MANAGING STRUCTURE RELATED RISKS FOR HIGHWAY TUNNELLING PROJECT IN MALAYSIA: A CONTINGENCY PLAN FOR MENORA TUNNEL

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ABSTRAK

Pada masa kini, terowong telah dibina secara meluas dan digunakan sebagai infrastruktur kerana potensinya dan sifat mereka yang unik. Umumnya, terowong dan struktur bawah tanah biasanya mudah terdedah kepada kemungkinan risiko terutama dari segi struktur terowong itu sendiri. Prasarana ini mempunyai banyak risiko berkaitan terowong yang perlu dikenalpasti untuk meningkatkan pengurusan pengendalian dan penyelenggaraan projek terowong seiring dengan risiko. Oleh yang demikian, matlamat kajian ini adalah untuk mengenal pasti struktur terowong berpotensi yang berkaitan dengan risiko dan kedudukan keutamaan mereka ke arah kejayaan untuk mengurus operasi dan penyelenggaraan projek terowong lebuh raya. Maklumat – maklumat dalam kajian ini telah dikumpulkan dari kajian kes yang mempunyai risiko struktur terowong yang berkaitan. Tambahan pula, temu ramah dan kajian kes yang luas juga dijalankan dengan beberapa anggota utama operasi dan penyelenggaraan untuk Menora Tunnel seperti OPUS dan PLUS untuk mendapatkan maklumat lanjut dan justifikasi risiko yang dikenalpasti. Oleh itu, keputusan temu bual ini digunakan bagi menentukan kedudukan risiko di antara risiko menggunakan analisis AHP. Melalui analisis AHP, tiga (3) risiko tersenarai boleh dikategorikan sebagai faktor risiko utama yang merupakan kegagalan struktur terowong, kerja penyelenggaraan kontingensi akibat risiko terowong, dan kos ditangguhkan beroperasi akibat risiko terowong. Oleh itu, dengan mengenalpasti risiko yang berpotensi dan disusun mengikut keutamaannya, ia akan memudahkan pihak yang bertanggungjawab untuk mengkaji semula prosedur operasi dan pelan penyelenggaraan dengan menggunakan semua maklumat yang didapati melalui kajian ini.

ABSTRACT

Nowadays, tunnel is widely constructed and being utilised as an infrastructure due of their potential applications and their unique characteristics. Generally, tunnelling and underground structure works are usually easy to be exposed to possible risks especially in terms of the tunnel structure itself. These kinds of infrastructure have numerous tunnel related risks that need to be identified in order to improve the operation and maintenance for tunnelling project according to their potential risks. Therefore, the aim of this study is to identify the potential tunnel structure related risks and their priority-importance ranking towards successful delivery of highway tunnelling projects in term of operation and maintenance. The tunnel structure related risks for this research has been gathered from pilot study based on case study. Furthermore, an extensive interviews were conducted with a number of key personnel who involved in operation and maintenance stage for selected case study project in Menora Tunnel including OPUS and PLUS in order to obtain further information and justification for the identified risk. Thus, the results of these interview were used to determine their risk ranking through Analytical Hierarchy Process (AHP) analysis. Based on the results gathered from AHP analysis, the top three (3) listed risk on top can be categorized as predominant risk factors which are tunnel structure failure, contingency maintenance works due to tunnel risk, and cost overrun in operation due to tunnel risk. Thus, by identifying potential risk and be ranked accordingly to its prioritize, it will eventually facilitate the operator and authorities that in charge further revise the operation procedure and maintenance plan by including all this information. As a result, the current risk management plan in tunnelling projects can enhance the operation and maintenance of tunnelling projects in present and future by tackling unforeseen tunnel structure related risks.

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LIST OF ABBREVIATIONS

JKR	**J**abatan **K**erja **R**aya
LLM	**L**embaga **L**ebuhRaya **M**alaysia
RTN	**R**unning **T**unnel **N**orth
RTS	**R**unning **T**unnel **S**outh
HGV	**H**eavy **G**ood **V**ehicle
SMART	**S**tormwater **M**anagement **A**nd **R**oad **T**unnel
MRT	**M**ass **R**apid **T**ransit
SVS	**S**mart **V**ideo and **S**ensing
LRT	**L**ight **R**apid **T**ransit

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Nowadays, tunnel is widely constructed and used as an infrastructure because of their potential application and their unique characteristic. According to the Fouladgar et al., (2012) tunnels can be defined as an artificial underground space in order to provide a capacity for particular goals such as storage, underground transportation, transportation, mine development, power and water treatment plants, civil defence, and other activities. For transportation, the tunnel is used for travel shipping and others. Tunnel is actually just like a path way or road way usually ran above ground, but most of the tunnel are construct through the hard rock like mountain.

Besides, for the public works tunnels, it usually is used in order to carry water, sewage or gas lines across great distances. The earliest tunnels were used to transport water and sewage away from heavily populated regions. While, for mining tunnel, it has been used for extraction, enabling labourers or equipment to access mineral and metal deposits deep inside the earth. According to Asakura and Kojima (2003), tunnel are differ from on-ground structures, and the design conditions (topography, geology, underground water, and others) vary case by case. 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 t.o occur after tunnel completion and during usage.

1.2 Problem Statement

Generally, tunnelling and underground structure works that usually exposed toward possible risks. These kinds of work have numerous uncertainties and risks, which would lead to increase of the size and the complexity of a project. The risk is very general which is can be defined in different ways. Risk can be defined as an uncertain event or condition and its occurrence will have either a positive or negative effect. It would lead to time, cost, scope, or quality (Sayed et al., 2017)

Smith (2006) stated that risk actually acts as unforeseen event which is would be occurred any kind of process such as before, during and after construction projects. As an example, the highway project usually is exposed to risks. Risks that occur would lead to the inability to achieve the desired project objectives. The negative effect of risk such as project delays, cost overruns and reduction of availability of resources will eventually affect the projects. Therefore, it is essential to have an effective management in term of risk assessment, risk allocation, and risk management while working on the project to avoid any upcoming problems (Szymański, 2017)

The design of a tunnel should be addressed with future inspection and maintenance of tunnel systems to ensure that the tunnel would be able to operate effectively. Routine inspections play an important role in order to avoid any upcoming risks and problems towards the operation of tunnel. Besides, the development of the tunnel framework in world-wide is expanding day by day. A lot of tunnels have been constructed with complex system, as example, the Eisenhower Memorial Tunnel is known as the highest vehicular tunnel in the world. While, in Malaysia the longest tunnel is known as SMART Tunnel which is 9.7km long (Nuhu and Maimunah., 2015)

Nowadays, infrastructure of tunnels plays an important role in the transport network. Tunnel has become one of the most important infrastructure systems where it is always create links among users in order to move from one place to another. The functionality and the effectiveness of tunnel depend on its structural and durability performance. In the climate of an increasing scarcity of resources, the proper and effective maintenance for the infrastructure is becoming increasingly important (Baji et al., 2016). As known, tunnel is a structure which always be seen as a pathway or roadway, that usually ran above ground. Most of the tunnel was constructed through the hard rock mountain. As an example, of the tunnel constructed would be the Menora Tunnel constructed underneath the Kledang Mountain in Perak. It can also be classified as underground structure. Thus, regarding to its underground structure, it eventually can be worsened due to more exposed to unknowns and uncertainties relating factors such as underground water and soil or rock that eventually would affect the operation of tunnel infrastructure (Baji et al., 2016).

Furthermore, most collapses of tunnel structures in the world are related to tunnel deterioration due to the lacking in maintenance and operational risk. For instance, according to Kawahara et al. (2014) three large rocks fell in the Eucumbene Snowy tunnel in Australia which is used for water conveyance which is completely chocking the tunnel in July 1969 and more recently in December 2012, about 300 ceiling panels in the Sasago tunnel in Tokyo collapsed which has killed nine people.

Besides, tunnel is exposed toward several risks in term of the tunnel itself which could be seen in the operational delay, cost overrun in operation, contingency maintenance works and cost overrun in maintenance due to the tunnel. Therefore, the proper maintenance in term of operation of the tunnel should be well conducted to minimize the possible risk. In an ageing tunnel system, the tunnel will easily expose toward the various potential deficiencies such as seepage, crack, delamination, drainage, convergence and settlement of the lining structure can cause reading the operational of the tunnel (Baji et al., 2016). Different deterioration processes can lead to different forms of failure in tunnel structures.

According to Howard (2001), the primary cause of damage and degradation in underground tunnels is usually caused by the water infiltration through tunnel. The underground water frequently causes ongoing problems, will not only give effect toward the tunnel, but also the structures and fittings within the tunnel. In addition, there are several tunnel related risk during operation and maintenance of highway tunnelling projects in Malaysia. The risk includes structure failure, operational delay, and cost overrun in operation, contingency maintenance works and cost overrun in maintenance due to the tunnel. Therefore, the proper maintenance in term of operation of the tunnel should be well conducted in order to minimizing the possible risk toward the structure. Tunnels are specific engineering structures, which are constructed to shorten transport routes and improve road safety. Therefore, it is very important to make sure that the tunnel is in a safe operation (Jancaríkova et al., 2017)

In addition, there are several failures that can lead to the structure failure. For an example, for the tunnelling project, tunnel structure would be potentially failed due to the degradation of concrete lining. When the surface of the tunnel is exposed towards the presence of several factors like exposing toward the changes of weather, environment effect, corrosion of concrete and others, the surface of the structure would be degraded.

Throughout this process, the thickness surface of the tunnel which is made from the concrete will be spalled due to the degradation concrete process. Then, the reinforcement bar will be exposed where the strength and the stiffness of the tunnel will eventually decrease. Thus, the durability of the structure would be decrease and possibility of the structure failure can be occurred.

According to Olumuyiwa (2013), structure failure can be defined as the loss of the load-carrying capacity of a component or member within a structure or of the structure itself. Structural failure is initiated when the material is stressed to its strength limit, thus causing fracture or excessive deformations. In a well-designed system, a localized failure should not cause immediate or even progressive collapse of the entire structure.

In Malaysia, there are several numbers of building cases that faced structural failure due to some factors that affected such as inability of the foundation to sustain the building load, defect and deterioration of concrete, lack of the maintenance and others. For example, on 1993, an apartment building known as Highland tower collapsed in Ulu Klang Selangor, Malaysia which was caused 48 people dead. Besides that, a sport stadium roof in Kuala Terengganu collapsed on 2009. Throughout this cases, Goh (2010) observed some of the causes in the collapsed of the sports stadium in Kuala Terengganu in Malaysia and concluded that some of the factors are familiar and common in our construction industry and almost every site faces these issues. He analysed that not following the laid down standard and procedure of constructing, inadequate design, roof not being properly erected resulted into misalignment always resulted into such structure collapsed.

Besides that, there are landslide event that occur at PLUS North-South Expressway nearby the Gua Tempurung on 2004. Gue and Cheah (2007) stated that this kind of problem occurring when the retaining wall of the slope cannot sustain the overburden load from soil resulting landslide. This resulting two lanes for southbound traffic bridge of North-South Expressway near Gua Tempurung were closed for three months for rehabilitation works.

In summary, this kind of structure failure could also happen in highway tunnelling project since that the material that is used for tunnelling usually made form concrete structure. Structural defects in concrete can occur over time due to deterioration, wear and tear, overloading, and poor maintenance. Therefore, this kind of problem is important and need to be well managed in order to help in minimising the potential tunnel related risk and enhance the operation and maintenance of tunnelling projects in present and future by tackling unforeseen risks.

1.3 Objectives

The main aim of this research is to develop an effective contingency plan from several gaps identified in the current practice for managing tunnel structures related risks of selected tunnelling projects in Malaysia which is Menora Tunnel.

In order to achieve that, there are three (3) objectives to be achieved:

1) To identify the potential tunnel structures related risks and their priority-importance ranking towards successful delivery of Menora Tunnel, Malaysia.
2) To determine current tunnel structures related risk monitoring control practices that implemented in Menora Tunnel.

3) To develop an effective contingency plan from gaps identified in the current practice for managing risks during operation and maintenance of Menora Tunnel.

1.4 Scope of Work

This research uses a case study as a pilot project where the initial and important information of the tunnel-related risk will be gathered through it. Tunnelling projects which is Menora Tunnel were selected as a case study. The potential tunnel structures-related risk that obtained through the interview and case study will be analyse through Analytical Hierarchy Process (AHP) based questionnaire model. There are several potential risk that can be identified from the highway tunnelling project. However, throughout this study, the scope of research for this study is only focusing on one part of potential risk which is tunnel structure risk during operation and maintenance work due to time constraint.

1.5 Limitation of Study

Tunnelling project usually exposes to several potential risks such as it term of tunnel structure failure, slope, drainage pavement and others. Therefore, throughout this research, the study only focusing on one potential risk which is tunnel structure risk during operation and maintenance works due to time constraint. The result obtained is limited to the Menora Tunnel only since Menora Tunnel is used as case study for this research.

1.6 Significance of Study

Currently, the contingency plan for managing risks during operation and maintenance of selected tunnelling projects has not developed yet in Malaysia. This proposed research project is very important in tunnel-related risk management in order to improve the management for operation and maintenance in risk for highway tunnelling project in Malaysia. The outcome of this research which is the contingency plan for managing tunnel structures related risks of Menora Tunnel is significant to various parties such are project managers and operations managers from LLM, maintenance staff and operation managers from PLUS and OPUS.

The government, client of the tunnelling projects, Jabatan Kerja Raya (JKR) and Lembaga Lebuhraya Malaysia (LLM), the maintenance and operation team of tunnelling projects like PLUS and also toward public will be benefited as the amounts of cost that are allocated as a reserve to deal with unforeseen circumstances in the current practice can be identified. As an example, the operator or authorities that in charge will be able manage the operation and maintenance efficiently by revising the entire plan that has been included in this proposed project. In addition, all those important information regarding the risk management of the tunnelling project can be used as a guideline during operation and maintenance works.

The end use of tunnelling projects especially road user will be benefited in term of safety and time as the contingency plan can provide alternative or excavation plan when an unlikely risk event occurs. As the outcome of this research, the existing and new upcoming tunnelling 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 Introduction of Tunnel

In developing countries, where most of this uncontained population growth will take place, the rapidly expanding cities will need to meet the increased demands for infrastructure (Chen et al., 2017). Therefore, the effective and efficient transport infrastructure, it will eventually help the movement of the people. Without the efficient transport infrastructure, it will lead to several problems toward the community. The entire cities will sprawl away from the urban core, which strains the environment by creating more traffic congestion and travel time, loss of valuable farm land, and inequitable allocation of resources.

Broere (2016) stated that an urban population that is increasingly aware of the factors that improve the quality of living like to reliable and safe transport of people and goods; sustainability of the environment and limited urban sprawl, green spaces and recreational areas; reduced energy use, efficient use of real-estate and other. The important things that need to be considered is about the transportation. In existing urban areas these demands pose significant challenges, as the space needed for developing new functions or relocating and improving existing ones is often not readily available.

By constructing the infrastructure and other facilities underground presents an opportunity to find the needed space, but it is often considered only as a last resort. People usually have a thought that the underground is considered only when surface space is exhausted and no other solutions exist anymore for the complex urban problems to be tackled.

Nowadays, the uses of tunnel as a one of transportation medium are ever-increasing due to its unique characteristic and their application. This kind of system makes it more convenient for people or thing to move from one place to another. According to the Fouladgar et al. (2012) tunnels can be defined as an underground space which is equipped with unique characteristics and potential applications that able to function as railway transportation, roadway transportation, storage, civil defense, and other activities.

On the other hand, tunnelling is a complicated effort as it differs from the soil structure and different design conditions like topography, geology, underground water, and others for such variety of purposes (Lee et al., 2017). Tunnel classify based on three categories, namely: mining, public works and transportation. Therefore, tunnel systems have several purposes in term of road transportation, mining, public works and others. Transportation is the most type of tunnel that has been used as artificial waterways, for travel, shipping and irrigation.

A tunnel also is more than just a hole in the ground to provide for a desired movement of people or material. To accomplish the movement satisfactorily, one or more of a variety of facilities in simple or complex form must be provided in addition to the continuous space. Fresh air must be supplied in proportion to tunnel usage. The air also must be of reasonable purity. Therefore, this requires constant monitoring for pollutants and consequent adjustment of the air supply and exhaust. In low-use rural tunnels, the vehicles' headlights may suffice. In high-use (generally urban) tunnels, a sophisticated system of high-level, adjustable lighting is necessary both for safety and for ensuring maximum appropriate speeds. Fire life safety, ventilation, and lighting are also important to railroad and transit tunnels, although in quite different degree. Lighting requirements are much reduced, needed more for orientation and maintenance than for passage.

2.2 Tunnel Construction

Basically, the construction of tunnels is one of the most expensive constructions due to its complicated design and need to cope with several challenges that may be come out during the construction work (Qian and Lin, 2016). The tunnel is actually just like a pathway or roadway usually ran above ground, but most of the tunnel are constructed through the hard rock like mountain. In Malaysia, majority highway tunnel is usually design and constructed through the hard rock layer as mountain. As an example, the Menora Tunnel is constructed underneath the Kledang Mountain in Perak.

Dowen et al. (2018) did mention that along the development of its transportation infrastructure, some country is currently experiencing the increasing and vigorous planning and construction work that related to the underground works. The underground work that’s currently in planning which is had potentially able in improving traffic efficiency such as mountain tunnels and urban metro lines (Dowen et al., 2018) However, the construction of underground works in deep underground spaces with complicated strata results in numerous challenges that include large deformation, collapse, rockburst, gushing water, and gushing mud. Of these, the large-deformation hazard of long tunnels is the most salient risk.

During the construction of the tunnel, generally there are consist of two basic techniques to advance a tunnel as the process of tunnelling depends on the several factors of the ground which are the location the proposed tunnel and the length and it depth (Moretti et al., 2016). Besides, the process of the tunnel construction also depends on the shape and the design of the tunnel. Thus, it can be said that the process of tunnel construction will eventually consume a lot of time in order to make sure that tunnel is well function without occur any risk.

Moretti (2016) stated that first basic techniques to advance the tunnel is during the full-face method, the entire diameter of the tunnel will be excavated at the same time. This kind of method is the most suitable for tunnels passing through strong ground or for building smaller tunnels. The second technique is the top-heading-and-bench method. In this technique, workers dig a smaller tunnel known as a heading. Once the top heading has advanced some distance into the rock, workers begin excavating immediately below the floor of the top heading. One advantage of the top-heading-and-bench method is that the heading tunnel can be used to gauge the stability of the rock before moving forward with the project (Moretti et al., 2016).

In modern tunnel and underground cavern excavation, it is possible to select from many different methods. The following factors should be taken into consideration when selecting the method during construction of tunnel which are tunnel dimensions, tunnel geometry, length of tunnel, total volume to be excavated and other several factors. The methods can be divided into drill and blast, and mechanical excavation. Mechanical methods can be split further to partial face such as hammers, excavators and many more while full face it consist of Tunnel Boring Machine (TBM), shield, pipe jacking, and micro tunnelling.

2.3 Tunnel Infrastructure

Generally, infrastructure systems usually involves in the design, analysis, and management of infrastructure which is supporting human activities. As an example, infrastructure work usually related to the electric power, oil and gas, water and wastewater, communications, transportation, and the collections of buildings that make up urban and rural communities. These networks deliver essential services, provide shelter, and support social interactions and economic development thus; infrastructure plays an important role in the development.

The functionality and the effectiveness of tunnel usually depends on its structural and durability performance. In the climate of an increasing scarcity of resources, the proper and effective maintenance for the infrastructure is becoming increasingly important (Baji et al., 2016). Baji et al., (2016) did mentioned that tunnel is an essential infrastructure that plays a pivotal role in transportation network, economy, prosperity, social well-being, quality of life and the health of its population.

Furthermore, the traffic conditions in a road tunnel should in principle correspond to those in open air. Road tunnels are, however, special section for a road and demand stringent requirements for their construction, maintenance and operation. Road tunnels have to meet particular requirements regarding road safety and operational safety. When the needs of traffic management are balanced against economy, it is therefore necessary and justifiable in many cases to limit the speed compared to parts of the road in the open air. The permitted maximum speed is thus normally limited to 90km/h in road tunnels which inevitably differentiates the traffic flow in tunnels from road in the open air (Bent et al., 2004).

Therefore, operational and maintenance work need to be established to ensure that all actions required are handled in a consistent and safe way. This is important in order to make sure the tunnel is successfully operated and efficiently managed. 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).

2.4 Tunnel Operation and Maintenance

The operational of the tunnelling project plays an important role in order to provide a systematic and efficiency of safe tunnelling toward the road user. The tunnelling itself should be able to provide requirement that might be vary among the tunnel facilities due to the traffic level, the feasibility of alternative routes, accessibility to existing utilities, availability of emergency responders, and other conditions for each tunnel. Highway tunnel agencies need to employ the appropriate personnel to operate the tunnel safely and provide reliable levels of service. Since tunnel operations differ among various facilities, the duties and responsibilities need to be organized to match requirements for each tunnel facility.

2.5 Tunnel Risk Management

Generally, tunnelling and underground construction works are exposed to several risks on all parties involved. The very nature of tunnel projects implies that any potential tunnel owner will be facing considerable risks when developing such a project. Due to the inherent uncertainties, including ground and groundwater conditions, there might be significant cost overrun and delay risks as well as environmental risks (Lee et al., 2017). Also, as demonstrated by spectacular tunnel collapses and other disasters in the recent past, there is a potential for large scale accidents during tunnelling work.

Furthermore, for tunnels in urban areas there is a risk of damage to a range of third party persons and property, which will be of particular concern where heritage designated buildings are involved. Finally, there is a risk that the problems which the tunnelling project cause to the public will give rise to public protests affecting the course of the project.

Technically, risks have been managed indirectly through the engineering decisions taken during the project development. These guidelines consider that present risk management processes can be significantly improved by using systematic risk management techniques throughout the tunnel project development. By the use of these techniques potential problems can be clearly identified such that appropriate risk mitigation measures can be implemented in a timely manner.

As mentioned above, tunnel usually is associated with risk-taking. Therefore, each project should undergo the efficient risk management before the implementation project in order to identify the possible risk. This is because; these risks may dramatically give impact toward the operation resulting in major cost, time and safety issues (Lee et al., 2017). Usually, a risk management which involves a number of approaches, including the identification, evaluation, and control of risk should be carry out in effective and efficient way in order to mitigate the problems (Lee et al., 2017). However, tunnel risks are the consequences of interaction between site and project specific factors. Large variation and uncertainty in ground conditions as well as project singularities usually raise particular risk factors and very specific potential impacts. Therefore, a risk contingency plan which is devised for an outcome other than in the usual (expected) plan for managing unforeseen risks during operation and maintenance of tunnelling projects in Malaysia is needed.

Peggy (2006) stated that risk management plan actually does not have to be complicated, costly or labour – intensive, but the plan actually does need to be consistent in its activities and in the methods for identifying and treating the risks. Any risk management plan should be incorporated the basic steps of risk assessment, implementation of risk management activities, and monitoring for results. Furthermore, Peggy (2006) did mention that risk management is a continuous management process with the objective to identify, analyse and assess potential risks in a system or related to an activity, and to identify and introduce risk control measures to eliminate or reduce potential harms to people, the environment or other assets. Some of these stress that risk management is a proactive and systematic approach to setting the best course of action under uncertainty and that it also involves communicating the risk to the various parties. Therefore, an efficient risk management plays an important role in order to minimize negative impacts on tunnelling operation and performance in relation to cost, time and quality objectives (Szymański, 2017).

Besides, the risk assessment can be defined as the process of evaluating potential for any kind of accident, risk that happen and others. Risks areas are important things that need to be prioritized and possible risk treatment approaches are needed to be considered (Benekos and Diamantidis, 2017). In addition, a risk analysis is always a proactive approach in the sense that it deals exclusively with potential accidents. This is opposed to accident investigation which is a reactive approach that seeks to determine the causes and circumstances if accidents that have already happened.

Risk evaluation is process in which judgement are made on the tolerability of the risk on the basis of a risk analysis and taking into account factors such as socio-economic and environmental aspects. The identification of risks in construction projects is based primarily on determining what types of risks may affect the project, identifying their characteristic parameters and estimating the probability of their occurrence in the project. The need for risk identification stems from the decision making conditions under which an investor is at the moment (Eskesen et al., 2004)

Banaitiene and Banaitis, (2012) stated that risk evaluation is a part of risk management helps decision makers in order to rank the existing risks, list out the potential tunnel-related risk, the mitigation measure for the current practice and finally, throughout this process of evaluation, it will eventually be able to overcome the problem. Risk evaluation in tunnelling is done because of the several reason which is to reduce risks that effect project goals and objectives, to demonstrate options that are comprehensively and rationally evaluated, the process will reveal useful information even if threats do not eventuate. Due to the critical importance of risk in underground construction, different researches are accomplished in order to evaluate and assess risk.

Therefore, each project should undergo the efficient risk management before project implementation in order to identify the possible risk. Although, tunnel structures related risk rarely happens in highway tunnelling project in Malaysia, but this kind risk is still have potential to occur which can lead to serious consequences. Therefore, throughout this kind of mitigation process, it will eventually help to reduce the possible risk and cope with the problem when it occurred.

2.6 Tunnel Structure Related Risks (Case study)

There are several tunnel structure related risks that happen in tunnelling highway projects in all over the world. 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, throughout the cases study from several tunnelling highway project like tunnelling project in United Kingdom, Japan and others can help in identifying the potential structure related risk in tunnel.

2.6.1 Channel Tunnel

The Channel Tunnel is constructed in 1998 and opened in 1994. The tunnel is in the forms the rail link which is connected between the United Kingdom and France. Technically, the tunnel consists of three parallel tunnels which are two running tunnels, each with a single rail track, on either side of service tunnel. The total length of tunnels are approximately 50 km long (37km of which is under the English Channel). The tunnel runs north-west to south-east, the northernmost tunnel is referred to as ‘Running Tunnel North’ (RTN) and generally handles traffic from the UK to France, with the traffic coming from

France generally using ‘Running Tunnel South’ (RTS). According to the Carvel (2010), stated that the service tunnel has three main safety functions which are to provide normal ventilation for the running tunnels, to provide a safe haven for passengers and crew in the event of an evacuation and to facilitate the speedy arrival of the emergency services.

Basically, there are three major fire incidents have occurred in the Channel Tunnel since it opened in the early 90s which are on 1996, 2006 and 2008 respectively. The fires on the 18th November 1996 and the 11th September 2008 grow to involve many heavy goods vehicles (HGV) on carrier wagons and caused damage to the tunnel structure. The fire on the 21st August 2006 involved only a single HGV and did not spread, although the adjacent HGV was damaged by heat.

a) 18th November 1996

The 1996 fire occurred on Heavy Goods Vehicle (HGV) Shuttle Mission 7539, which departed the French terminal at 21:42 hours on the 18th November. The fire ultimately involved the rearmost ten HGV carries and destructively damaged the rear loader wagon and locomotive.

Table 2.1: Timeline of the 1996 fire. (Source : Carvel, 2010)

Time	Event	Comment
21:42	Train departs station	Fire visible on 2nd rake. On wagon 7 or 10 (witnesses)
21:48	Train enters tunnel	
21:51	Onboard fire alarm	On rear locomotive.
21:58	Train stopped	Driver initially tried to keep going. Decision to stop on basis of a faulty system warning light. Once stopped, driver unable to see tunnel walls to identify location.
22:13	SVS activated	Fan blades set incorrectly. No longitudinal flow
22:22	SVS fully established. Evacuation carried out.	Ventilation flow now about 2.9m/s
22:53	Fire brigade assess fire	5 wagon on fire at the rear.
23:39	Fire fighting begins	Takes about 6 hours

b) 21st August 2006

The 2006 fire occurred on HGV Shuttle Mission 7370, from the UK to France, which departed the Folkestone terminal at 13:23 hours on the 21st of the August. The main events related to ventilation conditions and fire behaviour are summarized in Appendix A.

c) **11th September 2008**

The 2008 fire incident can be summarized as below:

- The fire started near the front of the train (it was visible by the passengers)
- The fire extended along most of the length of the train (the damage to the tunnel was 170m- i.e. approximately 8 wagons- longer than In the 1996 fire, which involved almost half the train.

Figure 2.1: The infrastructure of Channel Tunnel was damaged and a fire on a truck caused a great deal of damage during 2008 fire incident (Sources: Carvel, 2010)

2.6.2 Tsukayama Tunnel

The Tsukayama Tunnel was constructed in 1967, with a total length of 1766 m, as a double-track railway tunnel. It is geologically in the Green Tuff region, facing the Japan Sea, where Tertiary sedimentary soft rock pervades extensively. The Tsukayama Tunnel is located at the anticlinal limb part, constituting a partially active folding zone. The overburden of the deformed section is approximately 70 m. The surrounding ground is mudstone, with a uniaxial compressive strength of 3–6 MPa. It is susceptible to slaking, and the competence factor ranges from 2 to 4. The tunnel was excavated by the bottom drift method, and the excavation and the lining were completed without problems. The thickness of lining is 50 cm and invert concrete was not installed.

Shortly after the construction of the tunnel is completed, the tunnel is deformed in such a way that both sidewalls were pushed into the tunnel space accompanied by mud-pumping at the tracks and heaving at the base. The arch crown was pushed upwards and failed in a bending and compressive manner.

As a countermeasure against this deformation, invert concrete was installed to close the tunnel section. According to the convergence measurements between the sidewalls, the convergence had reached a maximum of 40 mm/year before the installation of the invert concrete. This was still not completely subdued by the installation of the invert concrete.

Figure 2.2: Compressive failure caused a longitudinal crack line in the Tsukayama Tunnel (Sources: Asakura & Kojima, 2003)

Twenty years later in 1990, however, a relatively wide area of the crown settled where compressive failure had occurred, and many shear cracks developed in a radial manner with their centre at the settled part. The possible collapse of the area was a serious concern.

2.6.3 Rebunhama Tunnel

Asakura and Kojima (2003) stated that Rebunhama Tunnel located at Japan which is has a total length of 1232m was completed in 1975. It has a double-track cross section electrified by alternating currents. It was excavated by a bottom drift method. The lining was cast-in place concrete without reinforcement. On November 28, 1999, a freight train in the Rebunhama Tunnel of the Muroran Main line spotted something unusual on the tracks and applied the emergency brake. It was too late to avoid the object, however, and the train hit it and derailed. From the investigation, it was found that five pieces of concrete blocks, as large as several tens of centimeters, lay on the track and that those blocks had fallen from the tunnel arch.

Besides that, Asakura and Kojima (2003) did mention that the site of the incident was under a rock slope of a steep sea cliff, where there was an overburden of 40 m, and the geology consisted of relatively stable Tertiary andesite or pyroclastic rock, both generally being hard. Andesitic rock block, with a size of approximately 2–3 m, was observed directly above the spalled lining, and above that relatively weak rock was confirmed. Most of the surface which had ruptured was thought to have done so because of shear failure, and it had already been carbonized. Only approximately 1 m2 of the ruptured surface was fresh, and at the top of the ruptured surface, cut-off sheet and rock were exposed and protruded into the lining concrete.

2.7 Tunnel in Malaysia

In Malaysia, there are few well-known tunnels available in the construction industry. The Stormwater Management and Road (SMART) Tunnel is a storm drainage and road structure in Kuala Lumpur, Malaysia. It's known as a major national project in the country which was opened in 2007. Next, the Genting Sempah Tunnel is known as the first highway tunnel in Malaysia which located on the Kuala Lumpur-Karak Expressway. The total of this tunnel is about 900m and this tunnel connects Hulu Gombak in Selangor to Genting Sempah, Pahang which was opened in 1979. The Menora Tunnel is an 800m highway tunnel on the North-South Expressway Northern Route. Menore Tunnel located near Jelapang, Perak, Malaysia. The tunnel was opened officially in 1986.

Besides, both Genting Sempah Tunnel and Menora Tunnel are located at the hill area as shown in Figure 2.3 and 2.4 respectively. The possibility of structure failure to be happened is quite high due to exposure toward the excessive load. Therefore, it may eventually cause inability to support the overburden load above the structure.

Figure 2.3: Genting Sempah Tunnel located at hill area at Kuala Lumpur-Karak Expressway, Malaysia (Source Nuhu and Maimunah, 2015)