EFFECTIVE CONTINGENCY PLAN FRAMEWORK FOR RISK MANAGEMENT IN THE OPERATION AND MAINTENANCE OF MALAYSIAN HIGHWAY TUNNEL

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by

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LIST OF SYMBOLS AND ABBREVIATIONS

°C	Degree Celsius
AHP	Analytical Hierarchy Process
ASEAN	Association of Southeast Asian Nations
ATMN	Autorout et Tunnel du Mont Blanc
cm	Centimeters
HGV	Heavy goods vehicle
km	Kilometers
m^2	Square meters
m^3	Cubic meters
MHA	Malaysia Highway Authorities
mm	Millimeters
MPa	Mega Pascal
NDT	Non-Destructive Testing
PLUS	PLUS Malaysia Berhad
PPE	Personal protective equipment
PWD	Public Works Department Malaysia
RC	Reinforced concrete
SEM	Sequential excavation method
SITMB	Societa Italiana del Traforo di Monte Bianco
SMART	Stormwater Management and Road Tunnel
St.	Saint
TBM	Tunnel boring machine

RANGKA KERJA PELAN KONTINGENSI YANG BERKESAN UNTUK PENGURUSAN RISIKO-RISIKO SEMASA PERINGKAT OPERASI DAN PENYELENGGARAAN BAGI PROJEK TEROWONG LEBUHRAYA MALAYSIA

ABSTRAK

Projek-projek terowong lebuhraya adalah diperlukan semasa pembinaan infrastruktur baru kerana ciri-ciri unik dan aplikasi yang berpotensi. Walau bagaimanapun, adalah sangat biasa untuk apa-apa risiko berlaku terutamanya semasa peringkat operasi dan penyelenggaraan bagi projek-projek tersebut. Sejak dahulu, banyak kemalangan dan bencana telah berlaku dan pengulangan kejadian risiko yang sama menunjukkan keutamaan bagi pihak pengurus terowong lebuhraya untuk menguruskan risiko dengan berkesan. Malangnya, pelan pengurusan risiko tradisional adalah tidak mencukupi untuk menguruskan risiko-risiko yang residual atau tidak dapat dijangka. Oleh itu, matlamat utama kajian ini dijalankan adalah untuk mewujudkan pelan kontingensi yang berkesan dari jurang-jurang yang dikenalpasti dalam kerja-kerja operasi dan penyelenggaraan semasa untuk pengurusan risiko semasa operasi dan penyelenggaraan bagi projek terowong lebuhraya Malaysia. Kajian kes yang dipilih ialah Terowong Meru-Menora yang terletak di Lebuhraya Utara-Selatan berhampiran Jelapang, Perak pada KM260.00. Dalam kajian kes, terdapat beberapa teknik pengumpulan data termasuk pengumpulan data sekunder, temuduga kumpulan focus, pemerhatian kerja-kerja operasi dan kaji selidik Proses Hierarki Analisis (AHP) telah digunakan. Dua puluh enam (26) sub-risiko yang terdiri daripada lima (5) risiko utama yang berkaitan dengan saliran, turapan, cerun, struktur terowong dan lain-lain struktur telah dikenal pasti. Kaji Selidik Proses Hierarki

Analisis (AHP) telah dijalankan untuk menentukan keutamaan dari segi risiko bagi semua sub-risiko ini. Hasil kajian menunjukkan bahawa tujuh (7) sub-risiko kritikal dengan keutamaan yang paling tinggi dari segi risiko telah dikenalpastikan iaitu kegagalan yang disebabkan oleh cerun, kegagalan yang disebabkan oleh struktur terowong, kerja-kerja penyelenggaraan kontingensi yang disebabkan oleh risiko cerun, kerugian kos operasi yang disebabkan oleh risiko cerun, risiko banjir saliran, kerja-kerja penyelenggaraan kontingensi disebabkan oleh struktur terowong dan kerja-kerja penyelenggaraan kontingensi disebabkan oleh risiko saliran. Semua sub-risiko kritikal ini mempunyai potensi besar yang dapat mempengaruhi prestasi operasi dan penyelenggaraan Terowong Meru-Menora dan harus diuruskan dengan baik. Kerja-kerja pengurusan risiko semasa telah disiasat dan dinilai. Rangka kerja pelan kontingensi telah dibangunkan dan disahkan dengan Teknik Delphi. Beberapa strategi dalam rangka kerja pelan contingency telah digunakan termasuk mengamalkan kaedah kerja-kerja operasi dan penyelenggaraan yang baru dan berkesan untuk menguruskan risiko, meningkatkan kekerapan kerja-kerja operasi dan penyelenggaraan yang bersesuaian untuk menguruskan risiko dan mencadangkan pelan kontingensi baru untuk mengendalikan risiko-risiko yang tidak mempunyai amalan pengurusan risiko pada awalnya. Penyelidikan boleh diuji lagi dalam projek-projek terowong lebuhraya Malaysia yang lain untuk masa depan.

EFFECTIVE CONTINGENCY PLAN FRAMEWORK FOR RISK MANAGEMENT IN THE OPERATION AND MAINTENANCE OF MALAYSIAN HIGHWAY TUNNEL

ABSTRACT

Highway tunnel projects are indispensable during the installation of new infrastructures despite their unique characteristics and potential applications. Yet, it is not uncommon for any risks to occur especially during the operation and maintenance stage. Over the past few decades, a lot of major accidents and disasters occurred and the re-occurrences of similar major risk incidents which even showing criticality for highway tunnel operator to manage the risks effectively. Unfortunately, the traditional risk management plan is insufficient to manage residual or unforeseeable risks. Therefore, this research aims to develop an effective contingency plan framework from gaps identified in the current practices for risk management in the operation and maintenance of Malaysian highway tunnel. The selected case study for this research is based on Meru-Menora Tunnel that located along North-South Expressway near Jelapang, Perak at KM260.00. In the case study, there are several data collection techniques include secondary data collection, focus group interview, actual site observation, and Analytical Hierarchy Process (AHP) were employed. Twenty-six (26) sub-risks which fall under five (5) main risks; drainage-related, pavement-related, slope-related, tunnel structure-related and other structure-related risk were identified. An Analytical Hierarchy Process (AHP) expert survey was conducted to determine the priority ranking of all the sub-risks. The results revealed that seven (7) critical sub-risks with highest ranking; slope failure, tunnel structure failure, contingency maintenance works due to slope risk, cost overrun in operation due to slope risk, drainage flood risk, contingency maintenance works due to tunnel structure risk and contingency maintenance works due to drainage risk. All the critical sub-risks have great potential to influence the operation and maintenance of Meru-Menora Tunnel which should be managed properly. The current risk management practices were investigated and evaluated. A contingency plan framework was developed and validated by Delphi Technique. There are several strategies used in the contingency plan framework include the introduction of new and effective risk management practice methods, the improvement of frequency of current risk management practices where appropriate and the suggestion of a new contingency plan for those risks without risk response plan. The future research can be tested in other Malaysian highway tunnels.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Highway tunnelling projects are indispensable during the installation of new infrastructures in congested areas as well as when enhancing the quality of existing urban living. Highway tunnels are characterised as enclosed roadway with vehicle access that has restricted portals yet applicable to various types of tunnel structures and tunnelling methods. Highway tunnels are practically another option to cross water body or to penetrate through physical barriers including railroads, mountains, existing roadways or other facilities to meet ecological or environmental requirements.

Over the past few decades, there has been a significant growth in the construction of highway tunnels worldwide. For instance, there are several numbers of world's longest highway tunnels recorded in Europe; St Gotthard Tunnel in Switzerland with 16.9km lengths, Laerdal Tunnel in Norway with 24.5km lengths and Frejust Tunnel between France and Italy with 12.9km lengths (Miclea et al., 2007). Mont-Blanc Tunnel between France and Italy, one of the most famous highway tunnels in the world was once the longest highway tunnel with 11.6km lengths upon its completion in 1965. In Hong Kong, additional four subsea tunnels were constructed prior to completion of Cross-Harbour Tunnel that connects the highway transport between the Hong Kong Island and Kowloon peninsula (Morris et al., 2016).

In Malaysia, there are three major highway tunnels currently in their operation and maintenance stage; namely Genting Sempah Tunnel, Stormwater Management and Road Tunnel (SMART) and Meru-Menora Tunnel. Genting Sempah Tunnel is the first highway tunnel constructed between 1977 and 1979 in Malaysia, located along the Kuala Lumpur-Karak Expressway. SMART Tunnel in Kuala Lumpur serves two purposes, which are to ease the traffic congestion at Sungai Besi, Kuala Lumpur Southern Gateway and solve the flooding problems at Kuala Lumpur (Kannapiran, 2005). Meru-Menora Tunnel is situated along West Malaysia's North-South Expressway near Jelapang Perak and completed in 1986.

The highway tunnelling projects are complex endeavours as they are differed from on ground structures and design conditions vary case by case. In other words, it is relatively difficult to construct highway tunnels in all types of locations and most importantly it is not uncommon for any form of risks to take place especially after completion of highway tunnel, which is during operation and maintenance stage.

Generally, the highway tunnelling projects impose risks on all parties involved directly or indirectly within the project. These risks may dramatically impact on operation and maintenance of highway tunnels especially in time, cost and quality aspects. Due to inherent uncertainties, the highway tunnels are exposed to various hazards resulted from risks during operation and maintenance such as seepage crack, concrete delamination, steel corrosion, drainage damage, pavement settlement and decay of the lining structure.

1.2 Problem Statements

There are a lot of major accidents and disasters occurred during operation and maintenance of highway tunnels. For example, landslide occurrences at Pucara Headrace Tunnel (Micheli et al., 2013) and Beaminster Tunnel (Andrew, 2012), fire occurrences at Channel Tunnel (Carvel, 2010), Mont-Blanc Tunnel (Siang et al., 2017) and St Gotthard Tunnel (Kim et al., 2010) and structural failure occurrences at Tsuyakama Tunnel and Rebunhama Tunnel (Asakura & Kojima, 2003).

The re-occurrences of similar major risk incidents during operation and maintenance of highway tunnels require special attention from highway tunnel operators to manage the risks effectively. For example, the Channel Tunnel between France and England experienced several serious fire incidents during operation and maintenance stage in 1996, 2006 and 2008 respectively (Carvel, 2010). All these fire incidents occurred repeatedly. In addition, the Beaminster Tunnel located in England also underwent significant repairs due to landslide occurrence in 1968 and again in 2009 (Andrew, 2012).

According to World Health Organisation (2015), there was an approximately 1.25 million people died caused by traffic incidents along highway. Malaysia has recorded the highest road casualties among the ASEAN countries by 24 deaths out of 100,000 inhabitants. The poor pavement quality is one of the major factors that contributed to occurrence of traffic incidents in Malaysia (Baskara et al., 2019).

There is a total of 49 large landslide cases recorded and 88% of them are attributed to manmade slopes (See-Saw & Tan, 2006). The large landslides are covering more than 5,000 m^3 of area. There are a lot of landslides incidents occurred along Kuala Lumpur-Karak Highway. The most recent landslide incident occurred at km 52.4 of Kuala Lumpur-Karak Highway during operation and maintenance stage in 2015 The main factors that triggered the occurrence of landslide are caused by soil erosion and structural failure of soil retaining structures (Tariq & Fadzil, 2015).

Currently, most of the highway tunnel operators often carried out traditional risk management plan to conduct risk response control but it only has limited functionality in the face of residual risks or unforeseeable risks. Apparently, the current traditional risk management plan is insufficient to maintain the excellent operational of highway tunnels. Therefore, there is a need for development of guideline for contingency plan to manage all the risks during operation and maintenance of Malaysian highway tunnels.

1.3 Aim and Objectives

The fundamental aim of this research is to develop an effective contingency plan framework from gaps identified in the current practices for managing risks during the operation and maintenance of Meru-Menora Tunnel. This has been achieved by addressing all the following objectives:

1) To identify and prioritise the potential risks based on their importance for the operation and maintenance of Malaysian highway tunnel;
2) to investigate the adequacy and effectiveness of current risk management practices in Malaysian highway tunnel; and
3) to develop and validate a contingency plan framework that improve the overall risk management of Malaysian highway tunnel.

1.4 Scope of Work

This research is only restricted to a single case study of Malaysian highway tunnel, Meru-Menora Tunnel. The selection of single case study is based on the availability of data provided by the concessionaire. For another two main highway tunnels in Malaysia; namely Genting Sempah Tunnel and SMART Tunnel, the data are not accessible from the concessionaires respectively.

The Meru-Menora Tunnel is currently in its operation and maintenance stage for more than 30 years. The location of Meru-Menora Tunnel is situated along route section N5 of West Malaysia's North-South Expressway near Jelapang, Perak. The scope of work for this research is only limited from starting point of Meru Tunnel (known as tunnel 1, south bound) and Menora Tunnel (known as tunnel 2, north bound) at KM260.00 (see Appendix A) until the end stretch of both tunnels. The total length of Meru Tunnel is 861m and Menora Tunnel is 832m.

In this research, the identification of risks is only limited to secondary data collection and perspective from respondents in the selected case study. Besides that, the investigation of current risk management practices is referring to actual risk management practices conducted by appointed contractors in the selected case study only. Although there is limitation in this research, the developed risk contingency plan framework is validated by external parties that involved in other highway tunnels to ensure the proposed framework is practical.

1.5 Significance of Study

The findings of this study will enhance the current risk management plan of highway tunnels considering that the proposed risk contingency plan framework plays an important role to mitigate the risks when the current risk management practices are ineffective. This study would be beneficial to the government, client of the highway tunnelling project, Public Works Department Malaysia (PWD), Malaysia Highway Authorities (MHA), PLUS Malaysia Berhad (PLUS) and the highway tunnel operator.

All the critical risks were highlighted in this study to heighten the awareness of the highway tunnel operator to pay more attention on those risks. Besides that, all the effectiveness of current risk management practices will be evaluated. The risk contingency plan flowchart will assist in setting up a comprehensive guideline whenever necessary responses can be conducted by relevant engaged parties such as main contractor and sub-contractor if the current risk management practices are not effective.

This study has provided a validated risk contingency plan framework that is more applicable to other highway tunnels that can act as baseline information when drafting a new risk management plan or revising the current risk management plan. The quality, time and cost of the highway tunnels during operation and maintenance stage will be improved with the aid of validated risk contingency plan framework.

1.6 Structure of Dissertation

This research comprised of six (6) chapters in total.

Chapter 1 presents the brief overview of the research topic. The problems statements were established and followed by aim and objectives. The scope of work explains where all the limitation of this study was highlighted. The significance of study where how the findings of the study can be beneficial to selected individuals are explained.

Chapter 2 addresses the literature review focused on highway tunnels and their risk management. The relevant literature review includes the definition, shape and internal elements, classes of highway roads and vehicle sizes, traffic capacity, route studies, financial studies and operation and maintenance issues. All the major highway tunnels in worldwide and Malaysia were presented. The risks during operation and maintenance of highway tunnel were identified and discussed. Then, the current risk management practices of highway tunnels were described.

Chapter 3 describes the methodologies employed in this research involving data collection, data analysis, model development and model validation. The selected triangulation method for data collection that combined both qualitative and quantitative approach are explained. Then, the selected data analysis methods are discussed. The latter part of this chapter explains the validation method used to validate the contingency plan framework.

Chapter 4 presents all the identified risks during the operation and maintenance in the selected case study of Meru-Menora Tunnel. All the risks were ranked and analysed based on their priority importance through the application of selected research methodology. The effectiveness of current risk management was investigated and evaluated.

Chapter 5 aims to propose a framework for the operation and maintenance of risk contingency plan in Meru-Menora Tunnel. Based on the gaps identified in current risk management practices for each critical risk from previous chapter, a contingency plan is proposed and explained. Next, the validation of framework for operation and maintenance of risk contingency plan in Meru-Menora Tunnel are presented.

Chapter 6 concludes the findings of all the objectives for this research including the aim of objective, methodologies used, results and significance of the results. The latter part of this chapter highlights the future recommendation of this research.

CHAPTER 2

THE HIGHWAY TUNNEL AND RISK MANAGEMENT

2.1 Introduction

This chapter addresses the literature review focused on highway tunnels and their risk management. The relevant literature review includes the definition, shape and internal elements, classes of highway roads and vehicle sizes, traffic capacity, route studies, financial studies and operation and maintenance issues. All the major highway tunnels in worldwide and Malaysia were presented. The risks during operation and maintenance of highway tunnel were identified and discussed. Then, the current risk management practices of highway tunnels were described.

2.2 Tunnel

Tunnel is defined as an underground space equipped with unique characteristics and potential applications. Tunnel is able to serve any of innumerable functions including railways transportation, roadway or highway transportation, pedestrian passageway, storage, civil defence, wastewater collector or transport, power and water treatment plant, space for other utilities and other activities (Fouladgar et al., 2012).

In other words, tunnel is also known as an underground infrastructure built artificially to facilitate transportation or conveyance of people, water, sewage, material, other gas and fluids in pipes penetrate through obstructions including mountains, rivers and other obstructions including industrial structures, buildings and other infrastructure such as railway tracks and roads (Ponnuswamy & Victor, 2016).

Tunnel is indispensable during the installation of new infrastructure in congested areas as well as when enhancing the quality of existing urban living of a country. Tunnel improves connections and shorten lifelines. By serving the purpose of moving traffic underground, tunnel improves the quality of life above ground and has significant economic impact (Kolymbas, 2005).

Tunnel is not similar to other civil engineering structures because it does not has defined and testable properties (Chapman et al., 2017). Table 2.1 shows the comparison between tunnel construction and above ground construction in term of construction material, loads and safety.

Table 2.1. Comparison between tunnel construction and above ground construction (Source: Chapman et al., 2017).

	Above ground construction	*Tunnel construction*
Construction material	The defined properties of the construction materials are guaranteed by the quality control procedures during the production process, including control testing.	The ground, with all its uncertainty, and the general inability to influence its properties (notwithstanding ground improvement techniques) is the construction material.
Loads	The loads for which the structural analysis is carried out are mostly known.	Only by making assumptions is it possible to estimate the loads possible, which means that the magnitude of the load is based on assumption and is thus basically unknown.
Safety	Because the properties of the construction materials and the loads are known, the safety factor relative to failure can be determined.	Because of the number of uncertainties related to the loads and material properties it is not possible to calculate a quantitative factor regarding the safety of the tunnel construction.

There are several methods to construct a tunnel such as by drilling and blasting method, by mechanised means such as continuous miners or tunnel boring machines, by cut-and-cover methods, in long prefabricated sections sunk in place as in immersed tubes and in short prefabricated sections pushed into place from jacking pits.

In cross section, the tunnel takes any of a few shapes including multicurve, circular, cathedral arch, arched, horseshoe or flat-roofed and in cavern form which is wider. A tunnel can be placed in any of a few of places including mountains, cities, rivers, lakes, sea estuaries, straits, or bays. Finally, a tunnel is constructed in one of innumerable media-soft ground, mixed face, rock, uniform, jumbled, layered, dry, wet, stable, flowing, squeezing (Kuesel et al., 2012).

Most of all, a tunnel exists because there is demonstrated need to move people or material where no other means is practical or adequate, or to accomplish the required movement more directly, more quickly, or less obtrusively. The need may be for storage, either short term as for storage of stormwater flows to reduce the otherwise high peak capacities required of wastewater treatment plants, or longer term as for storage of vital raw materials or products.

In general, tunnel can be separated into two categories; conveyance tunnel and transportation tunnel. Conveyance tunnel serves its purpose to convey liquids and may include hydroelectric power station tunnel, water supply tunnel, sewer tunnel, tunnel for the intake and conduit of public utilities, sewer tunnel and tunnel in industrial plants. Transportation tunnel can be further divided into railway tunnel, pedestrian highway, navigation tunnel, subway tunnel and highway tunnel (Kuesel et al., 2012).

2.3 Highway Tunnel

Highway tunnel is defined as an enclosed roadway with vehicle access that has limited portals but applicable to all types of tunnel structures and tunnelling methods including tunnel mined and bored in rock, soft or hard ground, jacked box tunnel, cut and cover tunnel, and immersed tunnel (National Highway Institute US, 2010).

Highway tunnel is practically an alternative solution to cross water body or penetrate through physical barriers such as railroads, mountains, existing roadways or any other facilities to accommodate ecological or environmental requirements. The highway tunnel is feasible to reduce potential environmental impacts including pedestrian movement, traffic congestion, noise pollution, air quality, trespass on visual; to conserve historical or cultural value of districts or buildings; or other sustainability reasons, for instance to avoid any damages on natural habitat surrounding nearby areas (Fouladgar et al., 2012).

Multidisciplinary involvement and assessments were taken into considerations in planning for a highway tunnel and should acquire the same standards as for surface roads and bridge options with certain exceptions. Several issues should be considerate for highway tunnel such as life-safety, lighting, ventilation and also operation and maintenance. A life-cycle cost analysis should be taken into consideration in addition to capital construction cost as life expectancies of a highway tunnel is significantly longer that other infrastructures (Chapman et al., 2017).

2.3.1 Highway Tunnel Shape and Internal Elements

Three main shapes of highway tunnel are circular, rectangular, and horseshoe or curvilinear. The rectangular tunnel (see Figure 2.1) is generally constructed by the cut and cover method, by jacked box tunnelling or by the immersed method. Circular tunnel (see Figure 2.2) is generally constructed by drill-and-blast in rock or a tunnel boring machine (TBM). Horseshoe or curvilinear tunnel (see Figure 2.3) is often constructed either by following the Sequential Excavation Method (SEM) or by using drill-and-blast in rock (National Highway Institute US, 2010).

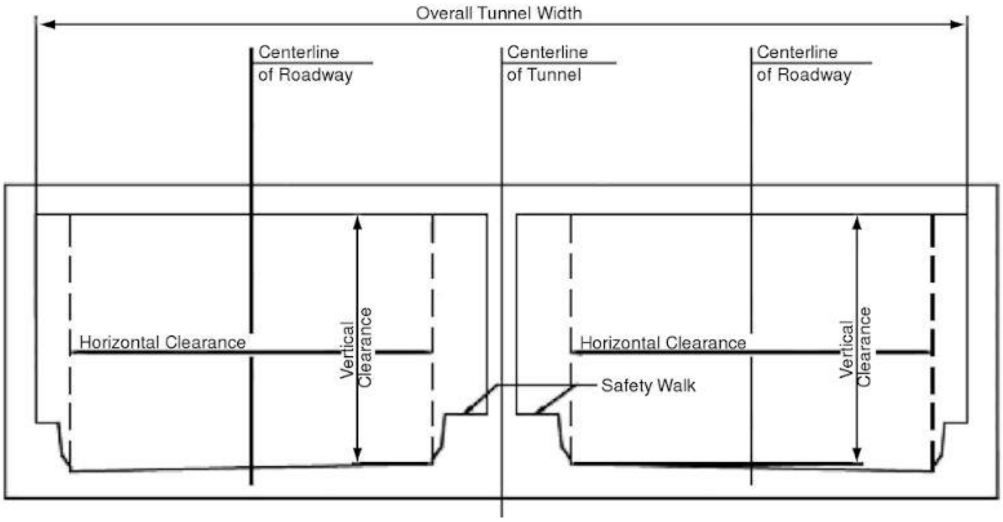

Figure 2.1. Rectangular Tunnel (Source: National Highway Institute (US), 2010).

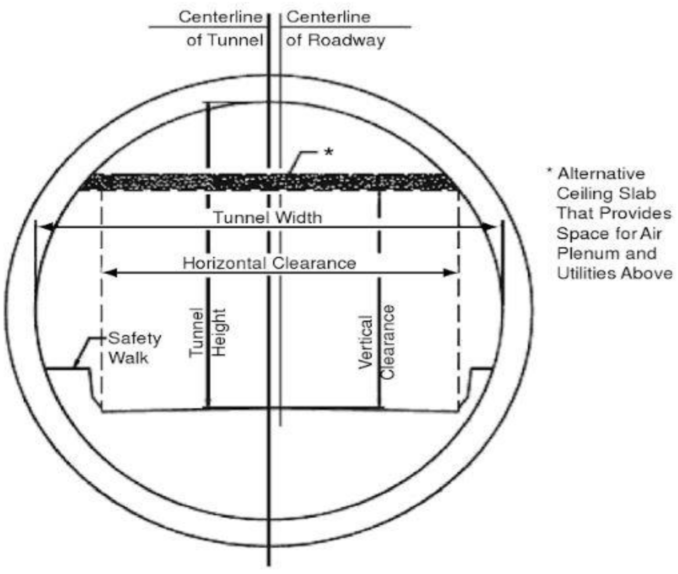

Figure 2.2. Circular Tunnel (Source: National Highway Institute (US), 2010).

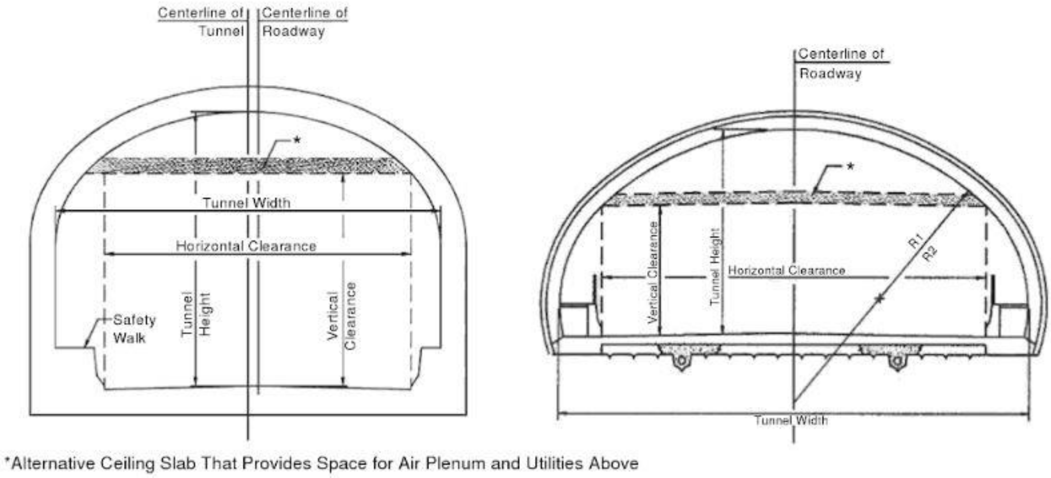

Figure 2.3. Horseshoe or Curvilinear tunnel (Source: National Highway Institute (US), 2010).

Highway tunnel is usually lined with concrete and interior finished to satisfy safety and maintenance requirements. Walls and ceilings often receive a finish surface, while the roadway is often paved with asphalt pavement. Interior finishes, which are usually mounted or adhered to the final lining, consist of ceramic tiles, epoxy-coated metal panels, porcelain-enamelled metal panels, or various coatings. Interior finishes provide enhance tunnel lighting and visibility, provide fire protection for the lining, attenuate noise, and provide a surface easy to clean. The highway tunnel is usually equipped with various systems including ventilation, lighting, communication, fire life-safety, traffic operation and control including messaging, and operation and control of the various systems in the tunnel (Gafari & Aminzadeh, 2015).

2.3.2 Classes of Highway Roads and Vehicle Sizes

A highway tunnel can be designed to accommodate any class of road and any size vehicle. Alignments, dimensions, and vehicle sizes often are determined by the responsible authority based on the classifications of the road. However, most regulations were formulated on the basis of open roads. Ramifications of applying these regulations to highway tunnels should be considered. For example, the use of full-width shoulders in the tunnel might result in high cost. Modifications to these regulations through engineering solutions and economic evaluation should be considered in order to meet the intention of the requirements (Dekovic and Pili, 2012).

The size and type of vehicles to be considered depend upon the class of road. Generally, the highway tunnel's geometric configuration should accommodate potential vehicles that use the roads leading to the highway tunnel, including over-height vehicles such as military vehicles, if needed. However, the highway tunnel height should not exceed the height under bridges and overpasses the road that leads to the tunnel. On the other hand, certain roads, such as parkways, permit only passenger vehicles. In such cases, the geometrical configuration of a highway tunnel should accommodate the lower vehicle height, keeping in mind that emergency vehicles such as fire trucks should be able to pass through the highway tunnel unless special low-height emergency-response vehicles are provided. It is necessary to consider the cost (National Highway Institute US, 2010).

2.3.3 Traffic Capacity

Highway tunnel should have at least the same traffic capacity as surface roads. Studies suggest that in highway tunnels where traffic is controlled, throughput is greater than that of an uncontrolled surface road, suggesting that a reduction in the number of lanes inside the highway tunnel may be warranted. However, traffic will slow down of the lane width is less than standard like too narrow and will shy away from highway tunnel walls if insufficient lateral clearance is provided inside the highway tunnel. Also, very low ceilings give impression of speed and tend to slow traffic. Therefore, it is important to provide adequate lane width and height, comparable to those of the approach road. It is recommended that traffic lanes for new highway tunnels meet the required road geometric requirements. It is also recommended to have a reasonable edge distance between the lane and the highway tunnel walls or barriers (Pais et al., 2013).

Highway tunnel, especially those in urban areas, often have cargo restrictions. These restrictions may include hazardous materials, flammable gases and liquids, and over-height or over-wide vehicles. Provisions should be made in the approaches to tunnels for detection and removal of such vehicles (National Highway Institute US, 2010).

2.3.4 Route Studies

A highway tunnel is an alternative vehicular transportation system to a surface road, bridge, or viaduct. Highway tunnel is considered to shorten travel time and distance or to add extra travel capacity through barriers such as mountains or open waters. They also reconsidered to avoid surface congestion, improve air quality, reduce noise or minimise surface disturbance. Often a tunnel is proposed as a sustainable alternative to a bridge or surface road. In a highway tunnel route study, the following issues should be considered:

- Subsurface, geological, and hydrogeologic conditions
- Constructability
- Long-term environmental impact
- Seismicity
- Land use restrictions
- Potential air right developments
- Life expectancy
- Economical benefits and life-cycle cost
- Operation and maintenance
- Security
- Sustainability

Often sustainability is not considered; however, the opportunities that highway tunnels provide for environmental improvements and real estate developments over them are hard to ignore and should be reflected in terms of financial credits. In certain urban areas where property values are high, air rights developments account for significant income to public agencies, income which can be used to partially offset the construction cost of highway tunnels (Martani, 2015).

When comparing alternative, such as a highway tunnel versus a bridge or bypass, it is important that the comparative evaluation includes the same purpose and need and the overall goals of the project, but not necessarily every single criterion. For example, a bridge alignment may not necessarily be the best alignment for a highway tunnel. Similarly, the life cycle cost of a bridge has a different basis from that of a highway tunnel (National Highway Institute US, 2010).

2.3.5 Financial Studies

The financial viability of a highway tunnel depends on its life-cycle cost analysis. Traditionally, the highway tunnels are designed for a life of 100 to 125 years. However, existing old highway tunnels still operate successfully throughout the world. Recent trends were to design tunnels for a 150-year life. To facilitate comparison with a surface facility or bridge, all costs should be expressed in terms of life-cycle costs. In evaluating the life-cycle cost of a tunnel, cost should include construction, operation and maintenance, and financing if any using net present value. In addition, a cost-benefit analysis should be performed with consideration given to intangibles such as environmental benefits, aesthetics, noise and vibration, air quality, right-of-way, real estate and potential air rights developments (Au-Yong et al., 2014).

The financial evaluation also should consider construction and operation risks. These risks are often expressed as financial contingencies or provisional cost items. The level of contingencies would be decreased as the project design level advances. The risks are then better quantified and provisions to reduce or manage them are identified (Faremi et al., 2015).

2.3.6 Operation and Maintenance Issues

In planning a highway tunnel, provisions should be made to address the operational and maintenance aspects of the tunnel and its facilities. Issues such as traffic control, ventilation, lighting, life-safety systems, equipment maintenance, tunnel cleaning, and the like should be identified and provisions made for them during the initial planning phases. For examples, items requiring more frequent maintenance, should be arranged to be accessible with minimal interruption to traffic (National Highway Institute US, 2010).

2.3.7 Highway Tunnels Worldwide

There has been a significant growth in the construction of highway tunnels worldwide over the past few decades. In Europe, there are several numbers of world's longest highway tunnels in its operation and maintenance stage; St Gotthard Tunnel in Switzerland with 16.9km lengths, Laerdal Tunnel in Norway with 24.5km lengths and Frejust Tunnel between France and Italy with 12.9km lengths (Miclea et al., 2007). Mont-Blanc Tunnel between France and Italy, one of the most famous highway tunnels in the world was once the longest highway tunnel with 11.6km lengths upon its completion in 1965. In Hong Kong, additional four subsea tunnels were constructed prior to completion of Cross-Harbour Tunnel that connects the highway transport between the Hong Kong Island and Kowloon peninsula (Morris et al., 2016).

Mont-Blanc Tunnel (see Figure 2.4) is a highway tunnel located under the Mont-Blanc massif, the road of Western Europe that connects between France and Italy (see Figure 2.5). The total length of Mont-Blanc Tunnel is 11.6km and it was the longest highway tunnel in the world upon its completion in 1965 (Leonelli et al., 2012).

Each half of the Mont-Blanc Tunnel is controlled by one operating entity, SITMB (Societa Italiana del Traforo di Monte Bianco) in Italy while ATMN (Autorout et Tunnel du Mont Blanc) in France. The tunnel has the total width of 8.5m comes with a cross-section area of about $50m^2$ and the maximum height of the vault-shaped ceiling is 6m **(**Vuilleumier et al., 2002).

Figure 2.4. Mont-Blanc Tunnel between Italy and France (Source: Leonelli et al., 2012).

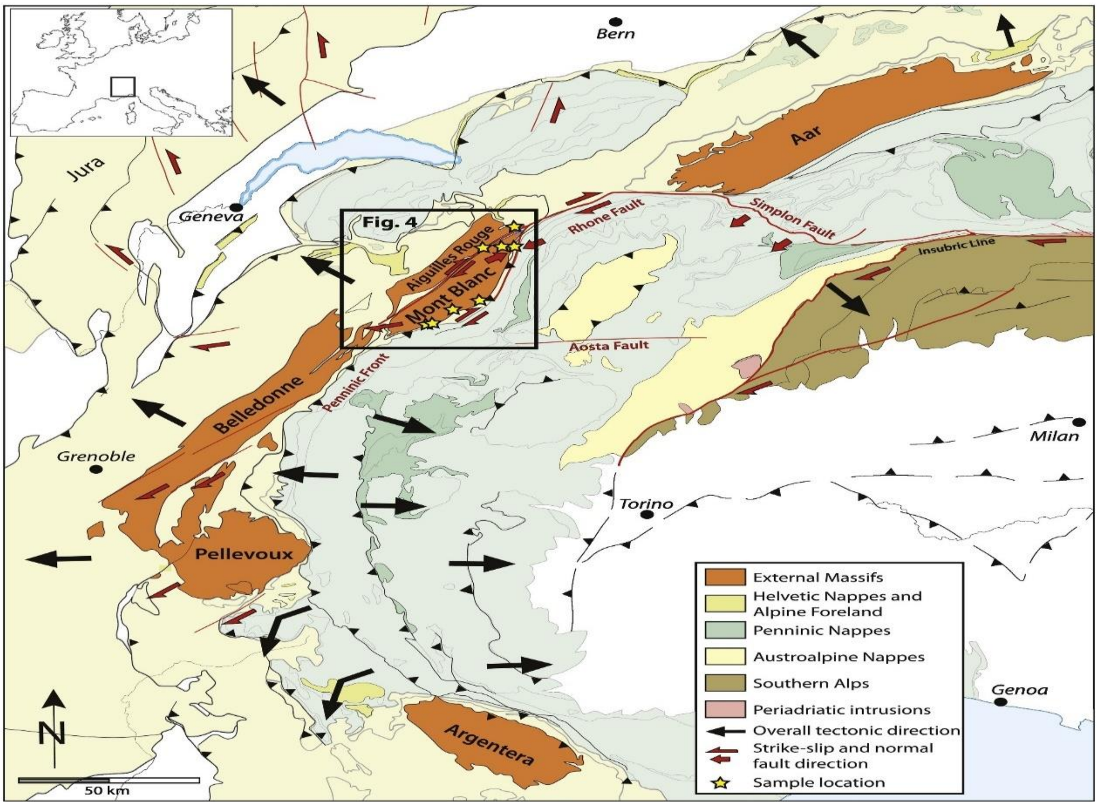

Figure 2.5. Location of Mont-Blanc Tunnel (Source: Steck et al., 2013; Schmid et al., 2004).

St. Gotthard Tunnel (see Figure 2.6) is a two-lane highway tunnel that was built between 1970 and 1977 that connects between the northern and southern parts of Switzerland (Zangerl et al., 2008). The St. Gotthard Tunnel is located between Goshenen and Airolo in Switzerland and it is part of Swiss A2, connects the Italian border (Chiasso) with Germany and France (Basel) (Kim et al., 2010).

The St. Gotthard Tunnel is the highway tunnel with two lanes in one tube that serves bi-directional traffic. The height of the tunnel above sea level is about 1.12km and the total length of the tunnel is 16.872km including cut and cover section north of 550m. The cross section of the tunnel is 40.5m^2 (Steinemann et al., 2004).

Figure 2.6. St. Gotthard Tunnel in Switzerland (Source: Steinemann et al., 2004).

Cross-Harbour Tunnel (see Figure 2.7) is one of the oldest highway tunnels that was built and starts to operate since 1972 in Hong Kong. The purpose of the construction of the Cross-Harbour Tunnel is to ease the traffic congestion problems due to growing population and economics in Hong Kong. The Cross-Harbour Tunnel connects the Hong Kong island and the Kowloon peninsula under the harbour (Morris et al., 2016).

The Cross-Harbour Tunnel was the longest sunken tube tunnel in Asia at that particular time. The tunnel has 5.1m clearance height and a carriageway of length 1.856km and width 6.6m. The cross-section and longitudinal profile of Cross-Harbour Tunnel are shown in Figure 2.9 (Chow & Li, 2001).

Figure 2.7. Cross-Harbour Tunnel in Hong Kong (Source: Morris et al., 2016).

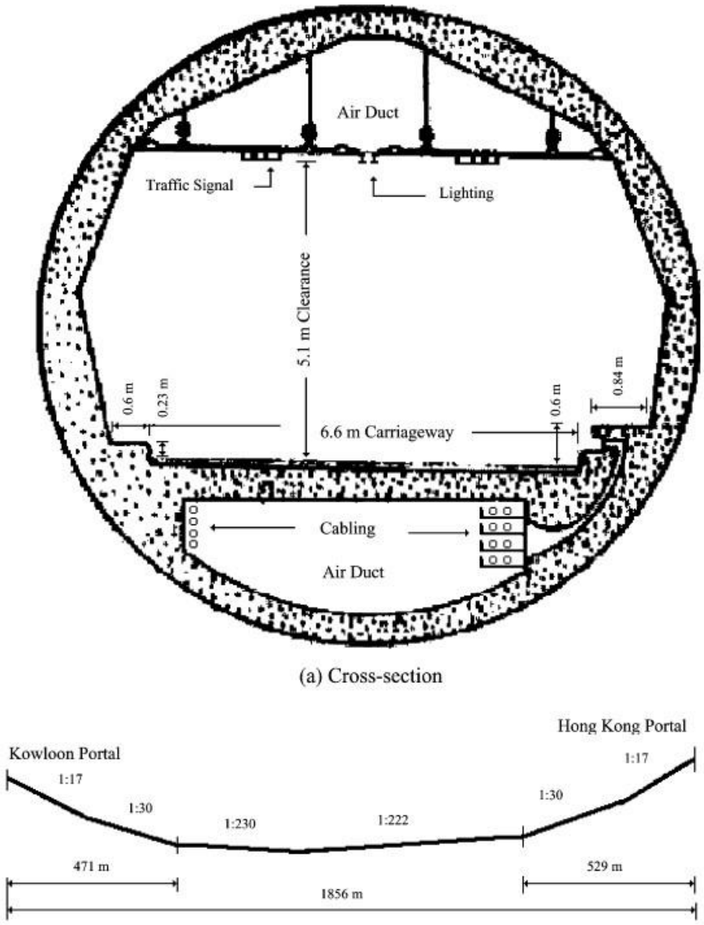

Figure 2.8. Cross-section and longitudinal profile of Cross-Harbour Tunnel (Source: Chow & Li, 2001).

Beaminster Tunnel or Horn Hill Tunnel (See Figure 2.9) is a road or highway tunnel that has a total length of 105m located on A3066 road between Beaminster and Mosterton in Dorset, England. The tunnel was completed between 1830 and 1832. The Beaminster Tunnel is the first tunnel built in Britain and it was built to take a toll road underneath a steep hill to the north of Beaminster and makes way for traffic to travel from the coast to the hinterland of Dorset (Andrew, 2012).

Figure 2.9. Beaminster Tunnel (Source: Andrew, 2012).

Tauern Tunnel (see Figure 2.10) is a bi-directional highway tunnel with total length of 6.40km located in the province Salzburg in Austria that connects the region Pongau and Lungau. The Tauern Tunnel is ranked as one of the most frequently travelled highway tunnels in Austria upon its completion in 1975. The tunnel has 5m height and 9.5m wide. The southern entrance of the tunnel is at Zederhaus (Lungau) and the north entrance is at Flachauwinkel (Salzburg) (Kim et al., 2010).

Figure 2.10. Tauern Tunnel (Source: Kim et al., 2010).

2.3.8 Highway Tunnels in Malaysia

There are three main highway tunnels in Malaysia; namely Genting Sempah Tunnel, SMART Tunnel and Meru-Menora Tunnel.

2.3.8(a) Genting Sempah Tunnel

Genting Sempah Tunnel (see Figure 2.11) is known as the first highway tunnel constructed between 1977 and 1979 in Malaysia, located along the Kuala Lumpur-Karak Expressway. The Genting Sempah Tunnel is a 900m tunnel connects Hulu Gombak in Selangor to Genting Sempah, Pahang (Mohamed Jais, 2017). There are two tunnels that connect to the east and west peninsular of Malaysia, each with two lanes with the length of 1km each (Shahar & Majid, 2008).

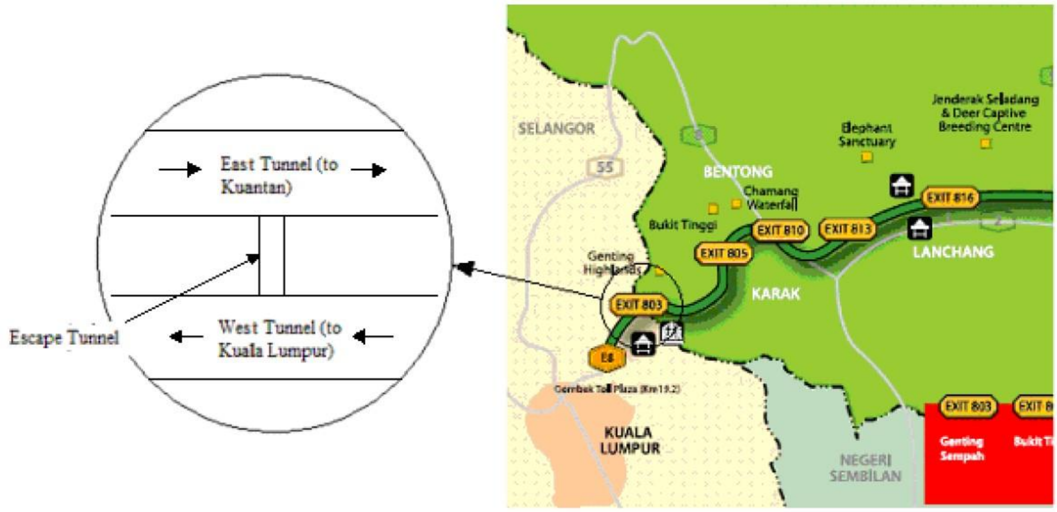

Figure 2.11. Genting Sempah Tunnel and the plan view location (Source: Shahar & Majid, 2008).