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SEISMIC VULNERABILITY STUDY OF GUILLEMARD RAILWAY BRIDGE

TEOW CHING CHING

A project report submitted in fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil – Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JUNE 2008

I declare that this project report entitled “Seismic Vulnerability Study of Guillemard Railway Bridge” is the result of my own except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidate of any degree.

Signature : …………………………………………

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For my beloved family

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ABSTRACT

Malaysia is surrounded by countries that had experienced many great earthquakes. Records have shown that we do sometimes experience some off-set tremors originating from the Indonesian zone. Therefore it would be unwise to totally ignore the effects of earthquakes on structures. The purpose of this study is to present the results of the case study of the earthquake response on the Guillemard Railway Bridge. The bridge had been remodeled using SAP 2000. The behavior of Guillemard Railway Bridge under the earthquake loading can be obtained by analyzing the Free Vibration Analysis, Time History Analysis and Response Spectrum Analysis with different levels of ground acceleration (0.074g, 0.15g, 0.25g and 0.35g), in different directions (x, y, z). Moment and shear force capacities for each element are calculated to enable comparison to be made between element capacity and element loading. The purpose is to check to what extend Guillemard Railway Bridge could survive under different ground acceleration and to identify the critical part of the bridge under earthquake loading. From the results, it is noticed that the column failure could occur even in low intensity earthquake acceleration. Deck failure is caused by its inability to hold the design ultimate resistance moment of earthquake loading. Earthquake which happens in horizontal transverse direction has very little effect to the seismic performance of the bridge deck. The bridge deck may fail when earthquake happens in vertical direction, under all various earthquake intensities. For horizontal longitudinal earthquake direction, the bridge deck is safe up to 0.15g earthquake intensity. The most earthquake-vulnerable part of Guillemard Railway Bridge is the fourth span and the fourth pier. Moreover, the top chords at the highest point of the truss and the connection between the spans also most likely to be vulnerable if earthquake occur.

ABSTRAK

Malaysia dikelilingi oleh negara-negara yang kerap mengalami gempa bumi. Rekod telah menunjukkan kesan gempa bumi dari kawasan gempa bumi Indonesia kadang kala dirasai juga. Maka, pengabaian kesan gempa bumi ke atas struktur adalah perbuatan yang kurang bijak. Tujuan kajian ini adalah untuk mempersembahkan keputusan respon Guillemard Railway Bridge terhadap gempa bumi. Jambatan ini telah dimodelkan semula dengan menggunakan SAP2000. Kelakuan Guillemard Railway Bridge di bawah pembebanan gempa bumi boleh diperolehi dengan menjalankan analisis Free Vibration, analisis Time History dan analisis Response Spectra, dengan mengenakan pelbagai keamatan gempa bumi (0.074g, 0.15g, 0.25g dan 0.35g) pada arah yang berlainan (x, y, z). Kapasiti momen dan kapasiti daya ricih untuk setiap elemen telah dikira supaya perbandingan dapat dibuat antara kapasiti elemen dengan pembebanan elemen. Tujuannya untuk menyemak kepada tahap manakah Guillemard Railway Bridge sanggup bertahan di bawah pelbagai keamatan gempa bumi dan juga untuk mengenalpastikan bahagian jambatan yang paling kritikal di bawah pembebanan gempa bumi. Daripada keputusan yang diperolehi, didapati bahawa kegagalan tiang berlaku walaupun untuk gempa bumi berkeamatan rendah. Kegagalan papak pula disebabkan ketidakmampuan untuk menampung momen rintangan muktamad daripada pembebanan gempa bumi. Gempa bumi yang berlaku pada arah datar-melintang meninggalkan kesan yang sangat kecil kepada papak jambatan. Papak jambatan mungkin akan gagal apabila gempa bumi berlaku pada arah menegak, di bawah pelbagai keamatan gempa bumi. Untuk gempa bumi yang verlaku pada arah datar-membujur, papak jambatan adalah selamat sehingga 0.15g keamatan gempa bumi. Bahagian jambatan yang paling lemah ketika dikenakan gempa bumi ialai rentang keempat dan tiang keempat. Tambahan pula, bahagian atas pada titik tertinggi yang terletak pada kerangka jambatan dan sambungan antara rentang juga berkemungkinan besar gagal jika berlakunya gempa bumi.

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LIST OF SYMBOLS

C – damping

K – stiffness

M – mass

N – total number of contributing nodes

u – displacement of the mass

$\dot{u}$ – velocity of the mass

$\ddot{u}$ – acceleration of the mass

$\ddot{u}_g$ – ground motion acceleration

Z – maximum value of the some response quantity

CHAPTER 1

INTRODUCTION

1.1 Introduction

An earthquake is produced by the sudden rupture or slip of a geological fault. Faults occur at the intersection of two segments of the earth’s crust. Peninsula Malaysia lies in the Eurasian Plate and also within the Indian-Australian Plate. Geologically, small faults also exist in East Malaysia. Records have shown that we do sometimes experiences some off-set tremors originating from the Indonesian zone. Thus there is a need for some seismic checking to be incorporated in the design process so that the structures would be resistant to earthquake.

Malaysia was affected by the Indian Ocean earthquake on 26 December 2004. The worst affected areas were the northern coastal areas and outlying islands like Penang and Langkawi. The number of deaths stands at 68. Houses in fishing villages along coastal area were damaged in Penang, Kedah and Langkawi. Therefore it would be unwise to totally ignore the effects of earthquake on structures.

The Guillemard Railway Bridge was built across the Kelantan River in Kursial near Tanah Merah. Construction of the railway began in 1920 and was completed in July 1924. This bridge consists of 2 spans of 200 feet and 2 spans of 250 feet. Today, the railway bridge is used only for trains and makes up part of the Jungle Railway line. The Jungle Railway is the railway line serving the East Coast states of Kelantan and Pahang in Malaysia. Guillemard Bridge also happens to be the longest railway bridge in Malaysia. However, the design of Guillemard Bridge excluded the seismic effect, thus in this project the seismic vulnerability of the bridge will be studied.

1.2 Problem Statement

In recent years, low intensity earthquakes have been occurred in least expected places, such as Malaysia. But most of the structure designs in Malaysia do not take earthquake into consideration. Therefore, the situation where there is complete ignorance and unawareness of earthquake should be avoided.

In bridge engineering, a large amount of bridges have experienced damages at region of low to high intensity earthquake. For example, the Loma Prieta earthquake which was a major earthquake that struck the San Francisco Bay Area of California on October 17, 1989. The earthquake measured 6.9 on the Richter magnitude scale which caused one 15-meter section of the San Francisco-Oakland Bay Bridge collapsed, causing two cars to fall to the deck below, leading to the single fatality on the bridge. There was little use of nonlinear analysis in the design of bridge. In order to correctly analyze bridge performance in a major earthquake of long duration, the use of nonlinear analysis technique is important.

1.3 Objective of the Study

The objectives of the study are:

(i) To determine the structural behaviour of Guillemard Railway Bridge under earthquake.

(ii) To identify to what extend Guillemard Railway Bridge could survive under ground acceleration.

(iii) To identify the critical part of the bridge under earthquake loading.

1.4 Scope of the Study

The scope of the study includes the following items:

(i) Study the architectural and structural drawings of Guillemard Railway Bridge.

(ii) The Guillemard Railway Bridge is modelled using SAP 2000 computer software.

(iii) The dynamic linear analysis using SAP 2000 is divided into free vibration analysis, time history analysis and response spectrum analysis.

(iv) The dynamic nonlinear analysis using SAP 2000 is divided into free vibration analysis and time history analysis.

(v) Different level of earthquake intensities: 0.074g, 0.15g (low intensity), 0.25g (moderate intensity) and 0.35g (high intensity) is applied to the bridge model respectively.

(vi) Each level of earthquake intensity is applied in x direction, y direction and z direction respectively.

(vii) Calculate the element capacity.

(viii) Comparison to be made between element capacity and element loading.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is mainly focuses on literature reviews that have been studied to acquire a better understanding of the project overall.

2.2 Basic Seismology

An earthquake is produced by the sudden rupture or slip of a geological fault. Faults occur at the intersection of two segments of the earth’s crust and along the west coast of Malaysia where the boundaries of two tectonic plates, the Indo-Austrian plate and Eurasian plate, are located [1].

The sudden release of energy at the focus or hypocenter of the earthquake causes seismic waves to propagate through the earth’s crust and produces vibration on the earth's surface. The amplitude of the vibrations diminished with distance from the epicentre, the point on the earth's surface immediately above the hypocenter, and may last for a few seconds or for more than one minute.

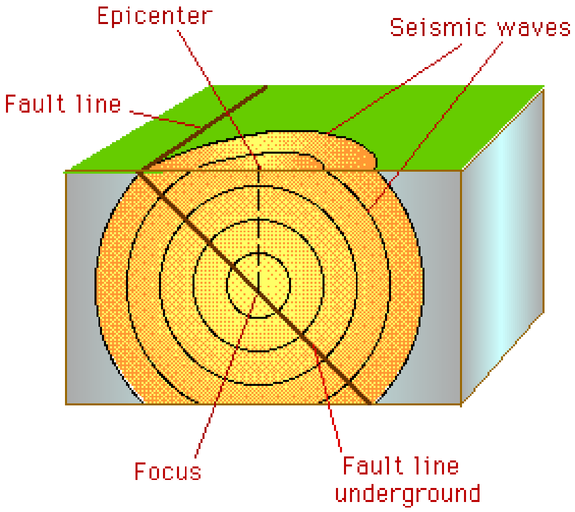

Figure 2.1: Epicenter [1]

2.3 Seismic Waves

Two principal types of seismic waves are generated: body waves, which travel from the hypocenter directly through the earth's lithosphere, and surface waves, which travel from the epicentre along the surface of the earth. Body waves consist of the primary wave or P wave, a compressive wave, and the secondary wave or S wave, a transverse wave [1].

The motion of P wave is the same as that of a sound wave in a fluid. As it spreads out, it alternately pushes (compresses) and pulls (dilates) the rock. P waves are able to travel through both solid rock and liquid material.

The slower wave through the body of rock is called the S wave. As an S waves propagates, it shears the rocks sideways, at right angles to the direction of travel. Thus S wave can produce both vertical and horizontal motions. However, S waves cannot propagate in the liquid parts of the earth and their amplitude is significantly reduced in liquefied soil.

Another type of earthquake wave is called surface wave because of its motion is restricted to near the ground surface. Surface waves consist of the Love wave, which produces a sideways motion, and the Rayleigh wave, which produces a rotary wave-like motion.

The motion of Love wave is essentially the same as that of S waves that have no vertical displacement. It moves the ground side to side in a horizontal plane parallel to the Earth's surface, but at right angles to the direction of propagation.

The second type of surface wave is known as Rayleigh wave. The pieces of rock disturbed by a Rayleigh wave move both vertically and horizontally in a vertical plane pointed in the direction in which the waves are travelling, just like rolling ocean waves.

Body waves have a higher frequency range and attenuate more rapidly than surface waves. Hence, structures with longer natural periods, such as high-rise buildings and bridges, are most at risk some distance from the epicentre than low-rise buildings, which have a short natural period.

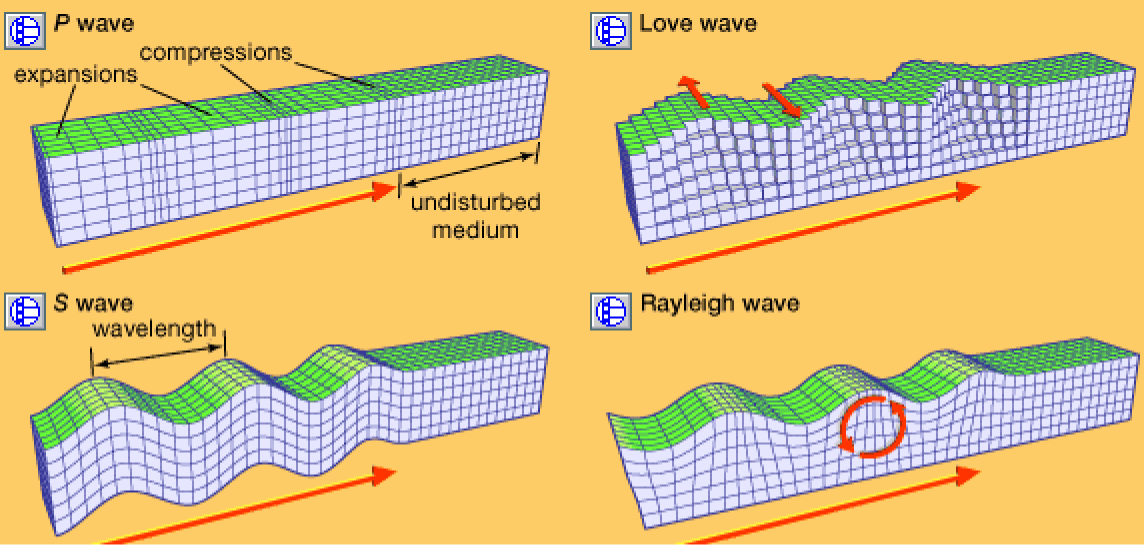

Figure 2.2: Types of seismic waves [1]

2.4 Measurement of Earthquake Magnitude and Intensity

The Richter magnitude scale is a logarithm-based scale which utilizes the amplitude of seismic vibrations, recorded on a standard seismograph, to determine the strength of an earthquake. Earthquakes of Richter magnitude 6, 7 and 8 are categorized respectively as moderate, major and great earthquakes [1].

Earthquake intensity is measured on the modified Mercalli index which is based on the observed effects of an earthquake at a specific site and a qualitative assessment of the damage caused and is an indication of the severity of ground shaking at that site. Modified Mercalli intensity values range from a value of I to a value of XII. Index value XII is classified as strong shaking causing damage to older masonry structures, chimneys and furniture. Index value VIII is classified as very strong shaking causing collapse of unreinforced masonry structures, towers and monuments. Because of the subjective nature of the Mercalli scale, different values of intensity may be assigned by different observers.

Table 2.1: Modified Mercalli Intensity Scale [1]

GRADE	**ABRIGED DESCRIPTION**	**ESTIM. EPICENTRAL VIBRAT. VELOCITIES**	**RANGE OF ESTIM. LATERAL ACCELERATIONS**
1	Almost imperceptible.	0.055 in./sec	0.001g to 0.003g
2	Feeble. Felt by a few on upper floors.	0.11 in./sec	0.002g to 0.004g
3	Very slightly. Felt by persons at rest. 6	0.22 in./sec	0.0025g to 0.006g
4	Slight. Felt by many persons indoors.	0.44 in./sec	0.005g to 0.008g
5	Weak. Felt by nearly all.	0.89 in./sec	0.010g to 0.015g
6	Moderate. Felt by all. Slight damage.	1.8 in./sec	0.015g to 0.033g
7	Strong. Considerable damage to poorly built structures.	3.6 in./sec	0.025g to 0.071g
8	Very strong. Considerable damage to ordinary buildings. Chimneys fall.	7.1 in./sec	0.050g to 0.16g
9	Severe. Partial or total destruction of many buildings.		0.10g to 0.20g
10	Violent Destruction. Most 0.001g to 0.003g masonry and frame structures destroyed.		0.25g
11	Catastrophic.		0.50g
12	Absolute ruin.		0.50g to 1.0g

A specific earthquake has a number of different Mercalli intensities at different distances from the source but has only one value of the Richter magnitude [1].

2.5 Ground Motion

Earthquake ground motion is measured by a strong motion accelerograph which records the acceleration of the ground at a particular location. The characteristics of earthquake ground motion which are important in earthquake engineering applications are [2]:

- (i) Peak ground motion
- (ii) Duration of strong motion
- (iii) Frequency content

2.5.1 Peak Ground Motion

Peak ground motion influences the response of a structure. It includes the peak ground acceleration, velocity displacement, earthquake magnitude, epicentral distance and site description for typical records from a number of seismic events. Peak ground acceleration has been widely used to scale earthquake design spectra and acceleration time history.