UNIVERSITI TEKNOLOGI MALAYSIA

DECLARATION OF THESIS / UNDERGRADUATE PROJECT PAPER AND COPYRIGHT

Author's full name : ROZAINA BINTI ISMAIL

Date of birth : 6th MAY 1983

Title : THE APPLICATION OF ARTIFICIAL NEURAL NETWORK IN SEISMIC EVALUATION OF BUILDINGS

Academic Session: 2007/2008

I declare that this thesis is classified as :

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)*
√	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)*
☐	**OPEN ACCESS**	I agree that my thesis to be published as online open access (full text)

I acknowledged that Universiti Teknologi Malaysia reserves the right as follows:

1. The thesis is the property of Universiti Teknologi Malaysia.
2. The Library of Universiti Teknologi Malaysia has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by :

SIGNATURE	**SIGNATURE OF SUPERVISOR**
830506025700	**PROF. DR AZLAN ADNAN**
(NEW IC NO. /PASSPORT NO.)	**NAME OF SUPERVISOR**
Date : 10 December 2008	Date : 11 December 2008

NOTES : * If the thesis is CONFIDENTAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

11 December 2008

Librarian

Perpustakaan Sultanah Zanariah

UTM, Skudai

Johor

Sir,

CLASSIFICATION OF THESIS AS RESTRICTED

- *"THE APPLICATION OF ARTIFICIAL NEURAL NETWORK IN SEISMIC EVALUATION OF BUILDINGS"*

BY ROZAINA BINTI ISMAIL

Please be informed that the above mentioned thesis entitled ***"THE APPLICATION OF ARTIFICIAL NEURAL NETWORK IN SEISMIC EVALUATION OF BUILDINGS"*** be classified as RESTRICTED. The reasons for this classification are

(i) The study involved collaboration works between Universiti Teknologi Malaysia (UTM) and Public Work Department (PWD) Malaysia and the results can only be disclosed after consultation with both parties.

(ii) This thesis contains sensitive information involving the design of building data and the results of the building performance.

Thank you.

Sincerely yours,

PROF. DR. AZLAN ADNAN
Structural Earthquake Engineering Research,
Faculty of Civil Engineering,
Universiti Teknologi Malaysia.
Email: *azelan_fka_utm@yahoo.com*

We hereby declare that we have read this thesis and in
our opinion this thesis is sufficient in terms of scope and
quality for the award of the degree of Master of Engineering (Structures)

Signature	:	
Name of Supervisor I	:	Prof. Dr. Azlan Adnan
Date	:	11 December 2008
Signature	:	
Name of Supervisor II	:	Assoc. Prof. Dr. Siti Mariam Shamsuddin
Date	:	11 December 2008

BAHAGIAN A – Pengesahan Kerjasama*

Adalah disahkan bahwa projek penyelidikan tesis ini telah dilaksanakan melalui kerjasama antara

…………………………………dengan…………………………………………

Disahkan oleh:

Tandatangan : ………………………………… Tarikh …………...……

Nama :

Jawatan :

(Cap rasmi)

** Jika penyediaan tesis/projek melibatkan kerjasama.*

===

BAHAGIAN B – Untuk Kegunaan Pejabat Sekolah Pengajian Siswazah

Tesis ini telah diperiksa dan diakui oleh:

Nama dan Alamat Pemeriksa Luar : --

Nama dan Alamat Pemeriksa Dalam : --

Disahkan oleh Ketua Jabatan Pengajian Siswazah di FKA:

Tandatangan : .... Tarikh: ....

Nama : ....

THE APPLICATION OF ARTIFICIAL NEURAL NETWORK IN SEISMIC EVALUATION OF BUILDINGS

ROZAINA BINTI ISMAIL

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Structures)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

DECEMBER 2008

I declare that this thesis entitle "*The Application of Artificial Neural Network in Seismic Evaluation of Buildings*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

.

Signature : ………………………………

Name : Rozaina Binti Ismail

Date : DECEMBER 2008

Special thanks for my lovely Mom and Dad,

Ismail Bin Zakaria

Rokiah Binti Ramli

"For every time, both of u has taken time

to show your cares, to say a prayers,

to give a day your loving touch...

thank you, Mom and Dad, so very much.

I've always cherished

your expressions of love

over the years, the hugs,

...and even more grateful

that ***ALLAH*** has given me a **PARENT** like both of you."

For my dearly siblings,

Rozaihan Binti Ismail

Khairuddin Bin Ismail

Nor Fariha Binti Ismail

Last but not least for my special life partner,

Mohd Salem Bin Sher Dill

Eina

December 2008

ACKNOWLEDGEMENT

During the completion of this thesis, I have come into contact with many individuals who have contributed towards my understanding and thoughts. In particular, I wish to express my sincerest appreciation to my supervisor Prof. Dr. Azlan Adnan and my co-supervisor Assoc. Prof. Dr. Siti Mariam Shamsuddin for their guidance, valuable advice and inspiration encouragement throughout the process of this assignment. I am also grateful for the trust and confidence that he and she had in met me to accomplish this assignment by individually to the best of my ability.

Special gratitude to Miss Sophia C. Alih for providing some of the methodology (ANN), presentation flow and style as well as the ANN software design as per developed in her thesis, "Alih, C. S. (2007). *The Application of Artificial Neural Network in Nondestructive Testing for concrete Bridge Inspection Rating System*. University of Technology Malaysia". I would like to thank the technicians and staff of UTM for their assistance in conducting my work especially Miss Jati, Miss Norsuriana, Miss Suhana, Mr. Hendry and Mr. Meldi from SEER. My gratitude and appreciation to all the lecturers and staff of the faculty of Civil Engineering who has made my life in UTM, a fulfilling and memorable one throughout the duration of my studies.

Most of all, I would like to express my appreciation to my parents, Rokiah Binti Ramli and Ismail Bin Zakaria , whose support and understanding has been most valuable to me. Undoubtedly, I wouldn't be here today if it wasn't for them. Last but definitely not least, I would also like to thank my special life partner, Mohd Salem Bin Sher Dill and my friends especially, Nurhidayah Hamzah and those that I have not mentioned here for their help and support throughout this assignment and has always been there for me through thick and thin, hardships and laughter.

ABTRACT

The performance of buildings during earthquake is unknown in Malaysia. The most existing building owners and regulators must ensure that their buildings are safely operated and present no risk to the public in case of an earthquake. The adequacy and safety level of buildings must be determined. Thus, the objective of this study is to specify the structural damage level of buildings under earthquake load through Finite Element Analysis. This study was conducted to apply the intelligent seismic evaluation of building which can simulate human decision-making ability through the use of Artificial Neural Networks (ANN) engine which is based on past experience in the prediction of damage level for building under earthquake loading. The digital form of ATC21 and ATC22 as user friendly programme was developed in this study by using Borland C++ Builder as the interface for the intelligent system. 34 buildings were analysed with various intensity of 0.05g, 0.10g, 0.15g, and 0.10g in this study. This study addresses the performance of earthquake non-linear dynamic analysis by Finite Element Modeling (FEM) using IDARC-2D for the purpose of specifying the damage level of buildings. Since the computer program IDARC 2D is limited to 20 storeys, there are only 34 buildings that have lower than 20 storeys. From the finite element modeling results, the earliest building experienced the first yielding on beam element at 3.57sec with the intensity of 0.05g. There are 28 buildings with 122 samples were used in both training and testing phase and 13 buildings with 52 samples were used in validation phase. From the vulnerable study of modal frames, it indicates that most of the buildings were categorised in the moderate damage level where there is no structural damage but only had some non-structural damage. From the application of ANN, building samples gave the lowest value of mean square error (MSE) equal to 0.027 when 15 hidden neurons applied and the highest linear correlation coefficient was obtained when r is equal to 0.839 in testing phase and 0.762 in validation phase. Out of 112 samples in the testing phase, 104 samples were predicted accurately for degree of damage rating for the building which represents 93% from the total data used. In the validation phase, 39 out of 52 samples were predicted accurately with 75% accuracy. The results of this study indicate that the ANNs provide an efficient means of damage forecasting and can be used by the owners of the building to predict building conditions under seismic load.

ABSTRAK

Keupayaan dan tingkahlaku bangunan di Malaysia terhadap gempabumi masih tidak diketahui. Pemilik dan pihak berkuasa harus memastikan bangunan yang sedia ada ini berfungsi secara selamat dan tidak mendedahkan apa-apa risiko kepada orang awam apabila berlakunya gempabumi. Tahap keselamatan dan kesempurnaan bangunan perlu dikenal pasti. Oleh yang demikian, objektif kajian ini adalah untuk mengenalpasti tahap kerosakkan bangunan terhadap beban gempabumi melalui kaedah Permodelan Unsur Takterhinggaan. Kajian ini dijalankan untuk mengaplikasikan penilaian gempabumi yang pintar terhadap bangunan yang mana mampu bertindak seperti pemikiran manusia dalam membuat keputusan menggunakan rangkaian saraf buatan (RSB) sebagai enjin berdasarkan ramalan tahap kerosakan bangunan terhadap beban gempabumi. Borang ATC21 dan ATC22 yang berbentuk digital serta program Borland C++ Builder sebagai antara muka untuk sistem ini akan dibangunkan. Didalam kajian ini, sebanyak 34 bangunan telah dianalisis untuk kekuatan gempabumi yang berbeza iaitu 0.05g, 0.10g, 0,15g, dan 0.20g. Kajian ini menunjukkan kelakunan terhadap analisis gempabumi dinamik tak linear dengan kaedah permodelan unsur takterhingga untuk tujuan menentukan tahap kerosakkan bangunan dengan menggunakan program IDARC-2D. Memandangkan program ini terhad kepada bangunan 20 tingkat, hanya 34 bangunan yang dianalisis didalam kajian ini. Daripada keputusan analisis permodelan unsur takterhingga yang diperolehi, bangunan yang terawal menunjukkan tanda alah adalah pada saat ke 3.57 iaitu pada elemen rasuk dengan kekuatan gempa 0.05g. Dari analisis rangka bangunan, menunjukkan kesemua bangunan yang dianalisis dalam kategori selamat iaitu tiada kerosakan pada struktur dan hanya mengalami kerosakan bukan struktur. Sebanyak 28 bangunan dengan 122 sampel telah digunakan didalam fasa pengajaran dan ujian dansebanyak 13 bangunan dengan 52 sampel untuk fasa pengesahan. Selepas mengaplikasikan RSB, sampel bangunan yang memberi nilai *mean square error (MSE)* yang terendah iaitu 0.027 apabila 15 *hidden neurons* digunakan dalam kajian ini dan memberi pekali pertalian linear, *r* yang terendah iaitu 0.839 untuk fasa ujian dan 0.762 untuk fasa pengesahan. Sebanyak 104 daripada 112 sampel didalam fasa ujian telah diramal dengan betul tahap kerosakannya iaitu dengan ketepatan 93%. Didalam fasa pengesahan pula sebanyak 39 daripada 52 sampel telah diramal dengan betul iaitu dengan ketepatan 75%. Kesimpulan daripada aplikasi ANN dapat dilihat dari hasil keputusan kajian ini yang mana boleh digunakan oleh pemilik bangunan untuk meramal keadaan bangunan terhadap beban seismik.

CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A_a	-	Coefficient of acceleration
A_c	-	Area of the compressive reinforcing bars
A_t	-	Area of the tensile reinforcing bars
A_v	-	Velocity related acceleration coefficient
b_{sl}	-	Effective slab width for a rectangular beam
β	-	Model constant parameter
β_c	-	Model constant parameter for concrete
C_d	-	Deflection amplification factor
C_s	-	Seismic design coefficient
C_t	-	Building system coefficient
$[C]$	-	Viscous matrix of the structure
c	-	Factor to amplify the curvature due to inelasticity of the concrete
c_{corr}	-	Correction coefficient (usually taken as one)
d	-	Depth to rebar in inches.
d_c	-	Cover depth for compression bars
D	-	Actual data value
D_{min}	-	Minimum data value of each variable
D_{max}	-	Maximum data value of each variable
δm	-	Maximum experienced deformation
δu	-	Ultimate deformation of the element
$\{\Delta F\}$	-	Vector of applied load increments
$\{\Delta F_{err}\}$	-	Vector with the unbalanced forces in the structure

$\{\Delta P_V\}$, $\{\Delta P_{FR}\}$, $\{\Delta P_{HY}\}$, and $\{\Delta P_{IW}\}$	-	Restoring forces from viscous dampers, friction dampers, Hysteretic dampers and infill panels respectively
$\{\Delta_u\}$,	-	Vector of unknown nodal displacement increments
$\{\Delta u\}$, $\{\Delta \dot{u}\}$, and $\{\Delta \ddot{u}\}$	-	Incremental vectors of displacement velocity and acceleration in the structure respectively
$\Delta\ddot{x}_{gh}$ and $\Delta\ddot{x}_{gv}$	-	Increment in the horizontal and vertical ground accelerations
E_i	-	Total absorbed energy by the component or storey "i"
E_k	-	Dissipated energy in the section
ε_c and $\varepsilon_c^{'}$	-	Maximum compression and tension strains in the concrete
ε_0	-	Strain at maximum strength of the concrete
ε_y	-	Strain at yield stress of steel
f_c and $f_c^{'}$	-	Compression and tension concrete strength in ksi
$H_{input}h$	-	Input of the h hidden neuron
h	-	Height of the building
HBE	-	Hysteric energy-based strength decay parameter
HBD	-	Ductility-based strength decay parameter
HC	-	Stiffness degrading parameter
HS	-	Slip or crack-closing parameter
I	-	Normalized data value
I_g	-	Gross section for beam
I_i	-	Value at input neuron
φ_y	-	Yield curvature
φ_{yf}^{-}	-	Negative yield curvature
φ_{yf}^{+}	-	Positive yield curvature
k	-	Coefficient for various units in the code of CP3
k'	-	Neutral axis parameter (similar to k).
$[K_t]$	-	Tangent stiffness matrix

L	-	Overall length of the building
$\{L_h\}$ and $\{L_v\}$	-	Allocation vectors for the horizontal and vertical ground accelerations
λi	-	Energy weighting factors
$[M]$	-	Lumped mass matrix of the structure
M_{cr}	-	Cracking moment
M_{cr}^{+} and M_{cr}^{-}	-	Positive and negative cracking moments
M_u	-	Ultimate moment
M_u^{+} and M_u^{-}	-	Positive and negative ultimate moments
M_y	-	Yield moment
M_y^{+} and M_y^{-}	-	Positive and negative yield moments
N	-	Axial load in kips
n_o	-	Axial load in kips on beam
n	-	Number of floors
$(O_{input})_k$	-	Input at each of k neurons
P_y	-	Yield strength of the element
PCP	-	Cracking shear (positive)
PYN	-	Yield shear (negative)
PYP	-	Yield shear (posiyive)
p	-	Number of input neuron
q	-	Number of hidden neuron
Q_k	-	Threshold of the k output neuron
R	-	Response modification factor
r	-	Number of output neuron
r	-	Linear correlation coefficient
S	-	Soil profile coefficient
θ_M	-	Maximum rotation attained during the loading history
$\int dEh$	-	Hysteretic energy absorbed by the element during the response history
T	-	Fundamental period of the structure
u_{max}	-	Maximum strength deterioration

u_y	-	Yield strength deterioration
V	-	Design base shear
W	-	Seismic dead load
W_{ih}	-	Connection weight from the *i* input neuron
W_{hk}	-	Interconnection weight between the hidden neuron and each of the k output neuron
X	-	Prediction value
Y	-	Actual value

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 General

In a global sense, earthquake results from motion between plates comprising the earth's crust. With the present understanding of the earthquake generating mechanism, the times, sizes and locations of earthquakes cannot be reliably predicted. Although newer buildings in a community may have been properly designed and constructed to resist earthquake loads, there may be many buildings that pose a life-safety threat if subjected to an earthquake. The identification of life-safety hazard in an existing building consists of determining whether any of the events could potentially happen for the building during an earthquake that could be expected to occur during its lifetime. There are major tectonic plates around Malaysia. Earthquake had caused major loss to human lives and structural damage.

Undeniably, there is no better vehicle for identifying a vulnerable building than the considered judgment of an experienced professional. But this is an expensive vehicle, especially in regions of infrequent earthquakes. There is a need to provide reasonably objective criteria to be used for initial filtering of the building inventory. These criteria need to be at a very low level of sophistication in deference to the principle of proportionality. The required levy of calculation has to be proportional to the quality of input.

The readily accessible data for an existing building are the dimensions and arrangement of its structural elements and the floor area. The challenge is to determine whether these properties alone may be used to determine the seismic vulnerability of a building inventory at a given location. In a paper related to damage caused by the Tokachi-Oki earthquake of 1968, Shiga, Shibata, and Takahashi presented a format (referred to as the SST Format in following text) for evaluating the seismic safety of low-rise monolithic construction in reinforced concrete. They defined the critical attribute for seismic vulnerability to be the weight of the structure divided by the sum of the cross-sectional areas of the walls and the columns.

1.2 Statement of the problems

The performance of buildings during earthquake is unknown. The most existing building owners and regulators must ensure that their buildings are safely operated and present no risk to the public in case of an earthquake. The adequacy and safety level of buildings must be determined. Intelligent seismic evaluation can simulate human decision-making ability through the use of ANN engine which is base on past experience in the prediction of score for building and forecasting the building's performance under earthquake loading.

1.3 Objectives

In this research, several objectives have been revised for a guidelines. The objectives of this study are:

1) To develop the seismic evaluation of building digital form of ATC21 and ATC22 based on *Applied Technology Council*.

2) To specify the damage level of buildings and determine the performance of buildings under seismic loading, and damages that might occur.

3) To predict the degree of damage level of building by using Borland C++ Builder as the programming tool for the intelligent system.

1.4 Scope of Work

In order to achieve the objectives, the research scopes have to be followed and revised. The scopes of the study are:

1) To propose new digital form for earthquake evaluation of buildings based on ATC21 and ATC22 manual form.

2) To study the performance of buildings with less than 20 stories by using Finite Element Modeling for dynamic non-linear analysis (IDARC 2D).

3) To use a variation of low earthquake intensities (0.05g, 0.10g, 0.15g, 0.2g) in the analysis with the ground motion scale of 5% damped spectral acceleration.

4) To integrate the intelligent system by Artificial Neural Network (ANN) with Back-Propagation Neural (BPN) algorithm to predict damage level for buildings.

5) To develop a User-friendly Interface. Borland C++ Builder will be used as the programming tool.

1.5 Methodology

This study can be represented in sixth phases as shown in Figure 1.1. The steps taken in this study are described below.

Phase I: Literature, Collecting and Compilation of Data, and Development of Database System.

In the early stage of this study, literature studies are carried out in various fields especially in building performance, seismic evaluation procedure and ANN. The collection of data and results from existing study was emphasized at this stage. Selected building data for modeling analysis were collected from the authorities. The development of database system used Borland C++ Builder as the programming tool. All the data will be stored in this database system to be used in the next phase.

Phase II: Seismic Evaluation by Rapid Visual Screening of Building, Development of Digital Form for ATC21

The seismic evaluation procedure presented in ATC21, which is meant to be the preliminary screening phase for identifying hazardous buildings, was reviewed. Buildings identified by this procedure as potentially hazardous must be analysed n more detail by a professional engineer with experience in seismic design. Each step and procedure in ATC21 has been looked into as well. Then the development of digital form for ATC21 was carried out.

Phase III: Detailed Visual Analysis, Development of Digital Form for ATC22

The further seismic evaluation process were continued with ATC22 which is involves the detailed analysis of the building including evaluation on both structural (column, beam, slab, etc) and nonstructural (stud, finishing, etc.) element. The building is evaluated using a checklist suitable to its structural system type. Each step and procedure in ATC22 was studied. The development of the digital form for ATC22 was conducted.

Phase IV: Finite Element Analysis (IDARC2D), Analysis and Damage Identification for selected buildings.

To study the performance of buildings, the computer program IDARC 2D was conceived as a platform for nonlinear structural analysis. Several buildings were analysed to evaluate the structural damage. After all the buildings were analysed, the application of ANN engine is commenced.

Phase V: Integration of ANN for Evaluation of Damage Forecasting

The integrating of ANN model begins with the selection of variables, determination of network structure, training process, and finally validation process. Again, Borland C++ is used as the programming language. This ANN model is used to predict results from structural damage using previous data.

Phase VI: Conclusion and Discussions

Finally, results and findings from this study will be concluded. The digital form of ATC21 and ATC22 is presented in this phase. The overall results for buildings using IDARC2D structural analysis and their correlations with damage level are discussed to determine the practicality of applying IDARC2D as a platform for nonlinear structural analysis tool in the building evaluation. The accuracy of results predicted by ANN is discussed to evaluate their performance and recommend any improvement for future studies.

1.6 Organisation of Thesis

This thesis is organized into seven chapters. Chapter 1 will cover the general introduction, statement of the problems, objective of the study, scope of work, and the methodology used. The literature reviews are presented in Chapter 2. The performances of the reinforced concrete buildings from existing studies will be reviewed. Procedures involved in evaluation of buildings will be briefly discussed. Chapter 3 will discuss the theoretical background. This chapter will include the procedures of seismic evaluation for buildings. Besides, further analysis on dynamic non-linear is also emphasized in this chapter. In Chapter 4, methodologies applied in this study will be reviewed in detail. Chapter 5 will focus on modeling techniques applied for finite element analysis. The analysis results from the finite element modeling are also being emphasized in this chapter. The findings and results from the application of ANN in the evaluation of building will be covered in Chapter 6. Chapter 7 will conclude all the discussion and findings in this thesis. Recommendations are listed in this chapter to improve the research for future development.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will include the literature study in detail. The study on performance of existing buildings in Malaysia will be presented. The building response will also be reviewed. Then the seismic evaluation procedure for concrete buildings will be discussed. The goal of conventional methods for evaluation of seismic vulnerability is to select buildings with a high probability of survival. A simple method is presented to help identify buildings with a high probability of severe damage. A literature review about the seismic evaluation of building has been conducted from a variety of aspects including the overall philosophy which has developed in recent years to evaluate the existing buildings subjected to seismic hazards. This chapter then will discuss the application of finite element analysis in identifying the performance of buildings. The next part in this literature review will look further on the appliances of artificial neural network in this study. A background and advantages of the neural network will be presented accordingly by their application in various part of civil engineering field. A few examples of research studies on application of neural network in predicting structural damage will be reviewed.

2.2 Case Study on Performance of Existing Buildings in Malaysia

A comparative study of the effect of earthquake loads on the performance of reinforced concrete buildings by Suhana, (2007) was carried out using Finite Element Analysis. This study investigated seven existing buildings from Peninsular and East Malaysia. The buildings were categorised as medium and high-rise reinforced concrete moment resisting frames. The UBC-97, CP3:1972 and the MS 1553:2002 are used as the design codes in determining the lateral loads from earthquake and wind.

A case study conducted by Tan, (2002) on the behavior of high-rise building under seismic effect for Petronas Twin Tower (KLCC) used Finite Element Analysis. UBC-91 static procedure is an approach to estimate approximate response in the preliminary state of the study. The studies on performance of high rise buildings in Malaysia with various intensity of earthquake using Finite Element Modeling have been conducted by Noor Aishah, (2002) and Yew, (2000). Three main categories of earthquake intensity in response spectrum analysis were selected in the analysis. There are low intensity (0.02g, 0.075g, 0.15g), moderate intensity (0.25g, 0.35g) and high intensity (1.17g). Ground acceleration at San Fernando earthquake, 1971 was used for time history analysis. By comparing the maximum design capacity with the maximum shear and bending forces for each beam and column under various intensities, the failure of beam or column element was detected when bending moment and shear force exceeded the design capacity. From this study, it shows that the performance of high buildings in Malaysia. Low intensity earthquake regions such as Malaysia, would have intensity level of 0.074g such as Kompleks Tun Abdul Razak will be unsafe under low intensity earthquake effect.

2.3 Building Responses

The studies of Earthquake Shaking and Building Response were published in 1999 by the joint venture partnership of the Applied Technology Council (ATC) and the Structural Engineers Association of California (SEAOC). Different individual buildings shaken by the same earthquake respond differently. The effects of earthquake ground shaking depend on the specific response characteristics of the type of structural system used. One important building characteristic is the fundamental period of vibration of the building (measured in seconds). The fundamental period of a building depends in a complex way on the stiffness of the structural system, its mass, and its total height. Seismic waves with periods similar to that of the building will cause resonance, and amplify the intensity of earthquake forces the building must resist. These common terms and factors affecting shaking intensity at a given site are illustrated in Figure 2.1. Shape or configuration is another important characteristic that affects building response. Earthquake shaking of a simple rectangular building results in a fairly uniform distribution of the forces throughout the building. Irregularly shaped buildings, shown in Figure 2.2, are subject to special design rules because otherwise they can suffer greater damage than regularly shaped buildings.

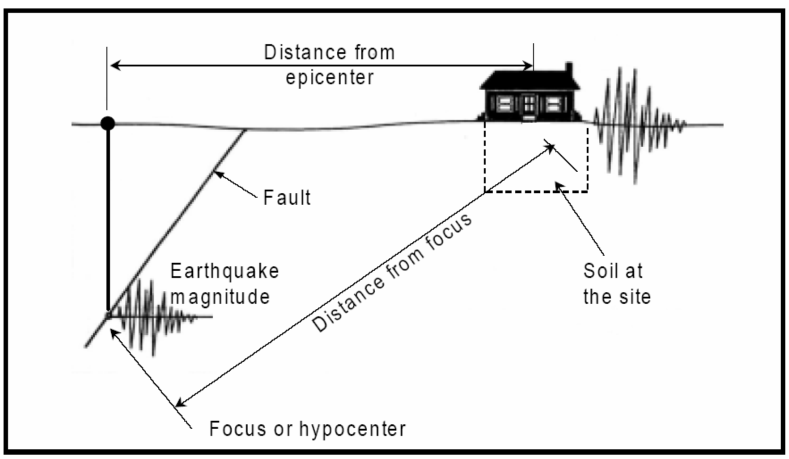

Figure 2. 1: Common terms and factors affecting shaking intensity at a given site (ATC/SEAOC et al., 1999)

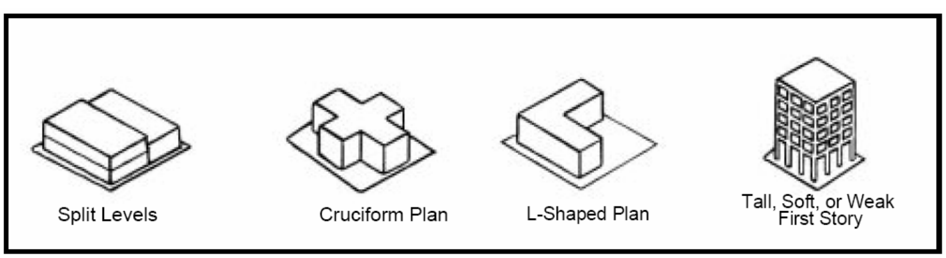

Figure 2. 2: Examples of buildings with irregular configurations (ATC/SEAOC et al., 1999)

2.4 Development of Seismic Hazard Map in Malaysia

The seismic hazard assessment in Malaysia using deterministic method has been performed by Adnan, A. *et al.*, (2002). This method calculates the seismic hazard based on worst-case scenario of earthquake expected in a region and it covers the estimation of maximum magnitude that is probable to occur in that region. As shown in Figure 2.3, the result of deterministic analysis has divided the PGA map of Peninsular into two zones, i.e. the zone six is for range between 30 and 50 gals (0.03 to 0.05g) on the east side of Peninsular Malaysia and the zone seven is between 50 and 70gals (0.05 to 0.07g) on the west side. While the PGA at East Malaysia has been divided into seven zones: i) zone 1 (150 gals and above), ii) zone 2 (130 to 150gals), iii) zone 3 (110 to 130gals), iv) zone 4 (90 to 110gals), v) zone 5 (70 to 90gals), vi) zone 6 (50 to 70gals), vii) zone 7 (30 to 50gals).

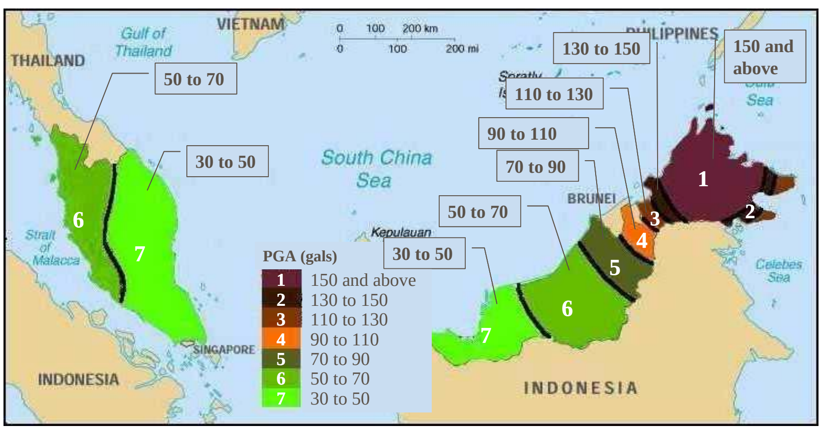

Figure 2. 3: Peak Ground Acceleration (PGA) contour based on deterministic method *(*Adnan, A. *et al.*, 2002*)*

From the study by Adnan, A. *et al.* (2002) on the development of seismic hazard map for Peninsular Malaysia at 10% and 2% probability of exceedance (PE) in 50 years gives the four and seven of contour increased constantly from northern side to the southwest of Peninsular Malaysia respectively. Figure 2.9 shows that the ground motion range between 20 gal and 100 gal for 10% PE in 50-year hazard level, while Figure 2.10 shows the ground motion range between 40 gal and 200 gal for 2% PE in 2500-year hazard levels.