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General Risks For Tunnelling Projects: An Overview

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Abstract. Tunnels are indispensable when installing new infrastructure as well as when enhancing the quality of existing urban living due to their unique characteristics and potential applications. Over the past few decades, there has been a significant increase in the building of tunnels, world-wide. Tunnelling projects are complex endeavors, and risk assessment for tunnelling projects is likewise a complex process. Risk events are often interrelated. Occurrence of a technical risk usually carries cost and schedule consequences. Schedule risks typically impact cost escalation and project overhead. One must carefully consider the likelihood of a risk's occurrence and its impact in the context of a specific set of project conditions and circumstances. A project's goals, organization, and environment impacts in the context of a specific set of project conditions and circumstances. Some projects are primarily schedule driven; other projects are primarily cost or quality driven. Whether a specific risk event is perceived fundamentally as a cost risk or a schedule risk is governed by the project-specific context. Many researchers have pointed out the significance of recognition and control of the complexity, and risks of tunnelling projects. Although all general information on a project such as estimated duration, estimated cost, and stakeholders can be obtained, it is still quite difficult to accurately understand, predict and control the overall situation and development trends of the project, leading to the risks of tunnelling projects. This paper reviews all the key risks for tunnelling projects from several case studies that have been carried out by other researchers. These risks have been identified and reviewed in this paper. As a result, the current risk management plan in tunnelling projects can be enhanced by including all these reviewed risks as key information.

INTRODUCTION

Tunnels are indispensable during the installation of new infrastructure in congested areas as well as when enhancing the quality of existing urban living. Tunnels are underground space equipped with unique characteristics and potential applications that able to serve as railway transportation, roadway transportation, storage, civil defense, power and water treatment plants, space for other utilities and other activities [1]. Over the past few decades, there has been a significant increase in the building of tunnels in the world. For instance, the capital of China, Shanghai does not even own a metro framework before 1995. However twelve years later, it had a systematic metro framework with most of them are consisted of underground tunnels. In world-wide, the tunnel frameworks have been expanding trailed by fast development of tunnels and it is shaping parts of the complex systems, for instance the Oresund link situated between Denmark and Sweden has a few structures in its system including a tunnel and a bridge [2]. And also, the Gotthard Base Tunnel, currently in the operation stage after two decades of construction work in Switzerland, will, at 57km, be the longest tunnel in the world.

Tunnelling projects are complex endeavors as they are differ from on-ground structures and design conditions vary case by case. In other words it is relatively difficult to construct tunnels in all types of locations and most importantly it is not uncommon for any forms of risk to occur especially after tunnel completion, during operation and maintenance stage. Tunnelling impose risks on all parties involved directly or indirectly in the project. These risks may dramatically impact on operation and maintenance of tunnels especially in major cost and time delays. Due to the inherent

uncertainties, the tunnels are exposed to various hazards resulted from risks such as seepage, crack, concrete delamination, steel corrosion, drainage and decay of the lining structure in the tunnel.

These hazards may resulted in fatal incidents and huge loss of life and properties. A few well-known incidents that have focused attention especially on fire during operation and maintenance stage have been tabulated in Table 1 [3, 4].

TABLE 1. Major Tunnel Fire History [3, 4]

Country	Year	Tunnel	Death/persons
Azerbaijan	1995	Baku Subway	289
Austria	1999	Tauern	12
Italy	1999	Mont-Blanc	39
Austria	2000	Kaprun	155
Switzerland	2001	St Gotthard	11
Switzerland	2006	Viamala	9
Melbourne	2007	Burnley	3
California	2007	Santa Clarita	3

The construction of the Channel Tunnel between France and England stimulated both experimental and theoretical research work. But this did not prevent a few serious fire incidents taking place in the Channel Tunnel about 2 years after opening, year 1996 and also during year 2008. Fortunately there were no deaths in both fire incidents [3]. Even when fire does not result in deaths, the damage can cost millions of losses and bring towards severe disruption and consequential losses. As mentioned, following the fire in year 1996 and 2008 at the Channel Tunnel, the third closure due to fire in the tunnel's history, full service was not resumed until year 2009 after repairs costing an estimated 60 million Euros. Besides, the estimated cost to the Italian economy of the three years Mont Blanc Tunnel closure after fire incident during year 1999 was 2.5 billion US-Dollars, while the cost of upgrading the service was 206 million Euros [4]. The Heathrow Express Link tunnel in the UK (1994) and the Shanghai Metro in China (2003) have incurred losses of 141 million US-Dollars and 80 million US-Dollars respectively due to tunnel collapsed [5]. In short, the occurrences of accidents and other dangerous events may be not that critical sometimes in tunnel but it can result in catastrophic consequences as per mentioned.

This paper reviews all the key risks for tunnelling projects from several case studies that have been carried out by other researchers. Tunnelling projects as a very special and sophisticated branch of the engineering sciences is characterized by high risks even after project completion, which is during operation and maintenance stage. In order to be in position to cope with risks in tunnelling a high degree of transparency is required. The final outcome of this paper is the overview of risks for tunnelling projects based on initial findings obtained from in depth study of major tunnelling projects' accidents.

MAJOR ACCIDENTS IN TUNNELLING PROJECTS

The Pucara headrace tunnel is a 2.6m diameter tunnel forming part of the Pucara hydroelectric power plant located in the province of Tungurahua, 35km East of Pillaro city and 160km South East of Quito, the capital city of Ecuador. The plant was one of the prime plants supporting power supply system.

A landslide due to a large scale of slope failure which was taking place parallel and adjacent to the end stretch of the headrace tunnel with about 300m affected area had cut off the normal operation of the plant in September 2011 as shown in Fig. 1. There are a few damages detected in the concrete lining during the incident, for example displacement and cracking at the end stretch of the headrace tunnel [6]. The slopes failure usually puts human life in critical danger and it is also a disaster for the economy.



FIGURE 1. The landslide that affected the headrace tunnel [6]

The continuously cracking propagation has seriously caused the damage impact to the arch effect on the concrete lining of the tunnel. A compression of both semi-circumferential concrete parts happened which has developed the maximal compressive stress resulting the rock spalling at the tunnel roof as shown in Fig. 2.

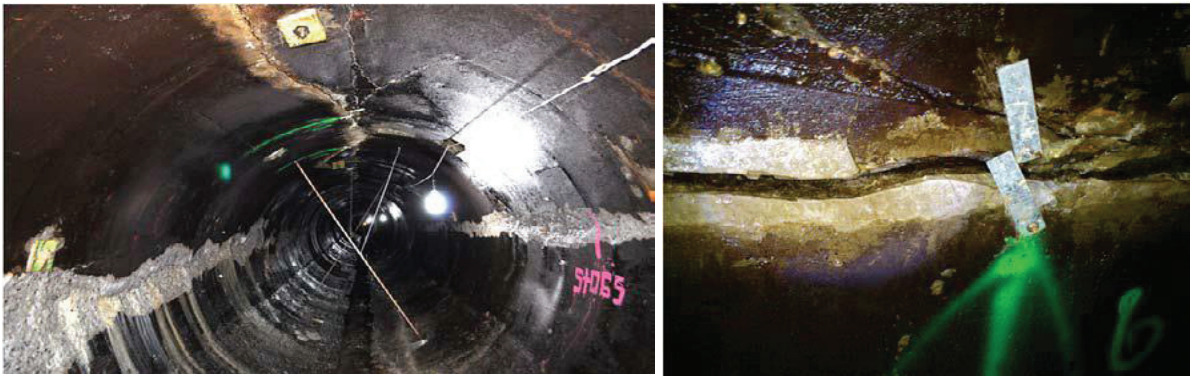


FIGURE 2. Stretch of damaged headrace tunnel and fracture detail [6]

The location of the Pucara headrace tunnel is surrounded by a lot of inherent uncertainties where a very complex geological conditions take place. For example, the tunnel may have the high risks of facing many geological faults such as open fissures and discontinuities. From the report, it clearly indicates that the actual excessive seismic loads caused by intensive rainfalls and also decrease of water due to filtration had also lead to the slope instability which eventually causing landslide to the tunnel [6].

One of the major problems in rocky mountainous and high hill slopes area is landslide and the roots of the problems are presence of heavy rainfall, high angle cut slopes, unplanned slope geometry and discontinuities [7].

Preventive maintenance and regular monitoring works are required for checking the slope instability surrounding the tunnel structure.

The Channel Tunnel (Fig. 3) is a tunnel forming the rail link between UK and France and starts its operation since 1994. The overall length of the tunnel is approximately 50km where 37.9km located under the English Channel which is a submarine section. There are a remarkable numbers of passenger had travelled through the tunnel where reached above 280 million passengers by 2012. Therefore it is one of the most significant representative tunnels in the world [8]. The tunnel has three sub-tunnels; the southernmost tunnel which is known as ‘Running Tunnel South’ (RTS) that handles all the traffic from France to UK, the northernmost tunnel which is known as ‘Running Tunnel North’ (RTN) that handles traffic from UK to France, and a service tunnel is located between the two running tunnels as mentioned above [9].



FIGURE 3. The Channel Tunnel at UK/France [10]

Three major fire incidents have occurred in the Channel Tunnel since it opened in the early 90s. The fires during 1996 and 2008 involve many heavy good vehicles (HGV) on carrier wagons and cause damage to tunnel structures as showed in Figure 4.



FIGURE 4. The fire damage to Channel Tunnel [10]

During 1996 fire incident in the Channel Tunnel, the structural damage is significant. Along a 50m length of the tunnel, the normally 0.4 meter thick tunnel lining was reduced to a mean depth of 0.17m, with the thinnest area being 0.02m. Over a 240m long section (70m towards Britain, 170m towards France), damage to the concrete extended as far back as the first set of reinforcement bars. Superficial damage to the surface of the concrete segments was evident along a further 190m of tunnel length. In the vicinity of the fire, services were destroyed, including high-voltage cables, low-voltage cables, communications, lighting systems, traction and junction boxes over a length of 800m.

The 2008 fire incident in the Channel Tunnel destroying six carriages and one locomotive. Thirty-two people on board the train were led to safety down a separate service tunnel; fourteen people suffered minor injuries, including smoke inhalation, and were taken to hospital. About 650m structure of tunnel was damaged by the fire, 50% more than during the fire of 1996.

The economic damage was estimated to be over twice the cost of the actual tunnel repairs. The direct repairs to the tunnel cost an estimated 60 million Euros while the additional costs in lost business, replacement of infrastructure, materials (for example lorries, train carriages and others) together with the impact of the tunnel closure on other, unrelated business brought the economic loss alone to some 215 million Euros [9, 10].

Mont-Blanc tunnel (Fig. 5) is a tunnel connecting Italy and France that starts its operation since 1965. The total length of the tunnel is 11600m and each half of the tunnel is specifically controlled by one operating entity; SITMB (Societa Italiana del Traforo di Monte Bianco) in Italy while ATMN (Autorout et Tunnel du Mont Blanc) in France. The tunnel has the total width of 8.5m comes with a cross-section area of about 50m² and the maximum height of the vault-shaped ceiling is 6m [11, 12].

In every 300m, there are vehicle rest areas placed and every other rest area has safe refuge area which is designed in purpose to supply fresh air and it has a two-hour fire rating as well. A U-turn area is located at opposite of the rest area and there are safety niches placed every 100m. And they have two fire extinguishers comes with a fire pull box. Besides, in every 150m, there are fire niches comes with water for fire-fighting purpose.

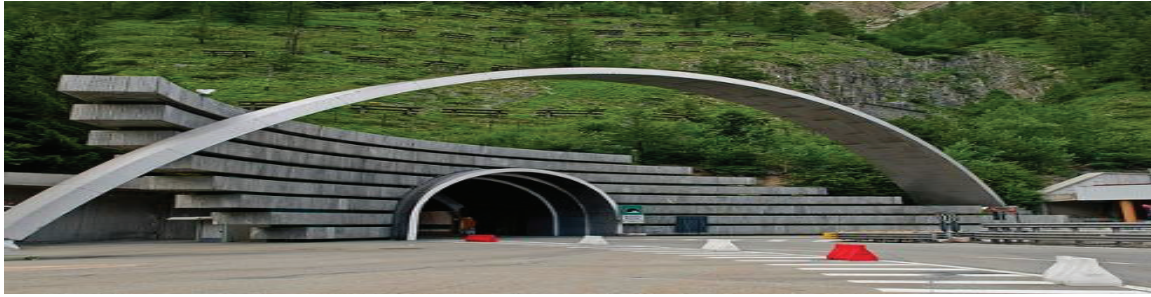


FIGURE 5. Mont-Blanc Tunnel at France/Italy [13]

Major fire incident occurred in Mont-Blanc Tunnel (as shown in Fig. 6) during 1999, which an HGV carrying 9 tons of margarine and 12 tons of flour started to produce smoke when driving through the tunnel and stopped about 6.5km from the French portal. Shortly after stopping, flames could be seen and the fire spread to the trailer. The fire continued to spread to other vehicles at a high rate. A total of 26 vehicles (including motorcycle) on the French side and 8 HGVs on the Italian side were trapped in the smoke and later ignited. Thirty nine drivers and passengers died including a fireman who was evacuated out of an emergency shelter. Most of the victims were found dead in or near their car. The cost of repair for Mont-Blanc Tunnel being estimated at approximately 206 million Euros and the economic cost at some 205 million Euros. In Table 2, the fire protection systems in the Mont-Blanc tunnels in 1999 (at the time of the fire) and in 2002 (after refurbishment) are described [13, 14]. Before that, there is a minor fire occurred once during 1990 which involve an HGV with unknown casualties and damage but assumed to be minor.



FIGURE 6. The fire damage to Mont-Blanc Tunnel [13]

TABLE 2. The fire protection system in Mont-Blanc Tunnel before and after the 1999 fire [14]

At time of fire (1999)	After refurbishment (2002)
Safety niches at every 100m containing a fire pull box and two fire extinguishers.	Fire-resistant stainless steel cladding fitted to walls.
Fire niches at every 150m with water supply for fire-fighting.	Concrete-lined pressurized emergency shelters at every 300m (37 in total), fitted with fire doors and connected to a safety corridor parallel to the tunnel.
Alarm and fire detection system.	A total of 116 smoke extractors at every 100m.
Pressurized safe refuge or emergency shelter at every 600m with two-hour fire rating (18 in total) without a safety.	Heat sensors at both ends of the tunnel to detect overheated trucks before they enter the tunnel.
Outdated ventilation system with ducts underneath the roadway and limited smoke extraction capacity.	Three command and control centers; the newly added central center has a round the clock fire-fighting team.
Two command and control centers at both ends with a fire fighter team at the French entrance.	More traffic lights and flashing warning signs.
Traffic signals every 1.2km.	

RISKS IN TUNNELLING PROJECTS

Tunnels are often subjected to unpredictable soil and groundwater conditions depend on the types of locations they have been built on. Therefore, there is a large potential for several types of incidents happen to tunnels, including fire,

landslide and flooding that may lead to delay risks, environmental risks, and cost overrun risks. Besides, there may be a risk resulted from public complaints as if the tunnelling projects are affecting the public in any forms that will eventually bring significant impact the course of the project. In addition, there is a possible risk of damage occur to surrounding properties and persons which do not fall under that particular tunnelling projects especially in non-rural areas [15].

Types of specified associated risks with tunnelling projects are as following [16]:

- The risk of damage or defect with death potential and individual damage, extensive material and economic risks and loss of credibility of individual involved
- The risk of failed to achieve standards and defined criteria in design, operational, maintainability and quality standards
- The risks of a significant delay of project delivery and execution of revenue operations
- The risk of significant hike of project and support costs

In some other sources, risks are divided into three categories [17]:

- Material damage to the building, machinery, devices and equipment
- Material damage to property of third parties
- Physical injury to employees or third parties

According to Yogaranpan [18], the general risk of tunnelling projects have been classified into four types: natural (floods, storms, earthquakes, and other natural diseases), external (economic and political), internal (strategic and improper planning) and manpower (accidents resulting in injury):

- Risk in construction and design
- Risk in operation and maintenance
- Other risks, for example changes in government policies

Furthermore, the risks of tunneling projects also refer to special problems that are occurring in the construction of underground spaces and there are difficulties for Geotechnical studies makes it check and emphasize on the creation causes of accidents in underground spaces are essentially natural or technological, and natural factors that related to geological formation, uncoordinated, groundwater conditions, and geological processes [19].

Generally, key risks such as political risk, force majeure risk, technical risk and economic risk are those risk that are not particularly linked to construction, operation and maintenance yet involved in all types of business activity. For underground structures especially tunnels, technical risk is described a specific risk and divided into three categories in the course of tunnelling: risk linked with the structure as misjudgment and construction-mistakes especially in final lining and prime support of a tunnel, which render it nearly impossible or difficult to construct the tunnel efficiently yet to use it in safely condition (construction risks), risk linked with the contract documentaries of tunnelling projects (contractual risks) and risk in connection with misjudgments and mistakes or purpose and task of tunnel, which makes the constructed tunnel unfit for its purpose (functional risks). The functional risk is particularly present in the course of tunnel operation and maintenance. Tunnel management has the purpose to ensure unhindered and safe traffic flow throughout the tunnel and it is required to optimize all parameters of the tunnel as a whole, ranging from tunnel equipment systems, to the maintenance and monitoring of tunnel structure. The prime goal of tunnel operation is to manage the key risk: functional risk [20]. Tunnel management has the aim to ensure unhindered and safe traffic flow throughout the tunnel and it is necessary to optimize all parameters of the tunnel as a whole, ranging from tunnel equipment systems, to the maintenance and monitoring of tunnel structure.

In overall, sets of tunnelling project risks are classified into two categories namely internal and external risks, which have been summarized from various sources of information as shown in Table 3.

TABLE 3. The risk breakdown structures internal and external resources tunnelling projects [19, 21, 22, 23, 24, 25 and 26]

Risks From External Sources	Risks From Internal Sources
1) Political risk	1) Contractual risk
2) Social risk	2) Investment risk
3) Economic risk	3) Employer risk
4) Legal risk	4) Management risk
5) Environmental conditions at the project site	5) Planning risk
6) Natural disasters	6) Time overrun
	7) Human risk
	8) Equipment and material resources-related risk
	9) Financial commitments and guarantees
	10) Technical risk (design and implementation)

There are several key risks have been selected and reviewed from Table 3. Political risk is due to foreign and domestic policy, government relationship, change in government policies and internal and external threats. The effect of applied pressure groups and interest groups may potentially change the expectations of the political events that may have significant impact to successful delivery of tunnelling projects. Economic risk is extremely dependent of the market conditions. For example, the factors such as price volatility, currency and deals, interest rate and inflation rate will determine the effectiveness of operation and maintenance of tunnelling projects due to the budget limitation time to time. Management risk in tunnelling projects refers to unrealistically goals that cause by several factors. The poor control in term of organizing, improper distribution of financial resources, human and material, no use of techniques in project management and the lack of definition of the tasks involved in the project are those factors. Management is oeof an effective tool to identify the risks or problems, plan, execute and review the plan and repeating the cycle to reach the goal. In tunnelling projects, especially during operation and maintenance, a lot of uncertainties occur for example tunnel collapse due to landslide. Time overrun refers to schedule inaccurate and unrealistic change in the timing of completion of the project-concurrency works and payments, force majeure business interruption and suspension. It is due to the uncertainty of the limitation and constraints in planning, delay in the final approval scheduled by the employer advice and the delay in the delivery of land and resources. A tunnelling activity that is completed later than the anticipated date could result on a serious effect on the delivery of subsequent works or activities [5].

CONCLUSIONS

Tunnelling projects as a very special and sophisticated branch of the engineering sciences is characterized by high risks even after project completion, which is during operation and maintenance stage. In order to be in position to cope with risks in tunneling a high degree of transparency is required. In risk management plan, it is essential for tunnel operators to collect situation information necessary for establishing appropriate operational strategies as soon as possible that can be retrieved from the past incidents happened. Situation information includes type of incident, the number of vehicles involved, the number and location of trapped people, the infrastructure state and also tunnel asset management condition. And the collected information should be transmitted to the incident commanders of the first arriving teams as soon as possible through the revised plan. The operators or authorities in charge should always revise the operation and maintenance plan by including all those information by establishing more effective risk management approach through their previous experience. And all the general risks that have been identified and reviewed throughout the intensive studies of several case studies are definitely one of the most valuable information that all tunnel operators are seeking for.

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