SEISMIC FRAGILITY ASSESSMENT OF MOMENT-RESISTING CONCRETE FRAME WITH SETBACK UNDER REPEATED EARTHQUAKE

LAU JI WEI

SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2017

SEISMIC FRAGILITY ASSESSMENT OF MOMENT-RESISTING CONCRETE FRAME WITH SETBACK UNDER REPEATED EARTHQUAKE

By

LAU JI WEI

This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2016/2017

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: Seismic Fragility Assessment of Moment-Resisting Concrete Frame with Setback under Repeated Earthquake

Name of Student: LAU JI WEI

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

Signature:

Approved by:

____

____

(Signature of Supervisor)

Date:

Name of Supervisor:

Date :

Approved by:

____

(Signature of Examiner)

Name of Examiner:

Date :

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere and deepest gratitude to my FYP supervisor, Dr. Fadzli Mohamed Nazri for his advices, supervisions and encouragement. I am fortunate to have a supervisor who gave me the guidance starting from the beginning until the completion of this dissertation. He always makes himself available and contactable although he was busy with his own works. Besides that, he always inspires me to work harder and never give up no matter what happens. I have learnt a lot of knowledge from him related to the field of earthquake engineering. I also thanked to my supervisor for providing financial support to me from his grant. This really helped to ease my burden as I was able to print out many related journal articles and also my FYP draft without spending my own money.

Next, I would like to have special thanks to Ms. Nik Zainab Nik Azizan for her help throughout this research. She was always willing to share her knowledge with me and patiently answered my doubts and questions whenever I encountered problems during the research. I really appreciated her efforts on this matter very much.

Next, I am grateful to have a good friend and FYP mate, Tai Joon Hong. He was very generous to share any related information with me. When I faced difficulties in the software analysis, he always be there to help me to solve the problems together. He also cheered me up to do the Final Year Project. This indirectly boosts my confident and provide me spiritual support to complete my dissertation.

Last but not least, a token of gratitude to my family for giving me support and cares along the way to complete this dissertation. Without their love and support, this journey would not be easy. Thank you all for your support.

ABSTRAK

Kajian penyelidikan ini dijalankan adalah untuk menganalisis tingkah laku seismik 10 jenis Bingkai Enam Tingkat Kerangka-Konkrit Penahan Momen (MRCFs) iaitu 1 bingkai tetap dan 9 bingkai "setback" dengan konfigurasi bangunan yang berbeza. Bangunan "setback" amat ditekankan dalam analisis ini kerana mereka menjadi semakin popular dalam pembinaan bangunan berbilang tingkat yang moden atas sebab fungsi seni bina dan estetik. Analisis Dinamik Tambahan (IDA) telah dijalankan pada bingkai tersebut bersamaan dengan tiga set rekod pergerakan tanah berulang. Berdasarkan keluk IDA, tahap prestasi keselamatan nyawa (LS) akan dianggap sebagai garis panduan utama untuk membangunkan lengkung kerapuhan. Peratusan drift maksimum antara tingkat pada setiap tingkat untuk semua bingkai dan lokasi plastik engsel bagi setiap bingkai boleh ditentukan dengan jelas melalui IDA. Berdasarkan keluk IDA, min dan sisihan piawai untuk puncak pecutan bumi (PGA) pada drift 1.5% bagi bingkai ditentukan dalam usaha untuk membangunkan lengkung kerapuhan dengan tahap prestasi keselamatan nyawa. Daripada hasil keluk kerapuhan, kebarangkalian mencapai atau melebihi tahap prestasi keselamatan nyawa boleh ditentukan. Rangka tetap menunjukkan kebarangkalian yang paling rendah berbanding dengan bingkai lain. Seperti yang diramalkan, ia mempunyai prestasi seismik yang lebih baik berbanding dengan bingkai lain. Antara bingkai "setback", Model 6T 6 menunjukkan kebarangkalian tertinggi dalam mencapai atau melebihi tahap prestasi keselamatan nyawa manakala Model 6T 3 menunjukan kebarangkalian terrendah di bawah sebarang nilai PGA. Oleh itu, Model 6T 3 mempunyai prestasi seismik yang terbaik manakala Model 6T 6 mempunyai prestasi seismik yang buruk. Maka, dapat diketahui bahawa konfigurasi bangunan bingkai mengawal prestasi seismik bangunan dan dengan itu ia perlu diambil kira dalam reka bentuk bangunan seismik.

ABSTRACT

This research study is carried out to analyse the seismic behaviour of 10 types six-storey Moment-Resisting Concrete Frames (MRCFs), namely 1 regular frame and 9 setback frames with different building configurations. The setback buildings were mainly emphasised in this analysis because they are becoming increasingly popular in modern multi-storey building construction due to its functional and aesthetic architecture. Incremental Dynamics Analysis(IDA) have been performed on these frames under three sets of repeated ground motion records. Based on the IDA curve, the Life Safety (LS) performance level will be considered as main guideline in order to develop the fragility curve. The maximum inter-story drift percentages at each story level for all the frames and the location of the plastic hinges for each frames can also be determined clearly through IDA. Based on the IDA curve plotted, the mean and standard deviation of the Peak Ground Acceleration (PGA) at drift 1.5% for the frames were determined in order to develop the fragility curve with the life safety performance level. From the results of the fragility curves, the probability of reaching or exceeding the life safety performance state can be determined. The regular frame showed the lowest probability compared to the other frames. As predicted, it has the better seismic performance as compared to the other frames. Among the setback frames, the Model 6T 6 recorded the highest probability of reaching or exceeding the life safety performance level while Model 6T 3 recorded the lowest probability of reaching or exceeding the life safety performance level under any PGA values. Thus, the Model 6T 3 has the best seismic performance while the Model 6T 6 has the poor seismic performance. Thus, it can be known that the building configuration of the frames governs the seismic performance of the building and thus it should be taken into consideration in the building seismic design.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

DM	**D**amage **M**easure
EC2	**E**uro**c**ode **2**
EC8	**E**uro**c**ode **8**
EDP	**E**ngineering **D**emand **P**arameter
EN	**E**uropean **S**tandard
FEMA	**F**ederal **E**mergency **M**anagement **A**gency
IDA	**I**ncremental **D**ynamics **A**nalysis
MDOF	**M**ultiple **D**egree of **F**reedom
MRCF	**M**oment-**R**esisting **C**oncrete **F**rame
PBSD	**P**erformance **B**ased **S**eismic **D**esign
PEER	**P**acific **E**arthquake **E**ngineering **R**esearch **C**enter
PGA	**P**eak **G**round **A**cceleration
SDOF	**S**ingle **D**egree of **F**reedom

NOMENCLATURES

a_g	Design Ground Acceleration
a_{gR}	Peak Ground Acceleration on ground
A_s	Area of reinforcement required
F_b	Base shear
$(F_b)_{ult}$	Ultimate base shear
F_i	Horizontal force acting on level 1
G_k	Permanent action
H	Framework height
L_c	Length of column or storey height
L_{c1}	Height of the first storey
L_{c2}	Height of the second storey
M_{GQ}	Bending moment
M_T	Total moment capacity
Q_k	Temporary action
$S_d(T_1)$	Design spectrum at T_1
$S_e(T)$	Elastic response spectrum
T_1	Fundamental Period of vibration

CHAPTER 1

INTRODUCTION

1.1 Background

The major earthquakes are rare in Malaysia as Malaysia lies outside the Ring of Fire that is seeing a lot of seismic activity. Malaysia is situated on the Southern edge of the Eurasian Plate. However, it is near to the most seismically active plate boundaries, the inter-plate boundary between the Indo-Australian and Eurasian Plates on the west and the inter-plate boundary between the Eurasian and Philippines Sea Plates on the east. Therefore, tremors originating from the major earthquakes of these plate boundaries have been felt in Malaysia. Since most buildings in Malaysia are not constructed based on earthquake-resistant design code, therefore they may encounter structural damage easily during earthquake.

In the multi-storeyed framed buildings, the structural weaknesses present in the lateral load resisting frames tend to accentuate the structural damage which will eventually lead to the complete collapse of the structure. Normally, these weaknesses are caused by the vertical geometrical irregularities. The common type of vertical geometrical irregularities in building structures is the presence of setback, which is the sudden reduction of the lateral dimension of the buildings at specific level of the elevation. This kind of irregularity causes an abrupt discontinuity in stiffness, strength and mass of building frame. Dynamics characteristics of such building differ from the regular building due to changes in geometrical and structural property.

The following figures show some setback buildings found in Malaysia.

a) Hilton Hotel, Kuala Lumpur 	b) Precinct 11 School Complex, Putrajaya, Malaysia 
c) Wisma Sanyan, Sibu, Sarawak 	d) Grand Dorsett Labuan Hotel 

Figure 1.1: Examples of setback building found in Malaysia

There are many analytical methods that can be conducted to evaluate the behaviour and performance of moment-resisting concrete frame with setback during earthquake. The analytical methods involve linear static, linear dynamic, nonlinear static and nonlinear dynamic analysis. Among these four methods, nonlinear dynamics analysis will be chosen for this research as it is the most accurate way of simulating response of structures subjected to strong levels of seismic excitation. Nonlinear dynamics analysis which involves Incremental Dynamics Analysis (IDA) can perform a series of nonlinear dynamic analyses of a structural model under repeated ground motion records with each scaled to several levels of seismic intensity.

Performance-Based Seismic Design (PBSD) is important in earthquake-resistant design and therefore it is performed for this research. It is expressed as a maximum desired extent of damage to a structure under specific earthquake performance level. It will provide clear and quantitative measure for structural damage caused by earthquake. It also can help to predict the seismic performance accurately and therefore allow engineers to determine the performance level of the building. The maximum desired level of damage to a structure under specific earthquake design level is expressed as performance level. Based on Vision 2000 (1995), the performance level can be divided into four performance stages, mainly fully operational, operational, life safety and near collapse. It proposed the permissible drifts of 0.2% for fully operational, 0.5% for operational, 1.5% for life safety, and 2.5% for near collapse.

Based on the results from IDA and PBSD, the fragility curve for the structure can be produced. The fragility curve is the lognormal functions that express the probability of damage to building. It is a useful tool for the evaluation of structural damage probability caused by earthquake as a function of ground motion indices otherwise design parameters. According to Bakhshi and Asadi (2013), the fragility curve is developed to evaluate the probability parameters such as, Peak ground Acceleration (PGA), important factor and typical over-strength and global ductility capacity. In this research, the relationship between the probability of failure and peak ground acceleration (PGA) can be represented by the fragility curve.

1.2 Problem Statement

The time has come for Malaysian people to be prepared for such calamities as the occurrence of earthquakes is not uncommon in Malaysia. Earthquakes are inevitable, but being prepared can reduce injuries, deaths and loss of property. Hence, the seismic performance of building should be emphasized and taken as consideration for the design of buildings in Malaysia.

In general, most of the buildings in Malaysia are designed according to BS 8110, which do not take into account for their seismic performance. Due to the recent frequent seismic activities in Malaysia, it is vital for us to consider the seismic performance of existing building in Malaysia. Eurocode 8 (BS EN 1998:2004) should be considered as a design guideline to design buildings with good seismic vulnerability as it provides the general provisions and requirements for earthquake-resistant design. Besides, most of the constructions in Malaysia involve the use of reinforced concrete. Therefore, Eurocode 2 which specifies the details related to the design of concrete structure should be used as design guideline.

Nowadays, setback buildings become popular in modern multi-storey building construction. Therefore, the seismic performance of this kind of building should be evaluated properly as the vertical discontinuities of the structure had caused many examples of building failure in the past earthquake. During the past earthquake, irregular configurations either in plan or elevation were often recognized as the main cause of failure. Therefore, in this research, the moment-resisting concrete frames with setbacks were investigated to determine the seismic performance of each building frames with different configuration.

1.3 Objectives

The objectives of proposed study are:

i. To investigate the seismic performance of Moment-Resisting Concrete Frames with setbacks under repeated earthquakes.
ii. To develop the fragility curve of Moment-Resisting Concrete Frame with life safety performance level.

1.4 Scope of work

i. Design one type of 6-storey regular building frame and nine type of buildings with setbacks.
ii. Choose the suitable ground motion records from Pacific Earthquake Engineering Research Center (PEER) website.
iii. Perform the Incremental Dynamic Analysis (IDA) by using ETABS 2016 Software.
iv. Analyse the seismic performance for each types of buildings and develop the fragility curve for life safety performance.

1.5 Dissertation Outline

Chapter 1 gives a brief introduction about the background of this research. It emphasises on the effect of the earthquake to the seismic performance of the building structure in Malaysia. This chapter also highlights the importance of this research in determining the building configuration with the best seismic resistant. The objectives of this research are well-defined.

Chapter 2 discuss about the previous research study which is related to this topic. The past researches were reviewed to get more understanding on the structural response of the building in order to develop the fragility curve. It also includes the analysis related to the ground motions records, Incremental Dynamics Analysis (IDA), and Performance-Based Seismic Design (PBSD).

Chapter 3 explains the methodology in the study with the aid of flowchart and description stating the steps and flow of the study. It describes the code of practice used to design the moment-resisting concrete frame. Non-linear Dynamics Analysis is carried out to assess the seismic performance. The structural modelling is done by using ETABS 2016 software.

Chapter 4 shows the results of the analysis after the non-linear dynamics analysis is carried out. A comparison is made between the seismic performance of regular frame and frames with setback by using the fragility curve. The outcome of the research is discussed in this chapter.

Chapter 5 concludes the study of this research. It also highlights the recommendations for the future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter discusses the number of studies that had been performed to evaluate the seismic performance of Moment-Resisting Concrete Frame with setback. In this research, the effects of dynamics loads acting on the structure during earthquake are considered and therefore the seismic performance of structures are analysed by using non-linear dynamics analysis which involves Incremental Dynamics Analysis (IDA). Recent researches done by the experts will be reviewed in order to develop the fragility curve. Besides that, this chapter also provides a review on the issues of the selection of repeated ground motion records and the Performance-Based Seismic Design (PBSD).

2.2 Setback building

Setback buildings are vertically irregular buildings where there are discontinuities with respect to geometry. The design code considers the ratio of lateral dimension of two adjacent stores as criteria to define vertical geometric irregularity. Based on design code (UBC,1997), setback building is defined as building where the horizontal dimension of the seismic force resisting system in any story is more than 130% of its adjacent story, as shown in Figure 2.1.

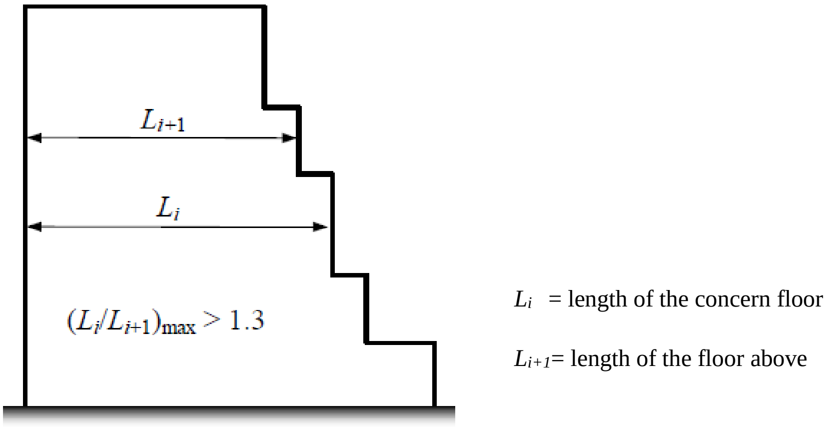

Figure 2.1.: Vertical geometric irregularity according UBC,1997.

Based on Aranda (1984) study, the ductility demands between setback and regular structures had been compared by using ground motions recorded on soft soil. He found that the ductility demands for setback structures is higher than the regular one and this increase more pronounced in the tower portion. Pinto and Costa (1995) investigated the structures with setbacks and they concluded that the seismic behaviour of regular and irregular structures are similar. In their study, the amount of setback as well as the proportion of base height to the structural height was small. Mazzolani and Piluso (1996) studied the behaviour factor of setback and counterpart regular frames and noticed that setbacks do not abruptly worsen the seismic responses. For example, they do not cause a considerable decrease of the behaviour factor.

Chintanapakdee and Chapra (2004) studied the seismic demands for regular frames and vertically irregular frames by non-linear response history analysis. 48 irregular frames of 12 story height were designed and tested as per strong column weak beam philosophy. In their study, three types of irregularities, namely Stiffness irregularity (KM), strength irregularity (SM), and combined stiffness- and-strength irregularity (KS) were considered. The effect of vertical irregularity on storey drift and floor displacement were also studied. They concluded that all the three types of irregularities KM, SM and KS affect the height-wise variation of story drifts, with the effects of strength irregularity being larger than stiffness irregularity, and the effects of combined stiffness-and-strength irregularity being the largest among the three.

Athanassiadou (2008) assessed the seismic performance of two irregular RC frames with setbacks designed according to EC 8. He concluded that the seismic performance of all irregular frames appears to be equally satisfactory, not inferior to that of the regular ones. Rana and Raheem (2015) had performed a comparative study between regular frame and vertical irregular frame with setback on the basis of shear force, bending moment, and storey drift and node displacement. From his finding, when the amount of setback increases, the critical shear force also increases.

Sahu (2016) adopted push over analysis, a non-linear static analysis to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake. In his study, he concluded that the displacement demand is highly rely on the geometrical configuration of frame and concentrated in the neighbourhood of the setbacks for setback structures. The higher modes significantly contribute to the response quantities of setback structure.

Bohlouli and Poursha (2016) carried out the seismic evaluation of geometrically irregular steel moment resisting frames with setbacks considering their dynamics analysis. They showed that in the case of geometrically irregular frames with setbacks, the effective modal participating mass ratio for the higher modes increases compared to the regular frames. This implies that the effect of higher modes in setback frames is more considerable.

2.3 Selection of ground motions

Ground motion records are vital in carrying out Incremental Dynamics Analysis (IDA). Based on Singhal and Kiremidjian (1996) study, the average spectral acceleration values over a specified period ranges were used as intensity measures. They had adopted the nonlinear dynamic analysis to represent the actual effects of ground motion characteristics. Shakib and Ghasemi (2007) assessed the general trends in the seismic response of plan asymmetric structures when subjected to near-fault and far-fault ground motions. They considered different criteria for reducing torsional response of asymmetric structures under near-fault and far-fault bi-directional excitation, employing Idealized single-storey models with uni-axial eccentricity.

The codes from UBC (1997), IBC (2000), and FEMA-356(2000) have recommended that selecting at least three or maximum seven ground motion records in a way that the mean spectral acceleration covers the design spectrum. Based on Ibrahim and El-Shami (2011), it is more reasonable to choose ground motions from real records as it considers ground motion characteristics like amplitude, frequency, strong motion duration, energy content and number of cycle.

Normally, most guidelines need earthquake ground motion amplitudes to be scaled in order to match the target spectrum over a certain period range. According to CEN (2004), ASCE (2000), and ATC (2012), the chosen ground motion records should have magnitudes, fault distances and source mechanisms that are representative of the earthquake scenarios that control the target spectrum.

2.4 Incremental Dynamics Analysis

Incremental Dynamics Analysis (IDA) is a computational analysis used to assess the structural response under seismic loads. Many researchers had used IDA to evaluate the structural performance. For instance, Lee and Foutch (2002) used IDA to evaluate the collapse capacity of multiple steel moment- resisting frames. From the calculated drift demands and assumed local and global capacities, they concluded that all the buildings considered in their study fulfill the collapse prevention performance objective.

Based on Vamvatsikos and Cornell (2002), IDA involves performing a series of non-linear dynamics analyses of a structural model under multiple ground motion records. It scales each record to several level of intensity. Mackie and Stojadinovic (2003) used IDA to determine the probability of exceeding specified structural demand levels. The IDA method is sensitive to the selection of ground motion and therefore it is recommended that the number of analysis not be decreased and representative sets of motions must be chosen carefully from the regional seismic hazard database of interest.

The development in computer power has caused large parametric IDA assessments to become conveniently even for complex multi-degree-of-freedom (MDOF) structures. Ibarra (2003) used IDA to evaluate simple moment-resisting frames with parametric beam-hinges while Haselton (2006) employed it to ascertain the collapse capacity of 30 ductile reinforced-concrete moment frames with heights ranging from one to twenty stories. Goulet et. al. (2007) also employed IDA to estimate the seismic losses for a reinforced concrete frame structure.

Many researchers also used IDA to run tens or hundreds of IDA analyses of complex MDOF structures. For instance, Liel et al. (2009), Dolsek (2009), and Vamvatsikos and Fragiadakis (2010) have employed anywhere from 10 to 200 multi-record IDAs each, using, for example, classic Monte Carlo with a response surface approximation, Monte Carlo with latin hypercube sampling or even approximate moment-estimating techniques.

2.5 Performance Based Seismic Design

According to Ghobarah (2001), the performance-based seismic design is a general philosophy in design which the standards design is achieving the feature design stated performance objectives when the structure is under seismic hazard. Performance-based seismic design is vital in providing clear and quantitative measure for structural damage caused by earthquake. It can help to predict the seismic performance accurately and therefore allow engineers to determine the performance level of the building. According to Ibrahim and El-Shami (2011), the maximum desired level of damage to a structure under specific earthquake design level is expressed as performance level. Based on FEMA-273 (1997) and Vision 2000 (1995), the performance level is classified into four categories, namely fully operational, operational, life safety and near collapse.

Fully operational means that the system is still functional with no damage to the structural and non-structural. Operational means the post-earthquake damage state in which only very limited structural damage has occurred. Life safety means the post-earthquake damage state in which significant damage to the structure has occurred, but some margin against either partial or total structural collapse remains. Near collapse means the building is on the verge of experiencing partial or total collapse. Based on Vision 2000 (1995), the permissible drifts of 0.2% for fully operational, 0.5% for operational, 1.5% for life safety, and 2.5% for near collapse.

2.6 Fragility Curve

Fragility curve indicates the probability of exceeding a specific damage state as a function of an engineering demand parameter that represents the ground motion. Figure 2.2. shows a typical fragility curve with Peak Ground Acceleration (PGA) along the x-axis and probability of failure along y-axis. A point in the curve represents the probability of exceedance of the damage parameter, which can be lateral drift, storey drift, base shear etc., over the limiting value mentioned, at a given ground motion intensity parameter.

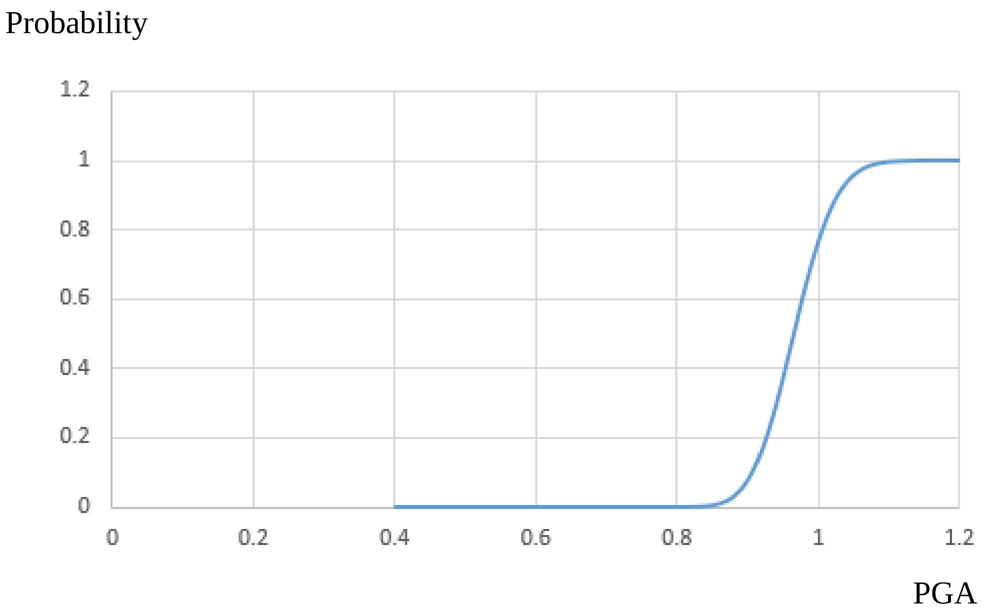

Figure 2.2: Typical type of Fragility Curve

There are many equations that can be used to develop the fragility curve. Table 2.1 shows some of the equations used by the previous researchers to develop the fragility curve.

Table 2.1 : Equations used to develop the fragility curve based on structure type

Authors	Equation	Parameters		Structure Type
		Symbol	Description	
Rosowsky and Ellingwood (2002)	$FR(x) = \Phi\left[In \frac{\left(\frac{x}{m_R}\right)}{\xi_R} \right]$	Φ []	Standardize normal distribution	Light Wood Frame
		m_R	Median capacity	
		x	Demand	
		ξ_R	Logarithmic standard deviation	
Kircil and Polat (2006)	$P(\leq D) = \mathbf{\Phi}\left[\frac{InX - \lambda}{\xi} \right]$	Φ []	Standardize normal distribution	RC Residential Building
		X	Lognormal distributed ground motion index (e.g PGA)	
		λ	Mean	
		ξ	Standard Deviation	
Ibrahim and El-Shami (2011)	$P[D/PGA] = \mathbf{\Phi}\left(\frac{In(PGA) - \mu}{\sigma} \right)$	Φ []	Standardize normal cumulative distribution	MRCF
		μ	Mean of natural logarithm	
		σ	Standard deviation of natural logarithm	

Based on the Ibrahim and El-Shami (2011), they used mean and standard deviation of PGA as main parameter. Equation 2.1 was used by them to develop the fragility curve for the Moment-Resisting Concrete Frames.

$$P\,[D/PGA] = \Phi\,[(\ln(PGA) - \mu)/\,\sigma] \qquad \text{Equation 2.1}$$

where

D = damage;

PGA = Peak Ground Acceleration

Φ= standard normal cumulative distribution;

μ =mean;

σ = standard deviation of the natural logarithm of PGA.

According to Bakhshi and Asadi (2013), fragility curve is developed to determine various probability parameters such as PGA, importance factor (I) and global ductility capacity (R). These illustrations were used to show when a coefficient or a number of parameters were used to improve the performance capacity of a structure. Based on the results, when R increases, the probability of damage exceedance is decreased. However, an increase in I for hospital buildings versus office buildings, cannot pledge a decrease in the chances of damage exceedance. The PGA randomness outcomes revealed that, considering PGA uncertainty does not mean that the probability of damage exceedance will be increased in general cases.

Aiswarya and Mohan (2014) carried out study on the flat slab system subjected to different ground motions and developed the fragility curve based on the predefined damage state. Fragility curves were developed by considering the damage states from

FEMA 356(2000). Based on their study, they concluded that flat slab systems are more vulnerable to seismic hazard because of their insufficient lateral resistance and undesired performance at high levels of seismic demand.

Vazurkar and Chaudhari (2016) investigated the vulnerability assessment of reinforced concrete buildings by using fragility curves. Fragility curve describes the probability of damage being exceeded a particular damage state. In this study, pushover analysis was conducted and the capacity curve was plotted. Results obtained from pushover analysis are used for plotting the fragility curves. They used the plotted fragility curves to study the seismic performance of building models.

2.7 Repeated Earthquake

Repeated earthquake is the repetition of medium-strong earthquakes at short time interval. Recently, the repeated earthquake was reported in many part of the world**.** The repeated earthquakes should be considered as the actual earthquake event occurs repetitively and the effect of the repeated earthquake is qualitatively acknowledged.

The effects of repeated earthquake ground motions on the response of single-degree-of-freedom (SDOF) systems with different hysteretic models were analyzed by Amadio et al. (2003). Hatzigeorgiou and Beskos (2009) found that the repeated earthquakes phenomenon has a significant effect on the inelastic displacement ratio and hence on the maximum inelastic displacement of SDOF systems

Hatzigeorgiou and.Liolios (2010) carried out extensive parametric study on the non-response of eight reinforced concrete (RC) planar frames which are subjected to forty five sequential ground motions. In this study, two families of regular and vertically irregular with setbacks frames are examined. They concluded that the seismic damage for multiple earthquakes is higher than that for single ground motions and also the ductility demands of structures appear to be increased under sequential ground motions.

The first strong ground motion database that used in their studies consists of five real seismic sequences, which have been recorded during a short period of time, by the same station, in the same direction, and almost at the same fault distance. These seismic sequences are namely: Mammoth Lakes (May 1980–2 events), Chalfant Valley (July 1986–2 events), Coalinga (July 1983–2 events), Imperial Valley (October 1979–2 events) and Whittier Narrows (October 1987–2 events) earthquakes. The complete list of these earthquakes were downloaded from the strong motion database of the Pacific Earthquake Engineering Research (PEER) Center. A time gap, which is equal to 100 s is applied between two consecutive seismic events. This gap has zero acceleration ordinates and is absolutely enough to stop the moving of any structure due to damping.

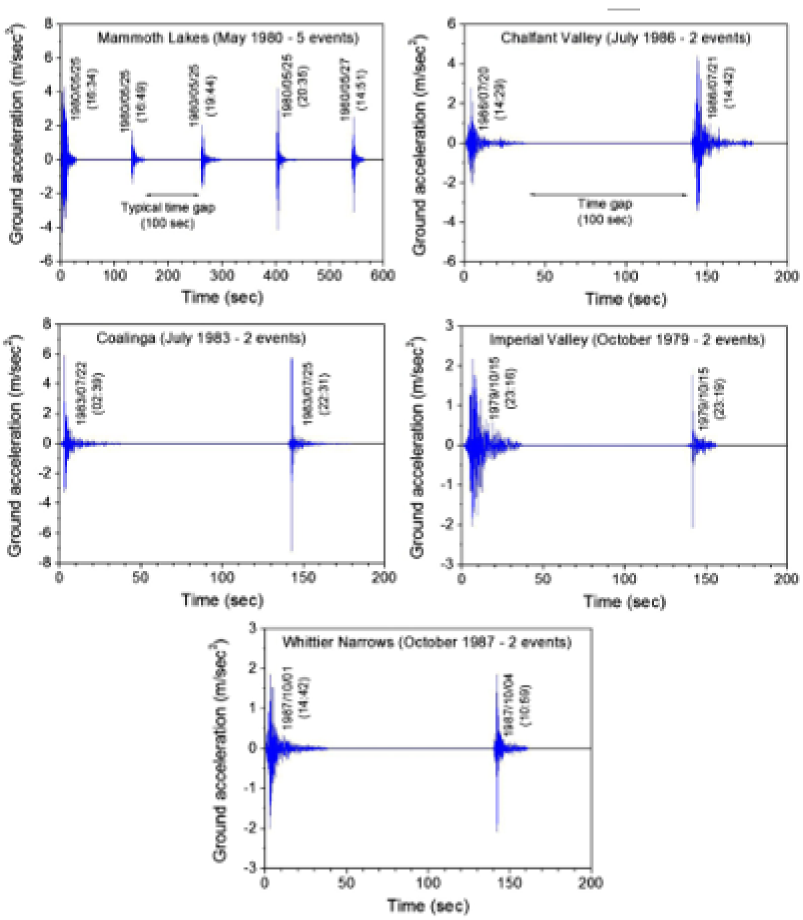

Figure 2.3: Ground acceleration records of the examined seismic sequences

2.8 Summary

In this study, the seismic performance of MRCF is analysed by using nonlinear dynamics analysis which involves Incremental Dynamics Analysis (IDA). 3 set of repeated ground motion records will be selected as an input for IDA. The ETABS 2016 software will be used to investigate to perform IDA. From the IDA curve, the life safety performance level will be used to develop the fragility curve since it is vital to determine the damage state where significant damage to the structure has occurred. Lastly, a comparison will be made based on these frames to acquire a comprehensive finding for better seismic design.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter describes the methodology used for this research with the aid of flow chart and description stating the steps and flow of the study. In this analysis, one 6-storey regular frame and nine 6-storey geometrically irregular frames with setbacks are designed based on Eurocodes 2 (BS EN 1992: 2004) and Eurocodes 8 (BS EN 1998:2004). EC 2 provides the design code for reinforced concrete frame while the EC 8 provides the general requirements for earthquake-resistance design. The seismic behavior of the frame structures are assessed through Incremental Dynamics Analysis (IDA). IDA curve generated will be used to develop the fragility curve with the life safety performance level. The structural modelling will be done by using ETABS 2016 software. The general flow chart will be showed in Figure 3.1.

3.2 Research Flow Chart

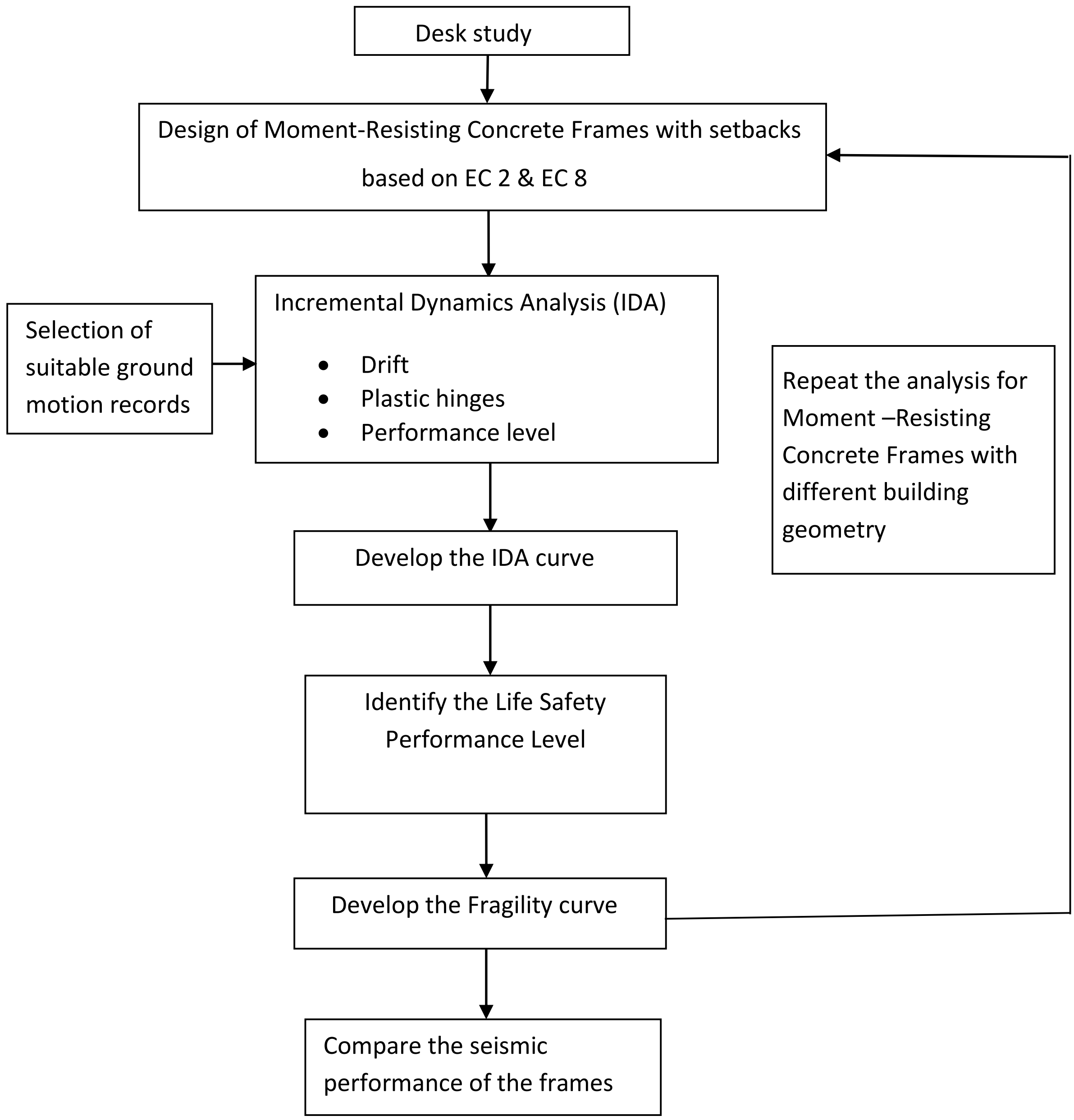

Figure 3.1: Flow Chart of Methodology

3.3 Moment-Resisting Concrete Frame (MRCF) Design

3.3.1 Building Geometry

In this research, 1 regular Moment-Resisting Concrete Frame (MRCF) and 9 MRCF with different setbacks as shown in Figure 3.2 and Figure 3.3 are designed based on Eurocode 2 and Eurocode 8. These building geometries represent varying degree of irregularity or amount of setback. The frame structures have identical storey height of 3 m. Each of the frames will have three bays with 6m per each bay. The regular frame is named as 6T0, while setback frames are named as 6T1, 6T2, 6T3, 6T4, 6T5, 6T6, 6T7, 6T8, and 6T9. The concrete is assumed to have the characteristics strength of 30 Mpa and the steel has the characteristics yield strength of 500 Mpa.

10 types of MRCF with different building geometry were designed based on EC 2 and EC 8. The design assumptions are as follow:

Bar diameter	:25mm
Link diameter	: 8mm
Cover to reinforcement	:25mm
Concrete strength	:30N/mm^2
Steel yield strength	:500N/mm^2
Beam width	:300mm
Beam depth	:700mm
Column size	:500mm×500mm

The dimension and the reinforcement of the beam and column for Moment-Resisting Concrete Frames are shown in Table 3.1 and Table 3.2 respectively.

Table 3.1: Beam dimension and its reinforcement

No of storey	Beam Size (mm)	Reinforcement(mm)	Shear link
6	300×700	5T 25	8mm link at 150mm c/c

Table 3.2: Column dimension and its reinforcement

No of storey	Column Size (mm)	Reinforcement(mm)
6	500×500	8T 25

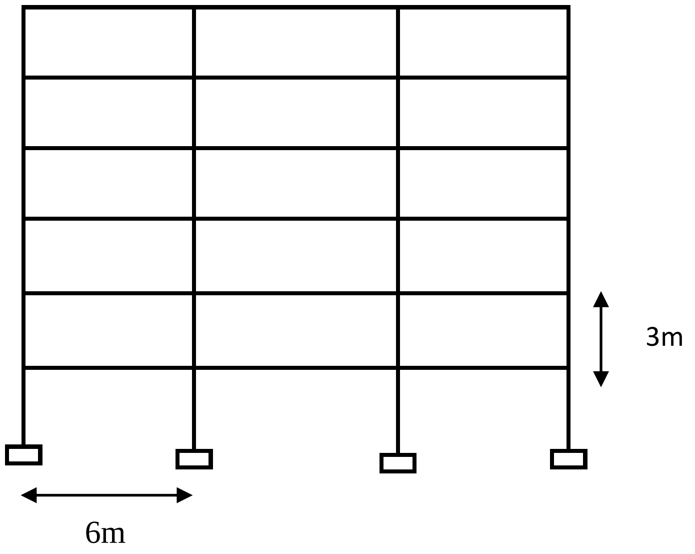

Figure 3.2:The building configuration of 6-storey regular frame, 6T 0

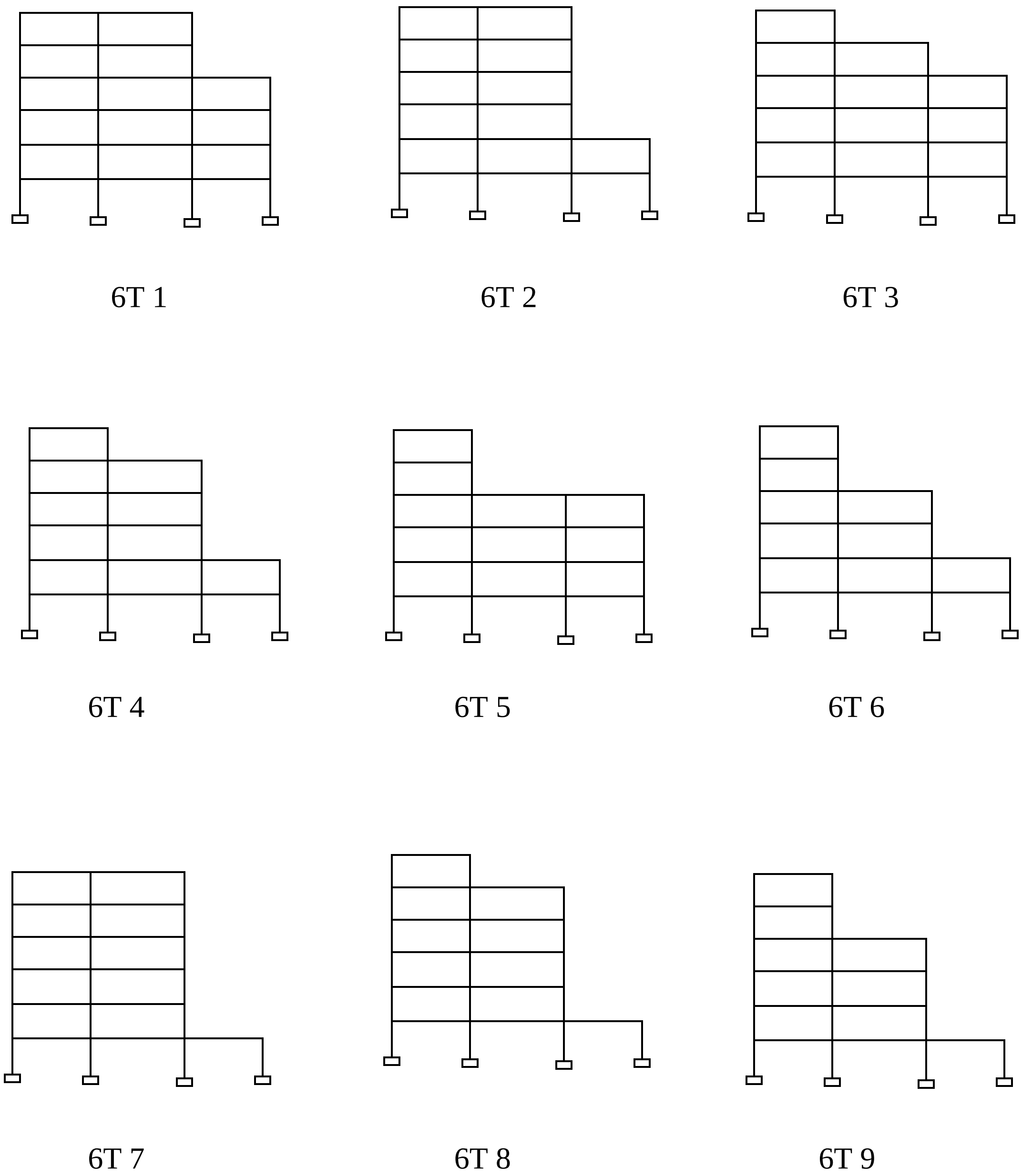

Figure 3.3: The building configuration of 9 MRCFs with setbacks