INFLUENCE OF VERTICAL EARTHQUAKE ON THE VARIATIONS OF AXIAL LOAD RATIO OF REINFORCED CONCRETE BUILDINGS

By

AWANG @ ABDUL HALIM BIN TAIB
(1432011293)

A thesis submitted in fulfillment of the requirements for the degree of Master of Science (Building Engineering)

School of Environmental Engineering
UNIVERSITI MALAYSIA PERLIS

JULY 2016

ACKNOWLEDGEMENT

Assalamualaikum w.b.t

All the praises and thanks to be Allah, the Lord of the Alamin. During preparation of my thesis, I was helped by many peoples to solve my research problems.

First and foremost, I would like to express my warmest appreciation to my supervisor and co supervisor, Mohd Zulham Affendi bin Mohd Zahid and Ir Dr Mohd Asri Ab. Rahim, for their guidance, encouragement, motivation and valuable advice. Without their support and guidance, this thesis would not have been the same as presented here.

The contribution of final year students, Ms Tan Mio Gin and Mr Doreen Bong Yin Yin are gratefully acknowledged. Financial support for this research was provided by the Ministry of Education, Malaysia through a grant FRGS 9003-00407. The RUAUMOKO software used in the study under licensed of Universiti Sains Malaysia.

I am also very thankful to my boss, Ir Hj Wan Saidi Wan Yahya, principal of Perunding W&W for granted permision for me to further my study. Special thanks go to Ir Saffuan Wan Ahmad and Ir Abu Hanifah Yusof for the noble guidance and valuable advice throughout the period of study. Their patience, time, and understanding are highly appreciated.

My sincere appreciation also extends to my lovely mother Nik binti Muda, my lovely wife Asliza Zuraini binti Mohd Yunus, my kids Aisyah Mardhiah, Ahmad Ikhwan, Ahmad Irfan and Ahmad Ihsan who have been supportive at all times. Finally, I would like to thank all my family members and dearest friends who were involved directly and indirectly in completing this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

M_L	Richter magnitude scale / local magnitude
A	maximum trace amplitude (mm)
A'	maximum ground displacement (μm)
M_s	surface wave magnitude scale
Δ	Angle from the seismograph to the epicenter distance (degree)
M_w	moment magnitude scale
μ	shear modulus of material along fault plane (N/m^2)
A_f	area of fault plane undergoing slip (m^2).
D	average displacement of ruptured segment of fault (m)
$S_e (T)$	Ordinate of the elastic response spectrum
T	Vibration period of a linear single degree of freedom system
a_v	Design vertical ground acceleration for the reference return period
T_B, T_C	Limits of the constant spectral acceleration branch
T_D	Value defining the beginning of the constant displacement response range of the spectrum.
η	Damping correction factor with reference value $\eta=1$ for 5% viscous damping
ξ	Viscous damping ratio of the structure, expressed in percent
q	Behavior factor
μd	displacement ductility demands
μs	storey ductility demand
Ki	Stiffness value
δi	Top lateral displacement
Vi	Total base shear

δu	ultimate displacement
δy	yield displacement
G	dead load
Q	live load
E	Earthquake load
M	mass matrix
u	relative displacement vector
C	viscous damping matrix
F_s	tangent (inelastic) stiffness matrix,
a_g	acceleration vector of ground motion and the upper dots stand for time derivatives
P-Δ	Second-order effects
P_{h+v}	axial load in column induced by horizontal + vertical earthquake
P_h	axial load in column induced by horizontal earthquake only

LIST OF ABBREVIATIONS

EC8	Eurocode 8
RC	Reinforced Concrete
PEER-NGA	Pacific Earthquake Engineering Research Center – New Generation Attenuation.
V/H	vertical to horizontal ratio
PGA_h	Horizontal Peak Ground Acceleration
PGA_v	Vertical Peak Ground Acceleration
MDOF	multi-degree of freedom
MMI	Modified Mercalli Intensity Scale
VDC	COSMOS Strong-Motion Virtual Data Center
SDOF	single-degree of freedom
IDR	interstorey drift ratio
MPF	Mass Participation Factor
VHGM	horizontal and vertical component of ground
HGM	horizontal component of ground motion
LOC	Left Outer Column
LMC	Left Middle Column
RMC	Right Middle Column
ROC	Right Outer Column

Kesan Gempa Bumi Menegak Kepada Variasi Nisbah Beban Paksi Kepada Bangunan Konkrit Bertetulang.

ABSTRAK

Bidang kejuruteraan gempa bumi semasa tidak mengambil kira kesan gempa bumi berulang dan gempa bumi arah menegak dalam reka bentuk dan analisis sistem struktur walaupun dalam keadaan yang sebenar kedua-dua fenomena memberikan kesan yang besar. Situasi ini beransur-ansur berubah disebabkan oleh peningkatan rekod gempa bumi berdekatan punca (nearfield) yang diperolehi kebelakangan ini, ditambah pula dengan laporan pemerhatian tapak yang mengesahkan kesan kemusnahan disebabkan oleh gempa bumi menegak yang kuat. Tujuan kajian ini adalah untuk menilai tingkah laku kerangka konkrit bertetulang yang seragam (regular) dan tidak seragam (irregular) terhadap gempa bumi berulang dengan komponen menegak. Kuantiti tindak balas struktur dinyatakan dari segi variasi beban paksi di dalam tiang. Nisbah beban paksi diperolehi dengan membahagikan beban paksi dalam tiang yang dihasilkan oleh gabungan komponen mendatar dan menegak gempa bumi (VHGM) kepada beban paksi dalam tiang yang dihasilkan oleh komponen mendatar gempa bumi (HGM) sahaja. Mendapatkan bentuk spektrum gempa bumi bagi kompenen menegak dengan menggunakan kaedah nisbah 2/3 terhadap komponen mendatar sesuatu gempa bumi seperti yang dicadangkan oleh banyak kod adalah satu pengabaian yang serius terhadap kesannya ke atas struktur yang terletak berdekatan dengan sumber gempa bumi dan sebaliknya bagi struktur yang terletak jauh dengan sumber gempa bumi. Model kerangka konkrit bertetulang dikenakan gempa bumi mendatar dan menegak dengan pelbagai nisbah antara pecutan bumi puncak mendatar dan menegak (V / H) dari 0.3 hingga 1.9 menggunakan perisian RUAUMOKO. Kajian ini mendapati bahawa gempa bumi menegak menunjukkan kesan yang ketara ke atas bangunan konkrit bertetulang dengan nisbah maksima beban paksi 54 dan 6 masing masing bagi kerangka konkrit bertetulang seragam dan tidak seragam. Model lapan tingkat berbentuk seragam menunjukkan graf tipikal dengan bentuk nombor tiga bagi nisbah beban paksi terhadap ketinggian. Nisbah beban paksi hampir kepada nilai satu pada aras bawah, pertengahan dan tingkat paling atas tetapi meningkat pada satu perempat dan tiga perempat daripada ketinggian bangunan. Model berbentuk tidak seragam pula menunjukkan graf tipikal dengan beban paksi yang lebih tinggi di tingkat bawah dan menurun di sepanjang ketinggian.

Influence of Vertical Earthquake on The Variaotions of Axial Load Ratio of Reinforced Concrete Buildings.

ABSTRACT

Current earthquake engineering field ignores the repeated and vertical ground motion in design and analysis of the structure system even though in actual condition these two phenomena impose the significant effect to the structural system. This gradually changing due to the increase in near source record obtained recently, coupled with field observation confirming the possible destructive effects of high vertical vibration. The aim of this study is to assess the behaviour of regular and irregular reinforced concrete frames due to multiple earthquakes with vertical component. The structural response quantities are expressed in term of variation of axial load. Axial load ratio obtained by dividing axial load in column induced by combined horizontal and vertical component of ground motion (VHGM) to axial load in column induced by horizontal component of ground motion (HGM) load. Obtaining vertical spectral shape by scaling the horizontal ground motion using V/H ratios of 2/3 rule as suggested by many codes can be seriously underestimate action on structures located near earthquake sources and overestimates action in far field regions. The frame models are subjected to the horizontal and vertical ground motions with various peak ground acceleration ratios between horizontal and vertical ground acceleration (V/H) ranging from 0.3 to 1.9 using RUAUMOKO software. This study found out that vertical ground motion showed significant effect to the reinforced concrete building with maximum axial load ratio of 54 for regular and 6 for irregular rc frame. Eight storey regular models showed typical graph with the shape of number three for plotted axial load ratio against height. Axial load ratio values was almost equal to one at base, mid and top floor but increases at one fourth and three fourth of the building height. Irregular model showed typical graphs with higher axial load at lower floor and decreased along the heights.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Current earthquake engineering field ignores the repeated and vertical ground motion in design and analysis of the structure system even though in actual condition these two phenomena impose the significant effect to the structure system. The repeated earthquake happened everywhere all over the world with the short time interval while earthquake in vertical excitation also reported as quantitatively occur but always ignored.

Therefore, this study attempts to assess the behaviour of reinforced concrete (RC) building due to multiple earthquakes with vertical component. For that purpose, this study will consider two group of eight-storey (medium rise) building model. Each group of the building consists of regular building as control sample and irregular in elevation, i.e. with setback. These models are designed to resist gravity load and gravity load with horizontal earthquake only according to current seismic code (i.e. Eurocode 8).

Furthermore, five hundred near field earthquake records will be downloaded from reliable ground motion records database, i.e. Pacific Earthquake Engineering Research Center – New Generation Attenuation (PEER-NGA) database. The vertical to horizontal ratio (V/H) of these ground motions records will be assessed and new V/H ratio will be established. From these 500 earthquake records, ten ground motions with V/H from 0.3 to near 2.0 will be selected to develop artificial repeated earthquake ground motions. Then, these ten real and twenty artificial repeated earthquakes will be employed in nonlinear dynamic analysis to assess the variation of axial load in the columns of regular and irregular buildings with setback under vertical ground motion with a higher V/H ratio.

1.2 Problem Statement

The structural earthquake engineering is usually not considering the vertical component of ground motion but this phenomenon is gradually changing after many events of near field earthquake recorded that indicates the presence of high vertical earthquake. High vertical earthquake also causes great damages to the building as reported by Elnashai & Sarno (2008) and Papazoglou & Elnashai (1996) especially near the source of the earthquake. The damaging effects of the vertical component are more evident since the vertical component attenuates faster than horizontal component (Ghorabarah & Elnashai, 1998).

An earthquake causes shaking of the ground in three direction, those are two directions in horizontal and one direction in vertical. Vertical to horizontal ratio (V/H) always referred to describe the relationship of these ground motions in an event of earthquake. Many of the record shows that the value of horizontal are greater than vertical which is give the value of V/H lesser than 1.0 but Table 1.1 shows otherwise (Elnashai & Sarno, 2008). Some earthquake give V/H ratio greater than 1.0, which is means the vertical excitation is bigger than horizontal excitation.

Table 1.1: Earthquake with high V/H ratios. (Elnashai & Sarno, 2008).

Earthquake	Country	Date	PGA_h (g)	PGA_v (g)	V/H Ratio
Gazli	Ex-USSR	17/05/1976	0.622	1.353	2.17
Coyote Lake	USA	6/08/1979	0.256	0.420	1.64
Loma Prieta	USA	17/10/1989	0.424	0.514	1.21

Most of the seismic code employed vertical spectra that are derived from their horizontal counterparts. The Uniform Building Code (UBC, 1997) recommends that using factor of 2/3 to define vertical spectra from its horizontal spectra as suggested by Newmark et al. (1973). The 2/3 rule for V/H is not conservative in the near field and over conservative at large epicentral distances (Sung & Amr, 2008). Evidence of many earthquake records with V/H ratio more than 1.0 shows that scaling vertical component from its horizontal component using the 2/3 rule can be a serious underestimate. Eurocode 8 (EC8) recommends utilizing factor of 0.45 and 0.9 for type 1 and type 2, respectively.

These codes also considered an exclusive adoption of isolated and rare design earthquake while at the same ignoring the phenomena of repeated earthquakes and its influence to the structures. It was reported by Hartzigeogiou & Liolios (2010) that only a few studies on multiple earthquakes have been reported, despite the fact that the problem has been qualitatively acknowledged. The damages of building structures occurred during the first earthquake may worsen and become completely inadequate after a series of earthquakes. The seven storey of The Van Nuys Holiday Inn hotel suffered serious structural damage in all columns of the third floor during the 1994

Northridge earthquake. The same building had already suffered extensive nonstructural damage during the 1971 San Fernando earthquake (Elnashai & Sarno, 2008).

Mwafy & Elnashai (2006) reported that the main influence of the vertical earthquake is an increased in axial force variation on RC columns that superimposed on the forces generated from overturning. The significant increase of variation of axial force on RC columns caused the reduction of the column shear capacity.

An increase in the axial force demand in the column such as the one imposed by the vertical components with significant amplitude results in an increase in the shear capacity of the column. This is beneficial to the seismic behaviour of the column. However, a decrease in the axial force demand on the column results in a decrease in the shear capacity of the column. Vertical ground motion can put a column into tension for short durations of time, thus reducing the column's shear capacity to just the shear strength of the transverse reinforcement. This may lead to the failure of the structure.

Therefore the study is carried out to investigate the influence of vertical earthquake on the variations of axial load ratio under excitation of single and multiple earthquakes to the eight story of regular and irregular RC building. This study is significant as a contribution to the knowledge of structural and earthquake engineering field and help other researchers to understand the behaviour of RC building under excitation of horizontal and vertical earth quake.

1.3 Objectives

The objectives of this study are:

1.3.1 To evaluate the variation of axial load of RC building under horizontal earthquake only and vertical and horizontal earthquake.

1.3.2 To assess the effect of vertical earthquake on the axial load variation in irregular and regular RC buildings.

1.3.3 To assess the effect of repeated earthquake with vertical component on the axial load variation in irregular and regular RC buildings.

1.4 Scope of Research

In this study, there are 500 near field strong ground motion records will be downloaded from Pacific Earthquake Engineering Research Centre–New Generation Attenuation (PEER-NGA). These results will be tabulated in graph V/H ratio versus source distance in km.

Ten earthquake records with V/H ratio 0.3 to 2.0 will be selected and normalized to develop artificial repeated earthquake ground motions based on method proposed by Hartzigeogiou & Liolios (2010) and also used by Ade Faisal et al (2012).

Three types of thirty assembled ground motion are generated and employed in this study, i.e. single horizontal earthquake as Case 1, single horizontal plus vertical earthquake as Case 2 and triple horizontal and vertical earthquake events (fore shock-main shock-after shock) as Case 3.

The building model used in this study consists of regular building as control sample and one model with irregular in elevation, i.e. with setback. In this phase nonlinear dynamic analysis of inelastic structural multi-degree of freedom (MDOF) system with viscously damped force-deformation relationship will be employed to investigate the structural behaviour for repeated near field earthquake with vertical ground motion. The variations of axial load in the columns for regular and irregular buildings with setback under vertical ground motion are assessed in this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Earthquakes is one of the world's most devastating and frightening natural hazards that result in great losses of lives, injuries, extensive property damages and many terrible after effects. Basically, an earthquake is a sudden movement of the earth's crust parts, followed and accompanied by a series of shakes or tremors which are triggered by the sudden release of strain that has gathered over a lengthy period.

For hundreds of millions of years, plate tectonics forces have shaped or formed the earth gradually as the huge plates under the surface of the earth moved under, over and past one another. The plates are locked or fastened together and unable to release the storing energy at other time. The plates will break free, once the accumulated energy is strong enough. If an earthquake happens in a populated area, it may trigger numerous deaths and injuries and even extensive property damages.

In truth, earthquake does not kill people, but collapse buildings and their contents. The greatest hazard in an earthquake is the collapse or fall of man-made and natural structures that cause an extensive loss of lives and properties. As a result, the seismic effects should not only be considered in the countries that have a high risk of a strong earthquake, but also for countries that are subject to low-to-moderate earthquakes for instance, Malaysia since the power of an earthquake is shown to be unpredicted (Ramli & Adnan, 2004).

An earthquake is the consequence of an unexpected release of energy in the earth's crust. This sudden energy release causes the ground to shakes that could create seismic waves. Due to the consequence rock breaking, seismic waves happen. It is a kind of energy that travels all the way through the earth. Seismic waves pass through either the length of the surface of the earth or through the interior of the earth.

Earthquakes are usually triggered when rocks underground suddenly break along a fault. Fault plane is the underground surface along the rocks that move and break. By using a seismograph, the magnitude or size will be determined by measuring the amplitude of the seismic waves that occur and the distance of seismograph from the earthquake. A seismograph consists of a seismometer (the detector) and a recording device that is located at every station of possibility of an earthquake to occur. The device will electronically amplify wave motions in the earth.

Earthquakes cause too many damaging effects to the surroundings they act upon. These include damages to man-made building structures and in worst cases, human deaths. The destruction of structures such as bridges, dams and buildings are caused by the rumbling impacts which are originated from an earthquake. Besides, an earthquake can also trigger landslides that have bad effects on human and animal lives.

Earthquakes usually cause dramatic changes, including ground movements, dropping and tilting of surfaces causing a different groundwater flow. Other than causing floods and damaging buildings, earthquakes that occur under waters can sometimes cause tsunamis or known as tidal waves. The condition of a tsunami is high water which travels at a short period of time. They destroy areas in coastlines which affect populations and cities.

2.2 Seismic Waves

A sudden release of stored energy which has built over a long time period will lead to earthquake phenomena which happen as an aftereffect of claiming tectonic development drives inside the earth. Most earthquakes happen along the deficiencies in the upper 25 miles of the earth's surface when one side quickly moves in respect to the opposite side of the fault.

This sudden movement stuns waves (seismic waves) to transmit from their purpose of source called the focus through the earth. The ground motion that is known as an earthquake is produced by two types of elastic seismic waves: body and surface waves. The ground shaking felt is generally a combination of these waves, especially for distance less than 25 km from earthquake source or near field.

Solid seismic waves can bring about awful harms nearby and they can travel in huge separations. However, significantly weaker seismic waves can go far and can be identified by sensitive experimental instruments called seismographs.