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Hazard Management in Tunnels' Construction: State-of-the-Art

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Abstract

The construction industry has one of the highest work accident rates in the world when compared to other industrial undertakings, particularly tunneling construction. Risk events are often interrelated. The occurrence of a technical risk usually carries a cost and scheduled consequences. Schedule risks typically impact cost escalation and project overhead. Some projects are primarily schedule-driven; other projects are primarily cost or quality-driven. The objective of this study is to perform a comprehensive investigation about hazards and risks in the construction process of tunnels by carrying out a state-of-the-art study on the most critical risks in tunnel construction projects. The methodology used was a systematic review of all available literature in the previous studies. As a result of the review, as ix-group risk categorization was developed, which includes risks associated with confined spaces, ventilation &air monitoring, fires, physical &chemical hazards, electricity, personnel safety& emergency plans. According to the output of this study, managing hazards and risks will aid managers and engineers in attaining their goals, achieving safety management, reducing, and controlling accidents and injuries in tunnel construction sites. This will result in a safer workplace, more worker awareness, and a reduction in project schedules and costs.

Keywords: Safety Management, Risks, Tunnel construction.

1. Introduction

With the rapid development of underground construction, a great number of tunnels will be created in locations with geological conditions that are unprecedentedly complicated [1].During construction, tunnels avoid disturbing or interfering with surface life and traffic. Beyond a certain depth, tunnels are more cost-effective than open cuts. Tunnels can be carved out of rock, soil, or a combination of the two. Because these constructions are made of natural materials like rock and soil, geological circumstances have a significant role in their stability.

Over time, many types of tunnels have emerged to better serve the public. [2]confirmed that ground considerations, access limits, computerized techniques, scale economies, and horizontal/vertical inclination are all geology and cultural factors that have influenced various sorts of construction. Drill and blast, cut and cover sequential excavation and mechanized boring methods are only a few of the tunnel excavation methods that have been explored. However, due to uncertain hydrological and geotechnical circumstances, insufficient supervision of risky conduct, hazardous constructions of equipment, and workplace environments, underground metro construction accidents occur regularly.

2. PROBLEM STATEMENT

Working in confined spaces, particularly tunneling construction, entailsa distinct set of risks, when compared to other construction projects.

It has been several incidents that have resulted in delays, over budget or in rare cases, more serious repercussions such as injury or death.

As a result, the risks have been identified and investigated to help project managers in managing risks and hazards, which can be implemented by following the stated methodology in this study.

3. PREVIOUS STUDIES

[3]presented a study that states that the construction sector is among the worst rates of fatalities and injuries when compared to its competitors, although innovative improvements and the establishment of efforts to improve occupational health and safety. The findings suggest that while simulation and optimization techniques have progressed over the last two decades, and when it relates to modeling safety-related threats, there is still scope for development.[46] stated that tunneling has recently gained recognition as a form of construction that is favorable to the environment, especially increasing transit and sewage network capacity in a world that is becoming overcrowded, featuring metro tunnels with big diameters and tunnels with modest diameters, which constructed throughout the year by utility organizations to transport water, drainage, and communication connection among other things.

[4] presented a study that identified the differences to be made between tunneling execution and general and mining execution. Even by their nature, practically all non-tunneling activities, including ordinary construction, do not work 24 hours a day, 7 days a week. As a result, non-tunneling labor does not require 24/7 shifts, and they are frequently employed only in specific circumstances and for a limited time.

Ryu indicated that the metro system provides a quick, convenient, and effective mode of public transit, and it plays an essential role in reducing traffic congestion and enhancing the city's operating efficiency tunneling techniques utilizing a Tunnel Boring Machine (TBM) are increasingly used in urban constructions (e.g., subways, roads, and power cable tunnels). TBMs, on the other hand, can occasionally result in unpredictable and unmanageable circumstances. One of the most important practical goals when using TBM techniques is to maintain a high level of safety [5].

[6]presented a study that indicates that even a consequence of the precautions for safety, reduced expenses, and improved effectiveness, the building of the tunnels has progressed from wooden support to steel arch support to shield tunneling (New Austrian Tunneling Method), NATM methods. [7]discussed the astonishing step of constructing the central underground segment of the first line of the Cairo Metro in the early 1980s, as well as several tunneling techniques. Boring machines were used for the first time in Cairo in the late 1980s to build the spine tunnel of the Greater Cairo Wastewater Project. These two projects' outstanding success aided in the transmission of much-needed new construction technology like diaphragm walls, bentonite slurry TBMs, pipejacking, and grouting. From 1994 to 1999, improved versions of these technologies were utilized to construct the second line of the Cairo Metro, which connected the three parts of Greater Cairo (Cairo, Giza, and Qalioubeya). They were also used in the building of other huge underground projects such as the Al-Azhar twin tunnels, which were built using a TBM, and the Orouba Road cut-and-cover tunnel, which was built with a diaphragm and tangent pile walls.

[8]indicated that employee attitudes toward, and perceptions of, health and safety behavior help compensate for the organization's safety climate. The perceptions of risk, management, and safety laws and procedures all influence construction employees' attitudes toward safety. Even though the study on safety climate has lasted more than two decades, no broadly recognized theory of safety climate exists. Nonetheless, in construction site environments, there is a favorable association between workers' safe behavior and the safety climate. Another study by[9]confirmed that "Safety First" should be one of the primary goals of any

construction project, particularly a tunnel, and it should be emphasized throughout the construction process.. It is impossible for a single person to accomplish it out of their own.

4. CATEGORIZATION OF RISKS AFFECTING SAFETY MANAGEMENT

Categorizing risks aids managers and engineers to focus on the most significant risks that affect the cost, schedule, and safety of tunnels' construction projects, accomplishing safety management and minimizing and controlling accidents and injuries in tunnels' construction sites. So, a risk categorization consists of six groups was developed, which are:

1. Confined spaces - related risks
2. Ventilation and air monitoring - related risks
3. Fire-related risks
4. Physical and chemical hazards - related risks
5. Electricity-related risks
6. Personnel safety and Emergency plans - related risk

These risks will be discussed according to each related group in the following section, as described below:

4.1 Confined spaces-related risks

[10]stated that oxygen deficit, pollutants inhaled through the air and climate, physical risks such as falls from height, electrification, rotating parts and machines, and the possibility of engulfment in free-flowing substances and fluids are all hazards in confined spaces. Many serious accidents occur because of working in confined places.[11]indicated that considering all the attempts at regulation and standard-setting, enterprises appear to be having trouble assessing risk for interventions in confined locations. In most fatal accidents, there was no risk identification or estimation.

[12] explained that guardrails, handrails, walkways, and platforms are commonly constructed from an open structure of horizontal, vertical, or inclined pipes. But, in some situations, such mechanisms are insufficient in preventing dropped things, such as tools, from escaping the bounds of the railing system and posing a hazard. [13]showed that to produce a secure underground project site, a safety boundary alert technology based on the Internet of Things (IoT) has been presented, which would create a system for hazardous energy tracking as well as utilize IoT to produce earlier alerts and sirens for hazardous energy on underground project sites as dynamic security boundaries. The Internet of Things (IoT) has been created to assist workers in modifying their hazardous habits and avoiding mishaps in the ever-changing locations of construction. The execution of the Yangtze River crossing Metro Tunnel project has demonstrated that safety has increased, and accidents produced by dangerous energies on-site may be avoided.

[14]has analyzed and ranked risks, with a risk rating of 21.5, and a risk degree classification of "Critical," rock fall risk was assessed to be among the most dangerous.[6] explained that rock falls occur at the cutting edge during the construction of a tunnel utilizing the mountain tunneling technique, particularly the New Australian Tunnelling Method (NATM), for a variety of reasons, including the Construction (Design and Management) Legislation, which do not place responsibility on the clients, allowing the contractor and subcontractor to manage the workers' health and safety on their own, or even when technicians explode explosions in the cutter face or place steel arches support.

Other factors have a significant role in fatal accidents that occur in confined places in Quebec, according to a comprehensive investigation. Moving components of machinery, for example, account approximately 20percent of the total death, with an accounting engulfment for 15percent,falling items accounting for 12.5 percent, and falls from a high place accounting for 12.5 percent of the total[15].

4.2 Ventilation and air monitoring-related risks

[16] stated that companies should provide a pleasant and comfortable working environment. According to research, 46.2 percent of employees in the study organization find that environmental aspects such as temperature, lighting, and ventilation are highly beneficial to work.

[17]showed that the dust emitted during the construction of a tunnel with the aid of a shield tunneling machine is a significant aspect that influences the environment of working. A dust-removal system in the ventilation system is an excellent instrument for preventing dust particles from spreading. The effects of a high-pressured air flow rate, flow rate of air extracting, and the diameter of the air duct, which is pressurized, on dust control distance are explored in depth using an orthogonal test. The dust control distance for the system of ventilation dust removal was 23.54 meters after using this ideal combination. As a result of this ideal ventilation system, the dust created around the primary engine can be managed,

and dust control performance can be significantly enhanced.

[18]explained that longitudinal ventilation was used in tests under various fire circumstances. The rate of fire spread is highly dependent on the speed of longitudinal ventilation. On a wide scale, the rise at a velocity of 2.9 m/s (0.60 m/s) is with the order of 2 times the fire rate of growth beneath the environmental temperature, and at 4.3 m/s (0.9 m/s), this is in the order of 3 times the fire growth rate.

Carbon monoxide caused 26% of the fatalities in confined workplaces induced by the atmosphere, oxygen shortage caused the death of 95 people, which represents18%, and hydrogen sulfide caused the death of 44people, which represents 11% of the fatalities. Unfortunately, in 52% of cases, the drug was not detected. in Quebec from 1998 to 2011, hydrogen sulfide was the highest prevalent hazardous atmosphere that causes confined space fatalities, accounting for 19.5% of all deaths. The large percentage of confined space policies, rules, and laws in each country studied that 19.5% is considered a minimum valid quantity of oxygen in terms of volume, but Canada is the only exception, that allows work to be done in an environment having low percent which is 18%[15]

4.3 Fire related-risks

[19]investigated that the fire properties of a tunnel during progress are likely to differ from those of a completed tunnel, as are the methods of evacuation and firefighting, as well as the safety equipment selections. Consequently, the risk of fire during tunnel construction may be greater than the risk of fire during typical tunnel operation. Several fires have previously arisen during tunnel construction, resulting in the death or injury of people, as well as disruptions and expenditures for equipment and the tunnel's structure, and significant project delays. The severity of these fires is determined by their location in the tunnel, as well as their effectiveness, the fire's features, the complexity of underground infrastructure, the rescue service's response, personnel, and equipment represent examples of resources. The control of tunnel fire risks throughout 2 TBMs operating in an underground coal region within Istanbul was aided by the 2 most unfortunate incidents in Turkish mining sites, as well as 2 fires that happened in 2 TBMs tunnels and the execution of 2 EPB TBMs in the petroleum-contaminated ground. The following are the main suggestions: Welding and cutting processes are banned near the lines of hydraulic power and conveyors' belt, and fire-resistant belts must be utilized. Then, in 2021, [20]showed a study that advised a methane risk level training session for tunnel workers and staff.[10]indicated that flammable climates could cause fires and explosions, putting employees in tight spaces at risk of injury or death. Workers' exposure to combustible atmospheres is limited bythe standards and practices of the legislation codes. This restriction is commonly expressed as a percentage of the (LEL) Lower Explosive Limit, which is described as the amount of gaseous, condensate, or moisture within the air beyond that a flame does not expand when it meets a source of fire. [21] investigated that under the construction of a lengthy and tiny tunnel, a numerical investigation of a water curtain technology for fire evacuation was conducted. The use of water curtains could help to keep the leaking of smoke outdoors by cooling it and allowing for safer evacuation. Outside the water barrier, it can significantly reduce carbon dioxide levels while significantly increasing oxygen levels. However, near the water tunnel's lowest part, the smoke density will be significantly increased, and visibility will be reduced, due to the water curtains.

4.4 Physical and chemical hazards-related risks

Heat stress can be caused by activities involving rising air degrees and moisture, sources of thermal radiation, touch with heated items on a physical level, or physical exertion tasks for individuals in specialized industries. Heat-related illnesses could arise in locations where heated conditions put at-risk personnel at risk. If not treated promptly and effectively, temperature extremes can cause developments in the body's symptoms, resulting in massive damage to the tissues, damage to the organs, as well as death. Heat in the workplace can be reduced through technical controls, standard operating procedures, and personal protective equipment.

[22]has categorized risks as follows: Toxic gases such as Ammonium vapors, dusty threats, extreme heat and wet industrial environments, slipping, hygiene, pharmaceutical contamination, O_2 shortage, illumination, loud sound, and also unguarded borders, they're all categorized as "Medium" risk[14]. In 2015, Burlet explained the major causes of death, which were poisoning and asphyxiation. Hydrogen sulfide was responsible for seven deaths.

Amongst the most common physical pollutants in the construction field is noise.[23]explained that the effects of exposure to noise on the hearing system are still the most severe, which can cause partial or complete deafness, as well as permanent deafness. These levels are so high that 60 to 70 percent of construction workers are subjected to a noise dose greater than 100 percent during their working day. Because of this lack of awareness, and because of the nature of the workplace, where machines must be operated throughout the working day, there is a significant level of noise exposure, with the high-frequency components being more.

[25]showed the most common incidents that resulted in lost work hours were those involving lifting and handling. To reduce the amount of manual handling work done by workers, it was advised that they use special tools and machines, as well as proper personal protection equipment, depending on the sorts of work they do, assuming that these tasks cannot be mechanized. Supervisors of workers should have appropriate expertise and understanding to encourage workers to complete their tasks securely [24].Also, Taha (2021) indicates that due to a lack of appropriate equipment, manual labor is encouraged, resulting in a long time to finish the task.

[26]stated that working more than 48 hours a week is considered extended work hours. Shift work and working long hours both have the potential to disrupt biological and social cycles.[27] also indicated that individuals who have trouble adjusting to irregular work hours, sleep, and rest may suffer unfavorable health consequences as a result of this.[28]explained that shift employment, particularly night work, has been connected with social problems, coronary heart disease, mental health issues, sleep disturbances, and digestive issues, according to studies.[25]confirmed that overtime causes an increase in accidents, a fall in morale, a reduction in supervision efficiency, an increase in absences, and a decline in job quality, all of which lead to more rework.

4.5Electricity related risks

[14]indicated that the risk scores for vibration and electrical hazards were found to be 13.35 and16, correspondingly, both are rated as possessing a significant degree of risk, while Selman (2018) explained that each year from 1988 to 1989, at least one worker died because of electrocution at work. Between 1988 and 1989 and 2004-05, with 39 people died as a result of electrocutions, accounting for 9.8% of all deaths (394) over that period [10].[29]stated that according to the CFOI, 1,651 workers died in the United States because of an electrical injury between 2007 and 2016. Although modifications to the OIICS coding system introduced in 2012 make it difficult to compare injuries before and after the same year, it is still possible to use total electrical injury totals from each of the ten years to demonstrate the trend in electrical fatalities at work. It reveals that fatalities have decreased over time, with a high of 212 fatal electrical injuries in 2007 and a low of 134 fatalities in 2015. Annual injury totals were lower in each of the five years from 2007 to 2011 than in any of the five years prior.

4.6 Personnel safety and Emergency plans-related risk

In 2017, a study explained many injuries and fatalities happen in construction workplaces, even including underground construction sites than in normal operations. Despite this, the construction sector has paid less attention to the monitoring of hazardous energy and safety barrier analyses. [13]. Also in 2021, a study investigated that tunneling constructions personnel are subjected to a variety of occupational circumstances that can make them more prone to fatigue, taking into account the external conditions, monotonous tasks that must be done repeatedly, shift schedules that vary, and work that requires manual labor, pressures resulting from shift work, exposure to demanding workload, and physical efforts such as manual digging, all of which can reduce optimal performance, sleepiness, and circadian disruption [4]. In 2017, a study was conducted to show that accident rates are high due to a variety of issues, including insufficient design safety, a shortage of construction planning, insufficient training in safety, the attitude of the employees, and a shortage of understanding of workplace laws. By offering appropriate training courses in the H&S for employees, focusing exclusively on H&S during the project planning phase, and strengthening consequences for unsatisfactory H&S conduct, the danger of construction to the life and well of workers might be reduced[24].

Wikins(2011) indicated that Findings clearly showed more comprehension leads to better practice and that if the training plan includes content that is relevant to the person, the likelihood of comprehensive learning increases considerably [30]. According to studies, Individuals' risky behavior, environment workplace, or unsafe industrial machinery are responsible for 80–90% of accidents, particularly within the industry of underground projects. As a result, there is a need to dynamically and automatically elevate worker awareness of the possible threat on the work site [28, 29].

Finally, Table 1 lists the other prevalent risks that have been found because of extensive review of previous research.

[45]concluded a flexible system for generating communications and training programs, to enhance the safety awareness of underground tunnel employees, which may also be advanced and updated by site safety staff. Using a smartphone-based interface, construction site staff can review the associated site's safety standards and complete the safety checklist as needed daily. Simultaneously, the site safety representative could create and give a workout plan and use the integrated system that is customized to the urgent and specific needs of each employee. Following up with an 'evaluation test,' the trainees will face obstacles in the construction and operation of beneath tunnels.

Table 1. Tunnel construction Risks

Categories	Risks that impact tunnel's safety management	References
Technical risks	• TBMs launch and arrival • Tunnel excavation • Later specification changes • Noncompliance with design standards • Site Access • Cooperation with utilities and adjacent neighbors.	[33] , [34]
Geological risks	• Failures in geotechnical investigations	[35]
Environmental risks	• Pandemic of COVID-19 • Inclement Weather • Climate change	[36]
Social risks	• Restrictions based on ethnicity and geography • Lack of collective consent • Worker's turbulences and strikes • The high unemployment	[37] , [38]
Human risks	• Productivity and skills • WorkforceAccess • Labor rights, Salaries, violations, wages, andSalaries	[39]
Political risks	• Government policy changes • Elections, Internal and external threats, • Changing expectations of political events (Wars, revolutions, coups, etc.)	[40]
Contractual risks	• Delay in resolving disputes • Payment delay • Variation of contract and amount of actual work	[41] ,
Cost and schedule risks	• Unrealistic cost estimates • Incorrect financing ways • Budget distribution	[42] , [43] , [44]

5. CONCLUSIONS

All inherent risks associated with the development of tunnel projects have long been a point of discussion.Thus, tunnel venture development firms and local experts must continue to strive toward safety and security management. Tunneling imposes risks on all parties involved directly or indirectly in the project. These risks may dramatically impact on construction, operation, and maintenance of tunnels, which most probably lead to cost and time delays.

The objective of this study is to perform a comprehensive investigation about hazards and risks in the construction process of tunnels by carrying out a state-of-the-art study on the most critical risks in tunnel construction projects. The methodology used was a systematic review of the literature in the previous studies.

As a result of summarizing, a six-group risk categorization was created, it includes risks associated with confined spaces, ventilation & air monitoring, fires, physical & chemical hazards, electricity, personnel safety & emergency plans.

As a result of this study, managing hazards and risks will aid managers and engineers in attaining their goals, achieving safety management, reducing, and controlling accidents and injuries in tunnel construction sites.

This will result in a safer workplace, more worker awareness, and a reduction in the project schedule. Construction risks to workers' lives and well-being will be reduced by providing sufficient safety training for personnel, emphasizing safety throughout the project design and implementation phase, and increasing penalties for unsafe behavior.

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