments given by participants in past conferences motivated the Department for Transportation Engineering of the Faculty of Civil Engineering at the University of Zagreb, to organise a new CETRA conference (CETRA 2020) on 20-21 May 2020 in Pula. However, due to the circumstances arising from the ongoing spread of COVID-19 - the continuing danger it still poses to public health and safety, together with an increase in travel restrictions - CETRA 2020 Organizing Committee has decided to further postpone the Conference. We held on for as long as we could, wishing that things would return to some semblance of normality. We were very optimistic, hoping that the situation with COVID-19 will be much better in October, trying our best to organize CETRA 2020 and to bring our professional and scientific community together one more time. However, the safety of the participants is our priority, and we decided it would be prudent to postpone the CETRA 2020 Conference to the spring of 2021. At the same time, postponing the Conference to the following year provided the members of our Committees valuable time to completely dedicate themselves to the determination of damage caused by the disastrous earthquake that hit Zagreb in March last year. Although we wished to organise the conference in 2020, even in the autumn of that year, we had to postpone the conference so as to be held in May 2021 on the same dates on which it was supposed to take place in 2020. We also partly kept the identity of the conference so that in 2021 the conference will be organized under the name of CETRA 2020*.

The CETRA conference has established itself as a venue where scientific and professional information from the field of road and rail infrastructure is exchanged. The idea on linking research organisations with economic sector has been the guiding concept for the realisation of this conference. Conferences of this kind are undoubtedly a proper place for establishing closer ties between the economy and university operators, and for facilitating communication and inspiring greater confidence, which might result in cooperation on new projects, especially those that contribute to greater competition. Lectures organized in the scope of the conference are based on interesting technical solutions and new knowledge from the field of transport infrastructure as gained on the projects already realised, projects currently at the planning stage, and those that are now being realized, in all parts of the world. In addition to presentations given by authors from the academic community, lectures are also presented by authors from engineering practice, the idea being to ensure the best possible synergy between the theory and practice. Because of great interest for the themes relating to the field of road and rail infrastructure, as shown during the past fourth conferences (CETRA 2010, CETRA 2012, CETRA 2014, CETRA 2016 and CETRA 2018), the Department for Transportation Engineering of the Faculty of Civil Engineering – Zagreb has assumed the responsibility to organise the new CETRA Conference in 2020 as well but, as already mentioned, the COVID-19 pandemic is the reason why the conference has been rescheduled for 2021 (but keeping the identity in the form of the name CETRA 2020*). However, due to the pandemic, the form in which the conference will be organised was also changed so that it will be held via an on-line platform.


This year, the 6th International Conference on Road and Rail Infrastructure – CETRA 2020* is organized with the intention of bringing together scientists and experts in the fields of road and railway engineering, so that they can present the results of their research, their findings and innovations, and analyse problems encountered in everyday engineering practice and, finally, offer solutions that will undoubtedly contribute to a more efficient planning, design, construction, and maintenance of transport infrastructure. The CETRA 2020* Conference serves as a platform for presenting a broad blend of scientific and technical papers in the fields of civil, transport, geotechnical, environmental, traffic and electrical engineering, with practical application in the road and rail infrastructure. Papers considered for publication are original papers that adequately contribute to the theory or practice of infrastructure engineering, and present either state-of-the-art work on topics related to infrastructure, or case studies in which theory is applied to solve significant infrastructure problems.

This year's CETRA Conference attracted a large number of papers and presentations from 32 countries. More than 140 papers were presented at the Conference and are contained in these proceedings **Road and Rail Infrastructure VI**. We believe that these CETRA 2020* proceedings will prove to be, just like the preceding five proceedings from the CETRA cycle, highly interesting and useful to all experts exhibiting a scientific and professional interest in road and rail infrastructure. The organizers of the Conference express their thanks to all Businesses and Institutions that provided support to this Conference. Special thanks are extended to the IRF - International Road Federation, and FEHRL – the Forum of European National Highway Research Laboratories, for their assistance and support in organizing very important conference sessions relating to innovations in roads maintenance and innovative transport infrastructure development. These operators have contributed, each in its own way, to the success of this conference. Great thanks are also extended to the following institutions that have supported the CETRA conference over the past ten years: University of Zagreb, Ministry of Sea, Transport, and Infrastructure, Ministry of Science and Education, and Croatian Academy of Engineering.

The Editor commends all authors for excellent papers contributed to these proceedings and wishes to thank members of the Organizing Committee and International Academic Scientific Committee, and numerous experts who participated in the review process. The gratitude is also extended to all participants for taking part in the CETRA 2020* Conference. The quality of the papers presented and the CETRA Conference is best demonstrated by the fact that a considerable interest is being expressed for most of these papers by researchers and industry operators from all parts of the world. This is not only due to the high visibility of the conference thanks to its presence in relevant databases, but is also a logical consequence of the quality of papers published in the scope of this conference series. Lectures that are organised at the conference are based on interesting technical solutions and latest findings in the field of transport infrastructure from the projects already realised, those that are at the design stage, or projects that are currently being realised in all parts of the world. In addition to representatives from the academic community, conference lectures are also given by industry operators, which constitutes the best possibly synergy of theoretical and practical achievements. Problems encountered in everyday engineering practice are analysed through papers presented at the conference, where practical solutions are offered in order to enable a more efficient planing, design, construction, and maintenance of transport infrastructure.

The organization of the CETRA 2020* Conference has proven to be a greater challenge compared to the organisation of the first CETRA 2010 Conference. The persistence of organisers and great perseverance of the authors who have accepted that their valuable scientific achievements and interesting professional projects are published not in 2020 but in 2021, i.e. in the year to which the conference has been rescheduled, are the proof that only by acting together we will be able to overcome challenges that inevitably occur in the society. High quality papers published in the Conference Proceedings are the result of great efforts of the authors and reviewers as they have worked in close synergy to achieve outstanding papers included in the proceedings and presented at the conference. All those who took part in the preparation of the proceedings (authors, reviewers, members of the Organizing Committee, technical editor, and the editor-in-chief) have worked hard to enable timely publication of the proceedings. We believe that the papers published in the proceedings will be interesting not only to our colleagues in the everyday engineering practice but also to students of technical faculties where disciplines from the field of road and rail infrastructure are studied.

Zagreb, May, 2021

THE EDITOR

Prof. Stjepan Lakušić

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METHODOLOGY FOR TUNNEL RISK ASSESSMENT USING FAULT AND EVENT TREE ANALYSIS

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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.

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.

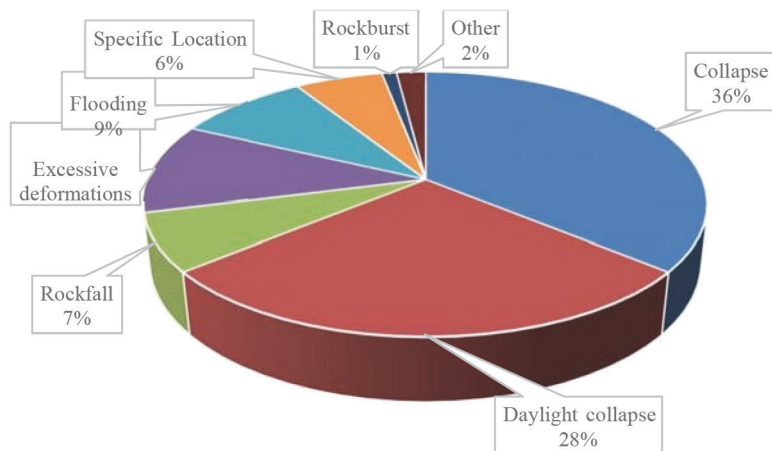


Figure 1 Distribution of hazards during construction of 132 tunnels around the world [1]

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%).

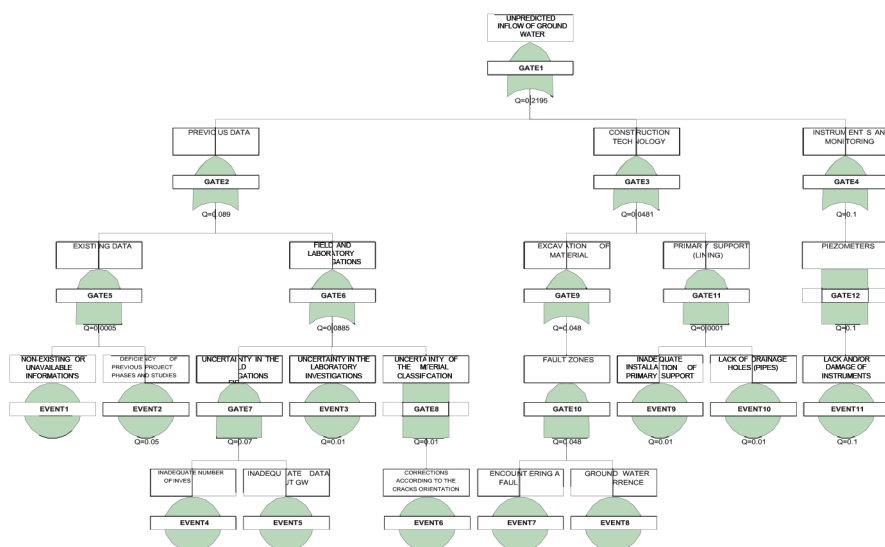


Figure 2 Figure 2. Fault tree analysis for unpredicted inflow of ground water

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

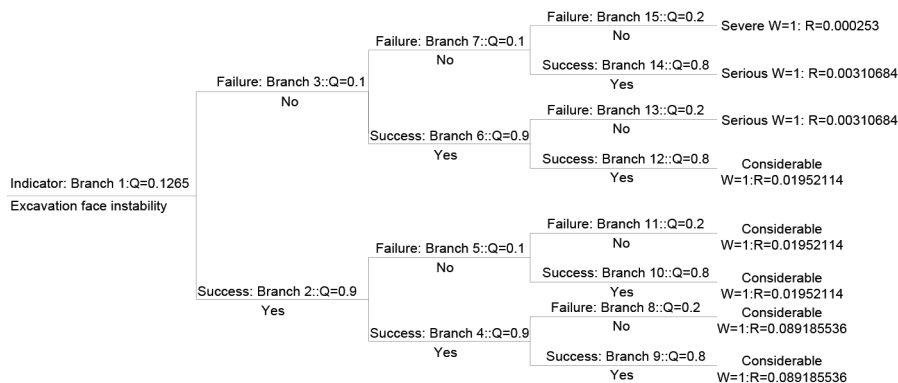


Figure 3 Event tree analysis for instability of the excavation face

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 assess the hazards and the event tree analyses the critical scenarios and 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.

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