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REDUCING ROCKFALL HAZARDS IN SABIHA GOKÇEN – TAVSANTEPE METRO PROJECT CONSTRUCTION BY USING ROOT CAUSE ANALYSIS METHODOLOGY

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Abstract

Original scientific paper

A realistic goal in efforts to reduce worker injuries related to rockfall incidents is to assess the conditions that create a rockfall hazard. If employers can properly assess the risks of rockfall and implement appropriate technical and administrative controls, they can better mitigate the risks. In order to achieve this goal, the methodology of Root Cause Analysis (RCA) can be considered as a method of risk assessment. An effective risk assessment method should include the ability to observe variable ceiling conditions and assess how much potential they represent for injuring workers. RCA's ability to prioritize the risks associated with changing conditions provides significant benefits to anyone responsible for designing, approving, or installing controls that are reasonably repeatable and stabilize the ceiling or reduce the risk of material falling from the roof. Herein, this study is based on a case analysis of the risks and causes of rock fall incidents in a metro construction project using the RCA methodology. This study explains the use of an RCA methodology that can help improve system-level failures and weaknesses, such as rocks falling from the ceiling of a tunnel. Furthermore, the present report examined the causes that led to the accidents and the predictors/variations were assessed using fishbone approach. Accordingly, inadequate training, lack of experience and the use of inappropriate equipment were identified as the causes of accidents. Careless behavior is also a major source of danger, in addition to failure to follow safety procedures.

Keywords: *Rockfall, occupational health and safety, hazard, root cause analysis.*

SABİHA GÖKÇEN – TAVŞANTEPE METRO PROJESİ İNŞAATINDA KÖK NEDEN ANALİZİ METODOLOJİSİ KULLANILARAK KAYA DÜŞMESİ TEHLİKESİNİN AZALTILMASI

Özet

Orijinal bilimsel makale

Bir metro inşaat projesindeki kaya düşmesi olaylarıyla ilişkili işçi yaralanmalarını azaltma çabalarında gerçekçi bir hedef, kaya düşmesi tehlikesi yaratan koşulları değerlendirmektir. İşverenler bu riskleri doğru bir şekilde değerlendirebilmesi ve uygun teknik ve idari kontrolleri uygulayabilmesi durumunda, riskleri daha iyi hafifletebilirler. Bu hedefi başarmak için Kök Neden Analizi (RCA) metodolojisi, risk değerlendirmesi yöntemi olarak düşünülebilir. Etkili bir risk değerlendirme yöntemi, değişken tavan koşullarını gözlemleme ve bunların işçileri ne kadar potansiyel olarak yaralayabileceğini değerlendirme yeteneğini içermelidir. RCA'nın değişen koşullarla ilişkili riskleri önceliklendirme yeteneği, tavanı istikrarlı hale getiren veya malzemenin tavanından düşme riskini azaltan kontrolleri tasarlama, onaylama veya kurma sorumluluğu olan herkes için önemli faydalar sağlar. Bu çalışma, bir metro inşaat projesindeki kaya düşmesi olaylarının risklerini ve nedenlerini RCA metodolojisi kullanarak bir vak'a analizi üzerinden incelemektedir. Bu çalışma, tavanın düşmesi gibi sistem düzeyindeki başarısızlıkları ve zayıflıkları geliştirmeye yardımcı olabilecek bir RCA metodolojisinin kullanımını açıklamaktadır. Ayrıca, mevcut raporlar, kazalara yol açan nedenler inceledi ve balık kılçığı yaklaşımını kullanarak bütün faktörler değerlendirildi. Buna göre, yetersiz eğitim, deneyimsizlik ve uygun olmayan ekipman kullanımı kazaların nedenleri olarak belirlendi. İhmalci davranışlar, güvenlik prosedürlerini izlemede başarısızlıkla birlikte, tehlike kaynaklarından biri olarak belirlendi.

Anahtar Kelimeler: *Kaya düşmesi, iş sağlığı ve güvenliği, tehlike, kök neden analizi.*

1 Introduction

Risks and hazards in the global competitive markets can have a devastating impact on an organization, resulting in costly consequences. Therefore, preventing risks and hazards within their own operations or products is a major concern for any organization. Risk assessment studies, workplace accidents, maintenance programs and strategies are designed and implemented with the negative consequences of machine or equipment failure in mind, minimizing unplanned downtime caused by such failures. [1]. It is clear that for organizations, particularly those

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operating in an expanding global economy, the cost of error can be very high and it is easy to see how failures affect the organization's ability to compete [2]. As a result, organizations often develop and implement innovative strategies, both technical and managerial, which are critical to achieving sustainable success.

As organizations incur significant costs due to unexpected downtime, it is important to learn from mistakes by identifying their causes and preventing their recurrence. However, resources for research and analysis must be made available to achieve this goal [3]. This leads to the question: "How can we reduce the cost of investment in identifying the causes of failure?

Root cause analysis (RCA), an effective method for achieving this goal, focuses on identifying the root cause of a failure through systematic causal analysis [4]. To achieve this goal, RCA uses a variety of methods and tools. The choice of these should be in accordance with their location and purpose. These include Pareto charts, Failure Mode and Effect Analysis (FMEA), 5 Whys, Ishikawa Fishbone Diagram, Fault Tree Analysis, 8D Report Template Checklist. However, there are three main barriers to using RCA. The first is that the methods and tools used to carry out RCA can be quite complex and difficult to use. This can result in RCA being used less frequently, taking more time and making it more difficult to maximize the learning potential within the organization. Secondly, some RCA methods or tools may require specialized software applications. These may have limited access and may require an initial capital investment. Thirdly, some methods or tools must be rigidly applied, which limits creativity and increases the likelihood of missing or abbreviating the real root cause(s) [5]. This is a method that focuses on identifying the root causes of a current event and subsequent events [6]. This method aims to solve the problem in its entirety by identifying the underlying causes, rather than focusing on a specific cause or effect of the problem. Therefore, in order to make it more effective, it needs to be made simpler, faster, and more reliable. To achieve this goal, RCA methods should be made more user-friendly within the company, accessible open source software should be used, and processes should be tailored to the organization's characteristics. As a result, there will be a reduction in costs and organizations will be able to make their risk analysis processes faster and more effective.

Instead of a culture of responsibility, there is a culture of blame in organizations. For RCA to be used effectively, it is important that the organization adopts a learning culture and encourages responsibility rather than blame in the problem-solving process. In this context, organizations must train their employees, encourage their identification of problems and offer solutions [7]. The lack of training and risk awareness among employees is another major obstacle to achieving this goal. In order to use RCA effectively, it is necessary to have a trained team that is familiar with the methodology. Especially, it is important to have the knowledge and skills necessary to understand the basic principles and tools of RCA, to ask the right questions, and to analyze the right data. Organizations need to invest in staff training programs, methods and tools.

They may also need to hire experts or set up a dedicated team. The fact that the studies require detailed analysis and data collection processes can create difficulties for organizations in terms of time and resources. The implementation of RCA needs to be prioritized and supported by all relevant stakeholders. It is also important that the budget planning process includes the allocation of an appropriate budget to provide the necessary resources.

In this study, a qualitative root cause analysis was applied to the rockfall event that occurred during tunnel excavation and support works, the subsequent events, and the effects of possible mitigation measures. In this RCA model, the fishbone method has been used for the consideration of each parameter in the chain of events leading to the accident. In assessing the rockfall initiating events, factors resulting from formation characteristics, support methods and material properties were investigated. A detailed study of the near misses or minor injuries that can occur in tunnelling, which is considered one of the most dangerous workplaces in terms of occupational health and safety, will help to develop strategies to prevent accidents from reaching a potentially serious level.

The metro tunnel connecting Sabiha Gökçen Airport and Tavşantepe station, the construction of which started in March 2015, has a length of 15 kilometers and there are a total of 4 stations on the line. Upon completion, the project will connect the airport to Istanbul's existing metro system. It is expected to reach a capacity of one million passengers per month.

According to the data of the Social Security Institute of 2022, 4491 work accidents occurred in tunnel and railway construction in our country, 11 of them resulted in death, 1090 of them in the form of injuries requiring more than five days of treatment. Similar accidents cannot be prevented, although all such accidents are analyzed and recommendations are made. Such a high rate of accidents can be explained with the not learned from the past experiences. The rock fall accident, in which many workers were injured during excavation and support activities in the study area, was the subject of analysis. Along with the present study, we hypothesized that, based on the former reports, the major reasons of the accident occurred in metro project could be associated with the environment and communication and education status of the personnel involved in the project. In order to test the hypothesis, we used a fishbone approach including "communication", "education", "and environment", "personnel factors".

2 Literature Review

Today, accident investigation and risk reduction, with a particular focus on occupational health and safety, are commonly used to analyze system and equipment failures by examining the reliability and maintenance practices of technological systems, identifying the causes of equipment malfunctions, and making improvements to prevent recurring problems [8-10]. Due to its widespread use in industry, it has also attracted interest in fields such as quality management, manufacturing, and services [11].

It performs detailed analysis to identify the root causes of errors or defects that occur at any stage of production, and then takes appropriate preventive action to ensure that these problems do not recur, thereby eliminating the causes of errors in the production process and improving quality

[12]. It also focuses on RCA business processes and investigates the reasons for errors in the structure of these processes [13], helping to construct a more efficient and effective workflow by identifying sources of errors in processes. Companies can reduce costs and increase customer satisfaction through the identification of errors in their processes [14].

Systems-based RCA is designed to combine change management, risk management and systems analysis applications [15]. It is also designed to deal with complex systems and use a systematic approach to understand problems and allocate resources effectively in large projects. It aims to identify potential errors in a system, determine their causes, and then produce appropriate solutions. System-based RCA considers errors and inconsistencies in subsystems by addressing the entire system. This provides a holistic view. If one of the components in the system fails, other components in the system may be affected [16]. Change management is the analysis of the impact of changes to a system and the implementation of appropriate measures. Risk management identifies potential risks and assesses their potential impact. Preventive measures are taken to mitigate risks.

In the area of occupational health and safety, RCA examines the reliability and maintenance practices of technological systems, as well as accident investigation and risk mitigation based on comprehensive data. Its aim is to identify the causes of equipment failures on the basis of all available evidence. In addition, data from similar incidents and experiences in other organizations can be used in RCA analysis. This data can help to understand the causes of past incidents and provide information on how to take preventative measures against possible future incidents [17].

In general, the RCA process begins with the formation of the team and continues with the definition of content and purpose and the collection of data. Identifying and structuring an appropriate method for analyzing the data collected is the most important step. As a result, corrective actions are taken and recommendations are made. To ensure that any additional risks or malfunctions are eliminated, the system is controlled in a closed loop (Fig. 1.).

RCA is performed using special analysis techniques such as "5 Whys" technique, Failure Mode and Effect Analysis, Fault Tree Analysis, Fishbone or Ishikawa diagrams, Pareto Analysis, and Root Cause Mapping [18].

The root causes of a problem can be identified using these structured analysis techniques. For example, the "5 Whys" technique involves repeatedly asking the question "why?" to determine the causes of the problem and get to the root causes (Fig. 1.). In this way, we can get to the most fundamental causes of the problem. To identify the sources of faults in a system and assess their impact, Failure Mode and Effect Analysis is used [7]. A fault tree analysis is a diagram that shows the causes of a failure in a system and the consequences of that failure. Fishbone diagrams, or Ishikawa diagrams, are graphical organisational tools that are used to identify the root causes of problems (Fig. 2.). To identify the most common causes of a problem, Pareto analysis is effective. Root Cause Mapping is a technique used to visualize all the factors involved in a problem and understand how they relate to one another [19]. The use of these analytical techniques is therefore one of the critical elements in the success of RCA. Choosing appropriate techniques leads to precise identification of problem causes and development of appropriate solutions. Identifying the root causes of problems is made easier by this structured approach to RCA. This allows continuous system improvement.

Cioca and Moraru [20] used root cause analysis, a combined and systematic approach to risk, to assess the risk of fire and explosion in gas mines. Even a small fire can cause major disasters, resulting in a potential explosion or fire, if a flammable atmosphere is created. Budiyanto and Fernanda [21] reported that traffic accidents at the container terminal are the most likely to occur and are caused by negligence, resulting in damage to both people and equipment.

In addition, Shahhossein et al. [22] reported that the root causes of the possibility of failure in the implementation of large-scale construction projects are that most of the problems in the projects arise from financial concerns and deficiencies in the bidding process.

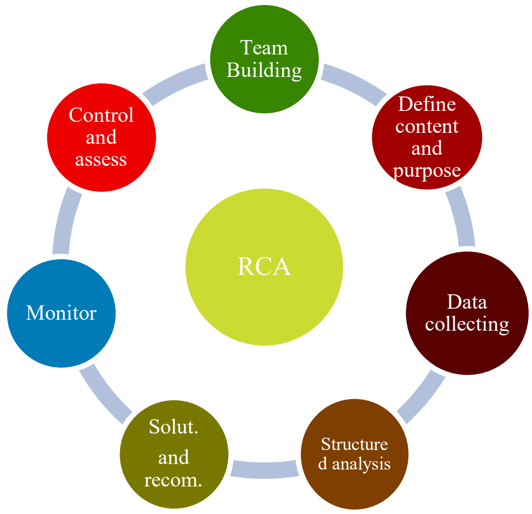

Figure 1. The steps of root cause analysis (RCA).

RCA is a process that starts with physical causes, progresses to human causes and finally to management or root causes, identifying the reasons for problems in order to develop solutions. In this way, the causes of any problems can be identified and appropriate corrective action can be in place. One of the outputs of RCA is the documentation of the data and evidence collected during the analysis process. These results will include findings in relation to the hypotheses that have been considered and the most likely root causes of the failure or loss. Hypotheses help to test different approaches to determine the cause of the problem. The results are presented based on the information obtained at the end of the analysis and provide a clear understanding of the causes of the problem. Recommendations for corrective action are one of the key outputs of RCA.

In order to prevent the recurrence of problems and to ensure continuous improvement of the system, these recommendations include warnings and suggestions. Based on the results of the analysis, recommendations for corrective action are determined and an appropriate plan for implementing solutions is provided. All of these outputs are part of the RCA analysis process and are used to take appropriate corrective actions and provide the necessary information to prevent similar problems in the future.

A commonly used tool in root cause analysis is the Ishikawa diagram shown in Figure 2. This diagram covers efforts to prevent defects in production, marketing, and service processes and includes the identification of all factors that affect the outcome. The causes of each defect are considered as a variation and are grouped in the diagram. The diagram has a fish-like shape; the defect or problem is written on the right-hand side, while the causes are shown as spiky thorns. Subgroups may be expanded depending on the range of causes.

This approach aims to uncover underlying relationships between variables and provide additional information on possible causes. Causes are usually identified through brainstorming sessions and grouped into categories within major industries. In the context of occupational health and safety, accidents are generally considered to be caused by training, personal characteristics, the work environment, or communication (Fig. 2.). For example, situations such as inadequate lighting or a lack of training for staff can have a negative impact. Picking the right fishbone among the causes is important. This methodology contributes to quality control and process improvement by providing a systematic approach to root cause identification.

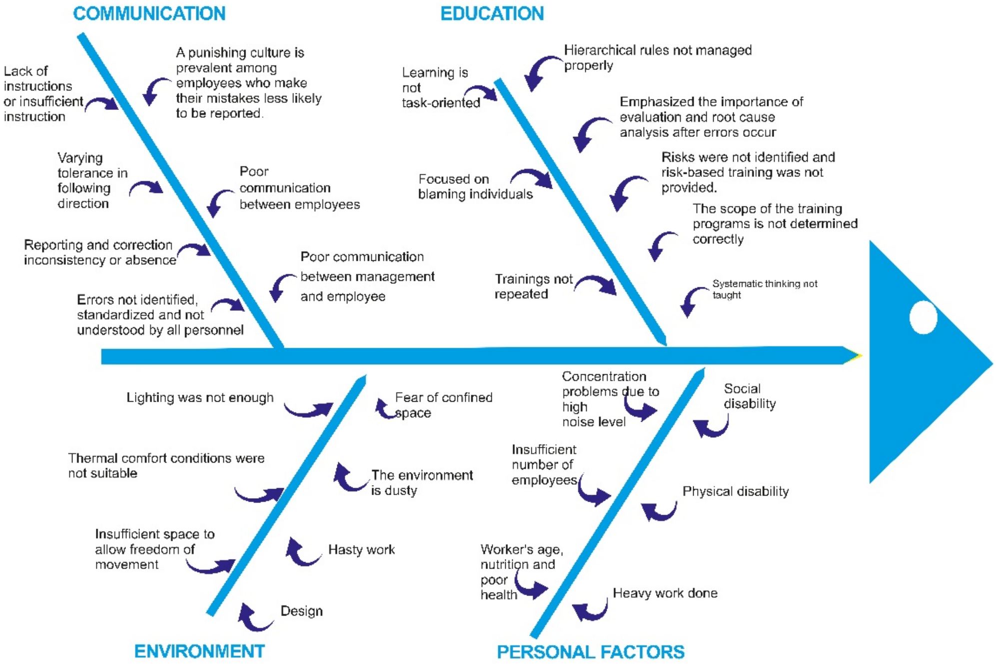

Figure 2. Fishbone or Ishikawa diagrams for root cause analysis (RCA).

3 Material and Metod

There are two main purposes for the identification of the causes of accidents in the work place. The first is to identify the causes of failures through failure investigations and to provide information on the risk situation in the workplace. This information includes determining the cause of the failures, identifying working conditions, raising awareness of risks, and identifying possible precautions. Secondly, the data is used to understand and prevent similar failures. Data from individual accident investigations are used to analyze similar accidents that occur in similar workplaces and to develop preventive measures. The first step in separating the factors that contributed to the accident is to identify the visible causes that led to the accident.

A team of experts with the necessary expertise to analyse the problem is required to perform RCA correctly. The opinions of supervisors, engineers, technicians, quality control experts and experienced tunnel workers were taken into account at this stage. The ideas of these experts approach the problem from different perspectives to understand the problem, identify the root causes, and support collaborative decision making. An investigation has been launched to gather information about the problem, including details of the time and place of the incident. The root cause of the problem or incident was determined and corrective actions developed by analyzing the data obtained. Using a results-oriented approach, the process continues with the evaluation of alternative solutions based on hypotheses. Were risks/hazards identified before the work was carried out? Were safety violations overlooked? Are there any design-related security flaws? Are the security systems in the environment working correctly? Was the work done in compliance with instructions? The identification of subfactors also includes the training that led to the accident, the way the work is performed and whether the work instructions are sufficient, as well as whether there are environmental factors that contribute to the accident (such as weather conditions, noise) and other factors that affect the worker's attention (such as overtime, stress, etc.). (Fig. 3.).

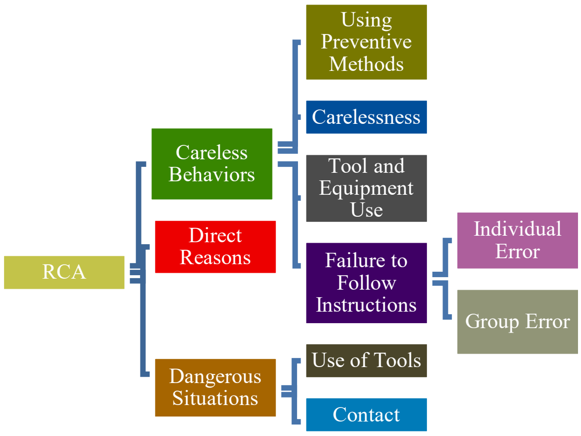

Figure 3. The search strategy of root cause analysis (RCA).

Through a systematic approach, this study identifies corrective actions to prevent the recurrence of the problem. Developing different solutions to the problem and implementing the most effective corrective action is the main purpose. Monitoring the implementation of corrective actions to ensure they are carried out correctly is the most critical step at this stage. The results of the implementation of the solutions should be evaluated and the necessary steps for further improvement should be in place. Analyzing data for accurate analysis, developing solutions, and continuously improving systems by identifying corrective actions prevents problems from recurring and continuously improves systems.

In this study, the causes of situations such as collapses and rock falls in tunnel excavation were examined in detail and a case study was presented using root cause analysis. In addition, the potential risks of these accidents were examined, emphasizing the need for engineering and administrative controls to prevent accidents and hazards. The aim was to identify the measures needed to prevent such accidents. This was done by analysing the causes of rockfalls in the Istanbul metro tunnel. A risk assessment was therefore carried out. The aim was to identify sources of risk and propose protective measures. The results of the study will provide guidance on how to prevent accidents during tunnel excavation.

4 Rockfall Hazards and Moment of Accident

Tunnel support structures are structural systems installed during or after tunnel excavation to provide ground support, maintain the opening, limit groundwater ingress, support fixtures and provide a sub-base for the final surface. These structures can be used to provide initial stabilization, to provide permanent support to the ground, or both [23].

Although the lining of a tunnel is a structural system, it has different behavior and stability characteristics to other structural systems. Their interaction with their environment is the main reason for these differences. Loss or inadequate support from the surrounding ground can cause tunnel lining failure. The ability of the tunnel lining to deform under load is determined by the relative hardness of the tunnel lining and the surrounding soil.

Tunnel linings are generally more flexible than the surrounding soil, and this flexibility allows the lining to deform in response to soil deformations during and after tunnel excavation. This deformation contributes to the development of strength and stability in the surrounding soil [24]. Due to the deformation of the tunnel lining, the moments redistribute the axial and eccentric loads within the lining. This shows that flexible and ductile tunnel liners are the most efficient [25].

Once excavation of the required tunnel opening has begun, the initial stress state is no longer valid and the excavated area is now subject to a new stress state. Soil is usually inhomogeneous and has been subject to large natural forces since excavation [26]. Once excavation is complete, appropriate support measures shall be taken to protect workers from falling materials, collapse hazards and other deterioration of the tunnel roof or crown. Figure 4 shows the material piled up in the working environment as a result of rocks falling from the excavation surface and roof following tunnel excavation.

Figure 4. Excavation surface and lining of surrounding rock.

In some formations, rockfalls can also occur if the face is not properly supported within a reasonable period of time after excavation. For these reasons, detailed field and laboratory studies should be carried out prior to excavation of underground structures to ensure proper and accurate reinforcement. This helps to prevent accidents and ensure safety at work [27].

As roof collapses and rock falls are among the most common causes of accidents in underground structures, it is necessary to understand the conditions that lead to them in order to prevent such incidents and take protective measures. The geological conditions, the stresses, the design of the tunnel and the impact on the environment can be noted as examples of these conditions [28]. In order to strengthen or balance the underground rocks, ground control is carried out. There are two stages for this purpose. In the first stage, measurements such as how excavation work will be done and which reinforcement will be used where are made during the design phase. The second stage consists of operational measurements. Depending on the design of the tunnel, measurements and precautions will be taken to adapt to changing conditions as the tunnel progresses [29].

Reinforcement systems should be designed in accordance with the geology, stress conditions and tunnel opening geometry. For a good reinforcement system, the dimensions and geometry of the tunnel should be well understood, and all factors such as blast damage, geological discontinuities and stress conditions should be taken into account. It is therefore necessary to investigate in detail all the factors that may have an influence on the formation of roof collapses and rock falls. The scientific, impartial and targeted assessment and management of potential risks during tunnel construction is of the utmost importance. This ensures the safety of tunnel construction. It also minimizes the risk of loss of life and property. Therefore, risk assessment and management should be carried out with great care in the design and implementation of tunnel projects.

The "Underground Space Use: Analysis of the past and lessons for the future" report published by the International Tunneling and Underground Space Association (ITA) provides detailed statistics on accidents that occur during tunnel construction [30]. According to the report:

- Since 1950, there have been at least 340 accidents in tunnel construction around the world.
- At least 660 people died and thousands were injured in these accidents.
- The most common cause of accidents is roof or floor collapse. About 50% of these accidents are fatal.
- Fire, explosion, collision with work equipment and industrial accidents are other common causes of accidents.

An investigation has been carried out into the accident that took place on 04.03.2021. The accident occurred as part of the Sabiha Gökçen-Tavşantepe metro project. RCA analysis was used in the investigation. Similar accidents in all tunnels can be predicted from the findings and results of the accident investigation. The progress of the tunnel excavation started at 07:00 and was completed on schedule at 08:30 with the completion of the 0.8 metre excavation step. Immediately after the tunnelling machine emerged from the tunnel face, a loader was brought in to remove the excavated soil, which was completed at 09:30.

The excavated area was then covered with sprayed concrete, with a thickness of 5-10 cm, and reinforcement work began. However, the ground collapsed during the reinforcement work. A 1.5 to 2 cubic meter section of the ground fell on four workers. The workers were trapped under 30 kg of steel mesh, and the steel mesh they were holding also hung down to the ground due to its weight. Three of the workers suffered serious injuries such as fractures and crush injuries due to the falling materials, while the other worker survived the accident due to being positioned near the edge of the loader bucket. Between 2018 and 2021, there were nine accidents at different construction sites on the project, all as a result of material fall incidents. The investigations revealed that the common cause of all these accidents was falling material. Three of the accidents resulted in serious injuries, including broken feet and hips, while the rest of the accidents resulted in minor injuries. These data show that tunnelling is a high-risk activity.

The route on which the accident occurred is the Sultanbeyli Formation, a structure consisting of unconsolidated sand, gravel, clay and sometimes block-sized fragments with horizontal and vertical transitions. The layers of this formation are named Orhanlı Member, Dudullu Member, Tuğlacıbaşı Member, Altıntepe Member, and İkiz Tepeler Member, each having different lithological characteristics. Specifically related to the examined accident, the left rear face of the Kuyruk Tunnel is located in the Orhanlı Member, which mainly consists of clay, silt, and fine sand-sized materials. These materials are bluish-gray when fresh and turn light brown as they weather. Fine-grained clay-silt materials dominate the rock type and occur as lenses and interbeds containing sand-gravel and block-sized unconsolidated materials in some areas. This formation also contains basal conglomerates of coarse material derived from the shoreline. Calcareous concretions are also present. Fine-grained clay-silt materials, which may contain varying amounts of limestone, predominate in all layers of the reservoir environment in the outlying parts of this formation.

5 Discussion

During the excavation, which was carried out entirely in the direction of tunnel advance, a 5cm layer of shotcrete was applied to the area opened up by the removal of the excavated material. The concrete was allowed to set for 15-30 minutes before reinforcing work began. During this process, however, particles of soil were falling on the workers when they broke off (Fig. 5). The soil excavated in the tunnel is generally composed of a clayey soil that contains sandy-clayey layers belonging to the Sultanbeyli Formation. Clay is a very cohesive material. However, it loses its cohesiveness when sand gets into it, and the sandy parts usually break and fall out [31]. Predicting fragmentation in such soils is extremely difficult [32]. In cases where we cannot prevent the main material from separating from the ground, it may not be possible to control or eliminate the hazard at source from an occupational safety perspective [33]. Therefore, control and prevention of this hazard must be achieved through the use of engineering methods. Techniques such as shotcrete, which is applied prior to excavation, are often used to prevent soil fragmentation. However, it was found that the shotcrete applied to the front of the fragment after an accident was not durable enough to hold the piece in place. There are two possibilities regarding the durability of the shotcrete used after the accident. The first possibility arises from the fact that the sprayed concrete may not have hardened sufficiently, which could result in inadequate strength.

However, there are a number of factors that can influence the setting process of the concrete [34], this requires an in-depth analysis by the quality department. According to the findings of the quality unit, the temperature values of the concrete produced at the time of the accident were approximately 12 degrees Celsius, and no evidence was found that the setting problem was caused by cold weather conditions. The concrete plant must therefore deal with any defects that may affect the concrete setting process. The second possibility is that the durability of the shotcrete that was applied was not sufficient to hold the separated piece in place. In the examination conducted by the Quality Unit, it was determined that the design and control studies of the shotcrete included cement and additive compliance tests, and the initial setting time of the concrete was approximately 1 minute. According to penetration measurements of 2.5 and 10 minutes in field tests, the values range from 0.6 to 2.1 MPa, and according to laboratory compressive strength tests, the value ranges between 27.5 to 31.6 MPa one day later. Although the laboratory results are positive, the field tests do not confirm this.

For the concrete to hold the separated piece in place, high tensile strength is required [35]. This can be achieved by increasing the thickness of the concrete. However, there is a limit to the maximum thickness of shotcrete that can be applied without reinforcement [34]. Unreinforced shotcrete can be applied up to a maximum thickness of 7cm, and can be applied at greater thicknesses and the tensile strength of unreinforced concrete remains low (approximately 2 MPa) [36]. As an alternative, reinforced concrete can also be used to solve the problem. This can be achieved by installing a mesh on the excavated surface. However, this approach can lead to workers being exposed to more hazards. To increase the tensile strength of the shotcrete, steel wire can be incorporated into the shotcrete [37]. In this way, not only can the strength of the concrete be increased, but also the falling of material from the ground can be reduced, and any fallen pieces can fall over time. In this way, the falling of material can be largely prevented, or workers can be given time to escape from the danger zone because the separated material will not suddenly fall.

The main causes were the workers' desire to work quickly, which resulted in more people than normal being in the loader bucket (the maximum should have been three), and insufficient escape space in the event of an accident. The use of a suitable basket platform for the reinforcement work could have remedied this situation. Compared to loaders, however, such basket machines are less manoeuvrable. In the event of a cave-in at height, the confined nature of the working area of these machines does not allow for rapid escape. Loaders are faster in this regard. In addition, to prevent workers from falling, the loader operator must be more careful when reversing. This was also a point of reference for the workers in their statements on the incident. Despite its shortcomings in this regard, the loader will always be faster and more advantageous than the basket machine in escaping from the danger zone (Figure 6.). The risk of overturning due to parts falling from the floor hitting the machine is another disadvantage of basket machines [38]. This can further worsen the possible outcome of the accident. However, it is important to remember that when using loaders, there is a risk of workers falling from the bucket during sudden reverse manoeuvres. Using different machines for each task in narrow areas such as tunnels is not very effective in terms of space.

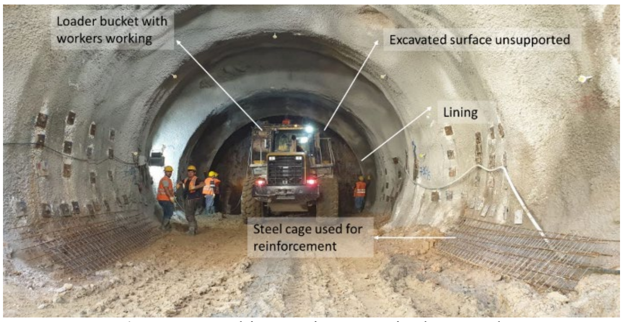

Figure 5. Working environment in the tunnel.

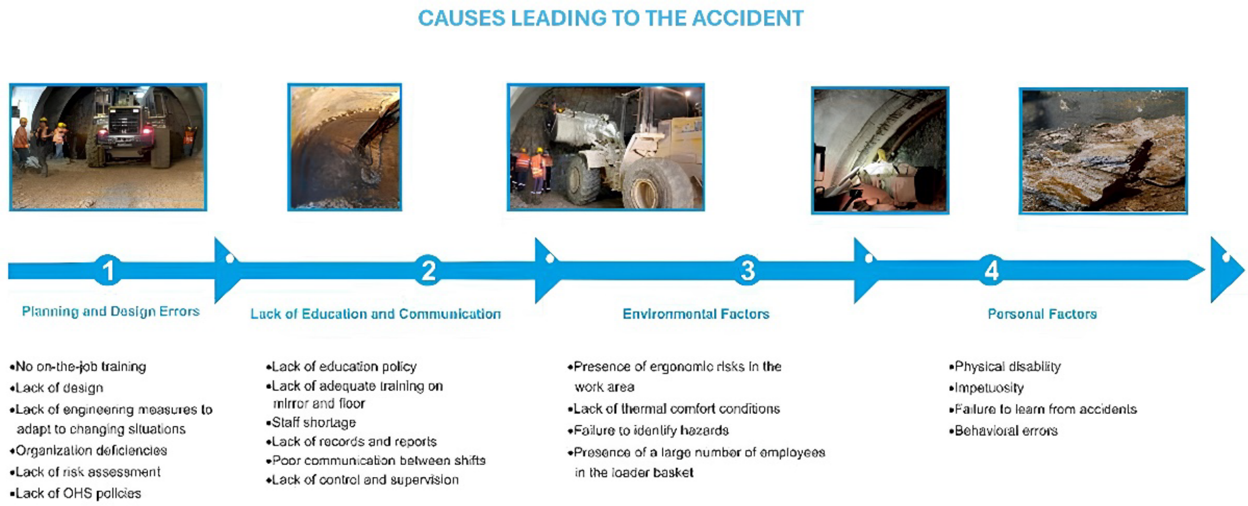

Figure 6. Causes leading to the accident.

Workplace-based training has been reviewed and its outcomes evaluated. The question "Why were these rules not followed?" was asked. Were these rules and procedures explained to those responsible, and was the importance of compliance understood? Do the control personnel have the necessary knowledge and experience? Negative answers to these questions are an indication that a safe environment has not been in place due to a lack of training. This can also be interpreted as a failure of management. The fact that the majority of workers answer 'yes' does not absolve employers of their responsibilities. Providing training does not absolve employers of their responsibilities; monitoring the use of authority and responsibility is the responsibility of the employer [39].

6 Conclusion

According to the findings of the study, it can be concluded that personnel, management and communication problems are often identified as the causes of accidents. Such problems have been then manifested as critical risks, which in turn have caused accidents.

Personnel problems can result from inadequate training and experience of workers, inadequate knowledge of how to use appropriate equipment, failure to follow safety procedures and careless behavior. Management deficiencies include physical deficiencies such as inadequate infrastructure, non-compliance with legal requirements, unclear roles and inadequate risk management strategies. Communication problems can arise from interactional breakdowns between workers and managers, inadequate or incorrect transmission of instructions, lack of accurate information during emergencies, or misunderstandings among other factors. A key role in preventing accidents will therefore be played by improving the way people work, manage and communicate in the workplace.

As also underscored above, root Cause Analysis (RCA) is the systematic investigation of the underlying, hidden causes of a system failing or causing an adverse event. RCA is a structured and process-oriented framework. It aims to address systems and organizational issues. It avoids negative individual blame. However, there are also significant methodological limitations to the RCA. RCAs are typically uncontrolled case studies and it is impossible to know whether the root cause identified by the analysis was actually the cause of the accident due to the incomplete predictability of accidents. Furthermore, these analyses are retrospective and may be affected by hindsight bias. Other biases may be the result of the depth of the investigation into the causes, or the prevailing concerns of the day. It is therefore important to plan the RCA process well beforehand and to conduct the analysis objectively and unbiasedly.

Declaration

Ethics committee approval is not required. The photos used in the manuscript were taken by the author of the study. For that reason, no any permission is required and no need to make any citations.

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