EARTHQUAKE EFFECTS ON TUNNEL FLOATING SLAB TRACK AND LINING WITH SLAB BEARING AND BASE ISOLATOR

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All praises to The Knower of All for endowing me with knowledge all this while...

To my husband, Muhammad Ghazali,

My lovely parents, Arjuna & Shamsiah, also Md Nor & Norsiah,

Beloved Ohana,

Akhawat fillah,

Jazakumullah Khairan Katsiran for the motivation and tremendous support.

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ABSTRACT

Earthquake is one of the biggest natural phenomena that causes damage and loss of life. Malaysia is prone to seismic tremors originating from nearby countries such as Indonesia and Philippines. The Sumatran earthquake in 2005 has raised questions about the structural stability and integrity in Malaysia including tunnel structures, given the substantial seismic effect from Sumatran earthquake. In addition, the waves that pass through soil medium would affect the behaviour of subsurface structure in tunnels. The scope of this study focused on Klang Valley Mass Rapid Transit (KVMRT Sungai Buloh – Kajang Line) in Malaysia. Rubber based isolators were inserted underneath the floating slab track of the tunnel to study the effectiveness of the isolated installation under earthquake loading and to identify the functions of the base isolator system used for the floating slab track of a tunnel. The finite element analysis of the individual base isolator conforms to the experimental laboratory testing under compression and shear loads. In order to verify the results of structural analysis, the finite element analysis was carried out for the base isolator under static analysis approach. Meanwhile, the tunnel floating slab track was modelled using finite element method (FEM) under dynamic analysis approach. Time history analysis was performed with peak ground acceleration to the structure to study the behaviour of tunnel lining and performance of floating slab track. From the results, it is found that the base isolator performed very well in reducing the seismic response of acceleration on floating slab track with a reduction of 17% from the actual acceleration. Moreover, the results have shown a slight reduction of tunnel lining internal forces if a base isolator is used on floating slab track. It can be concluded that a base isolator on floating slab track tunnel is recommended for human comfort and safety under earthquake effects.

ABSTRAK

Gempa bumi adalah salah satu fenomena semula jadi yang terbesar yang menyebabkan kerosakan dan kehilangan nyawa. Malaysia terdedah kepada gegaran seismik yang berasal dari negara-negara berdekatan seperti Indonesia dan Filipina. Gempa bumi Sumatera pada tahun 2005 telah menimbulkan persoalan terhadap kestabilan struktur dan integriti di Malaysia termasuk struktur terowong, dalam menghadapi apa-apa kesan seismik dari gempa bumi Sumatera. Selain itu, gelombang yang melalui medium tanah akan memberi kesan kepada kelakuan struktur subpermukaan di dalam terowong. Skop kajian ini memberi tumpuan kepada *Klang Valley Mass Rapid Transit (KVMRT Laluan Sungai Buloh - Kajang Line)* di Malaysia. Alas pemisah getah dimasukkan di bawah landasan papak terapung terowong untuk mengkaji keberkesanan pemasangan terpencil di bawah pembebanan gempa bumi dan untuk mengenal pasti fungsi-fungsi sistem alas pemisah digunakan untuk landasan papak terapung terowong. Analisis unsur terhingga bagi alas pemisah sahaja diuji dalam makmal eksperimen di bawah mampatan dan ricih beban. Untuk mengesahkan keputusan analisis struktur, analisis unsur terhingga telah dijalankan untuk alas pemisah di bawah pendekatan analisis statik. Sementara itu, landasan terapung di terowong telah dimodelkan dengan menggunakan kaedah unsur terhingga (FEM) di bawah pendekatan analisis dinamik. Analisis masa sejarah telah dilakukan dengan pecutan bumi puncak struktur untuk mengkaji tingkah laku lapisan terowong dan prestasi landasan papak terapung. Daripada keputusan, didapati bahawa alas pemisah menunjukkan prestasi yang sangat baik dalam mengurangkan tindak balas seismik pecutan pada landasan papak terapung dengan pengurangan sebanyak 17% daripada pecutan yang sebenar. Selain itu, keputusan menunjukkan sedikit penurunan pada beban-beban dalaman lapisan terowong jika alas pemisah asas digunakan di landasan papak terapung. Dengan kajian ini, ia dapat disimpulkan bahawa alas pemisah asas pada landasan terapung di terowong disyorkan untuk keselesaan manusia dan keselamatan daripada kesan gempa bumi.

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LIST OF ABBREVIATIONS AND SYMBOLS

MRT	-	Mass rapid transit
FEM	-	Finite element method
RB	-	Rubber bearings
FST	-	Floating slab track
MGDM	-	Minerals and Geoscience Department of Malaysia
MMI	-	Modified mercalli intensity
KVMRT	-	Klang valley mass rapid transit
LRB	-	Laminated rubber bearing
SRSS	-	Square Root of the Sum of the Square
DOF	-	Degree of freedom
BI	-	Base isolator
UX	-	Direction in x axis
UY	-	Direction in y axis
UZ	-	Direction in z axis
2D	-	2-dimensional
PGA	-	Peak ground acceleration
CQC	-	Complete quadratic combination
t	-	Thickness
R	-	Radius
K	-	The stiffness matrix
M	-	Thediagonal mass matrix
ϕ	-	The matrix of corresponding eigenvectors
ω_2	-	The diagonal matrix of eigenvalues
M	-	The diagonal mass matrix
a	-	Acceleration

C	-	The damping matrix
v	-	Velocity
u	-	Relative displacement with time
a_g	-	The ground acceleration
K_{eff}	-	Effective stiffness
K_H	-	Horizontal stiffness
G	-	Shear modulus
A	-	Area
t_r	-	Total thickness of the rubber
D	-	Displacement
γ	-	Shear strain
K_V	-	Verical stiffness
E_C	-	Compression modulus
S	-	Shape factor
ϕ	-	Diameter

CHAPTER 1

INTRODUCTION

1.1 General

The result of vibration forces arising from the acceleration of ground due to movement of crust is known as an earthquake. An earthquake happens when tectonic activity is connected to the plate margins and faults, when the stresses are in the outer layer of earth, which forces the surface of the fault to join together. The energy resulting from this incident contributes to the earthquake from the earth's crust.

There are seven primary plates involving in the tectonic activity around the world, namely African plate, Antartic plate, Eurasian plate, Indo-Australian plate, North American plate, Pacific plate and South American plates as shown in Figure 1.1. These plates are continually moving in relation to each another.

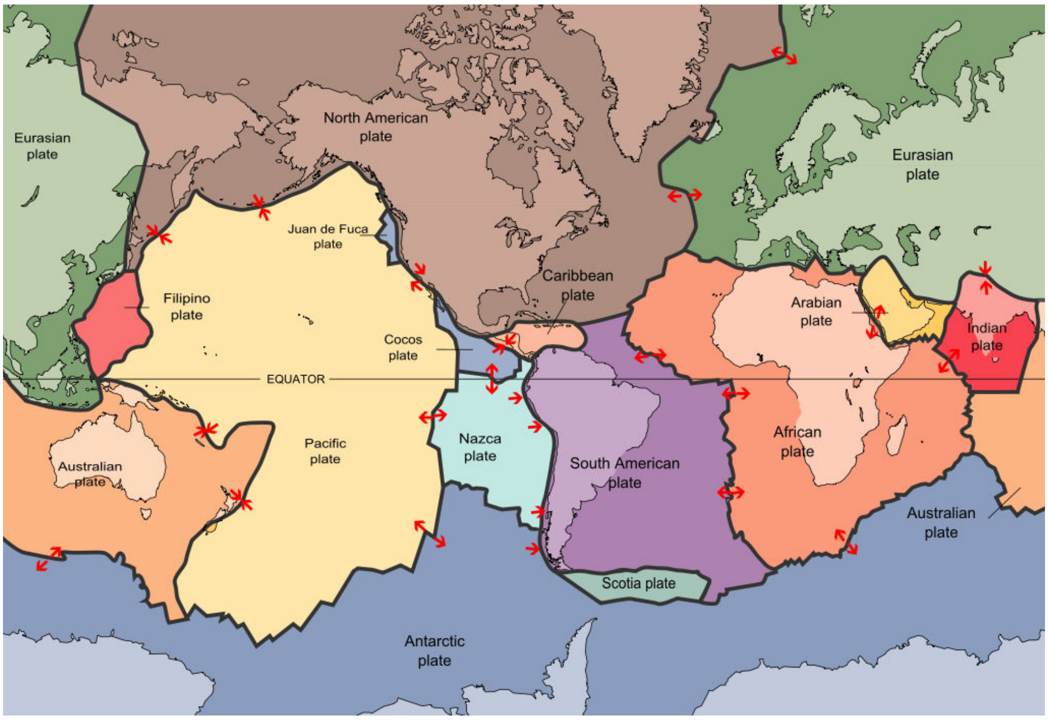

Figure 1.1: Tectonic plates of the world (USGS, 2011)

The damage from earthquakes can be reported with the numbers on the Moment magnitude scale and Ritcher scale. For the serious damage of large affected areas, the magnitude is usually classified above 7, while a magnitude 3 or lower is mostly imperceptible. Earthquake-related deaths are mostly caused due to the collapse of structures. Early earthquakes like the 1989 Lorna Prieta, 1994 Northridge earthquakes in California, and the 1995 Kobe earthquake in Japan have contributed for the loss of many lives and damage to the properties.

Malaysia is situated at the middle of Indonesia and Philippines, which are the two countries known to be present in the high seismic region. Indonesia lies on the several tectonic plates that are located between the two continental plates: Eurasian Plate (Sunda Plate) and Australian Plate (Sahul Shelf); and between the two oceanic plates: Philippine Sea Plate and Pacific Plate. Although the main cities in Peninsular Malaysia such as Kuala Lumpur, Putrajaya, Penang and Johor Bahru are located in the low seismic region when compared to the neighbouring countries, it may be vulnerable to distant earthquakes produced by active seismic resources located in more than 200 km along and off the west coast of Sumatra Island (Vaez Shoushtari, et. al., 2012). In general, seismic design has not taken into account in regions with low, moderate earthquake as the area has never happened any damages resulting from the earthquakes.

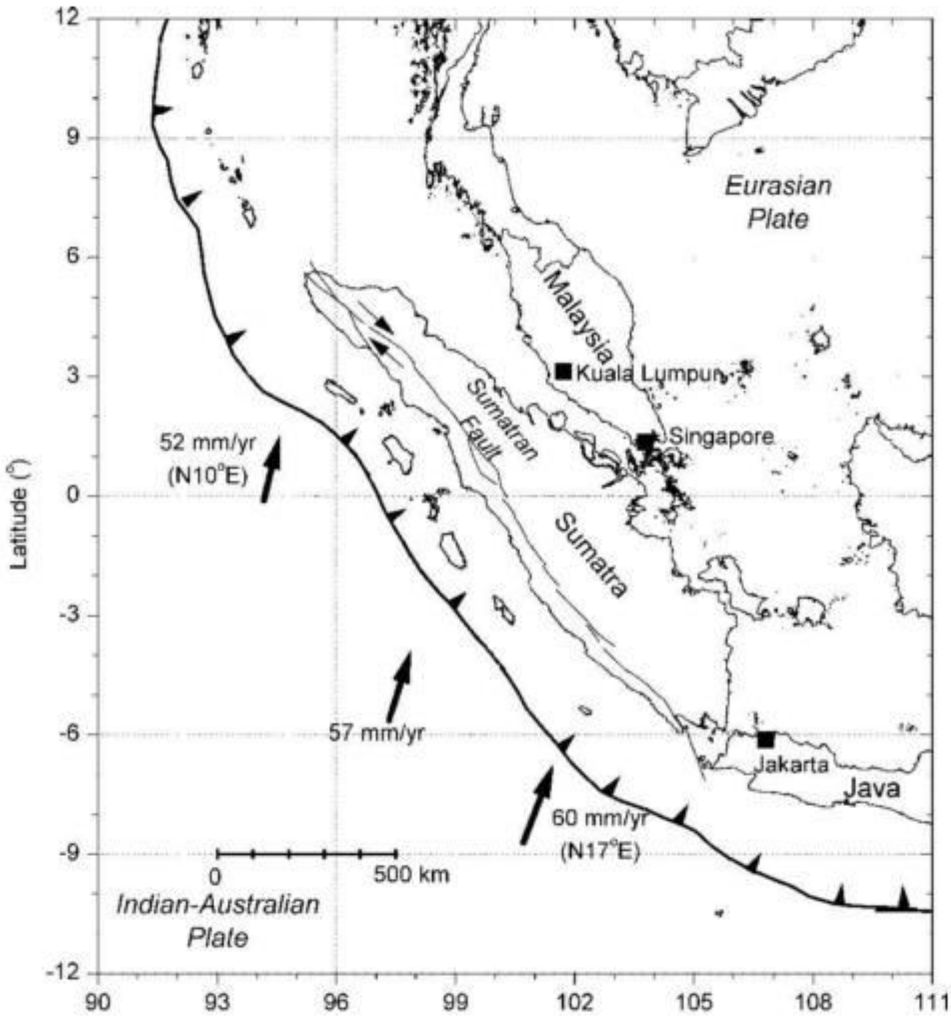

Figure 1.2: Regional tectonic setting that affected Malaysia
(Vaez Shoushtari et al., 2012)

The effects of earthquake on structures are the main problem for architects and engineers. Thus, this natural phenomenon is made many engineers to seek knowledge to encounter the problem. They have to consider the safety factors resulting from various loadings, including wind and earthquake, while designing the structures.

A concept has been developed to help engineers to overcome the earthquake forces in structures. This method is to meet the requirements of the problem that are absorbing the vibration coming inside the earth or deflecting the forces from the ground to the building. In structural earthquake engineering, this method is called as the base isolation system.

Base isolation and energy dissipation systems are two structural controls for earthquake safety structures. Both have been increasingly implemented worldwide during the last several years and have proven to be one of the most promising strategies in meeting the requirements of engineers to protect the structures during an earthquake.

In addition, Derham *et al.* (1985) have shown that structures experienced earthquake forces can be reduced by the same method as used in every other field of vibration engineering, which is the isolation system. Most seismic isolation depends on the rubber bearings (RB) known as the base isolator.

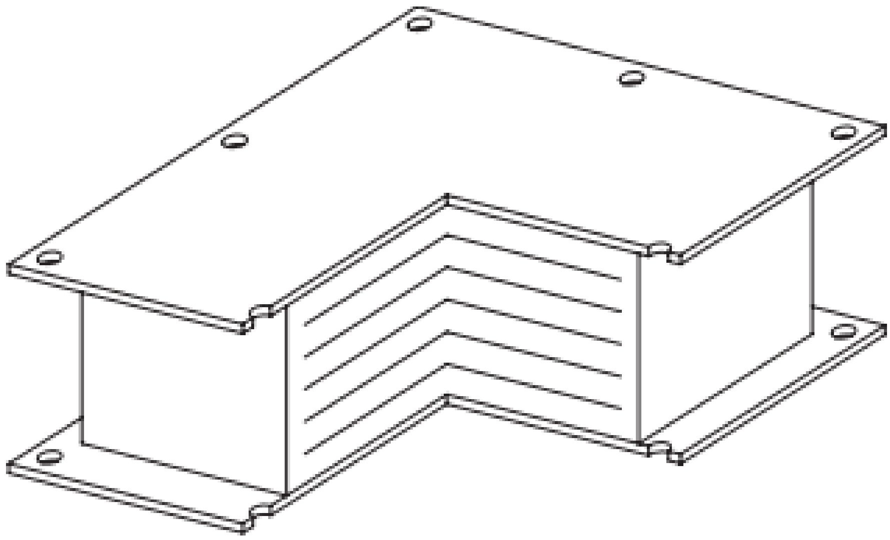

Figure 1.3: Base Isolator (Matsagar & Jangid, 2008)

The seismic isolation system used worldwide consists of laminated rubber bearings that are made of rubber and steel shim layer as shown in Figure 1.3. In this combination, the bearing can give a very high vertical stiffness and more flexibility in the horizontal direction. Both characteristics are important to ensure that it can support the loading from structure and prevent excessive side way movements from horizontal loading especially during an earthquake.

The application of base isolation systems had been widely practiced by many of the countries, especially in high seismic regions like New Zealand, Japan and United States. The first building which applied the earthquake-resistant system in the United States is the Foothill Communities Law and Justice Center in Rancho Cucamonga San Bernandino. This building was completed in 1985, using 98 isolators that were installed under the base of the building (Derham *et al.*, 1985). Besides, base isolator was also applied in Japan. During the 1995 Kobe earthquake, the largest base-isolated building in the world; West Japan Postal Computer Centre had survived the earthquake.

The rapid growth of superstructures in the late 19th century and due to the increasing of cars with limited highway area has affected transportation technology. Thus a transportation system introduces underground railway tunnel to overcome the traffic jam problem in land transportation. Railway tunnel has many advantages, but the noise and vibration problem creates problem to the neighborhood residents who are present along this route.

Studies related to vibration in railway tunnel has been widely applied due to the above mentioned problem. Floating slab track (FST) is one of the vibration isolations that isolate the train movement into the surrounding. Floating slab track is a good model of the vibration source isolation. It is because the resilient mats of railway functions as the vibration isolator (M.F.M. Hussein and Hunt, 2006).

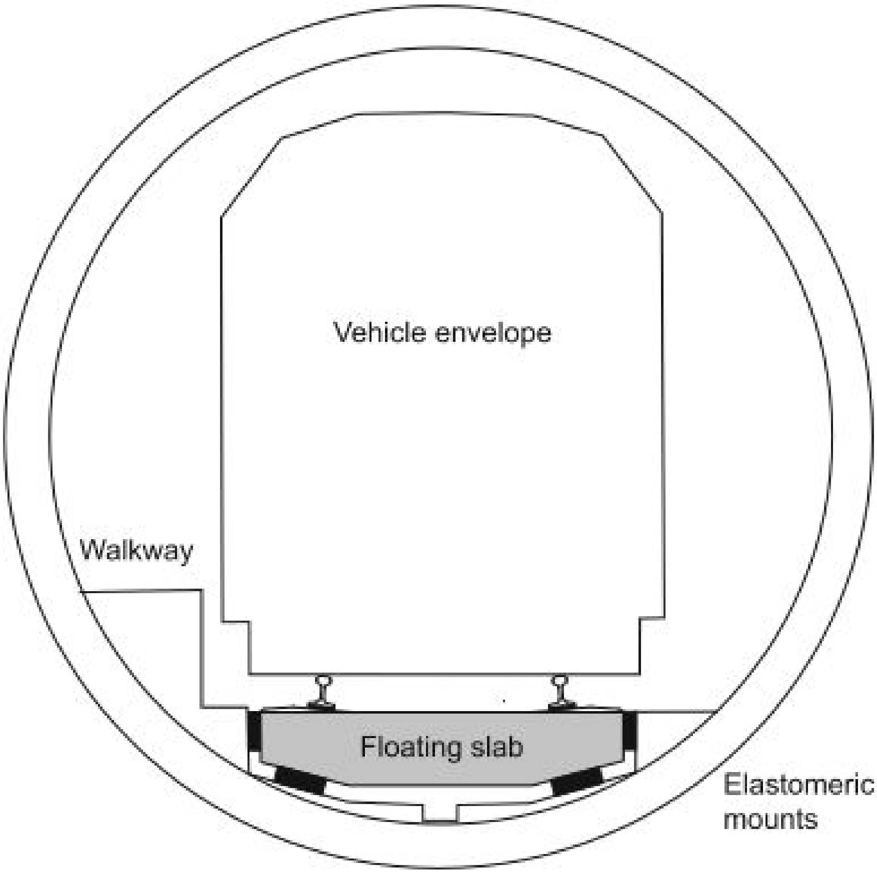

Figure 1.4: Floating slab track in a tunnel (Thompson, 2009)

The floating slab track in a tunnel lies on an elastomeric mounts which consists of resilient layer as shown in Figure 1.4. Most of the earthquake engineering studies are related to super structures only. Wang (1993) stated that tunnels are safer when compared to above ground structures during an earthquake. The statement is not quite valid due to a massive earthquake that striked Loma Prieta in 1989 which affected the Alamneda Tubes California.

1.2 Problem Statement

Many countries that are located in high seismic zones use seismic design in their buildings. New Zealand, Japan and United States are among the countries that has already considered this seismic design. Malaysia is situated in between Philippines and Indonesia in Pacific Ring of Fire region. In 1999, Sabah and Peninsular Malaysia experienced tremors from the Acheh earthquake in Sumatra.

The floating slab track system is a system present in the railway tunnel for absorbing the vibration that is coming from the train to the surrounding. This system mounts the entire track on a concrete foundation slab that rests on rubber bearings. However, the current floating slab track has unknown performance of human comfort and train safety to maintain on the track during an earthquake also the tunnel lining performance.

In contrast, base isolation system is designed to withstand the earthquake in structures. Base isolator is introduced to absorb the vibration from the earthquake. It is placed in between the base of the structure and the foundation of the structure. The advantage of the base isolator is, it can resist the vertical and horizontal movement from the ground into the structures, while maintaining the position of the building.

From the current issue, this research has been carried out to study the effectiveness of the base isolator on floating slab track comfort and tunnel lining performance under earthquake effects.

1.3 Objectives

The objectives of this research are:

i. To determine the dynamic characteristics of floating slab track with and without base isolator numerically and experimentally

ii. To identify the performance of tunnel lining with slab bearing on floating slab track and base isolator on floating slab track under earthquake using finite element modeling technique.

1.4 Scope of Study

In this study, the scope can be divided into the followings:

i) Modelling of Linear Static Analysis for floating slab track with slab bearing and floating slab track with base isolator using ANSYS software.

ii) Analysis of slab bearing and base isolator to obtain vertical and horizontal stiffness from Finite Element Modelling.

iii) Experimental testing of linear static for floating slab bearing.

iv) Modelling round shape tunnel of Klang Valley Mass Rapid Transit tunnel in Malaysia using SAP2000 software.

v) Analysis of Non-Linear Dynamic Analysis for floating slab track with slab bearing and floating slab track with base isolator using Time History Analysis.

vi) Analysis on performance of floating slab track with slab bearing and floating slab bearing with base isolator in terms of acceleration, displacement and tunnel lining.

1.5 Methodology

The research consists of four main activities. The flow steps based on the objectives and scope of the research are shown in Figure 1.5.

Step 1: Literature

The beginning step for the study is to look for an overview and knowledge of the existing slab bearing and base isolator including the performance of floating slab track. Earthquake study and design procedures for base isolator are also needed to make sure that the overall study meets the objectives. Past studies of floating slab track and the base isolator is being reviewed in order to collect more information about the study.

Step 2: Experimental Testing

Experimental testing is conducted to obtain the behavior of slab bearing. The results are compared with vertical and horizontal stiffness specifications.

Step 3: Performance of Floating Slab Track With Slab Bearing and Floating Slab Track With Base Isolator

Slab bearing and base isolator were modelled based on the previous literature related to the finite element technique as to ensure that the correct model is being used in this study. Next, vertical and horizontal stiffness results from the ANSYS computer program were input to the floating slab track as to compare the performance of the floating slab track with and without base isolator using SAP2000 computer software. The slab bearing and base isolator were modelled as a link element. The frame and beam elements were selected as to analyze the behavior of the floating slab track with and without the base isolator.

Step 4: Discussions and Conclusions

Analysis and results from the previous step are discussed and concluded in the last part of the study. Few recommendations and comments are being included for providing improvement in this study.

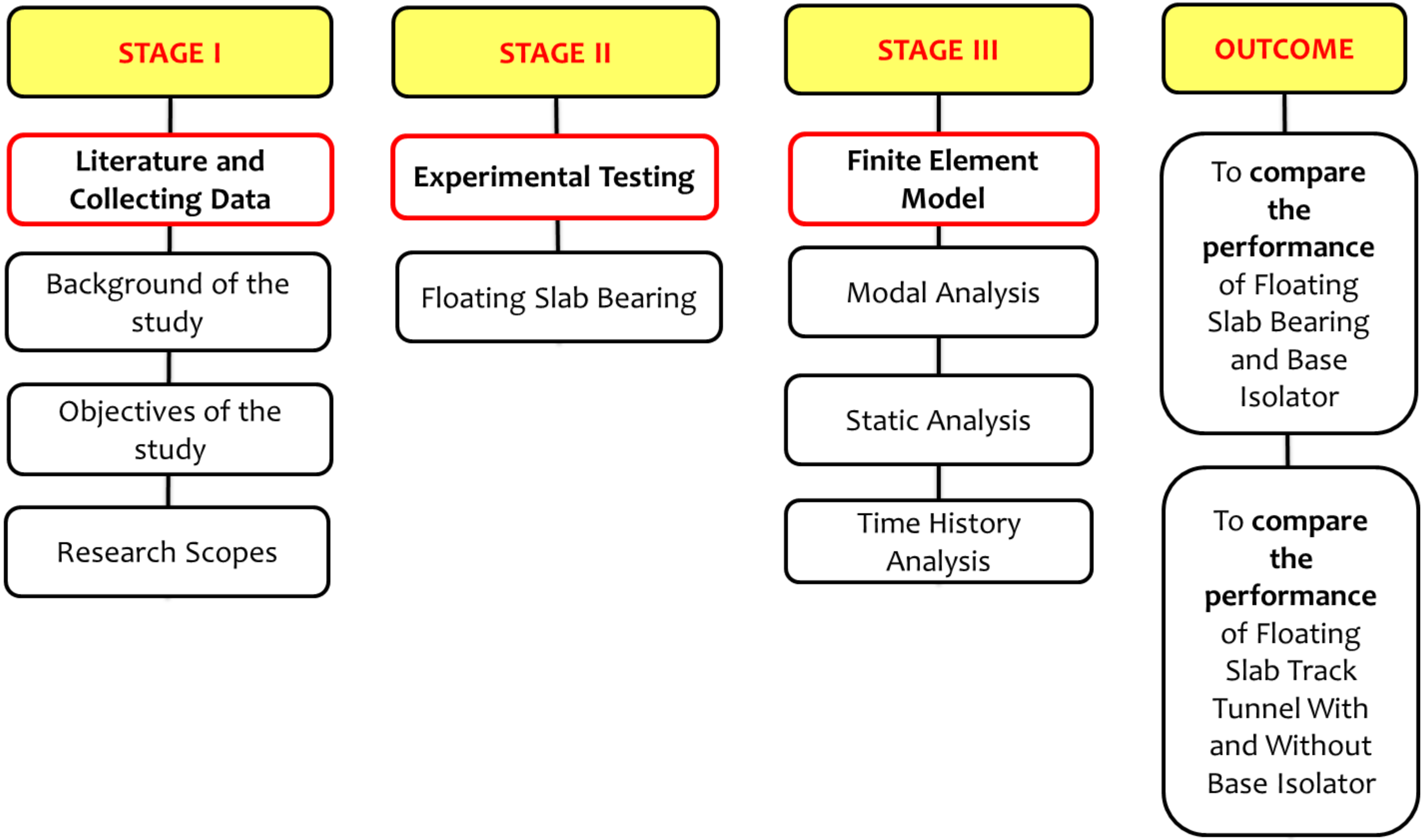

Figure 1.5: Research methodology

1.6 Organization of Thesis

The thesis is divided into six chapters. **Chapter 1** describes the general background of the study, objectives of the research, research scopes and structure of the thesis.

To study the behavior of the railway slab track with base isolator and floating slab track under earthquake loading, literature was done. The literature review is provided in **Chapter 2**. This chapter reviews the topics that are related to seismic isolation and floating slab track. **Chapter 3** describes the theoretical background of the study.

The methodology and results of the study are divided into two chapters, i.e Chapter 4 and Chapter 5. **Chapter 4** focuses on the experimental testing of floating slab bearing that is currently used in industry. **Chapter 5** focuses on the finite element analysis of floating slab track with slab bearing and floating slab track with base isolator, and tunnel. Conclusion and discussion of the study are described in **Chapter 6**.

iii. In this research, the experiments of floating slab bearing were done using only compression and shear test as to obtain the vertical and horizontal stiffness. It is recommended that more laboratory testing should be conducted to obtain the stability of floating slab track. All testing can be applied to base isolator for future study.

iv. The analysis from different type of earthquake loads such as Kobe earthquake and Northridge are required in order to have variety performance on the floating slab track. This is because, different earthquake has random ground response and it affects the structural response differently.

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