EFFECT OF GROUND MOTION ON SEISMIC DESIGN OF LOW TO MEDIUM RISE INFILLED MOMENT RESISTING CONCRETE FRAME

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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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Date :

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ABSTRAK

Struktur bangunan berdinding digunakan secara meluas di seluruh dunia termasuk kawasan seismik yang tinggi. Dinding biasanya dianggap sebagai unsur bukan struktur dan tidak termasuk dalam prosedur analisis dan reka bentuk. Objektif utama kajian ini adalah untuk menilai prestasi 2 dimensi Kerangka Konkrit Merintang Momen (MRCF) dengan dan tanpa dinding di bawah peruntukan seismik. Analisis statik dan dinamik tidak linear telah digunakan dalam kajian ini untuk menilai prestasi bangunan rendah ke sederhana bagi bangunan konkrit bertetulang. Tiga tingkat yang berlainan, N: 3, 6, dan 9 dengan konfigurasi dinding yang berbeza telah digunakan sebagai struktur model. Perisian SAP200 digunakan untuk menganalisis semua struktur model. Daripada analisis yang dijalankan, analisa pushover menunjukkan bahawa banguan sembilan tingkat mempunyai kekuatan ricih pangkal tertinggi berbanding tiga dan enam tingkat untuk kedua-dua struktur bingkai berdinding dan tiada dinding. Analisa sejarah masa telah dijalankan dengan menggunakan lima data gerakan tanah tunggal untuk mewakili gerakan tanah seismik sebenar. Lengkungan jarak daripada analisa tersebut menunjukkan bahawa kehadiran dinding dapat mengurangkan lengkungan jarak struktur bangunan. Nisbah pesongan antara tingkat (IDR) menunjukkan bahawa perubahan bentuk biasanya berlaku di tingkat yang lebih rendah kerana ia mempunyai peratusan IDR yang lebih tinggi.

ABSTRACT

Infilled structural frames are widely used across the world including high seismicity regions. The infills are usually considered as non-structural elements and not included in the analytical and design procedure. The main objective for this study is to evaluate the performance 2D moment resisting concrete frame (MRCF) with and without infill walls under seismic provision. Non-linear static and dynamic analysis had been used in this study to evaluate the performance of low-rise to medium rise reinforced concrete building. Three different number of storey, N: 3, 6, and 9 with different infill configuration were used as the structural models. SAP200 software was used to analyse all the structural models. From the analysis conducted, pushover analysis shown that nine storey infilled frame has highest base shear force compared to three and six storey for both infilled and bare frame. Non-linear dynamic analysis has been conducted by employing five single ground motion data to represent a real seismic ground motion. Displacement curve from the analysis shown that the presence of infills reduce the displacement of structural frame. Inter-storey drift ratio (IDR) shown that deformation usually occurs at lower storey as it has higher percentage of IDR.

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LIST OF ABBREVIATIONS

ATC	**A**pplied **T**echnology **C**ouncil
CP	**C**ollapse **P**revention
EC2	**E**uro**c**ode **2**
EC8	**E**uro**c**ode **8**
FEMA	**F**ederal **E**mergency **M**anagement **A**gency
HSR	**H**igh **S**eismicity **R**egion
IO	**I**mmediate **O**ccupancy
LS	**L**ife **S**afety
LSR	**L**ow **S**eismicity **R**egion
MSR	**M**edium **S**eismicity **R**egion

NOMENCLATURES

a_{gR}	References peak ground acceleration
$\mathrm{F_b}$	Base shear
$\mathrm{(F_b)_{ult}}$	Ultimate base shear
fyk	Strength of steel
fcu	Strength of concrete compression
F_b	Base shear force
Gk	Dead load
N	Number of storey
Qk	Live load
q	Behaviour factor
S	Soil factor
S_d	Design spectrum
T_1	Fundamental period of vibration of a building
λ	Correction factor

CHAPTER 1

INTRODUCTION

1.1 Background

Moment resisting frame systems are commonly used for both structural steel and reinforced concrete construction. The strength and stiffness needed to resist gravity and lateral forces are provided by the horizontal beams and vertical columns. The rigid connection between the beams and columns produce sufficient strength and stiffness to prevent these elements from rotating relative to one another. Titiksh and Gupta (2015) mentioned that moment resisting concrete frame is widely used in construction industry due to its energy dissipation capacities and superior deformation as shown in Figure 1.1.

The concept of strong column-weak beam mechanism is used in structural frames design. In multi-storey reinforced concrete buildings it is important to dissipate earthquake induced energy by yielding of the beams rather than the columns. The strength and stability of the column indicates the stiffness of the structure. Furthermore, axial compression reduces the ductility of reinforced concrete columns, therefore more stringent confinement reinforcement are required. The inelasticity is control by the column while dissipating most of the energy through yielding of the beams (Murat, 2009).

There are two types of moment resisting concrete frame which are the Ordinary Moment Resisting Frame (OMRF) and Special Moment Resisting Frame (SMRF). The OMRF is usually used in lower seismic zone and follow the standard design practices for all structural members (Richard, 2009). Meanwhile the SMRF is commonly used in certain constructions which require special detailing for ductile behaviour (Titiksh and Gupta, 2015).

Infilled walls reinforced concrete frame structures are commonly used in many countries. Masonry infill walls are mainly made of clay units, aggregate concrete units, and autoclaved aerated concrete units. It offers several benefits such as easy to build, economical, and aesthetic value for architecture. The infill walls are widely used in residential or office buildings which large number of infilled is occupied either as interior partition or exterior walls as shown in Figure 1.2. Nevertheless, masonry infill walls are considered as non-structural elements as they are often neglected in the design procedure and analytical modelling (Noh et al., 2017). Therefore, current study is conducted to study the behaviour of infill wall under earthquake.

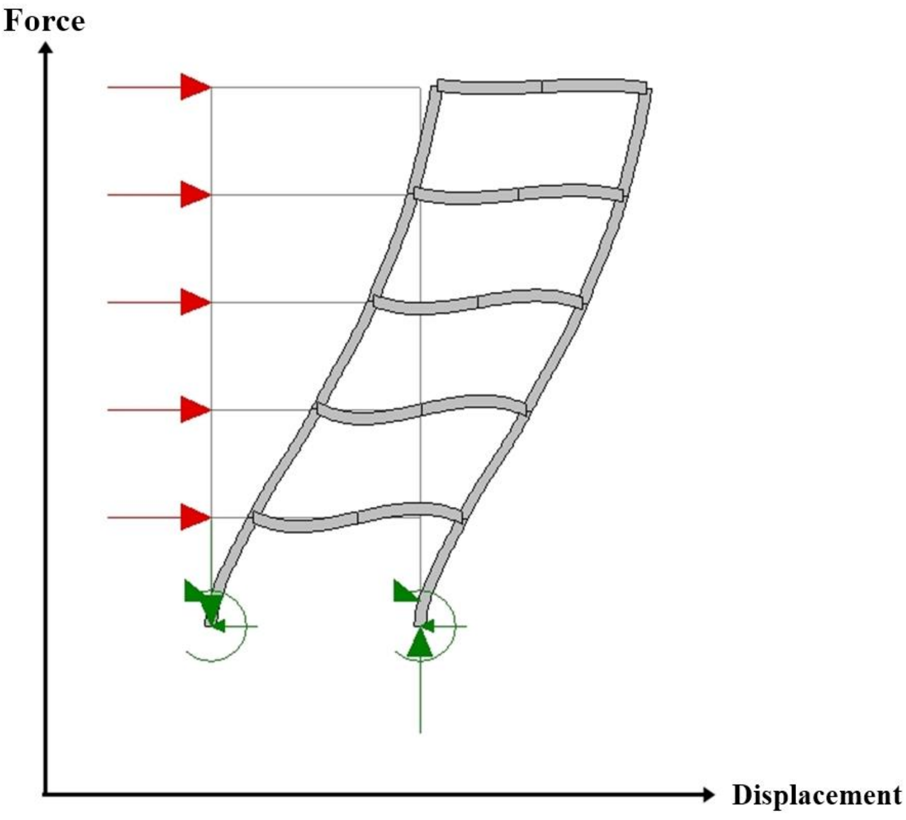


Figure 1.1: Deformation of moment resisting frames (Titiksh and Gupta, 2015)

Figure 1.2: Infilled moment resisting concrete frame (Hyun et al., 2014)

1.2 Problem Statement

Infill walls are considered as non-structural elements which commonly the reinforced concrete frame buildings are usually analysed and designed as bare frames (Noh et al., 2017). Hyun et al (2014) stated that infilled reinforced concrete structures in low-seismicity regions provides additional strength and stiffness because infill walls contribute to the over strength of the frame. During the earthquake, damages are occur on the infill walls at first place and affects the entire frame. In addition, the destruction of infill walls are observed in lower stories resulting soft storey effect during the earthquake. However, the behaviour of infill walls under ground motion is not clearly shows with regards to design level.

In the current design practice, the structural members are usually designed according to the strength and displacement demands imposed on the structures when they are subjected to various load combinations such as gravitational load and lateral loads. Even though infill walls are usually considered as non-structural members, it is well known that the infill walls act as struts in frame structures. Nonetheless, although many researchers have conducted experimental and numerical studies on progressive collapse of RC frame structures, they are barely taken the interaction between the infill walls and the frame members into consideration (Shan et al, 2016).

The infill walls can possibly reduce the seismic resistance capacity (Hyun et al., 2014). Thus it is concluded that there is a need to develop a robust seismic design procedures with consideration of infill walls into the design and analytical model. Therefore, current analysis is performed to study the behaviour of infilled frames according to seismic design under earthquake excitation.

1.3 Objectives

The objectives of this study are as follows:

i. To evaluate the moment resisting concrete frame with and without infill walls under seismic provision.

ii. To determine the seismic performance of frame subjected to earthquake.

1.4 Scope of Work

This study considers the following scope of work:

i. Seismic designed of moment resisting concrete frames with number of storey, N = 3, 6, and 9 with two number of bays.

ii. All frames were designed with and without infill walls.

iii. The value of behaviour factor, q had been considered for all frames are equal to 3.9 with ductility class medium (DCM) based on Eurocode 8 (2004).

iv. Type of ground was Type 1 with Soil Type B.

v. 2 dimensional frames were considered using SAP2000.

vi. 5 single ground motions were used for non-linear time history analysis.

1.5 Dissertation Outline

This dissertation consists a total of five chapters which named as Introduction, Literature Review, Research Methodology, Result and Discussion, and Conclusion respectively. Chapter 1 presents the general background of the research, problem statement, objectives, and scope of works. Chapter 2 consists of discussion and review on the previous researches which relevant to this current study. The research method and analysis used in this study is discussed in Chapter 3. The results obtained from this study are discussed precisely in Chapter 4. The final chapter is Chapter 5 which concludes all findings obtained from the research. Several recommendations for future research works also being highlighted.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is the review of the previous researches which is relevant to this current study. The chapter is divided into several main sections. The first two sections explained about the analysis used to analyse the structural frames which is non-linear static analysis and non-linear dynamic analysis. Previous findings related to the effect of ground motion on structural performance are available in the third section. The final section is the summary of all literature review which lead to the current study.

2.2 Infilled and Without Infilled Walls

Hyun et al., (2014) studied the effect of masonry infill walls on the seismic behaviours of RC building according to Uniform Building Code (UBC, 1997) under three difference seismicity regions which is low seismicity region (LSR), moderate seismicity region (MSR), and high seismicity region (HSR) respectively. Five storey of special moment resisting frame (SMRF) divided into three families which is family 1: Model F is a bare frame, family 2: Model S is an infilled frame except first storey and family 3: Model W is an infilled frame entirely. Non-linear time history analysis were carried out using two historical earthquakes and an artificial earthquake created based on the design spectrum. From the analysis it shown that infill walls contribute to the strength and stiffness of the frames. It is recommended to consider the strength and stiffness of the infill walls in the structural analysis model.

Mahdi and Bahreini (2013) conducted a research regarding seismic response of asymmetrical infilled concrete frames. Non-linear static analysis is carried out according to Applied Technology Council (ATC, 1996). The frames were designed using Iranian code. Intermediate moment resisting reinforced concrete frames of 3, 4, and 5 storey with unsymmetrical plan was evaluated. The analytical model was built with and without infill walls. Two types of infill walls were used which is strong and weak infill walls. The results shown that the performance of infilled frames provided higher shear forced with smaller displacements compared to the bare frames. Therefore, the bare frames were more vulnerable compared to infilled frames. Briefly the presence of infill walls is useful for increasing the resistance of the frame.

Das and Murty (2004) evaluated the performance of brick masonry infills considering seismic design and cost implications of RC framed building and the cost implications. Five storey of reinforced concrete frame buildings with brick masonry infills were designed according to Eurocode 8 (2004), Nepal Building Code 201 (1994) and Indian Seismic Code (2002). The analysis shown that the Nepal Building Code 201 was more economical compared to the other codes. Infill walls increased the strength and stiffness of structure while decreased the inter-storey drifts was attained. The studies found that the quality of infill material, workmanship and quality of frame-infill interface significantly affect the behaviour of infilled frames.

Cavaleri and Trapani (2015) conducted an experimental study on criteria of modelling structural behaviour of infills based on macro-modelling approach. The pivot hysteretic model was developed for the cyclic non-linear behaviour of diagonal struts equivalent to infill walls. A single-storey and single bay of infilled frames with different types of masonry subjected to lateral cyclic loads was carried out. The experimental result was compared with simulation result under non-linear time history analysis. The result shown that pivot hysteretic model approach proven feasible as the equivalent diagonal struts presented infill effects of structural models. The influenced of infills produces a significant modification of the behaviour of frames. The comparison of experimental and analytical shown good reliability of the structures performance.

Yuen and Kuang (2015) conducted a studies on the seismic response and failure mechanisms of infilled RC frame structure with five different infill configurations: (1) fully infilled frame, (2) 2/3-storey-height infills, (3) a soft first storey, (4) infills with window openings and (5) infills with door openings. The structures were subjected to four realistic earthquakes namely the 1979 El Centro, 1987 Supersition Hills, 1995 Kobe and 1999 Chi-Chi earthquakes. Non-linear time history was used to analyse the structures performance. From the analytical result, it shown that the regularity and the degrees of continuity of the infill panels were the main factors affecting the seismic response of structures. On the other hand, discontinuous infills caused serious damaged of localised at the points of discontinuity in the frame members noticed.

Yuniarsyah et al., (2016) carried out an experiment on light reinforced concrete walls in moment resisting frames under seismic loading. Four specimens of light RC wall were used to evaluate the effects of axial force, amount of shear reinforcement, and shear span to wall length ratio on the seismic response of structures. These prototype specimens represented the light RC walls that suffered several damage during the 2011 Tohoku earthquake. The quantitative seismic damage evaluation was assessed using the Architectural Institute of Japan (AIJ, 2004) guidelines. The experimental results shown that higher axial load ratio and lower shear span resulted higher lateral load capacity but decreased of drift capacity. The axial load ratio, shear span to wall length ratio, and the amount of horizontal reinforcement influenced to damage and failure mechanisms.

Basha and Kaushik (2016) evaluated the behaviour and failure mechanism of masonry-infilled RC frames in low-rise building subjected to lateral loading according to ASCE 41 (2007). Single-storey masonry infilled RC frames under low lateral loading was carried out. The result of the first stage shown that fully infilled frame and half infilled frame exhibited higher strength, stiffness and energy dissipation compared the bare frames. For second stage the frames were enhanced and improved. The results shown that shear failure occurred at the higher drift level and cannot be prevented.

Bolea (2016) conducted experimental and analytical studies on the seismic behaviour of existing reinforced concrete frame structures with infill masonry in the Bucharest, Romania. Reinforced concrete frame of 3 and 6 storey were analysed using non-linear time history analysis according to Romanian seismic design code (P100-1/2013) and FEMA standards. All the experimental studies conducted in the past showed the increase of strength and stiffness for the infilled frames compared to the bare frames. Therefore, masonry infills influences the dynamic response of the RC building and contribute to the increase of structural resistance against seismic action. The infills reduces the deformation demand and damage of structural elements which the analytical and experimental model data showed a relatively good accuracy.

Choi et al., (2017) investigate the diagonal strut mechanism of infilled RC frame for multi bays frames. The experimental tests was based on Turkish RC moment-resisting frame models. Two single-storey with one and two bays were studied to investigate the in-plane behaviour of the infill walls. From the results, it showed that the infilled frame with two bays has twice strength with respect to infilled frame with one bay. It can be identified that compressive struts of that single strut model are feasible for multi-bay infilled frames.

Furtado et al., (2017) carried out an experimental study of ambient vibration test of infill masonry wall on the structure dynamic response. The studies focused which focusing on the in-plane and out plane frequencies of the infill panels and the corresponding vibration modes. Two tests were conducted which are the in-situ and laboratory test. From the results, it was observed that out of plane frequencies was reduced around 20-40% due to the openings. Meanwhile, 38% of out plane stiffness and natural frequencies panel increased due to the axial load increment in the adjacent columns. Moreover, it can observed that major reduction of the out plane was about 35% reduction compared to in-plane due to previous damages of the existing buildings.

Kadid and Boumrkik (2008) carried out an analysis to evaluate the performance of existing building under future expected earthquakes in Boumerdes, Algeria. Five, eight and twelve storey of reinforced concrete frame structures were analysed using non-linear static analysis according to Algerian code (2003). The results obtained in term of demand, capacity curve and plastic hinges gave an insight into the real behaviour of structures. From the analysis, the failure of the reinforced concrete during the earthquake event was due to poor quality of structure material and also the fact that most of building constructed in Algeria are strong beam and weak column structures type.

Bento et al., (2004) carried out an analysis to evaluate and compare the response of two reinforced concrete building systems by using different methodologies which are ATC 40 (1996), FEMA 273 (1997) and Eurocode 8 (1998). Four and eight storey frames were analysed using non-linear static and dynamic analysis. From the results, it shown that the design weakness is in the elastic range due to storey mechanisms, excessive deformation demands and irregularities.

Oinam et al., (2006) investigated three geometrically similar frames having different configurations of masonry infills which are bare frame, fully infilled frame and open-ground infilled frame. This research was conducted to study the effect of masonry infills in the reinforced concrete frames during an earthquake event. Non-linear static analysis has been carried out to predict the seismic performance of structure frames. The results shown that the lateral strength of the infilled frame is significantly higher compared to bare frame and open-ground infilled frame.

2.3 Non-Linear Static Analysis

Non-linear static analysis is commonly used to identify inelastic seismic performance. This method is usually used to assess the capacity of the structure at different limit states or performance in terms of action and deformation (Elnashai and Sarno, 2008). Non-linear static analysis also known as pushover analysis is carried out to evaluate the expected performance of structural system by estimating its strength and deformation demands under seismic provision. The demands are compared with the capacities at the performance level. Several important parameters are considered for the evaluation which is inelastic element deformation, deformation between elements, global drift and inter-storey drift. The pushover analysis can be an effective design tool to determine the analysis model aspects for nonlinear response (Deirlein et al., 2010) and (Mahdi and Bahreine, 2013).

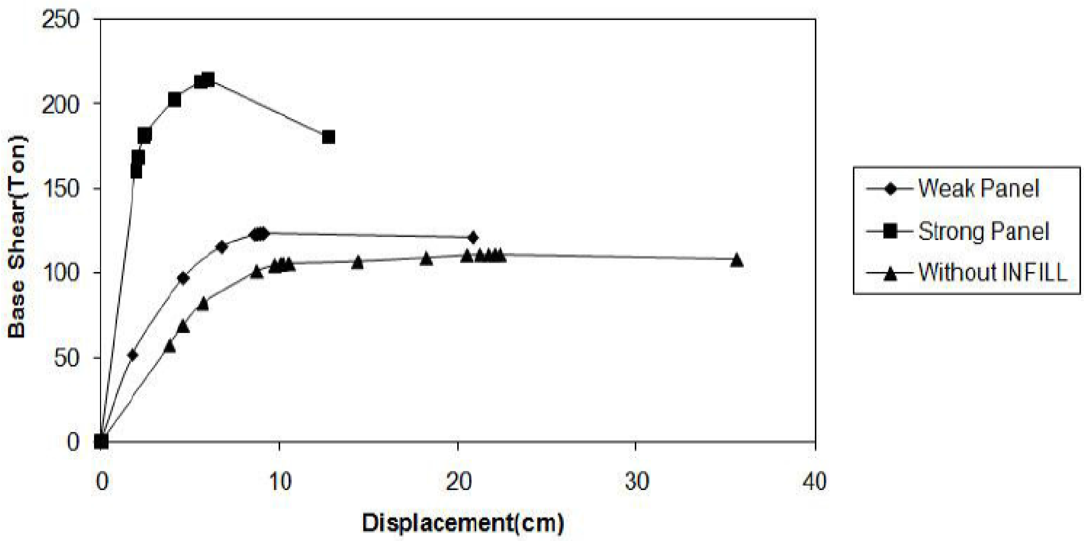


Figure 2.1: Typical capacity curves for three-storey frames with and without infill (Mahdie and Bahreini, 2013)

2.4 Non-Linear Dynamic Analysis

Non-linear time history is widely used to evaluate the response of structure under difference loading applied at specific time function. The important parameters obtained from the analysis are the displacement and inter-storey drift ratio as shown in Figures 2.2 and Figure 2.3. There are several methods of dynamic analysis of structures exist as shown in Figure 2.2. These method can be implemented in either in time or in the frequency domain. The modal, spectral and response history are the most common methods used for dynamic analysis of structures subjected to earthquake loads. Structures generally undergo deformations in the inelastic range when it is subjected to strong ground motion. The deformation is relatively large and geometric non-linearity may be significant. Due to changes in stiffness and periods of vibration, analysis of non-linear and inelastic system subjected to seismic loads involves continuously changing temporal solution characteristics (Amr and Luigi, 2008).

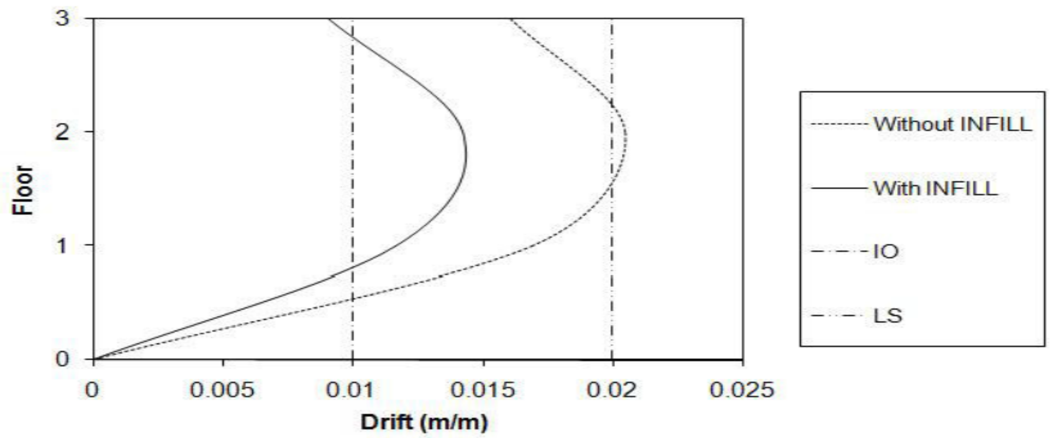
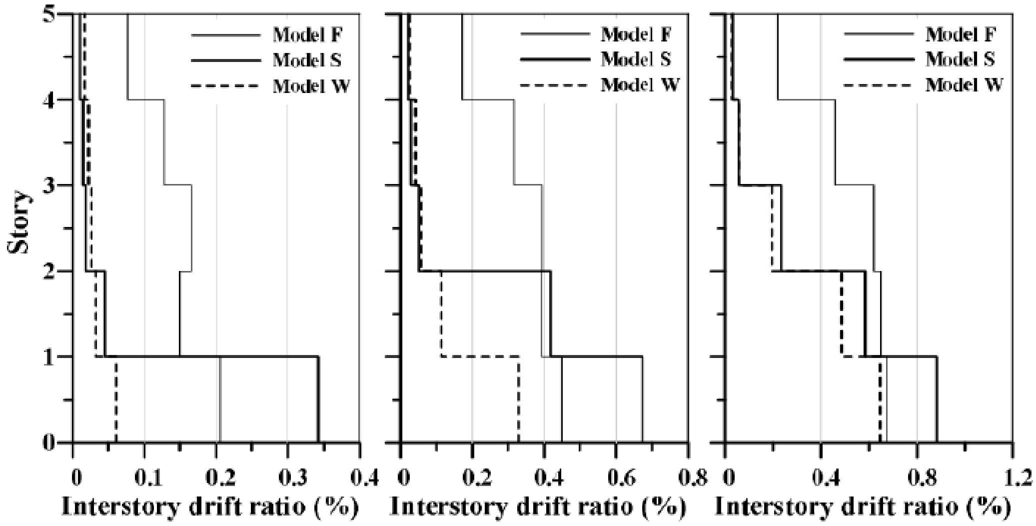


Figure 2.2: Typical displacements for three-storey frames (Mahdi and Bahreini, 2013)



(a) LSR (b) MSR (c) HSR

Figure 2.3: Typical inter-storey drift ratio of five storey at three different seismicity regions (Hyun et al., 2014)

2.5 Summary

This chapter explains in details the relevant findings of previous studies related to current research. It can be concluded that most of the past researches conducted to evaluate infilled frames performance using non-linear analysis and experimental model. Moreover, preview studied also focused on infill walls of low-rise frames. However, the behaviour of infill walls under ground motion is not clearly discussed with regards to design level. Table 2.1 shows a summarisation of past earthquake studies on low to medium rise reinforced concrete building. Current research is focusing on the effect of the ground motion on seismic design of low to medium-rise infilled moment resisting concrete frame with different infills configuration. Thus, at the end of this research, a final conclusion will be drawn regarding these three aspects which are the capacity curve, displacements and the inter-storey drift ratio on the behaviour of the structures under earthquake excitation.

Table 2.1: Summarisation of past earthquake studies on low to medium rise reinforced concrete buildings.

Reference	No. of Storey	Infill Configuration			Analytical Model		Experimental Model		Remarks
		Without Infill	Partially Infilled	Fully Infilled	Pushover Analysis	Time History Analysis	In-situ Test	Laboratory Test	
Hyun et al., (2014)	5	✓	✓	✓	-	✓	-	-	• UBC 1997 • 3 seismicity regions (Low, medium and high)
Mahdi and Bahreini, (2013)	3, 4, and 5	✓	-	✓	✓	-	-	-	ATC (1996) and Iranian Code (2007)
Das and Murty, (2004)	5	-	-	✓	-	-	-	-	Eurocode 8, Nepal Building Code 201 (1994) and Indian Seismic Code (2002).
Cavaleri and Trapani, (2015)	1	-	-	✓	-	✓	-	✓	-

Reference	No. of Storey	Infill Configuration			Analytical Model		Experimental Model		Remarks
		Without Infill	Partially Infilled	Fully Infilled	Pushover Analysis	Time History Analysis	In-situ Test	Laboratory Test	
Yuniarsyah et al., (2016)	1	-	-	✓	-	-	-	✓	Architectural Institute of Japan (AIJ, 2014) Guidelines
Basha and Kaushik, (2016)	1	✓	✓	✓	-	-	-	✓	ASCE 41 (2007)
Bolea, (2016)	3 and 6	-	-	✓	-	✓	-	✓	Romanian Design Code (P100-1/2013) and FEMA standards
Choi et al., (2017)	1	-	-	✓	-	-	-	✓	MRCF models
Furtado et al., (2017)	Multiple storey	-	-	✓	-	-	✓	✓	-

Reference	No. of Storey	Infill Configuration			Analytical Model		Experimental Model		Remarks
		Without Infill	Partially Infilled	Fully Infilled	Pushover Analysis	Time History Analysis	In-situ Test	Laboratory Test	
Yuen and Kuang, (2015)	2	✓	✓	✓	-	✓	-	-	Architectural Institute of Japan (AIJ, 2014) Guidelines
Kadid and Boumrkik, (2008)	5 and 12	✓	-	-	-	-	-	-	Algerian Code (2003)
Bento et al., (2004)	4 and 8	✓	-	-	✓	✓	-	-	ATC (1996), FEMA 273 (1997) and EC8 (1998)
Oinam et al., (2006)	3	✓	✓	✓	✓	-	-	-	-

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the outline of the methodology for current study. This research focused on analysis of regular moment resisting concrete frame (MRCF) which is the common type of building constructed in Malaysia. The design standards used in this study were Eurocode 2 and Eurocode 8 for gravitational loads and lateral loadings respectively. Three regular building of 3, 6, and 9 storey generic in 2D were used as a model which represent low to medium rise RC building. The structural models has different infill configuration which are bare frame and infilled frame. Non-linear static and dynamic analyses were used to analyse the structural element to evaluate the seismic performance of the model. The models were constructed using SAP 2000 software analysis. Figure 3.1 shows flowchart of current research methodology.

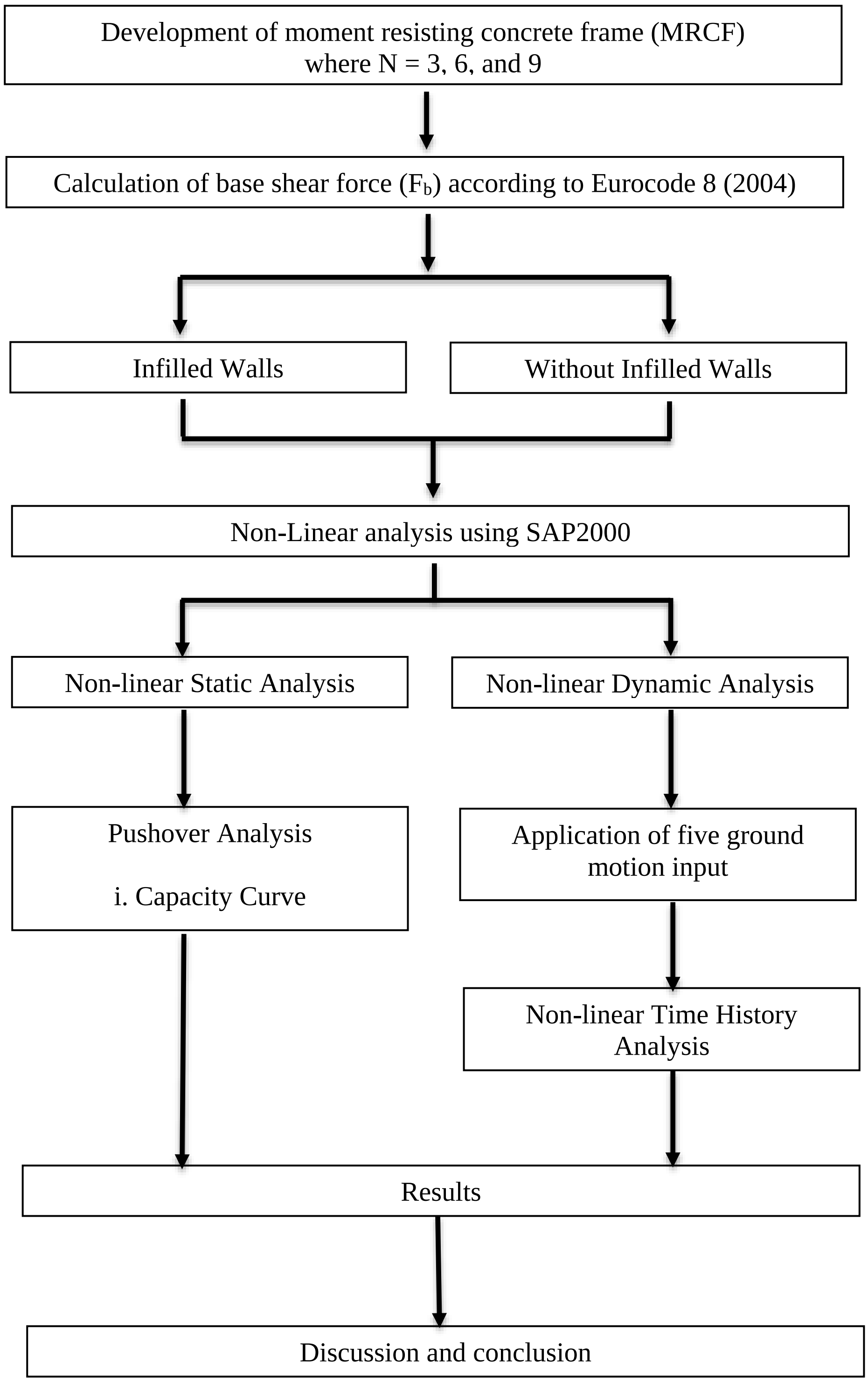


Figure 3.1: Flowchart of research methodology

3.2 Calculation of Base Shear Force

In this research, parameters from the previous research done by Hatzigeogiou and Liolios (2010) was adopted. The dead load (including selfweight), G_k is 20 kN/m and live load, Q_k is 10 kN/m, concrete compressive strength is 20 MPa and the strength of reinforcement 500 MPa. The load combinations used in this study were referred to Eurocode 8 (2004):

$$1.35G_k + 1.5Q_k \tag{3.1}$$

$$1.00G_k + 1.00Q_k + 1.00E \tag{3.2}$$

$$1.00G_k + 1.00Q_k - 1.00E \tag{3.3}$$

Table 3.1 shows the seismic mass calculation computed from equation 3.1

Table 3.1: Seismic mass calculation

Level	G (kN)	Q (kN)	Mass (tonne)
1	300	150	45.9
2	300	150	45.9
3	300	150	45.9
TOTAL			137.6

From Eurocode 8 clause 4.3.3.2.2, the seismic base shear force F_b, for each horizontal direction was analysed and determined using the following equation:

$$F_b = S_d(T_1)m\lambda \tag{3.4}$$

where,

$S_d(T_1)$ is the ordinate of the design spectrum at fundamental period T_1:

T_1 is the fundamental period of vibration of the building for lateral motion in the direction considered;

M is the total mass of the building;

λ is the correction factor, the value of which is equal to : $\lambda = 0.85$ if $T_1 < 2\ T_c$ and the building has more than two storeys, or $\lambda = 1.0$ otherwise.

$$T_1 = C_t\ H^{3/4} \tag{3.5}$$

where,

Ct is 0.085 for moment resistant space steel frames, 0.075 for moment resistant space concrete frames and for eccentrically braced steel frames and 0.050 for all other structures;

H is the height of the building, in m, from the foundation or from the top of a rigid basement.

Elastic response spectrum stated in clause 3.2.2.1 (EC8) that the earthquake motion at given point on the surface is represented by an elastic ground motion acceleration. From Clause 3.2.2.5, to avoid explicit inelastic structural analysis in design, the capacity of the structure to dissipate energy, through mainly ductile behaviour of its elements and mechanisms, is taken into account by performing an elastic analysis based on a response spectrum reduced with respect to the elastic one, using “design spectrum”. This reduction is accomplished by introducing the behaviour factor, q.

Table 3.2: Basic value of the behaviour factor, q_o, for systems regular in elevation (Eurocode 8, 2004)

Structural Type	DCM	DCH
Frame system, dual system, coupled wall system	3.0 αu/α1	4.5 αu/α1
Uncoupled wall system	3.0	4.5 αu/α1
Torsionally flexible system	2.0	3.0
Inverted pendulum system	1.5	2.0

Buildings which are regular in plan the following approximate values of α_u/α_1 is used for frames or frames-equivalent dual systems.

i. One-storey buildings: $\alpha_u/\alpha_1 = 1.1$
ii. Multiple storey, one-bay frames: $\alpha_u/\alpha_1 = 1.2$
iii. Multiple storey, multi-bay frames or frames-equivalent dual structures: $\alpha_u/\alpha_1 = 1.3$

According to Eurocode 8 (2004) ground type B is the deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth was adopted in the analysis. From Clause 3.2.2.2, the values of the parameters describing the recommended Type 1 elastic response spectra is as follow:

Ground type : B

S : 1.2

T_B (s) : 0.15

T_C (s) : 0.5

T_D (s) : 2.0

T (s) : 0.38

From the parameters given, horizontal components of the seismic action the design spectrum, $S_d(T)$, shall be defined by the following expressions:

$$T_B < T < T_C: S_d(T) : a_g\, S\, 2.5/q \quad (3.6)$$

where

T is the vibration period of a linear single-degree-of-freedom system

T_B is the lower limit of the period of the constant spectral acceleration branch

T_C is the upper limit of the period of the constant spectral branch

a_g is the design ground acceleration on type A ground (ag = γI.agR)

S is the soil factor

The distribution of the triangular lateral forces of the three storey model is shown in Table 3.3.

Table 3.3: Seismic triangular lateral forces

No. of storey	Triangular lateral forces (kN)
3	90.06
2	60.04
1	30.02