CONTINGENCY PLAN FOR MANAGING SLOPE-RELATED RISKS: A CASE STUDY FOR MENORA TUNNEL IN MALAYSIA

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By

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ABSTRAK

Pada masa kini, pembinaan terowong adalah sangat penting dan pembinaannya semakin meningkat kerana ciri-ciri yang unik dan kegunaan yang berpotensi tinggi pada masa akan datang. Walaubagaimanapun, pembinaan terowong menghadapi pelbagai masalah dan risiko seperti keselamatan, kestabilan dan pengaruh alam sekitar dalam kerja-kerja penggalian dan pengendalian operasi terowong. Di seluruh dunia, terdapat kegagalan serius dalam pembinaan terowong dan kes-kes ini telah mengakibatkan kematian, kerosakan harta benda dan akibat sosioekonomi. Objektif kajian adalah untuk mengenalpasti potensi risiko yang berkaitan dengan cerun dan kedudukan risiko mengikut kepentingan dari segi pengendalian kerja-kerja operasi dan penyelenggaraan terowong dalam sesuatu projek. Kajian ini melibatkan projek terowong Menora Tunnel di Jelapang, Perak. Sepanjang kajian, risiko-risiko penting dikenalpasti dan disusun mengikut perbandingan dalam *Analytical Hierarchy Process (AHP)*, menganalisis kepentingan bagi setiap risiko yang kritikal. Kebanyakan risiko cerun boleh dikenalpasti, dikira, dan diminimumkan untuk mengurangkan akibat dan kesan terhadap projek-projek yang berkaitan. Oleh itu, kegagalan cerun menunjukkan risiko yang paling penting berbanding dengan risiko yang lain kerana kegagalan cerun yang berlaku secara tiba-tiba akan memberikan impak yang negatif terhadap pengguna terowong di lebuhraya, sehingga mengakibatkan kadar kematian yang semakin tinggi. Hal ini kerana, hujan yang lebat akan memberi kesan kepada terowong dan mengurangkan struktur kekuatan tanah yang berhampiran. Oleh itu, perancangan kontingensi dilaksanakan untuk mengurangkan risiko cerun daripada berlaku. Pelan kontingensi adalah penting sebagai penyediaan yang mencukupi untuk memastikan perancangan akan bertindak balas dengan cepat dan berkesan apabila krisis berlaku. Tanpa perancangan yang sistematik, ia akan memberikan impak yang besar kepada keadaan terowong dan pengguna lebuhraya.

ABSTRACT

Nowadays, the world is witnessing an ever-increasing need for tunnels because of their unique characteristics and potential applications. However, tunnel is facing many problems and risks such as safety, stability and environmental influence in excavation and operation. Around the world, there have been serious failures in tunnel during operation and maintenance stage and these cases have resulted in fatalities, damage to property and other socio-economic consequences. The aim of this study is to identify the potential slope-related risks and determine their risk ranking according to their priority importance towards successful delivery of tunnelling projects. The selected case study tunnelling project is Menora Tunnel which is located at Jelapang, Perak. Throughout the study, the significant risks are identified and then ranked via the Analytic Hierarchy Process (AHP) pairwise comparison, which analyses the criticality and importance of each risk. Most of these risks are identified, quantified, minimized and prioritized to minimize the consequences and their impact on certain projects. There are total five slope-related risks have been identified. Amongst them, slope failure has the greatest importance due to the event of sudden collapse of the slope, there are potential impacts on highway tunnel users, thus resulting towards a higher fatality rate. Heavy rainfall will affect the condition and reduce the strength of soil near to the tunnel. Therefore, a risk contingency plan is needed to lessen the damage of all these risks when they occur. Contingency plan is playing an important role as an adequate preparation in order to make sure the planning will be respond quickly and effectively to a crisis situation when it occurs. Without the plan in place, the full impact of the risk could greatly affect the operation and maintenance of tunnel.

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AHP	Analytical Hierarchy Process
CRF	Critical Risk Factors
JKR	Jabatan Kerja Raya Malaysia
LLM	Lembaga Lebuhraya Malaysia
OPUS	OPUS Group Berhad
PLUS	Projek Lebuhraya Utara Selatan
RMP	Risk Management Process
UEM	United Engineers Malaysia Berhad

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nowadays, the world is witnessing an ever-increasing need for tunnels due to its unique features and potential applications. Tunnels are potential applications that able to serve as storage, underground transportation, mine development, railway transportation, roadway transportation, public work, space for other utilities and activities (Fouldagar et al, 2012). For such variety of purposes, tunnels are complicated underground structures as they differ from the soil structures and various design conditions like topography, geology, underground water, and others (Lee et al., 2017).

Besides that, it is relatively difficult to build tunnels in all types of locations because the tunnel constructions are being built depends on the geological area which involves excavation work by digging and blasting. However, it is usual for any forms of risk taking place especially during the operation and maintenance phase of tunnel. Basically, the design of tunnel should address future inspection and maintenance of all tunnel systems and equipment by providing for adequate, safe, and unimpeded access to all components (Khaled, 2011).

Furthermore, routine inspection is essential for the operation of tunnel. Age and increasing tunnel traffic are among the factors that demonstrate the need for routine inspections to help ensure that tunnels on public roads remain in safe condition and provide reliable services. The design and engineering of tunnels that are safe, functional and sustainable are required in ensuring reliability and efficient of tunnel systems (Wout, 2016).

In recent years, the occurrences of slope related risk in tunnel worldwide has increased significantly due to a lot of tragedies and damages that have happened towards the tunnels. One of the main problems in high hills slope areas is landslides. The roots of the problems are the presence of heavy rainfalls, cut of high angle slopes, and uncontrolled slope geometry and deficiency (Micheli et al., 2013). Therefore, preventive and monitoring maintenance is required to check the slope instability surrounding the tunnel structure. This is essential to mitigate their impact and optimized the infrastructure construction of the tunnel itself throughout the analysis of operation and maintenance outcomes.

1.2 Problem Statement

Tunnel construction is facing many problems and risks such as safety, stability and environmental influence in excavation and operation because tunnel is generally constructed in the vicinity of the existing structures and excavated at weathered soil and rock in shallow depth (Bhardwaj, 2014). Most of tunnelling project have been faced a risk in terms of planning, design and construction process. Around the world, there have been serious failures in tunnel construction (GEO, 2009). These case have resulted in fatalities, damage to property and other socio-economic consequences. Most of these are due to inadequacies in the management of geotechnical risks.

Basically, due to its own uncertainty, tunnels are exposed to various hazards resulting from risks such as seepage, cracks, concrete shrinkage, and corrosion of steel, drainage and decaying of lining structure in the tunnel (Micheli et al., 2013). However, tunnel impose risks to all parties involved directly or indirectly in the project. These risks may impact dramatically on the operation and maintenance of the tunnel, particularly in significant cost and time delays. For instances, the possible risk costs, measures and costs of the measures must be identified and suitable measures must be found in order to avoid errors in the future (Banaitiene and Banaitis, 2012).

However, the appropriate risk management are also needed in the construction of the tunnel to ensure the reliability of the highway tunnelling projects. In order to successfully and efficiently operate and manage a road tunnel, operational need to be established to ensure that all actions required are handled in a consistent and safe way. The level of safety provided for tunnel users is highly dependent upon the specific characteristics of the tunnel, but it also depends strongly on operational procedures and the people who are in charge of the tunnel (Bent et al., 2004). The management and day to day operation, as well as the maintenance of a tunnel, involve high operational costs and funding requirements.

For example, a landslide occurred in 2015 at km 52.4km of the Kuala Lumpur-Karak Expressway between Lentang and Bukit Tinggi, Pahang and Gombak-Bentong old roads. It has blocked all lanes in both directions on the Karak Highway in Malaysia. All lanes of the highway which links Kuala Lumpur to Kuantan in Pahang remained closed with clearing works. There are some cars are buried in during the landslide. Luckily there are no casualties reported during this incident.

According to the Fire and Rescue Department, the landslide at incidents was caused by an overflow of a water catchment area and logging activity on a nearby hill. The heavy rain over the last few days had caused the catchment to overflow, picking up sediment and mud which became a landslide. Thus, in appropriate management plan, a preliminary aerial inspection to assess the soil structure and water flow was conducted to identify the root cause of the problems which led to the occurrence of landslides in the Karak highway. The activity was done by remove the rocks and logs spotted on the hilltop to reduce the damage, in the event of another landslide occur.

Besides that, there was an area where the trees had been cleared and more water in the catchment area due to the clogging activities. Despite the series of protest, uncontrolled logging was still widespread, causing more forest land being stripped of vegetation, hence causing the massive mudslide on the Karak Highway. Genting Sempah Tunnel which located near to the Karak highway has been effected due to the landslides incidents that have been adversely affect the road user. The operation of tunnel was delayed due to the incidents happen. Thus, this research are focussing on the operation and maintenance works for managing slope-related risks and there is a need for contingency plan as it is aim in this research.

1.3 Research Aim and Objectives

The main aim of this research is to develop an effective contingency plan from gaps identified in the current practice for managing slope-related risks during operation and maintenance of tunnelling projects in Malaysia. In order to achieve that, there are three (3) objectives to be achieved.

The objectives of this research are listed below:

1. To identify the potential slope-related risks and their rankings according to their importance towards successful delivery of operation and maintenance for selecting tunnelling projects in Malaysia.
2. To investigate current slope-related risk monitoring and control practice implemented in selected tunnelling projects in Malaysia.
3. To develop contingency plan from gaps identified in the current practice for managing risk during operation and maintenance.

1.4 Scope of Work

There are several types of risks but this research is only focusing on the slope-related risks during operation and maintenance of highway tunneling project in Malaysia because of time constraints. The selected tunneling project for case study is Menora Tunnel with 800 meters highway tunnel located near Jelapang, Perak. Menora Tunnel are located at the hill area and the possibilities of occurring landslide at the hill area is relatively high. Therefore, risk contingency plan are performs in the form of checklist include all aspects related in terms of problem solving measures towards prioritized risks.

1.5 Significance of Study

Generally, the contingency plan for managing slope-related risks during operation and maintenance of tunneling projects has not been developed yet in Malaysia. Therefore, the outcome of this research which is the contingency plan for managing slope-related risks during operation and maintenance of selected tunneling projects is significant to various parties.

This research is beneficial for the government, client of the tunneling projects, Jabatan Kerja Raya (JKR) and Lembaga Lebuhraya Malaysia (LLM), the maintenance and operation team of tunneling projects to improve the management in order to developed and give an efficiency to manage the risk as the amounts of cost that have to held in reserve to deal with unforeseen circumstances in the current practice can be identified.

Besides, the end user of tunneling projects will be benefited in term of safety and time as the critical risk are identified through the analysis and the contingency plan can provide alternative plan when an unlikely risk event occurs to overcome the slope risks from occurring. However, the existing and new upcoming tunneling projects can be managed in more effective and efficient way in term of cost, time and safety in future.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Tunnel

Tunnels can be defined as underground passageway through a mountain, beneath a city constructed for the purpose of transportation connection between two points. Tunnel are classify based on three categories, mining, public works and transportation. Tunnel are functioning for transportation like trains, car, motor vehicles and general road traffic (Fouladgar et al., 2012). Some tunnels are constructed purely for carrying water especially for water consumption, hydroelectric purposes and as sewers. Transportation is the most type of tunnel that have been used as artificial waterways, for travel, shipping and irrigation.

The design of a tunnel should address future inspection and maintenance of all tunnel systems and equipment by providing for adequate, safe, and unimpeded access to all components (Khaled, 2011). Routine inspection are needed for the operation of tunnel. Age and increasing tunnel traffic are among the factors that demonstrate the need for routine inspections to help ensure that tunnels on public roads remain in safe condition and provide reliable service. Thus, it is not easy to rationally design and construct tunnel in all types of locations, and moreover it is not unusual for any forms of risk to occur after tunnel completion and during usage (Jafari, 2006). In addition, tunnels represent significant financial investments with challenging design, construction, and operational issues. Therefore, tunnels will be remain in service for extended periods of time, sometime beyond their intended service life.

2.2 Tunnel Construction

Tunnels represent the most expensive type of transportation structures, where the process involves a complicated design and it gives the greatest challenges that may be encountered during the construction. In Malaysia, railway and highway tunnel are usually constructed above ground but many required tunnel are design to pass efficiently the mountain. The construction of tunnel is built depends on the geological which involves excavation work by digging and blasting.

The process is dependent upon such factors as the ground and groundwater conditions, the location of the tunnel, the length and depth of tunnel, the design of the tunnel portals, the logistics of supporting the tunnel excavation, shape of the tunnel and any restrictions in the use of the area above the tunnel being determined in the planning process (Brown, 2012). This process requires long construction time and effective planning in terms of the infrastructure involved. Therefore, the tunnel construction takes so much planning in designing, construction, operation and maintenance to ensure that serviceability life of tunnel can be functioning well without any risk occur.

However, the appropriate risk management are also needed in the construction of the tunnel to ensure the reliability of the highway tunnelling projects. Any restrictions in use of the area above the tunnel must be clearly stated in the provisions of the plan. In tunnelling construction process, cut and cover are one of the method that is commonly used where trench is excavated and then covered over with an overhead support system which strong enough to carry the load above of the tunnel (Fouladgar et al., 2012). Besides, comprehensive tunnel inspection is needed on the structural, civil, and functional systems within the tunnel.

In order to successfully and efficiently operate and manage a road tunnel, operational need to be established to ensure that all actions required are handled in a consistent and safe way. The level of safety provided for tunnel users is highly dependent upon the specific characteristics of the tunnel, but it also depends strongly on operational procedures and the people who are in charge of the tunnel (Bent et al., 2004). Tunnels that are not adequately maintained usually need higher costs and extensive repairs. The management and day to day operation, as well as the maintenance of a tunnel, involve high operational costs and funding requirements (Banaitiene and Banaitis, 2012). In fact, tunnels are among the highest costs of a road network to be operated in terms of energy requirements, staffing and monitoring.

2.3 Tunnel Infrastructure

In recent years, tunnelling and similar underground construction methods have been increasingly adopted in a number of worldwide infrastructure development projects for the reasons of the environment impact minimization, limitation of surface space and more efficient use (Fouladgar et al., 2012). The design and engineering of tunnels that are safe, functional and sustainable are required in ensuring reliability and efficient of tunnel systems (Wout, 2016). This can mitigate their impact and optimized the infrastructure construction of the tunnel itself throughout the analysis of operation and maintenance outcomes.

The process is started by identifying the construction planning phase through complex geology and hydrogeology to complete underground infrastructure networks, mitigate and importantly avoid issues that could affect the construction and safe operation of tunnels. With forward thinking and excellence integrated into every phase of the project from planning to maintenance, it can deliver safety, aesthetic quality, durability and sustainability across every of tunnelling project involved in future. In addition, tunnels are one of the most efficient construction methods and the only viable solution in tunnel infrastructure while ensuring they comply with legal requirements for safety, health and the environment (Bent et al., 2004).

Today, with the development of urban areas and wider regions, the community needs a variety of tunnels to carry road and rail traffic across the mountains, transport water and other utilities to reduce congestion and environmental pollution to protect urban space well. This mitigation measures are important to convey people, transport safely and sustainably. All aspects of strategic and operational asset management are combining technical expertise, engineering and management in order to offer a wide range of asset management services to avoid extensive maintenance costs (Banaitiene and Banaitis, 2012). This can ensure the workability of the tunnel system and the operational and maintenance cost can be reduce within the budget.

2.4 Tunnel Operation and Maintenance

In tunnelling project, important infrastructure tunnels play an important role in transport network. The functionality of this infrastructure depends on its structural and durability performance. Therefore, optimum maintenance strategies are based on systematic condition assessment from thorough field investigations of the tunnel structure to maintain and ensure its safe and serviceable operation during its lifespan. If maintenance or repair work is needed a cost evaluation including road-user costs must be performed considering the best time for execution and taking into account durability and lifetime aspects (Wang, 2016).

Besides, the planning and the budgeting of maintenance and repair works are becoming more and more essential to tunnel owners and operators in order to minimize the impact on the day-to-day traffic and to ensure cost effectiveness at all times (Hassan et al., 2017). Services also important to evaluate the cost effectiveness of current tunnel maintenance strategies to ensure serviceable operation of tunnel structure with the intention to minimise the total risk.

However, operation and maintenance works in tunnels will most often have an adverse effect on the traffic in the tunnel. Hence, it is essential to plan operation and maintenance works rationally and effectively. The operation involved in tunnelling projects consist of routine inspection on the structure of the tunnel, surrounding behaviour, slope and water movement. This is to ensure the safe and efficient flow of traffic through the tunnel facility. These tasks are typically including:

i. Operation management systems
ii. Principal inspection and condition assessment of structures and installations
iii. Maintenance strategies and optimization of costs
iv. Cost estimation of operation and maintenance works
v. Planning of operation and maintenance works
vi. Short and long-term budgeting
vii. Design of repair and rehabilitation works
viii. Preparation of tender documents
ix. Supervision of repair and rehabilitation works
x. Structural monitoring.

2.5 Tunnel Risk Management

Generally, risk can be defined as the combination of probability or occurrence of prescribed hazards and magnitude of occurrence. Meanwhile, risk management is defined as the integrated process of identifying, monitoring and managing potential risks to minimize the negative impact that may occur (Olga, 2012). According to previous case study, tunnelling projects environmentally experiences various risks because it involves with the soil structure and economically issues related with the planning and construction of tunnels and underground structures.

Besides, there is large potential for a major accident to happen inside the tunnels during construction and even after completion, which is during operation stage. The major accidents which have occurred in recent years merely emphasize this. Hence, it is important that systematic risk management is implemented in tunnel projects to ensure an adequate level of safety in cost-efficient way (Huang and Zhang, 2015). In terms of safety, there are various mitigation measures that can be used to guarantee the feasibility of the research in tunnelling projects involved.

Furthermore, in developing this study through the effective risk management, important to develop a structured Risk Management Process (RMP) consisting of risk identification, risk evaluation, risk mitigation, risk control and risk monitoring (Hertz and Thomas, 1983). This RMP framework has been successfully applied to identify potential risk factors and to assess their likelihood of occurrence. The seriousness of associated consequences can be identified, and appropriate risk mitigating strategies can be developed (Burchett and Tummala, 1998).

2.5.1 Risk Management Process (RMP)

Risk management processes (RMP) are consistent and logically structured approach to describe and understand potential risk factors and assess the consequences and uncertainties associated with these identified risk factors (Rao and John, 1999). Managing risks is basically a process that includes risk assessment and mitigation strategies for those risks. Risk assessment includes both the identification of potential risk and the evaluation of the potential impact of the risk. The, risk mitigation plan is designed to eliminate or minimize the impact of the risk events that have a negative impact. The detail on RMP will be discussed in this chapter.

2.5.1.1. Risk Identification

Risk identification involves a comprehensive and structured determination by identifying the potential risks associated with the identified hazards. In identifying the risk, risk category has also been included in the overall framework (David and Adison, 2004). There are many possible risks which could lead to the failure and it is very important to identify what risk factors are acting simultaneously. Therefore, the affected areas need to be clearly identified and consequences need to be understood so that risk mitigation strategies can be implemented. In addition, care should be taken as some strategies may affect other risks in order to ensure that the potential risk can be developed well without occurring any problem related (Chopra and Sodhi, 2004).

2.5.1.2. Risk Evaluation

Risk evaluation is about developing an understanding of which potential risks have the greatest possibility of occurring and have the greatest negative impact. This process involves evaluating the probability of occurrence and resulting impact of each identified risk factor and shortlisting over the risks that possibly have the highest impact and should be managed first. The priority of the risk can be evaluated by combining effects of probability and impact of consequences.

2.5.1.3. Risk Mitigation

Risk mitigation is the development and deployment of a plan to avoid, transfer, share, and reduce project risks. After the risk have been identified and evaluated, the project team develops a risk mitigation plan, which plan to mitigate the effects of an unexpected events. The risk mitigation plan captures the risk mitigation approach for each identified risk event and the actions taken by the project management team to mitigate or eliminate the risks that may be occur.

2.5.1.4. Risk Control

Once the risk is evaluated, it has to be controlled. Thus, the steps involved are immediate directions preventing the risk and removing the hazard to eliminate the risk. This process of risk management gives an understanding what is being done to address the risk.

2.5.1.5. Risk Monitoring

Contingency planning is the development of alternative plans to address the occurrence of a risk events. Contingency plan is needed through risk monitoring control during the operation of the project if risk mitigation cannot be well developed to manage the risk. This process involves understanding the impact of the control mechanisms developed against the hazard (David and Adison, 2004).

In addition, the project team often develops an alternative method for achieving project goal when risk event has been identified. This approach allows the project team to track the use of contingency against the risk plan and also allocates the responsibility to manage the risk that has the possibility to occur. The contingency plan are important to ensure that risks are prevented from occurring.

2.6 Tunnel Case Study on Slope-related Risks

The uncertainties in many areas related to tunnels are well apprehended by most of the entities involved in the different parts of the process (Ribeiro et al., 2006). Therefore, some of the parties involved are agree that geotechnical works in general and tunnels in particular have high degree of risk that need to be assessed and managed. Most of the tunnel are damages due to the geotechnical aspects because underground tunnel is exposed to the soil structure. In this chapter, there are several tunnel case study which exposed to slope-related risks are selected to be discussed in the literature review.

2.6.1 Pucara Headrace Tunnel Case Study

The Pucara Headrace Tunnel is a 5475 m long with 2.6 m diameter tunnel that forms 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 built for almost 5 years and known as the first Ecuador's main plant in supporting the power supply system (Lee et al., 2017).

In September 2011, a landslide occurred due to a large scale of slope failure occurring parallel and adjacent to the end stretch of the headrace tunnel with about 300m of the 5.5 km long. Associated to geological damages, the affected area has cut off the normal operation of the plant (Micheli et al., 2013). Therefore, in result of damaging, the plant had to be closed after 34 years of operation and classified that slope failure is the major risk of the disaster event that happen on the highway tunnelling project in Ecuador.

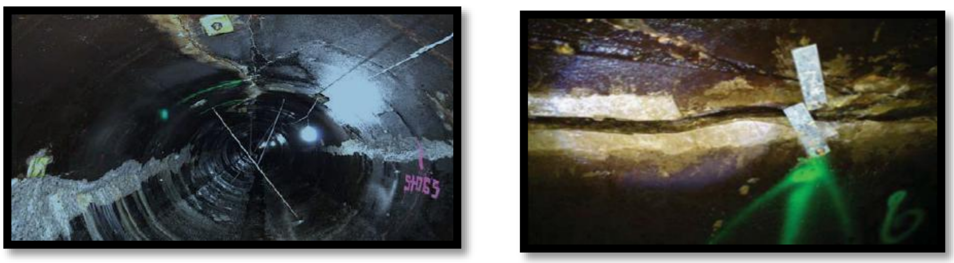
Figure 2.1: Landslide that affected the Pucara Headrace Tunnel.

(Source: Micheli et al., 2013)

2.6.1.1. Damages of Pucara Headrace Tunnel

There are a few damages that can be classified within the concrete lining of the tunnel with the appearance of open fissures and dislocations occurred at the end stretch of headrace tunnel. As consequences, damages in this incident causing a critical situation that the plant was prevented from operating. The suspension of the plant caused huge economic losses to the nation, not only due to the lack of energy production, but also due to the wastage of water from the reservoir (Micheli et al., 2013).

However, the plant was stopped due to the presence of concrete debris in the turbines. During an inspection of the headrace tunnel, there are a series of cracks and damages occurred in the concrete lining of the tunnel reinforced with steel bars (Lee et al. 2017). This situation affected the condition of the tunnel itself. From the report, the stretch was affected by the damages of crossing by geological fault.



(a) (b)

Figure 2.2: Pucara Headrace Tunnel (a) stretch of damaged and (b) fracture detail

(Source: Micheli et al., 2013)

In addition, the persistent cracking propagation has seriously resulted in damage effects to the curvature impact 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 (Micheli et al., 2013). The ancient slides over the tunnel stretch which was affected by damages, actually influenced the slope stability.

Besides, the damaged stretch of the headrace tunnel was rehabilitated with a by-pass tunnel, allowing to increase the minimum overburden and placing the new tunnel in a rock-mass of better quality (Benson, 1988). The location of the Pucara head tunnel is surrounded by many uncertainties which exist in a very complex geological situation occurs. For example, the tunnel may have the high risks of facing many geological damage such as open fissures and discontinuities.

From the case study, the result shows clearly that excessive seismic loads caused by intensive rainfalls and water degradation due to filtration and also lead to the slope instability which ultimately causing landslides to the tunnel (Micheli et al., 2013). One of the main problems in rocky hillsides and high hills slope areas is landslides and the roots of the problems are the presence of heavy rainfalls, cut of high angle slopes, and uncontrolled slope geometry and deficiency. Therefore, preventive and monitoring maintenance is required to check the slope instability surrounding the tunnel structure to avoid from any discontinuities.

2.6.2 Beminster Tunnel/ Horn Hill Tunnel Case Study

Beaminster Tunnel or Horn Hill Tunnel as shown in figure 2.2 is a 105m length road tunnel on road between Beaminster and Mosterton in Dorset, England. It is well-known for being the first road tunnels built in Britain and the only pre-railway road tunnel in the country can still be used. The tunnel 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 interior of Dorset.

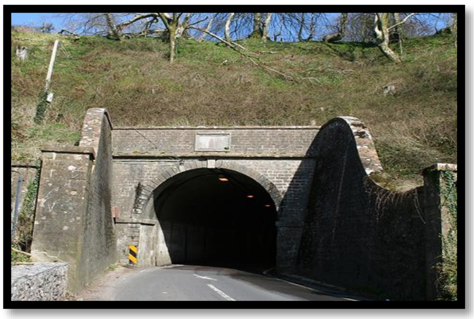


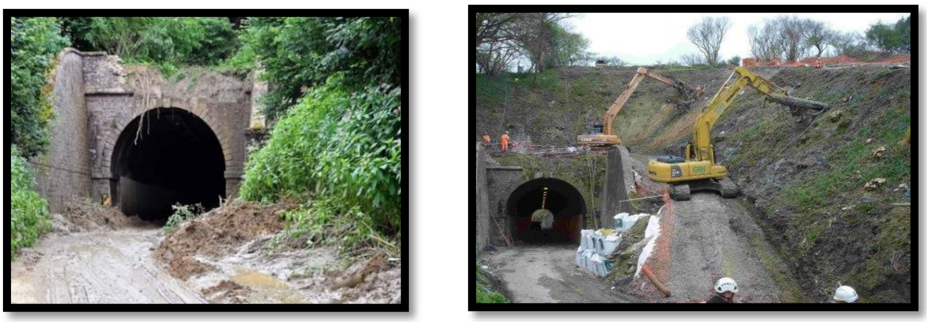
Figure 2.3: Beaminster Tunnel or Horn Hill Tunnel located in England.

(Source: Andrew et al., 2010)

2.6.2.1. Damages of Beaminster Tunnel

Shortly after a period of exceptionally heavy rainfall in July 2012, slope failures caused landslides above and around the north and south portals of tunnel. The damages showed 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 (Andrew et al., 2010). Therefore, from the tragedy two persons are killed in the incident.

Furthermore, due to damages occur as shown below in figure 2.4 (a), significant repair work as figure (b) was done to strengthen the structure of the soil. From now until the opening day the remaining work will be completed. This includes connecting the drains drilled deep into the hillside to the drains that go behind the retaining walls on the approaches, removing the temporary ramps that provided access for work above the tunnel, reinstating and testing the lighting on the approach and in the tunnel, and resurfacing the road on the approaches and within the tunnel (Andrew et al., 2010).



(a) (b)

Figure 2.4: (a) Slope failures caused landslides and (b) significant repairs.

(Source: Andrew et al., 2010)

The tunnel will be closed for some period of time to undergo significant repairs in 1968 and again in 2009 for the rehabilitation and maintenance work of tunnel. The walls at both ends have been protected with additional concrete walls constructed behind them and the walls on the approaches have been stabilised. Finally, after significant repair, Beaminster Tunnel are open a year after tragedy.

2.6.3 Karak Highway Landslide Case Study

Recently, on 11th November 2015, a landslide occurred at km 52.4km of the Kuala Lumpur-Karak Expressway between Lentang and Bukit Tinggi, Pahang and Gombak-Bentong old roads as shown in Figure 2.5. The tragedy has blocked all lanes in both directions on the Karak Highway in Malaysia. There are some cars are buried in during the landslide. Luckily there are no casualties reported during this incident.

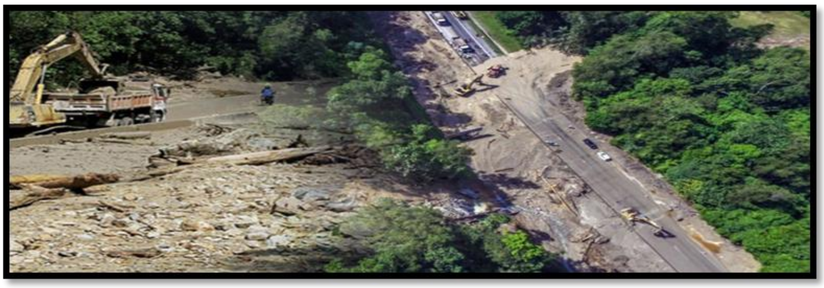


Figure 2.5: Landslide at Kuala Lumpur-Karak Expressway.

(Source: Tariq & Fadzil, 2015)

The following are the summary of landslide incidents reported along the Karak Highway since 1985 until 2015.

1977: Opened to traffic and has two toll plazas located in Gombak, Selangor and Bentong in Pahang.

1985: On November 23, a landslide occurred in Km 33 causing the route to be closed.

1987: On December 14, an express bus was hit by landslide in Km 35 causing it to crash into a steel barrier on the edge of a ravine. All 44 people inside the bus survived.

1990: On December 20, a landslide at Km36 and the route was closed due to flood waters of up to one meter.

1991: On November 11, a massive landslide occurred at Km 47.3. Large boulders tumbled across the road causing the highway to be closed for two days. No one was hurt.

1993: On November 23, a landslide occurred at Km25.2 after heavy rains. Communications between Kuala Lumpur and the east coast was almost cut off. There was no report of any casualties.

1993: On November 28, a landslide at Km 63 killed two motorcyclists.

1995: On June 30, a landslide incident occurred about 200 meters from the Karak junction on slippery road leading to Genting Highland during heavy rain. Twenty-one people were killed and 23 others injured. Various types of vehicles were involved.

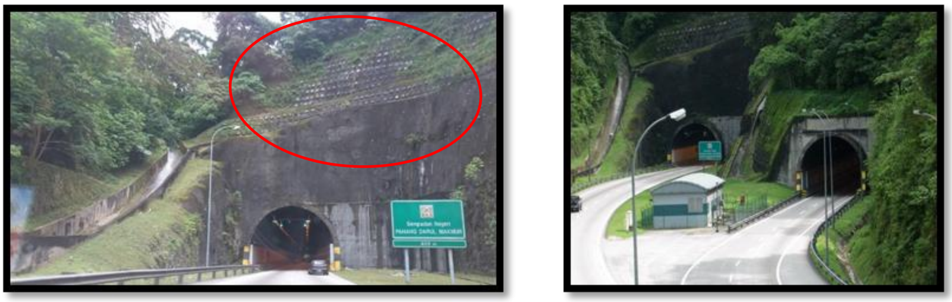
2003: On August 28, a 50-metre high hill slope near Bukit Tinggi collapsed, causing a traffic jam that lasted for five hours from Bentong to Kuala Lumpur. There was no casualties.

2004: On November 1, a similar incident occurred at Km 52 near Bukit Tinggi, Bentong following heavy rain that lasted for three hours. No casualties were reported.

2004: On November 3, a minor landslide at Km53.3 occurred at about 9 pm in the evening. No casualties were reported.

2015: On November 11, a landslide at Km 52.4 occurred near Lentang-Bukit Tinggi and caused the route to be closed. No injuries were reported

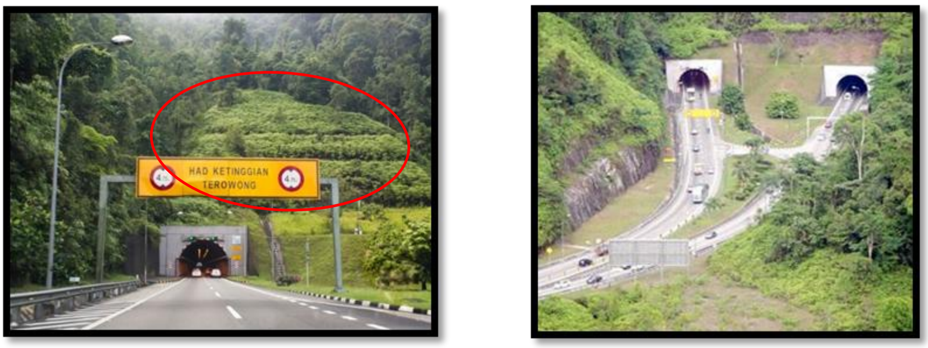
However, based on the previous case study, it is undeniable that all these landslides incidents have triggered a warning alarm to all of us. In Malaysia, both Menora Tunnel and Genting Sempah Tunnel are located at the hill area as shown below in figures 2.5 and 2.6 respectively. Hence, the possibility of occurring landslides at the hillside is relatively high.



(a) (b)

Figure 2.6: Genting Sempah Tunnel (a) located at hill area with (b) two-lane highway at Kuala Lumpur-Karak Expressway, Malaysia.

(Source: Tariq & Fadzil, 2015)



(a) (b)

Figure 2.7: Menora Tunnel located (a) at hill area with (b) two-lane highway near Jelapang, Perak, Malaysia

(Source: Tariq & Fadzil, 2015)

2.7 The Potential Slope Related-Risk in Tunnelling Projects

Most of tunnelling project have been faced a risk in terms of planning, design and construction process. From the case study referred, there are several slope-related risks identified during operation and maintenance for highway tunnelling projects. Most of the result shows slope failure is the major risk among the other factors of risk in geotechnical aspects. The detail on potential slope-related risks can be identified as shown below:

2.7.1 Slope Failures

Slope failures happen when a slope collapses abruptly due to weakened self-retain ability of the earth that cause damage to tunnel or relevant structure and adjacent infrastructure (Bhardwaj, 2014). The failures give a huge negative impact to the structure of the tunnel. Generally, slope failure is a great concern to the safety, constructability, and reliability of the alignments. The failure is due to large amounts of fined-grained sedimentary rocks which are generally extremely susceptible to weathering and erosion in their undisturbed state. Therefore, further increasing their permeability and susceptibility to weathering and erosion within the area of the tunnelling region.

Additionally, though generally strong in their intact, undisturbed state, the coarse-grained and sandstones in the area of the alignment have also been undergone extensive deformation throughout geologic time. Therefore, permeability has been increased accordingly. The orientation of bedding planes will also impact the risk of slope failure along the alignment, particularly where