SEISMIC ANALYSIS OF IRREGULAR REINFORCED CONCRETE BUILDING

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SCHOOL OF CIVIL ENGINEERING
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SEISMIC ANALYSIS OF IRREGULAR REINFORCED CONCRETE BUILDING

By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Kebanyakan bangunan di Malaysia tidak direka dengan muatan gempa bumi walaupun ancaman gempa bumi yang aktif dari Indonesia adalah benar. Tujuan projek ini adalah untuk mengkaji kesan ketidakteraturan terhadap bangunan menggunakan analisis statik dan dinamik serta mengkaji prestasi seismik bangunan konkrit bertetulang yang tidak teratur dalam tiga dimensi menggunakan STERA 3D. '*Nonlinear Static Pushover Analysis (POA)*' dan '*Incremental Dynamic Analysis (IDA)*' telah dijalankan. Analisis POA ini akan ditumpukan kepada lengkung hubungan geser dan ricih serta lengkung daya bangunan itu manakala IDA akan menggunakan lengkung '*Incremental Dynamic Analysis (IDA)*'. Terdapat tiga bingkai yang tidak teratur secara menegak dengan nombor tingkat 3, 6 dan 9. Untuk Analisis IDA bingkai tersebut tertakluk kepada tujuh jenis pergerakan tanah yang berlainan iaitu Chalfant Valley (Julai 1986), Coalinga (Julai 1983), Imperial Valley (Oktober 1979), Kobe (Januari 1995), Mammoth Lake (Mei 1980), Ranau (Jun 2015) dan Whittier Narrow' (Oktober 1987) dengan kenaikan magnitud sebanyak 0.2g, 0.4g, 0.6g, 0.8g dan 1.0g. Hasil dari POA untuk lengkung daya menunjukkan bahawa bingkai 3, 6 dan 9 tingkat mengalami bangunan runtuh selepas menghampiri keadaan had runtuh dan bangunan rendah mempunyai rintangan yang paling tinggi terhadap pergerakan tanah, manakala lengkung hubungan geser dan ricih menunjukkan bahawa sesaran tingkat untuk lantai pertama adalah yang tertinggi dalam setiap tingkat dan ia menaik dengan jumlah tingkat. Analisi IDA menunjukkan bahawa Imperial Valley mempunyai sesaran yang paling tinggi bagi bangunan 9 tingkat manakala Ranau mempunyai nilai sesaran yang rendah untuk bangunan 9 tingkat. Pergerakan tanah dengan pecutan puncak tanah yang tinggi akan menyebabkan peningkatan dalam nilai sesaran.

ABSTRACT

Most buildings in Malaysia are not designed with earthquake loading though threat of an active earthquake from Indonesia is real. The purpose of this project is to study the effect of irregularity using static and dynamic analysis along with the seismic performance of irregular reinforced concrete frame in 3D analysis using STERA 3D. Nonlinear static pushover (POA) and Incremental Dynamic Analysis (IDA) were run on the frames. The POA will be focusing on drift-shear relation and capacity curve of the building whereas the IDA will utilise incremental dynamic analysis (IDA) curve. There are three vertically irregular frame with different number of stories which are 3, 6 and 9. For IDA the frame were subjected to seven different type of ground motion which are Chalfant Valley (July 1986), Coalinga (July 1983), Imperial Valley (October 1979), Kobe (January 1995), Mammoth Lake (May 1980), Ranau (June 2015) and Whittier Narrow (October 1987) with increment of its magnitude by 0.2g, 0.4g, 0.6g, 0.8g, and 1.0g, respectively. The result obtained from POA for capacity curve shows that the 3, 6 and 9 story frames had undergone building collapse after nearing the collapse limit state and the low rise building has the highest resistance towards the ground motions while the drift-shear relation curve shows that the story displacement for first floor is the highest in every story and the value increases with the number story. In IDA the result shows that Imperial Valley has the highest displacement for 9 story while Ranau has the lowest value of displacement for 9 story and the ground motion with higher peak ground acceleration (PGA) value will caused an increase in the displacement value.

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LIST OF ABBREVIATIONS

IDA	**I**ncremental **D**ynamc **A**nalysis
POA	**P**ushover **A**nalysis
PEER	**P**acific **E**arthquake **E**ngineering **R**esearch
EC2	**E**uro**c**ode **2**
EC8	**E**uro**c**ode **8**
RC	**R**einforced **C**oncrete
3D	**T**hree **D**imensional
PBEE	**P**erformance **B**ased **E**arthquake **E**ngineering
FEMA	**F**ederal **E**mergency **M**anagement **A**gency
PGA	**P**eak **G**round **A**cceleration
NSPA	**N**onlinear **S**tatic **P**ushover **A**nalysis
THA	**T**ime **H**istory **A**nalysis
BS	**B**ritish **S**tandard
NSP	**N**onlinear **S**tatic **P**rocedure

CHAPTER 1

INTRODUCTION

1.1 Background

Earthquakes are prone to be the most unpredictable and devastating natural hazards and it pose multiple hazards to a community, economic, property including population loss (Dya and Oretaa, 2015). According to Mosleh et al., (2016) strong ground motions in the past years in densely populated area made great impacts on many buildings specially those designed according to older codes. Structures that does not designed with seismic loading are seismically vulnerable and damage under several devastating earthquakes, particularly the 1989 Loma Prieta, the 1994 Northridge earthquakes in California, the 1995 Kobe earthquake in Japan, the 2009 L'Aquila, the 2012 Emilia Romagna in Italy and finally the 2011 Lorca earthquake in Spain. As for the reasons why those structures are vulnerable during past earthquakes is due to the inadequacy of previous seismic codes and guidelines, low standards of construction due to inattention to local detailing and quality control with high variation in material properties.

Performance Based Earthquake Engineering (PBEE) is receiving a high attention in recent years as one of the important approach for the seismic assessment for existing buildings as well as designing new structures and the PBEE procedure as the structural response are also being estimated with the aid of a nonlinear static pushover analysis (NSPA), time history analysis (THA) and incremental dynamic analysis (IDA) for various intensity levels of seismic motion (Kostinakis and Athanatopoulou, 2016).

RC members which subjected to axial loads combined with biaxial bending moment are recognized as a research topic among researchers for buildings. Hence, non-linear analyses have been used to evaluate the safety of a structure designed according to the existing design codes.

Nowadays, irregular buildings constitute a substantial portion of the modern urban infrastructure. The group of people involved in constructing the building facilities, including owner, architect, structural engineer, contractor and local authorities, contribute to the overall planning, selection of structural system, and to its configuration which may lead to building structures with irregular distributions in their mass, stiffness and strength along the height of building (Aijaj and Deshmukh, 2013). Figure 1.1 shows the irregular building that can be found in Malaysia where (a) is the Kementerian Perusahaan Perladangan dan Komoditi (KPPK) while (b) shows the recently build bangunan Berlian located in Putrajaya.

(a)

(b)

Figure 1.1: Example of irregular buildings in Malaysia
(a) KPPK (Ministry of Primary Industries, 2009)
(b) Bangunan Berlian (Malaysia Stunning Green Diamond Building, 2012)

There are two types of irregularities in building which are plan irregularities and vertical irregularities. Figure 1.2 and Figure 1.3 show the example of building with plan irregularities and vertical irregularities, respectively.

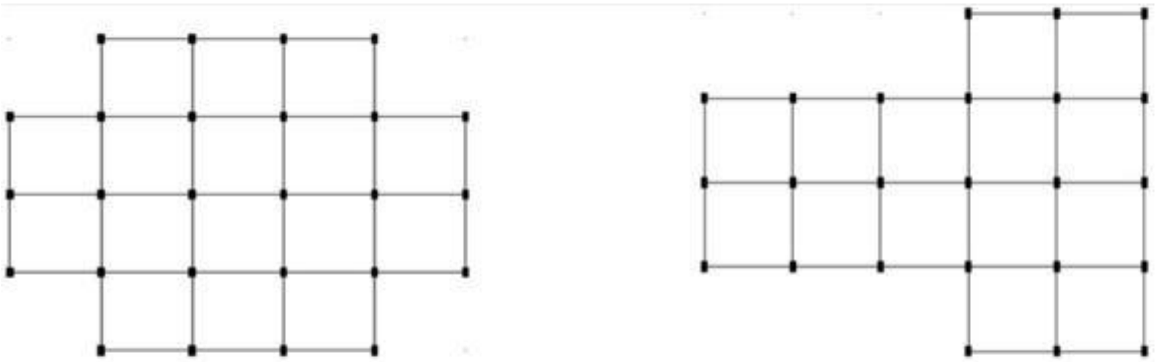

Figure 1.2: Example of building with plan irregularities (Aijaj and Deshmukh, 2013)

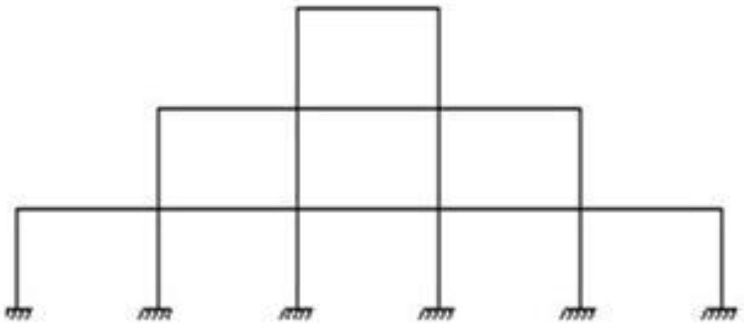

Figure 1.3: Example of building with vertical irregularities (Aijaj and Deshmukh, 2013)

According to Eurocode 8 (2003) irregularity in elevation is expected to have more severe effects in the design and in the seismic response of the building rather than the irregularity in plan. Thus, the static analysis with equivalent horizontal seismic loads is allowed to be applied only in buildings that are regular in elevation. It has also stated that buildings which are irregular in elevation, the behaviour factor, q will have to be reduced by 20% in comparison with buildings that are regular in elevation.

Regarding the implications of structural regularity on analysis and design, separate consideration is given to the regularity characteristics of the building in plan and in elevation referring to Table 1.1.

Table 1.1: Sructural regularity on seismic analysis and design (Eurocode 8, 2003)

Regularity		**Allowed Simplification**		**Behaviour factor, q**
Plan	Elevation	Model	Linear-elastic Analysis	(for linear analysis)
Yes	Yes	Planar	Lateral force	Reference value ,q = 3.9
Yes	No	Planar	Modal	Decreased value, q = 3.12
No	Yes	Spatial	Lateral force	Reference value, q = 3.9
No	No	Spatial	Modal	Decreased value, q = 3.12

Research in Malaysia on earthquake engineering is increasing though Malaysia is underlain by a tectonically stable crust. However, Malaysia still exposed to Indosina-Sundaland and surrounded by active seismically zone which is at least 300 km away. Peninsular Malaysia is exposed to the seismic risk. There are also several concrete historical evidences that show peninsular Malaysia is not immune to seismic risk forever (Marto et al., 2013). Even though, numerous studies have been conducted to explained significant damages of an earthquake to be within 100-200km radius from epicenter, but a high intensity earthquake could give impact up to 700 km as happened in Mexico 1985 (Megawati et al., 2005).

1.2 Problem Statement

Studies on irregular reinforced concrete building are still limited under seismic loading. On June 5th, 2015, Malaysia faced local earthquake from Ranau, Sabah. This earthquake caused some damaged to the reinforced concrete structure in Sabah as the magnitude of the earthquake reached 5.9 Mw. Existing building were severely damaged, especially at the ground column. Most buildings in Malaysia are not designed with earthquake loading though threat of an active earthquake from Indonesia is real. Malaysia is exposed of far field earthquake since 2004 where several metropolises such as Kuala Lumpur, Putrajaya, Penang, and Johor Bahru could be vulnerable to Sumatran fault and Sumatran subduction earthquakes distance within 300 km away. However, current design code (BS 8110) does not imply any earthquake loading especially for existing and new design structure which is seismically vulnerable (Shoushtari et al., 2016).

Several studies on the seismic performance of 3D reinforced concrete frame has gained interest especially on building irregularities biaxial bending combined with axial force in the columns (Mosleh et al., 2016) because in today era structure is design with irregularities in shape and elevation to meets the aesthetic value from the customer including the designer. Thus, 3D analysis is carried out using nonlinear static procedure (NSP) and time history to determine the effect of 3D irregular frame under influences of earthquake.

1.3 Objectives

The main objective of this project is to study the effect of irregularity using static and dynamic analysis along with the seismic performance of irregular reinforced concrete frame in 3D analysis using STERA 3D

1.4 Scope of Work

This study is limited to the following scopes:

i. 3D vertical irregular RC frames with 3, 6 and 9 number of stories.

ii. Behaviour factor, q = 3.12, Ductility Class Medium from EC8 for building which are not regular in elevation, the value of q should be reduced by 20%.

iii. Considering soil type B (very dense sand) with peak ground acceleration (PGA), a_{gR} = 0.2g.

iv. Eurocode 8: Design of structures for earthquake resistance for seismic design using SAP 2000.

v. Using the strength of steel, f_{yk}= 500N/mm^2 and the concrete compression strength, f_{ck}= 20N/mm^2.

vi. 7 single ground motions.

vii. Analysis of the 3D irregular RC frames using STERA 3D.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Malaysia is located on the southern edge of the Eurasian Plate. It is close to the most two seismically active plate boundaries, the inter-plate boundary between the Indo-Australian and Eurasian Plates on the west and the inter-plate boundary between Eurasian and Philippine Plates on the east as shown in Figure 2.1. Large earthquakes around these boundaries would extend some earthquake tremor that can be felt at certain regions in Malaysia. In east Malaysia, besides affected by large earthquakes located over Southern Philippines and in the Straits of Makassar (Ujung Padang, Indonesia), Sulu Sea and Celebes Sea (Philippines), it also experienced earthquakes from local origin. Several possible active faults and local earthquakes in East Malaysia appear to be related to some of them (Abas, 2001).

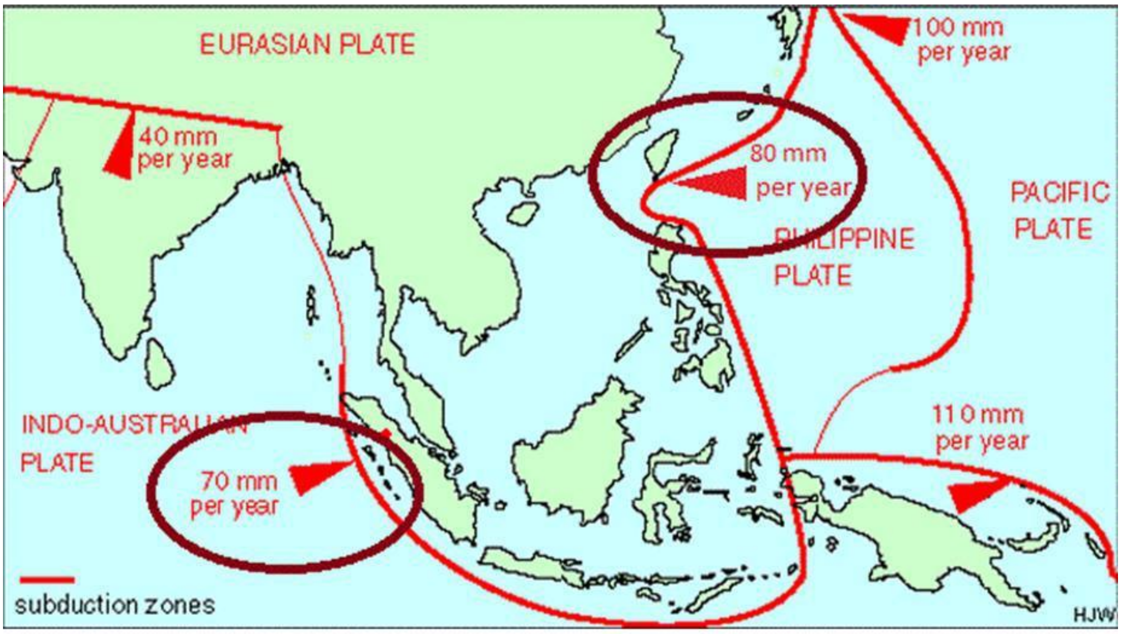

Figure 2.1: Plate boundaries of Malaysia (Wegener, 2017)

2.2 Seismic activity in Malaysia

The Sumatran seismic sources have generated numerous earthquakes, some of which have been felt in Kuala Lumpur (capital of Malaysia), Johor Bahru (the southern state of Peninsular Malaysia) and Singapore. Tectonic plates are in continuous steady motion. However, when an earthquake occurs, this steady motion is interrupted due to the seismicity of the earthquake. Seismicity or seismic activity refers to the frequency, magnitude and distribution of earthquakes in a given area (Gill et al., 2015). Malaysia is situated on the Sunda tectonic block, encompassing a large part of Southeast Asia (Simons et al., 2007). Previously, Malaysia was on a relatively stable continent where it was far from catastrophic events caused by tectonics plate such as earthquakes and volcanic eruptions. However, when the 9.2 Mw Sumatra-Andaman mega earthquakes occurred on December 26^{th,} 2004, the fact has been changed. During the Sumatra-Andaman earthquake, the nearest countries from the epicentre showed very large co-seismic displacements which are 27 cm in Phuket, Thailand, 17 cm in Langkawi, Malaysia, and 15 cm in Sampali, Indonesia (Vigny et al., 2005). Furthermore, after the 2004 Sumatran-Andaman, the post-seismic relaxation processes has been continuing for years in Andaman (Paul et al., 2007).

Sabah is situated on the Sunda Plate and it is located in a tectonically dynamic margin of Borneo where it is surrounded by active plates of the Sundae, Indo-Australian, and Philippines Sea plates. Thus, there is a high concentrated distribution of earthquakes around this region (Shah, 2015). There has been several number of earthquake cases detected in Sabah since 1874. Among the significant cases which have caused considerable damages are the 1976 Lahad Datu Earthquake, the 1991 Ranau Earthquake (Marto et al., 2013).

2.2.1 Lahad Datu Earthquake

Lahad Datu is one of the high seismic potential areas because of the frequent earthquakes activity which had occurred since 1874 and the worse situation was during 1976 (Marto et al., 2013). Table 2.1 shows Lahad Datu earthquake activities area while Figure 2.2 shows the seismic activity in Lahad Datu.

Table 2.1: Lahad Datu earthquake occurrence list (Cheng, 2016)

No	Year	Date/ month	Time	Epicenter	Depth (km)	Magnitude (M)	District
12	2012	28-May	16:44	4.786, 118.321	39	4.6	Lahad Datu
13	2010	21-Aug	19:43	5.370, 118.368	54	4.2	Lahad Datu
16	2008	9-Apr	00:51	4.838, 118.713	27	4.5	Semporna
27	1996	6-Dec	12:42	4.894, 118.605	33	4.4	Lahad Datu
34	1994	2-Nov	01:43	5.099, 118.643	55	5.7	Lahad Datu
35	1992	4-Jul	22:33	4.976, 118.454	10	4.6	Lahad Datu
48	1984	14-Mar	00:39	5.203, 118.387	50	5.6	Lahad Datu
50	1982	26-Nov	19:29	4.895, 118.387	33	4.5	Lahad Datu
51	1981	25-Dec	00:28	4.760, 118.477	39	5.4	Semporna
56	1976	14-Aug	11:10	4.714, 118.421	36	5.1	Semporna
58	1976	26-Jul	09:43	4.994, 118.550	33	5.1	Lahad Datu
59	1976	26-Jul	08:49	4.894, 118.342	33	5.3	Lahad Datu
60	1976	26-Jul	08:36	4.904, 118.052	33	5.3	Lahad Datu
61	1976	26-Jul	05:35	4.986, 118.594	33	5.2	Lahad Datu
62	1976	26-Jul	03:03	5.062, 118.385	33	5.3	Lahad Datu
63	1976	26-Jul	02:56	4.956, 118.308	33	6.2	Lahad Datu
64	1976	25-Jul	14:03	5.092, 118.287	33	5.3	Lahad Datu

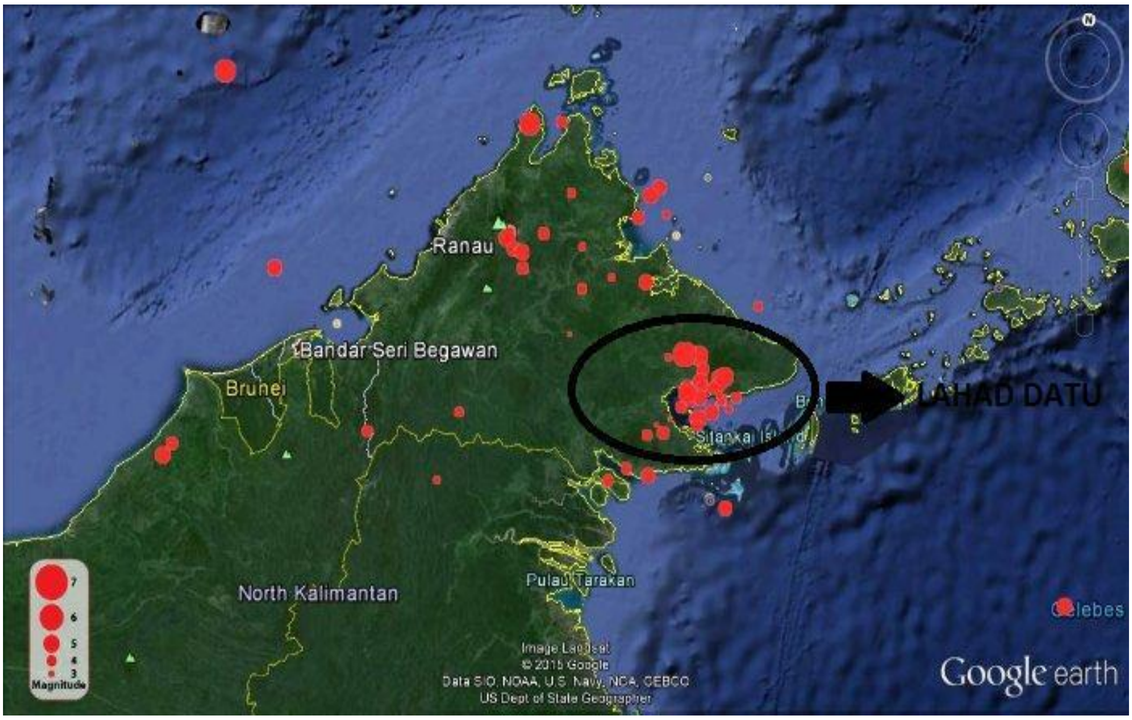

Figure 2.2: Seismic Activity at Sabah, Lahad Datu (Khalil, 2015)

2.2.2 Ranau Earthquake

Earthquake struck in Ranau, Sabah with a magnitude of 6.0 on 5th June 2015, lasted for 30 seconds was one of strongest earthquakes recorded in Malaysia (Earthquake Track, 2015). The news has drawn enormous attentions from the local government and related agencies to study the seismic activities in Sabah area. Table 2.2 shows earthquake list in Ranau (Cheng, 2016) whereas Figure 2.2 shows the seismic activity at Sabah while Figure 2.3 shows the damage that happen to rest house and mosque in Ranau, Sabah, respectively.

Table 2.2: Past Ranau earthquake activities list (Cheng, 2016)

No.	Year	Date-month	Time	Epicenter	Depth (km)	Magnitude (M)	District
1	2015	26-Jul	16:10	6.224, 116.868	15	4.6	Ranau
2	2015	23-Jun	09:32	6.159, 116.606	15	4.5	Ranau
3	2015	12-Jun	18:29	6.182, 116.651	11	5.3	Ranau
4	2015	6-Jun	05:45	5.956, 116.608	10	4.5	Ranau
5	2015	4-Jun	23:15	5.979, 116.529	10	6.0	Ranau
10	2014	1-Feb	11:35	6.157, 116.589	17	4.7	Ranau
19	2006	28-Sep	15:11	6.041, 117.398	10	4.5	Ranau
30	1995	11-Aug	06:21	6.340, 117.150	33	4.1	Ranau
39	1991	26-May	11:16	5.869, 116.815	18	5.1	Ranau
40	1991	26-May	11:14	5.718, 116.748	33	4.7	Ranau
41	1991	26-May	10:59	5.865, 116.746	33	5.1	Ranau
42	1991	26-May	07:02	6.113, 117.168	33	4.6	Ranau

Figure 2.3: Damages from Ranau earthquake (Awani, 2015)

2.3 Seismic analysis

Seismic analysis is a major tool in earthquake engineering used to study the response of buildings due to seismic excitations in a simpler manner. In the past, buildings were designed just for gravity loads while seismic analysis is a recent development. There are diverse types of earthquake analysis methods. Some of it which used in the project is as mentioned by (Bansal, 2014) are:-

i. Response Spectrum Analysis

ii. Time History Analysis

2.3.1 Response spectrum analysis

This approach permits the multiple modes of response of a building to be considered. The structural response can be defined as a combination of many modes. Computer analysis can be used to determine these modes for a structure. For each mode, a response is obtained from the response spectrum curve (Bansal, 2014), which is a plot of the peak or steady-state response(displacement, velocity of acceleration) of a series of oscillators varying natural frequency, that are forced into motion by the same base vibration of shock. The resulting plot can then be frequency of oscillation. One such use is in assessing the peak response of building to earthquakes (Kiriqi, 2015) which are combined to estimate the total response of the structure.

Figure 2.5 shows S represent the soil factor and η is the damping correction factor whereas T_B and T_C is the lower and upper limit of the period of the constant spectral acceleration branch and finally T_D is the value defining the beginning of the constant displacement response range of the spectrum in second, s.

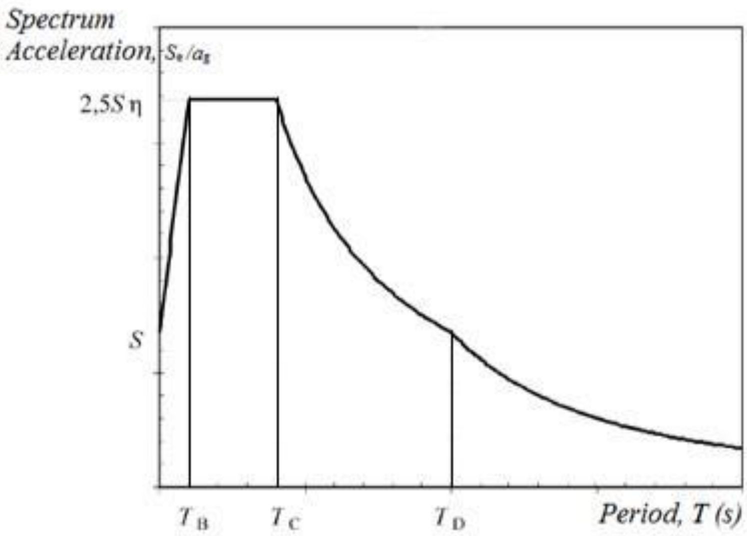

Figure 2.4: Response Spectrum Curve (Eurocode 8, 2003).

2.3.2 Time History Analysis (THA)

Time history analysis techniques involve the stepwise solution in the time domain of the multi degree of freedom equations of motion which represent the actual response of a building. The solution is a direct function of the earthquake ground motion selected as an input parameter for a specific building. This analysis technique is usually limited to checking the suitability of assumptions made during the design of important structures rather than a method of assigning lateral forces themselves (Bansal, 2014).

2.4 Non-linear static pushover analysis

Pushover Analysis is one of the methods available for evaluating buildings against earthquake loads. A structure is induced incrementally with a lateral loading pattern until a target displacement is reached or until the structure reaches a limit state (Dya and Oretaa, 2015). Pushover Analysis is a static nonlinear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern. With the increase in the magnitude of the loading, weak links and failure modes of the structure are found (Habibullah and Pyle, 1998).

2.5 Incremental dynamic analysis (IDA)

There are several methods that are being proposed to tackle the problem of accurate estimation of the seismic demand and capacity of structures. One of it is IDA (Vamvatsikos and Cornell, 2005). IDA is a procedure that offers demand and capacity prediction capability in regions ranging from elasticity to global dynamic instability by using a series of non-linear dynamic analysis under suitably multiple scaled ground motion records. This approach needs time-histories to be scaled and applied to the structure.

2.6 Research from previous study

According to Marto et al. (2013), there were high possibility of earthquake threat and the seismic impacts in Peninsular Malaysia in 20th century. The current seismic environment of Malaysia, particularly within Peninsular Malaysia has been reviewed by discussing the previous related studies on earthquake engineering in Peninsular Malaysia. The development on seismic sources and seismic hazard assessment has been considered along with considering earthquakes which had affected peninsular Malaysia were actually originated from Sumatra, particularly from the Sumatra Subduction Zone and the Sumatra Transform Zone. This research has highlighted the importance of regional seismic assessment through literature recommendation and the reactivation of ancient inactive faults within Peninsular Malaysia need be taken into future consideration including more related research of near field earthquakes experiences. The developments of seismic sources and seismic hazard assessment are also being highlighted in this article.

Rahman and Deshmukh (2013) investigated the proportional distribution of lateral forces evolved through seismic action in each storey level due to changes in stiffness of frame on vertically irregular frame. The research is according to Indian Standard (BIS) 1893:2002 (part1) provisions where vertically irregular building is modelled as a simplified lump mass model for the Analysis with stiffness irregularity at fourth floor. The analysis proves that the effect of stiffness irregularity on the vertically irregular structure is dangerous in seismic zone. Therefore, as far as possible irregularities in a building must be avoided. If irregularities have to be introduced for any reason, they must be designed properly following the codes provided.

Özuygur (2016) had performed seismic analysis for the 50-story tall reinforced concrete residential building, which was planned to be constructed in Istanbul. The seismic design of the building has formed the main part of the structural design process due to high seismicity of the proposed location and the extremely irregular floor plan. The building consists of two individual buildings linked through stronger link slabs at top 13 stories whereas relatively weak slabs at lower stories. The building has been designed for design basis earthquake by elastic response spectrum analysis and its seismic performance has been checked for maximum considered earthquake by nonlinear time history analyses carried out using PERFORM-3D. It is observed that the axial forces of shear walls at the outer boundary of the irregular floor plan obtained from nonlinear time history analyses are larger than that obtained from linear elastic analysis, and they exceed the accepted axial. It is recommended that special attention be paid to axial and shear force design of shear walls and columns of irregular tall buildings.

Bansal (2014) has investigated on response spectrum analysis (RSA) and Time history Analysis (THA) of vertically irregular RC building frames. The design ductility is based from Indian standard IS 13920 corresponding to equivalent static analysis and time history analysis using three types of irregularities which are mass irregularity, stiffness irregularity and vertical geometry irregularity. According to RSA results, the storey shear force was highest are at the first storey and it decreased to a minimum in the top storey in all cases. It was also found that mass irregular building frames experience larger base shear than similar regular building frames. As for the stiffness irregular building, it experienced lesser base shear and has larger inter storey drifts. Meanwhile for mass irregular structure, THA yielded slightly higher displacements for upper stories than that in regular building, as it levelled down, lower stories showed higher displacements as compared to that in regular structures.

An investigation was done by Varadharajan (2014) to find out the effects of various vertical irregularities on the seismic response of a structure. Response spectrum analysis (RSA) and Time history Analysis (THA) were used in analysing vertically irregular RC building frames. Comparison of the results of analysis and design of irregular structures with regular structure was done. The response of structures subjected to high, low and intermediate frequency content of earthquakes were evaluate using time history analysis. Three types of ground motion with varying frequency content, low (imperial), intermediate (IS code), high (San Francisco) frequency were used. Reviewing the results from RSA, the storey shear force was found to be high for the first storey and it has decreased to minimum in the top. The absolute displacements obtained from time history analysis of the irregular building at respective nodes were found to be greater compared to regular building for upper stories but gradually to lower stories, displacements in both structures tended to converge. Tall structures have low natural frequency, so it response towards an earthquake was found out to be highest in a low frequency earthquake.

Aijaj and Deshmukh (2013) studied the different irregularity response due to plan and vertical irregularity and the geometric irregular shaped building. They applied linear static analysis under earthquake forces and deflection in the columns is calculated. Buildings with irregularities are prone to earthquake damage, as observed in many earthquake occurrences. In their study, same building was analysed as regular building, building with soft storey and modified building (with soft storey) according to Indian standard IS 1893 (Part-I), 2002 Comparison of different parameters like bending moments, storey drift and storey displacement is done by using software. A three-dimensional analysis of a building using general purpose analysis computer programs can take care of the displacement and revealed that deflection is also a critical factor leads to major damage or complete collapse of buildings. Therefore, it is necessary that irregular buildings must be carefully analysed for deflection.

Mosleh et. al. (2016) carried out a research on seismic behaviour of RC building structures designed according to current codes. Two sets of six irregular buildings were used consists of frame structures, representative of the common practice in Portugal and it is designed without considering earthquake actions. Push-over and non-linear time history analyses were done, with non-linear 3-D models in longitudinal and transverse directions. The building responses were analysed in two different levels which are global and local. For the global response analyses, maximum displacement, floor rotation for each storey and base shear were compared. For local response, four columns were chosen and the variation of axial load in terms of base shear was connsidered. The seismic vulnerability was analysed under earthquake of different return periods, and the seismic demands were compared with limit proposed in international codes. The main goal of this investigation was to consider the application and methodology for the seismic assessment of existent real buildings. In fact, this is an important topic to understand the seismic vulnerability in existing buildings to assure that the common observation can be applied for a prototype building especially irregular ones. Also, one of the major observations in this study is the comprehension of the effect and importance of biaxial loading in columns and the influence of the axial load variation relating the position of the columns in plan and in height.

Hatzigeorgiou and Liolios (2010) investigated about the inelastic response of eight reinforced concrete (RC) planar frames which are subjected to forty five sequential ground motions. Two families of regular and vertically irregular (with setbacks) frames are examined. The first family has been designed for seismic and vertical loads according to European codes while the second one only for vertical loads, to study structures which have been constructed before the introduction of adequate seismic design code provisions. The whole range of frames is subjected to five real seismic sequences which are recorded by the same station, in the same direction and in a short period of time, up to three days. Furthermore, the examined frames are also subjected to forty artificial seismic sequences. Comprehensive analysis of the created response databank is employed in order to derive important conclusions. It is found that the sequences of ground motions have a significant effect on the response. In conclusion, the ductility demands of the sequential ground motions can be accurately estimated using appropriate combinations of the corresponding demands of single ground motions.

2.7 Summary

Many researches were conducted on seismic performance which is known to be the most common tool used in analysis structures today. Table 2.3 shows the summary to the literature review. However, there is still some drawback research on irregular building especially in 3D. A complex shaped building is getting much popularity nowadays, but it carries a risk of sustaining damages during earthquakes. Hence, such buildings should be designed properly taking care of their dynamic behaviour. Thus, this study was done to study the effect of earthquake on vertically irregular 3D moment resisting concrete frame especially in Malaysia.

Table 2.3: Summary of literature review

Author	Irregularities	2D/3D	Analysis
Özuygur, (2016)	50-storey tall residential building	3D	Elastic response spectrum and nonlinear time history
Aijaj and Deshmukh, (2013)	10-storey of geometric irregular building	3D	Linear static analysis
Rahman and Deshmukh, (2013)	11-storey of stiffness irregular building	3D	Elastic response spectrum
Bansal, (2014)	Vertically irregular RC building frames	3D	Elastic response spectrum and time history
Mosleh et. al., (2016)	6-storey of irregular RC building	3D	Static and time history
Depthi, (2016)	14-storey of geometrically irregular structure	2D	Equivalent static, response spectrum and time history
Hatzigeorgiou and Liolios, (2010)	4 regular and 4 irregular RC planar frames	2D	Response spectrum and time history

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discussed about the method and steps used to evaluate the seismic analysis of irregular three-dimensional reinforced concrete frame. There are three main steps in the methodology of this study. Load calculation, modelling the structure and analysing the model. The methodology starts with load calculation that was done by referring to Eurocode 2 and Eurocode 8 while the modelling of the structure and validation are done by using SAP 2000 according to Eurocode 8. There are three irregular building model with different number of stories which are 3, 6 and 9. STERA 3D was used in analysing the building model due to its user friendly features and it is less time consuming compared to other software, there are two analysis that have been done in this study which are static analysis and dynamic analysis. The static analysis will be focusing on drift-shear relation and capacity curve of the building whereas the dynamic analysis will utilise incremental dynamic analysis (IDA) curve. The results were discussed in chapter 4. Figure 3.1 shows the summary of the flow chart of this study.

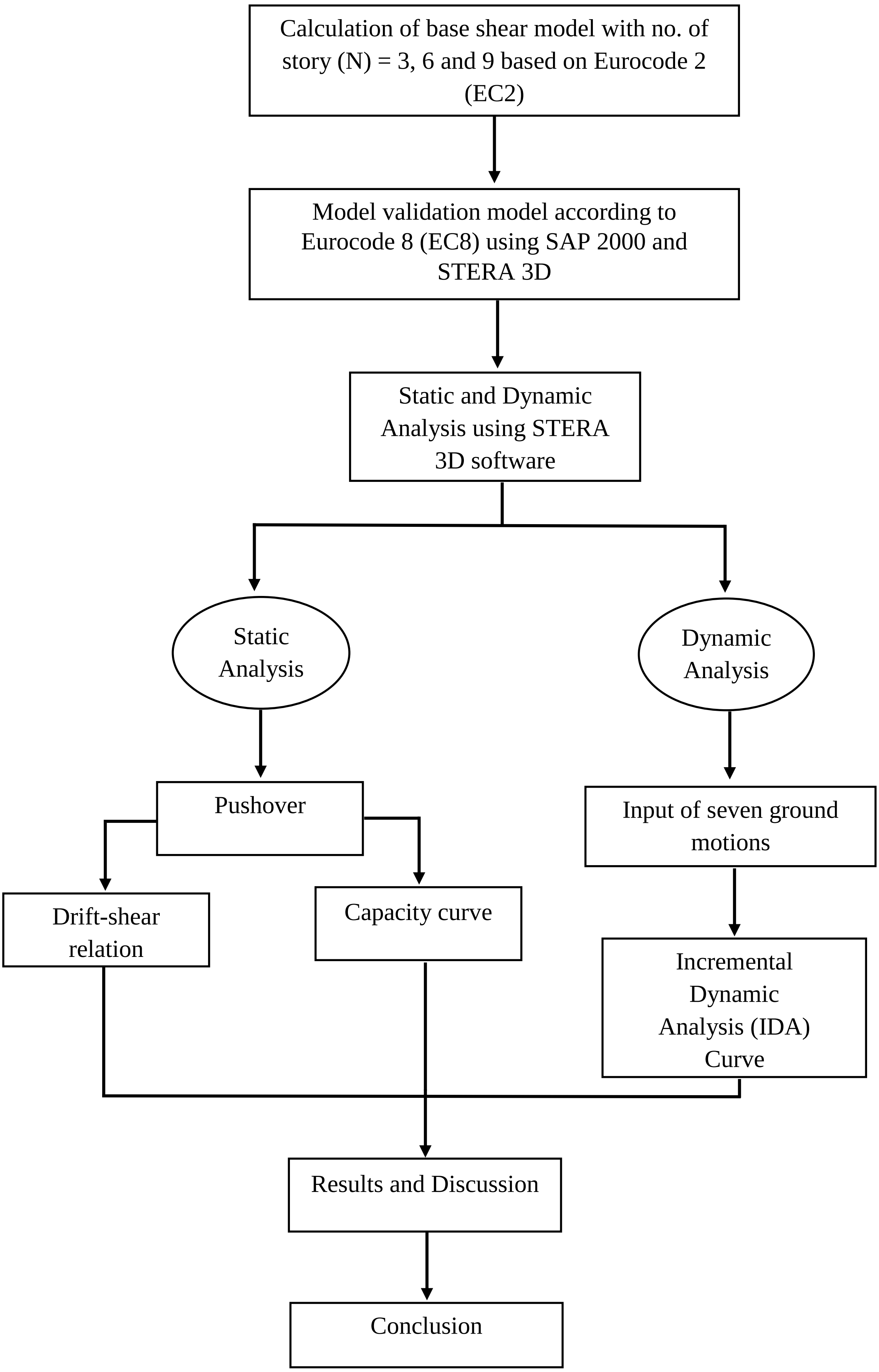

Figure 3.1: Flow Chart of Research Methodology

3.2 Base shear calculation

Base shear is used in estimating the maximum expected lateral force that will occur to the building due to seismic ground motion at the base of a structure. (Asafa, 2013) Calculations of base shear depend on soil conditions at the site which is obtain from Eurocode 8 which stated that there are two type of table to refer which are Type 1 and Type 2. If the earthquakes that contribute most to the seismic hazard defined for the site for probabilistic hazard assessment have a surface-wave magnitude, M not greater than 5.5, it is recommended that the Type 2 spectrum is adopted and the soil type was B. Table 3.1 the values of the parameters describing the recommended Type 1 elastic response spectra are being adopted.

Table 3.1: Parameters describing the recommended Type 1 elastic response spectra

Ground type	S	T_B (s)	T_C (s)	T_D (s)
A	1.0	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	1.15	0.20	0.6	2.0
D	1.35	0.20	0.8	2.0
E	1.4	0.15	0.5	2.0

3.3 Building Model Validation

The validation of the irregular reinforced concrete frame model were validated using SAP 2000 software. SAP2000 represents the most sophisticated and user-friendly release of computer programs. When initially released in 1996, SAP2000 was the first version of SAP to be completely integrated within Microsoft Windows. It features a powerful graphical user interface that is unmatched in terms of ease-of-use and productivity. Creation and modification of the model, execution of the analysis, and checking and optimization of the design, and production of the output are all accomplished using this single interface. A single structural model can be used for a wide variety of diverse types of analysis and design (SAP2000, C.S.I., 2011).

Hatzigeorgiou and Liolios (2010) irregular frame model was generated in SAP 2000 to validate his study so that it can be used as a reference. Figure 3.2 shows an example of the irregular frame model which were generate in SAP 2000.

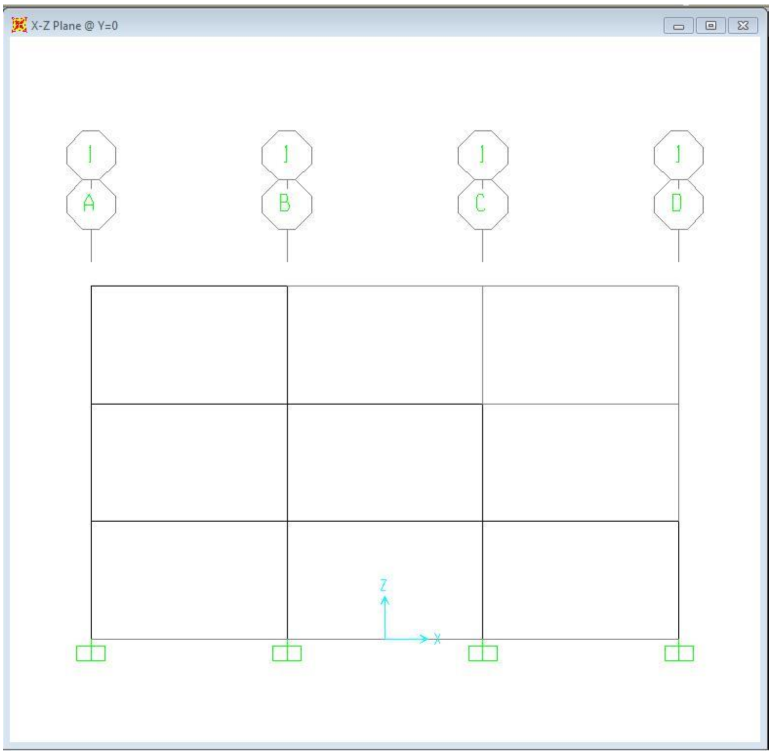

Figure 3.2: Hatzigeorgiou and Liolios, (2010) model