SLOPE-RELATED RISKS FOR OPERATION AND MAINTENANCE OF TUNNELLING PROJECTS: AN OVERVIEW

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ABSTRACT

The importance of slope-related risks associated with tunnelling projects requires special attention from tunnel operators to analyse and manage the risks. The optimal management of slope-related risks in tunnelling projects involves multiple objectives such as soil stabilisation control, minimisation of slope failure, maximisation of design capacity of slope retaining, and the optimization of overall slope-related risks management system. This paper focuses on identifying the key slope-related risks that have great potential of occurring in tunnelling projects. The outcomes of this research are developed based on findings obtained from extensive literature review and several case studies that have been carried out by other researchers. The identified drainage-related risks will be reviewed in this paper. All these risks can be included as key information when drafting a new risk management plan or to be added into the existing risk management plan in order to enhance the operation and maintenance of tunnelling projects.

Keywords: Tunnelling Projects; Slope-Related Risks; Operation; Maintenance

INTRODUCTION

Tunnels are underground links that able to serve as roadway transportation, storage, railway transportation, power and water treatment plants and other activities with its unique characteristics and potential applications (Fouladgar et al., 2012). Recently, there is an increasing demand in the formation of tunnels, world-wide. Shanghai, one of the major cities located in China able to own a systematic metro framework now with most of them are constructed by underground tunnels since year 1995. Globally, the tunnel frameworks have been expanding trailed by fast development of tunnels as they are forming parts of the complex infrastructure systems, for instance tunnel is forming parts of the Oresund link between Denmark and Sweden (Kauer, 2001).

Tunnelling projects are complex endeavours as the surrounding conditions are various from each other. In other words, it is relatively difficult to design and build tunnels in a particular area and most importantly it is very common for any forms of risk to occur especially during operation and maintenance stage.

Recently, there are a few major slope-related risks occurrences that have threatened the current operation and maintenance of tunnelling projects. There is a landslide due to a large scale of slope failures occurred 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 (Micheli et al., 2013). At Beaminster Tunnel, the slope failures that caused landslide after a period of exceptionally heavy rainfall in July 2012 has affected both structures above the north and south portals of the tunnel (Andrew, 2012).

The optimal management of slope-related risks in highway tunnelling projects involves multiple objectives that can be synthesized as soil stabilisation control, minimisation of slope failure, maximisation of design capacity of slope retaining, and the optimization of overall slope-related risks management system. It is very challenging for tunnel operators to manage the slope-related risks in highway tunnelling projects since the tunnel is usually surrounded by complex topography with unknown geological conditions take place.

This paper focuses on identifying the key slope-related risks that have great potential of occurring in highway tunnelling projects. The outcomes of this research are developed based on findings obtained from extensive literature review and several case studies that have been carried out by other researchers. The identified slope-related risks will be reviewed in this paper. All these risks can be included as key information when drafting a new risk management plan or to be added into the existing risk management plan in order to enhance the operation and maintenance of tunnelling projects.

GENERAL RISKS FOR TUNNELLING PROJECTS

Tunnels are 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 any types of incidents occur in tunnelling projects 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 (Eskesen et al., 2004).

Several types of specified associated risks with tunnelling projects are as following (Reilly and Brown, 2004):

- The risk of significant increase of cost in terms of support and project
- The risk of damage or defect with death potential and individual damage, substantial material, financial risk and decline in term of credibility of individual involved
- The risk of failed to achieve standards and defined criteria in operational, maintainability, quality and design standards
- The risks of a potential execution of revenue operations and late delivery of project

Risks in tunnelling projects have been divided into three sections as following in some other sources (Jafari and Colleagues, 2006):

- Risk with respect to material damage to property of third parties
- Risk with respect to material damage to device, equipment, machinery and building
- Risk with respect to physical injury to employees or third parties

According to Yogaranpan (1996), the general risks of tunnelling projects have been classified into four categories: internal (improper planning and strategic), external (political and economic), natural (storms, floods, earthquakes, and other natural diseases) and manpower (accidents resulting in fatality and injury):

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

The risks of tunneling projects can refer to uncommon problems that are occurring in the construction of underground areas 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 (Gafari and Aminzadeh, 2015).

A few major risks with high possibilities of occurrence in any tunnelling projects are geological condition, health and safety, design risk and force majeure. For instance, insufficient safe escape routes for workers, which usually execute tunnels within a confined working space during construction is one of the major issues related to health and safety whereby the disintegration of any parts of the primary tunnel structure could be catastrophic. In addition, minimal application of the Personal Protective Equipment (PPE) and standard safety procedure for scaffolding are also another health and safety risk which can give negative impact as well. The geological condition is very much crucial for underground structure especially during the primary reinforcement installation. Design risk is noticed when the desired service is not delivered or accommodate successfully. Finally, force majeure is another major risk issue that could dictate problems to tunnelling construction projects. Natural disaster events such as earthquake occurring from nearby countries may contribute to the occurring of risk events such as collapse of a tunnel (Farid and Wong, 2013).

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 make sure unhindered and smooth traffic flow without damage throughout the tunnel and it is required to all parameters of the tunnel are optimized as a complete set, start covering from tunnel equipment systems, to the maintenance and monitoring stage of tunnel structure. The prime goal of tunnel operation is to manage one of the key risks namely functional risk (Dekovic and Pili, 2012).

In tunnelling projects, 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 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.

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 by several researchers as shown in Table 1.

Table 1: The risk breakdown structures internal and external resources tunnelling projects [Source: Gafari and Aminzadeh, 2015; Dekovic and Pili, 2012; Jafari and Colleagues, 2006; Ansari, 2005; Eskesen et al., 2004; Reilly and Brown, 2004; McCabe, 2003; Balol et al., 2003; Edalati and Jialy, 2002; Miller and Lessard, 2001; Yogaranpan, 1996; Touran et al., 1994]

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)

MAJOR SLOPE-RELATED RISKS OCCURRENCES 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.

There is a landslide due to a large scale of slope failure occurred 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 Figure 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 (Micheli et al., 2013). 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 [Source: Micheli et al., 2013]

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 Figure 2.

Figure 2. Stretch of damaged headrace tunnel and fracture detail [Source: Micheli et al., 2013]

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 (Micheli et al., 2013).

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 (Bhardwaj et al., 2014).

Beaminster Tunnel or Horn Hill Tunnel is a 105m length road tunnel on A3066 road between Beaminster and Mosterton in Dorset, England. The tunnel was constructed between during year 1830-1832; it is notable for being the first road tunnels built in Britain and the only pre-railway road tunnel in the country still can use. It was built to take a toll road underneath a steep hill to the north of Beaminster and make it easier for horse-drawn traffic to travel from the coast to the hinterland of Dorset. The tunnel underwent significant repairs in 1968 and again in 2009 (Andrew, 2012).

It was shortly after a period of exceptionally heavy rainfall in July 2012 that slope failures caused landslides at Beaminster Tunnel (Figure 3) above and around the north and south portals. Part of the headwall of the north portal collapsed, and heavy debris, mud and water then crashed onto the roadway at the tunnel entrance below. Suddenly, direct northern access to Beaminster vanished, as did a primary route between Jurassic Coast World Heritage Site to the south and the town of Crewkerne- a railway station on the London-to-Exeter line- to the north. Two persons are killed in the incident.

Figure 3. Landslide occurred at the Beaminster Tunnel [Source: *Andrew, 2012*]

SLOPE-RELATED RISKS FOR OPERATION AND MAINTENANCE IN TUNNELLING PROJECTS

Based on the findings obtained from extensive literature review and several case studies, there were five slope-related risks been identified. Table 2 indicates the types of drainage-related risk and its descriptions in tunnelling projects.

Table 2: Types of slope-related risk and its description in tunnelling projects

No	Slope-Related Risk	Risk Descriptions
1	Slope failure	A slope collapses abruptly due to weakened self-retainability of the earth that cause damage to tunnel or relevant structure/adjacent infrastructure

2	Operational delay due to slope	Delay or interruption in term of operation due to slope damage
3	Cost overrun in operation due to slope	Operating cost higher than expected/allocated budget
4	Contingency maintenance works due to slope	Additional maintenance works to be carried out due to unforeseen incidents
5	Cost overrun in maintenance due to slope	Maintenance cost higher than expected/allocated budget

Slope failure risk as one of the most significant slope-related risks can lead to massive destruction of tunnel and also other adjacent structures or infrastructures as well. Most of the highway tunnels are usually built at the hill slope areas that characterised by a very complex geology and therefore it is highly exposed to high risk of slope failure. If the highway tunnel is affected by a slope failure, the possible damages such as concrete lining will cause a critical situation where the highway tunnel will be forced to shut down its operation due to safety issue. The suspension of the operating highway tunnel will cause major economic losses as all kind of transportation activities will be stopped. Moreover, the adjacent structures or infrastructures surrounding tunnel may experience damage as well. For example, the road surface of highway tunnel can be destroyed by rapid movement of rock or sand that fell from the slope failure. Operational delay due to slope risk is defined as delay or interruption in term of operation for slope retaining system. One of the main reasons is the inconsistencies monitoring of work done in term of operational slope retaining work. The occurrence of both cost overrun in operation due to slope risk and cost overrun in maintenance due to drainage risk are very common in tunnelling projects as most of the tunnelling projects experience loss in term of financial as the proposed budget allocation is insufficient to cover the actual cost. Lastly, the contingency maintenance works due to slope risk involves additional manpower, cost, time or even expertise required to manage the additional maintenance works due to unforeseen incidents. Amongst all the identified risks, the most significant risk is slope failure risk due to its catastrophic impacts.

CONCLUSION

Managing slope-related risks in tunnelling projects especially in slope prone areas has been recognized as a very essential process in overall risk management plan. Decisions are made nowadays in increasingly complex environments especially for tunnel. In more and more cases the use of experts in various fields in necessary. To overcome this difficulty, the slope-related risks for tunnelling projects were identified from extensive literature review and also from several case studies.

In order to manage the slope-related risks of tunneling projects effectively, the proper operation and maintenance of slope retaining systems especially in tunnel is very essential in order the systems are functioning to their designed capacity. This will include routine inspection of the systems, and carrying out necessary repair works for instance ground treatment works whenever applicable. The credibility and value of the risk process will be definitely enhanced if data are collected with care and using proper tools to access. Therefore, the tunnel operators should revise maintenance procedures including the frequency of inspection, programs for all kind of repair works, and documentation for maintenance records. Routine inspection and further preventive measures such as apply geo-textile, growing species and on side design modification are the best ways to minimise the slope-related risks in highway tunnelling projects especially slope failure risk. The identification and review of all key slope-related risks is important as all these risks can be included when drafting a new risk management plan or to be added into the existing risk management plan in order to enhance the overall operation and maintenance of tunnelling projects. The policy makers and tunnel operators will be benefited as the amounts of cost that have to held in reserve to deal with unforeseen circumstances in the current practice dealing with slope-related risks can be estimated in best will. Besides, the end user of tunnelling projects will be benefited in term of safety and time as the contingency plan can provide alternative or excavation plan when an unlikely slope-related risk event occurs.

The new strategy of slope-related risks management during operation and maintenance of tunneling projects should be focused on five fundamental risks; slope failure, operational delay due to slope, cost overrun in operation due to slope, contingency maintenance works due to slope and cost overrun in maintenance due to slope.

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