# SEISMIC EVALUATION OF LOW TO MEDUIM RISE OF REGULAR RC BUILDING

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SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2017

# SEISMIC EVALUATION OF LOW TO MEDIUM RISE OF REGULAR RC BUILDING

By

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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

June 2017

## SCHOOL OF CIVIL ENGINEERING
## ACADEMIC SESSION 2016/2017

## FINAL YEAR PROJECT EAA492/6
## DISSERTATION ENDORSEMENT FORM

Title:

Name of Student:

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 :

# ACKNOWLEDGEMENT

In the name of Allah S.W.T, and honour to Prophet Muhammad S.A.W, thanks for blessing and giving me the strength to complete this final year project.

First and foremost, I would like to express my gratitude to my FYP supervisor, Prof. Dr. Taksiah A. Majid for supervising me throughout this journey. I thanked her for the time spent teaching and sharing her wisdom. Without her advice, it was impossible to complete this study.

Secondly, I would like to thank Ms. Tahara for giving me knowledge especially regarding this dissertation. Although I know she was very busy completing her Ph.D, but she still spend her time in helping and guiding me in completing this study. She had given me the strength through her guidance when I find it difficult to proceed. Thank you for being there when I had my doubts.

Next, I want to thank my family especially to my beloved parent, Noor Aidy Bin Sukri and Patimah bt Abd Rahim because without them, I will never be able to finish it. They had given me their support and encouragement upon completing this study. Lastly, not to forget my FYP mates, Munira and Amelia for surviving together and also to my classmates. Thank you all.

# ABSTRAK

Gempa bumi berlaku disebabkan oleh pembebasan tenaga secara mendadak atau pergerakan yang tidak dijangka dari permukaan bumi. Tsunami yang berlaku pada 24 Disember 2004 yang disebabkan oleh gempa bumi bermagnitud 9.1 telah membawa kepada kerosakan bukan sahaja kepada struktur bangunan tetapi juga kepada kehidupan manusia. Kajian dalam prestasi seismik telah dilaksanakan sejak beberapa dekad yang lalu untuk menilai risiko dan kelemahan seismik di bawah gempa bumi. Objektif kajian ini adalah untuk menentukan prestasi 3D sekata *'Moment Resisting Concrete Frame'* (MRCF) di bawah peruntukan seismik. Analisis statik tidak linear dan dinamik telah digunakan dalam kajian ini untuk menilai prestasi bangunan rendah ke sederhana bagi bangunan konkrit tetulang. Analisis ini menyediakan maklumat dalam menilai prestasi bangunan struktur di bawah gempa bumi. Kajian ini menggunakan struktur 3D untuk mewakili bangunan sebenar di bawah beban seismik. Tiga tingkat yang berlainan, N: 3, 6, dan 9 telah digunakan untuk model struktur di mana beberapa parameter telah diambil dari  Hatzigeorgiou and Liolios (2010). Tujuh gerakan tanah tunggal telah dikenakan untuk mewakili gerakan seismik tanah. SAP 2000 dan STERA 3D adalah perisian yang digunakan untuk analisis. Keputusan dari analisa 'pushover' telah menunjukkan bangunan sembilan tingkat mempunyai peratusan drift yang paling tinggi berbanding bangunan tiga dan enam tingkat. *'Drift shear relation curve'* menyatakan tentang tingkat tinggi mempunyai anjakan tertinggi. '*Incremental Dynamic Analysis'* (IDA) menunjukkan anjakan bangunan meningkat apabila ada peningkatan dalam PGAIni membuktikan yang setiap gerakan gempa bumi mempunyai nilai anjakan yang berlainan untuk bangunan.

# ABSTRACT

Earthquake is caused by the sudden release of energy or an unexpected movement from the earth surface. Tsunami that occurred on the 24th December 2004 caused by earthquake with a magnitude of 9.1 had brought damages not only to structural buildings but also to human lives. Research on seismic performance had been carried out over the past decades to evaluate the risk and seismic vulnerability under earthquake. The main objective for this study is to determine the performance of regular 3D moment resisting concrete frame (MRCF) under seismic provision. Nonlinear static and dynamic analysis had been used in this study to evaluate the performance of low to medium rise RC building. These analysis provide information in evaluating the performance of the structural building under earthquake. This study implemented 3D structure to represent real building under seismic loading. Three different storey, N: 3, 6, and 9 were used as the structural models which some of the parameters used were adopted from Hatzigeorgiou and Liolios (2010). Seven single ground motions data were employed to represent the seismic ground motion. STERA 3D and SAP 2000 software were used to run the analysis. Results from the pushover analysis shows that nine storey has the highest percentage of drift compared to three and six storey. The drift shear relation curve exhibited that higher storey levels has the highest displacement. The Incremental Dynamic Analysis (IDA) shows that the displacement of the building increases when there is an increase in PGA. It can be proved that each earthquake ground motion has a different value of displacement for the structure.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| BS | **B**ritish **St**andard |
| CP | **C**ollapse **P**revention |
| DCH | **H**igh **C**lass **D**uctility |
| DCM | **M**edium **C**lass **D**uctility |
| EC 2 | **E**urocode **2** |
| EC 8 | **E**urocode **8** |
| FEMA | **F**ederal **E**mergency **M**anagement **A**gency |
| IDA | **I**ncremental **D**ynamic **A**nalysis |
| IO | **I**mmediate **O**ccupancy |
| LS | **L**ife **S**afety |
| MRCF | **M**oment **R**esisting **C**oncrete **F**rame |
| PGA | **P**eak **G**round **A**cceleration |

# NOMENCLATURES

| | |
|---|---|
| $a_g$ | Design ground acceleration |
| $E$ | Earthquake load |
| $F_b$ | Base shear |
| $F_b$ | Base shear force |
| $F_{\mathrm{ck}}$ | Characteristic strength of concrete |
| $F_{\mathrm{yk}}$ | Characteristic strength of steel |
| $\mathrm{G_k}$ | Dead Load |
| $H$ | Height of the building |
| $m$ | Mass of the building |
| $N$ | Number of storey |
| $q$ | Behaviour factor |
| $\mathrm{Q_k}$ | Live load |
| $S$ | Soil factor |
| $S_d$ | Design spectrum |
| $T_1$ | Fundamental period of vibration of a building |
| $\lambda$ | Correction factor |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Earthquake is caused by a sudden release of energy or an unexpected movement from the earth surface. Earth surface is made up of several plates which is known as tectonic plates. Malaysia is located close to the active seismic plate boundaries between Indo-Australian and Eurasian Plates as shown in Figure 1.1 and this plate is constantly moving slowly at rates up to 5 to 10 cm/year.

Malaysia is exposed to far-field earthquake from nearly Indonesia earthquake especially when the old buildings are not design with seismic loading. On the 24th December 2004, an earthquake with magnitude of 9.1 originated from Acheh, Indonesia has shocked the entire world as it brings damages to structural buildings and endanger to human lives. Malaysia was one of the countries affected from this earthquake when tremor and tsunami hits some places.

Nevertheless, Malaysia also faces with local earthquake such as in Ranau (Sabah) and Bukit Tinggi (Pahang). On the 5th June 2015, a moderate earthquake had strike Ranau, Sabah with magnitude of 6.0. The tremor felt in Ranau, Tambunan, K. Kinabalu, K. Belud, Pedalaman, and Tuaran, Sabah. The result of the earthquake causes 18 people died on Mount Kinabalu and also causes damages to the structural buildings such as school, hospital, and public buildings. Figure 1.2 shows the damage on the Ranau Hospital.

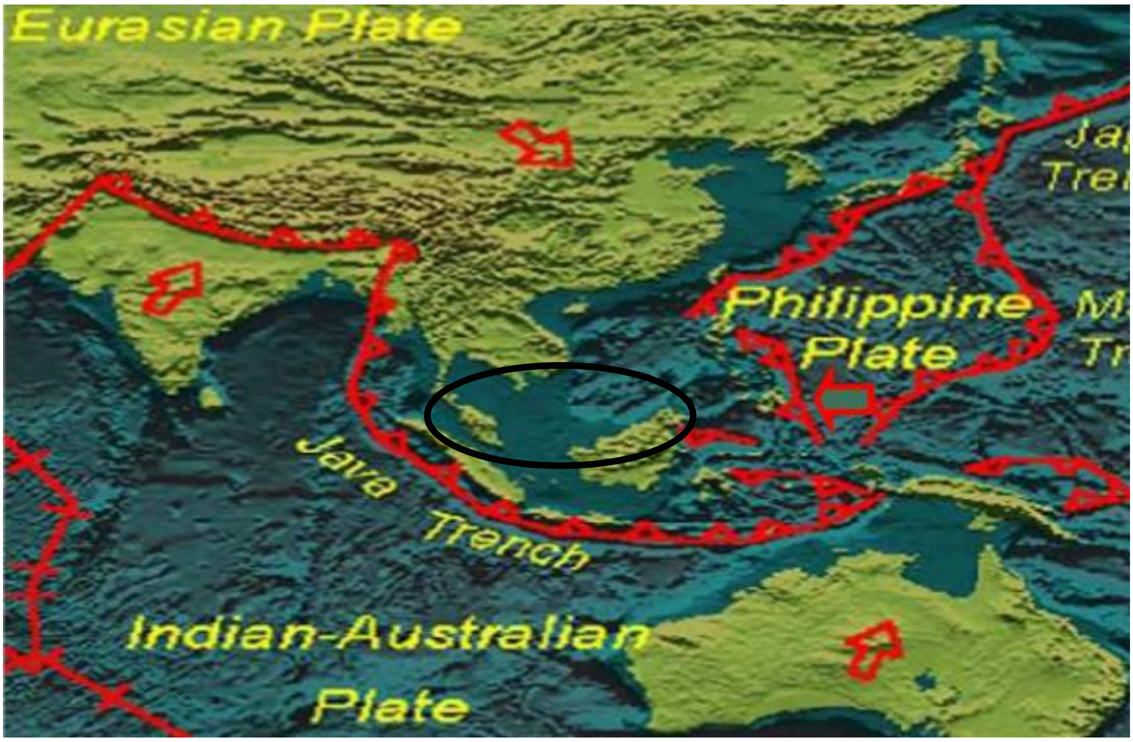


Figure 1.1: Active seismic plate boundaries which is the Indo-Australian and Eurasian plates (Abas, 2001)

Figure 1.2: Structural Damages of Ranau Hospital

Losses of life and damages to the structural properties is because buildings have consistently exhibited poor performance in the past earthquakes (Potty and Sirajuddin, 2011). Seismic performance of a structure is to evaluate the risk assessment and seismic vulnerability. Thus, designing structures under seismic provision might prevent large damage and level of risk damages can be reduced by determining the properties of building under earthquake. The performance of a building need to be determined first in order to lowering the rate of damages (Ercan, 2015).

In a seismic event, nonlinear response of a well-designed moment frame involves a strong column-weak beam mechanism (Visnjic, 2014). Reinforced concrete frame is commonly used in construction of a building as a lateral load resisting system which can resist strong ground motion shaking. This system is more ductile making it more preferable in seismic design application. Moment frames are composed of beams, columns, and joints which is the element that can resist the seismic forces of axial load, bending moment, and shear force actions. Moment frames have been widely used for seismic resisting system due to their superior deformation and energy dissipation capacities (Titiksh and Gupta, 2015).

## 1.2 Problem Statement

British Standard (BS 8110) is the current practice code used among engineers in designing a structural building in Malaysia. However, this code only consider gravity load and does not provide any seismic design provision. Hence, Eurocode 8 is used as reference for the seismic code provision to study on the seismic design and analysis. There are numerous studies carried out worldwide on seismic analysis but very limited conducted here in Malaysia. The government will soon launch the Malaysian National Annex (NA) on Eurocode 8 (EC8): Design of Structures for Earthquake Resistance

(Chiang, 2016) and as preparation to that, study on seismic analysis needs to be understood thoroughly.

On 5th June 2015, an earthquake with a magnitude of 5.1 had damaged several buildings in Sabah, which claimed to have low to moderate earthquake intensity. From the selected buildings in Sabah, it was found that the structural system is not critical to earthquake load. Public building in Peninsular Malaysia, Sabah and Sarawak is prone to earthquake damage when subjected to earthquake forces. Implementing seismic design is worth for building located in medium-high risk seismic zone (MOSTI, 2009).

Hence, seismic loading need to be considered as the threat to the structure especially to the existing and new buildings is obvious. Thus, this study is carried in 3D frames to address clear image of real building under earthquake especially in Malaysia due to most of the current study was done in 2D. Based on the previous research done by Causevic and Mitrovic (2011), Agha et al., (2008), Boonyapinyo et al., (2008) and Cavdar and Bayraktar (2014), nonlinear static analysis and Incremental Dynamic Analysis (IDA) was the tool used to evaluate the performance of the structural building. Hence, nonlinear static and time history analysis are carry out to determine the effect of earthquake on low-medium rise RC buildings as it is the common type of building in Malaysia with Eurocode 8 as a reference for the seismic code provision.

## 1.3 Objectives

The main objectives of this study is to determine the performance of regular three dimensional (3D) moment resisting concrete frame (MRCF) under seismic provision of Eurocode 8 using Nonlinear Static (pushover) analysis and Incremental Dynamic Analysis (IDA).

## 1.4 Scope of Work

In this research, the present work is conducted within the following scope:

i. Seismic design MRCF with 3 different number of stories, N = 3, 6, and 9 storey with two number of bays.
ii. The value of behaviour factor, q is 3.9 and the ductility classes is medium ductility (DCM) from Eurocode 8.
iii. The ground type is Type 1 with ground type B (deposits of very dense sand)
iv. 3D frames are considered using SAP 2000 and STERA 3D.
v. 7 single ground motions are used in nonlinear time history analysis

## 1.5 Dissertation Outline

This dissertation consists of five chapters. Chapter 1 provides an introduction of the study which explained the occurrence of earthquake and past earthquake occurred in Malaysia. This chapter includes the problem statement, objectives and also the scope of work for this study. Chapter 2 reviews the previous studies conducted by other researcher that are related to this study. Chapter 3 describes the method and steps used to conduct this research. Chapter 4 discusses the result obtained during the analysis of the structural element. The last chapter is the conclusion of the study which concludes the result obtained to achieve the objectives and recommendation for future works which are related to the topic.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter is the review of the past research as it is related to the current study and divided into several sub sections. The first section is about the moment resisting concrete frame (MRCF). The analysis of the RC structure using two types of analysis which are Nonlinear Static (pushover) Analysis and Incremental Dynamic Analysis (IDA) is discussed in second and third section, respectively. The fourth section will be the review of the past research on earthquake event and finally the summary of the literature review.

## 2.2 Moment Resisting Concrete Frame

Moment resisting concrete frame is widely used in high seismic region as lateral load carrying system (Erduran and Yakut, 2007). Moment frame is also being adopted due to its energy dissipation capacities and superior deformation as shown in Figure 2.1. Moment frame is rigidly connected which consist of column and beam that will resist the gravity load and lateral load. Lateral forces are distributed according to the flexural rigidity of each component. Rigid frame action developed bending moment and shear force in the members and joints of a structure.

Frames is design using the concept of strong column-weak beam mechanism. Moment resisting frame can be divided into two types which is the Ordinary Moment Resisting Frame (OMRF) and Special Moment Resisting Frame (SMRF). The difference between these two types of frames is OMRF did not meet special detailing requirement ductile behaviour while SMRF is specially detailed for ductile behaviour.

In lower seismic zone, OMRCF is the type of frame that is commonly adopted in construction but with the increasing of seismic risk, SMRF need to be used (Titiksh and Gupta, 2015).

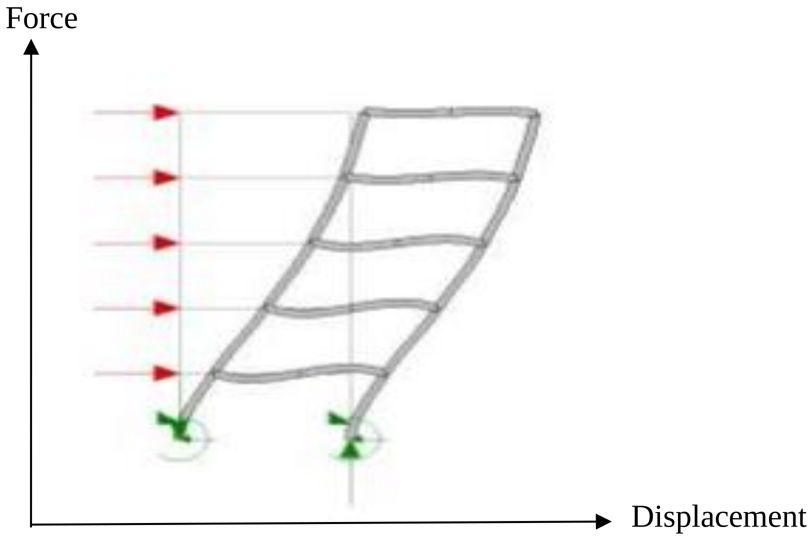


Figure 2.1:Deformation of moment resisting frames (Titiksh and Gupta, 2015).

### 2.3 Non-Linear Static Analysis

Nonlinearity regards flexural rotation while other deformation are assumed linear (Magliulo et al., 2007). Nonlinear static analysis is one of the method used to identify inelastic seismic performance. This method is categorized into two method which are the first-mode of pushover analysis and the other one is modal pushover analysis (MPA) (Boonyapinyo et al., 2008). Pushover analysis is conducted to evaluate the expected performance of a structural system by estimating its strength and deformation demands in design earthquakes. This demand is compared to the available capacities at the performance levels of interest. The important parameters for the evaluation include inelastic element deformation, deformation between elements, global drift and interstory drift. This type of analysis is the method to predict deformation demand and seismic forces when the structure is subjected to inertia forces that no longer can be resisted within the elastic range of structural behaviour (Krawinkler and Seneviratna, 1998).

Causevic and Mitrovic (2011) conduct pushover analysis which the structure is subjected to lateral load representing the inertia force act as ground acceleration. The pushover analysis provides a characteristic non-linear curve of force-displacement relation and is most frequently presented as a relation of the total base shear (V) and the top displacement (Dt). Determination of the distribution of lateral load is a vital step for implementation of pushover analysis.

## 2.4 Incremental Dynamic Analysis

Dynamic analysis is the approach towards the assessment of earthquake response, but is significantly more demanding than static analysis in terms of computational effort and interpretation of results. Incremental dynamic analysis (IDA) also known as dynamic pushover, is an analysis method that can be utilized to estimate structural capacity under earthquake loading. It provides a continuous picture of the system response, from elasticity to yielding and finally to collapse (Elnashai and Sarna, 2008). The result of the IDA curve will provides the indication of the system performance at all levels of excitation in a manner similar to the load displacement curve from static pushover. Incremental Dynamic Analysis (IDA) involves performing nonlinear dynamic analyses of the structural model under a suite of ground motion records, that is scaled to several intensity levels designed to force the structure all the way from elasticity to final global dynamic instability (Vamvatsikos and Cornell, 2002).

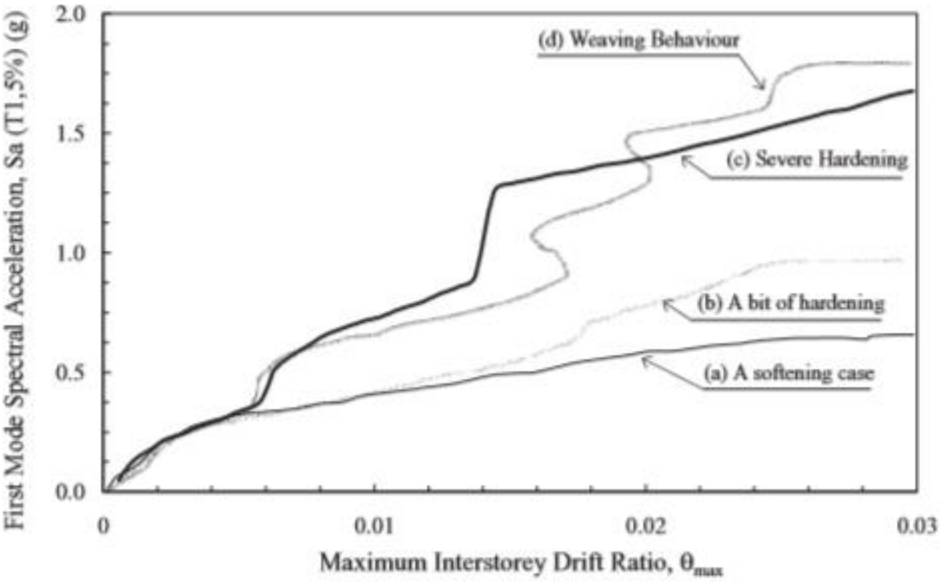


Figure 2.2: Typical IDA curves for a multi-storey building which subjected to four different earthquake (Vamvatsikos and Cornell, 2002).

A sufficient amount of earthquake ground motion should be implemented in the analysis because IDA is highly dependent on the records. A multi- record IDA results in an IDA curve set, which can be analysed statistically. IDA provides a better picture of changes in the nature of the structural response as the intensity of the ground motion increase for example changes in peak deformation patterns with height, onset of stiffness and strength degradation, and their patterns and magnitude (Elnashai and Sarna, 2008).

## 2.5 Review from the Past Research

Çavdar and Bayraktar (2014) investigate seismic performance of a 6 storey collapsed RC building in Van, Turkey design under seismic code provisions of Turkish Earthquake Code (TEC-1975). The performance levels is evaluated using two analyses which are the static pushover and nonlinear time history analysis and the code used to evaluate the performance levels with Turkish Earthquake Code (TEC-2007). From this study, the existing RC structure system of the residential building does not satisfy the performance levels as mentioned in the codes. It was found that the performance levels of building decrease due to not enough of detailing and reinforcement, low quality of concrete and poor workmanship. Irregularities of structure will affect the seismic performance. Damage ratios for first-storey beam and column is lower for linear and pushover analysis than nonlinear dynamic analysis.

Kam et al., (2010) carried out research on the performance of several reinforced concrete buildings classes under Darfield earthquake. The building classes includes pre-1976 low-rise, pre-1976 medium rise, modern low- and mid-rise, modern high-rise, industrial tilt-up buildings, advanced seismic systems and ground-failure induced damaged and retrofitted RC buildings. Buildings were examined with design before and after implementing of seismic code provision. The finding from this studies shows RC buildings that is built and design using the current seismic code shows the initial brittle failure modes.

Duan and Hueste (2012) study the seismic performance of multi-storey RC building based on the case study which was conducted for 5 storey RC office building. This research was done using Chinese Seismic Code (GB50011-2010) and other codes such as US standard Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-10) and Eurocode 8 (EC8 ) as the code comparison. The research was analyse using nonlinear static (pushover analysis) and nonlinear dynamic time-history analysis.The result requires at least 1.2 column to beam strength ratio for GB50011-2010 and ACI 318-08. Result from pushover analysis shown that soft storey failure mechanism at building drift in range of 2-3%. From the dynamic analysis, the seismic response met the ASCE/SEI 41-06 recommended Basic Safety Objectives (BSO) of LS performance for design earthquake (10% in 50 years hazard prevention) and CP performance for collapse prevention earthquake (2% in 50 years hazard prevention). It is recommended that the adoption of strong column-weak beam mechanism according to ACI 318 to be implement in Chinese seismic code.

Zahid et al., (2013) carried research on overstrength factor of RC frame design using Eurocode 2 (EC2) and Eurocode 8 (EC8). Two families of building are considered in this case study which is the regular RC frame and irregular frame with a setback. These two families of building is designed using only gravity load and also designed to resist seismic load with medium ductility and high ductility class. Pushover analysis is used to evaluate the overstrength factor of RC frames. The result from the analysis was found that higher ductility supply of building, the higher the overstrength factor. It can be proved that seismic designed building has greater load carrying-capacity, top diaplacement capacity and ductility supply compared to the gravity load designed buildings.

Hatzigeorgiou and Liolios (2010) study the inelastic behaviour of RC frames subjected to repeated strong ground motion application. The study is carried out on eight reinforced concrete building which divided into two families : regular and irregular (with setbacks). This two families have been design using gravity load only and other family using gravity and earthquake load. From the results, it was found that multiple earthquake produce more damage than single ground motions. Repeated ground motion can affect the distribution of plastic hinges compare to single seismic events. The ductility demand also increase when the sequential ground motion increased.

Mwafy and Elnashai (2001) carried out an investigation on 12 storey RC building with different characteristic using eight natural and artificial earthquake records. The study compared the static pushover and dynamic collapse analysis in RC frames. Analysis of the research was done in 2D modelling approach for each of the twelve samples and is adopted to create dynamic pushover envelopes which will be compared to static pushover result with different load pattern. From the result, pushover analysis provide elastic and inelastic response of building under earthquake. Static pushover analysis also is more suitable for short period and low rise frame structure. Well designed irregularities structure shown good correlation result in dynamic analysis. Each earthquake records has its own duration, sequence of peaks, amplitude, dictated by frequency content also peculiarities from the dynamic collapse analysis.

El-Betar, (2015) conducted a study on low to medium rise residential building in Egypt. The frame structure with different number of storey, N = 3, 6, 10 to represent typical structure in Egypt. Vulnerability of the existing RC building were investigated using nonlinear static pushover analysis as to identify the real strength of the buildings. From the research, it was found frames that is design using Egyptian Code have high resistance to resist earthquake than frames that is only design with gravity load especially in 6 and 10 stories due to lack of longitudinal reinforcement in top and bottom beam ends which result to high chances of damages. At peak ground acceleration (pga) greater than 0.125g, there is high probability of failure in 6 and 10 stories frames which design using gravity load only. Thus, this type of frames need to be retrofitted to avoid vulnerability.

Hatzivassiliou and Hatzigeorgiou (2015) conducted a research to study the inelastic behaviour of regular and irregular RC frames subjected to multiple earthquake in 3D. It focuses more on maximum displacement. structural damage, permanent displacement and interstorey drift ratio. From the result, structural damage has higher chances when subjected to repeated earthquake. Structural member behave elastically when subjected to single earhquake motion while behave inelastically for when there is a repeated earthquake which result to damage of the structure. Displacement is higher when for repeated earthquake so as the interstorey drift ratios.

## 2.6 Summary of the Literature Review

As a summary of the literature review, most of the research conducted to evaluate the seismic performance of RC frames using this two analysis: nonlinear static (pushover analysis) and also nonlinear dynamic analysis (IDA). This analysis is a common tool to identify the Performance Based Earthquake Engineering (PBEE) in seismic design study. However, still there are shortage of examples in 3D analysis solving problem related to earthquake. Hence, there is still a need study the low to medium rise buildings of 3D MRCF using Pushover Analysis and also Incremental Dynamic Analysis (IDA). Table 2.1 shows the summary from the past earthquake studies.

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

| Reference | Regular | Irregular | 2D | 3D | Pushover analysis | IDA | Remarks |
|---|---|---|---|---|---|---|---|
| Cavdar and Bayraktar, (2014) | - | 6 storey | - | ✓ | ✓ | ✓ | RC structure is design with Turkish Earthquake Code (TEC-1975) |
| Kam et al., (2010) | Multiple storey | Multiple storey | - | - | - | - | - |
| Duan and Hueste, (2012) | - | 5 storey | ✓ | - | ✓ | ✓ | - |
| Zahid et al., (2013) | 3 storey | 3 storey | ✓ | - | ✓ | - | Low seismic region. |
| Hatzigeorgiou and Liolios, (2010) | 3 and 8 storey | 3 and 8 storey | ✓ | - | - | ✓ | • Repeated earthquake<br>• High seismic region |
| Mwafy and Elnashai, (2001) | 8 and 12 storey | 8 storey | ✓ | - | ✓ | ✓ | Three design ductility class (high, medium, and low) |
| El-Betar, (2015) | 3,6 and 10 storey | - | ✓ | - | ✓ | - | - |
| Hatzivassiliou and Hatzigeorgiou, (2015) | 3 and 5 storey | 3 and 5 storey | - | ✓ | - | ✓ | Repeated earthquake |

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

This study focused on analysis of regular moment resisting concrete frame (MRCF) which is the common type of building constructed in Malaysia. Eurocode 8 was used as a reference for seismic code for the determination of seismic loading. The analysis included gravity and earthquake load. SAP 2000 was used for the validation of previous work done by Hatzigeorgiou and Liolios (2010). Three regular building were used as a model with different number of storey N: 3, 6, and 9 which represent low to medium rise RC building. Nonlinear static and dynamic analyses were used to analyse the structural element to evaluate the seismic performance of the model. The models were constructed in three dimensional software using STERA 3D to evaluate the nonlinear analysis. Figure 3.1 shows a flowchart of the study.

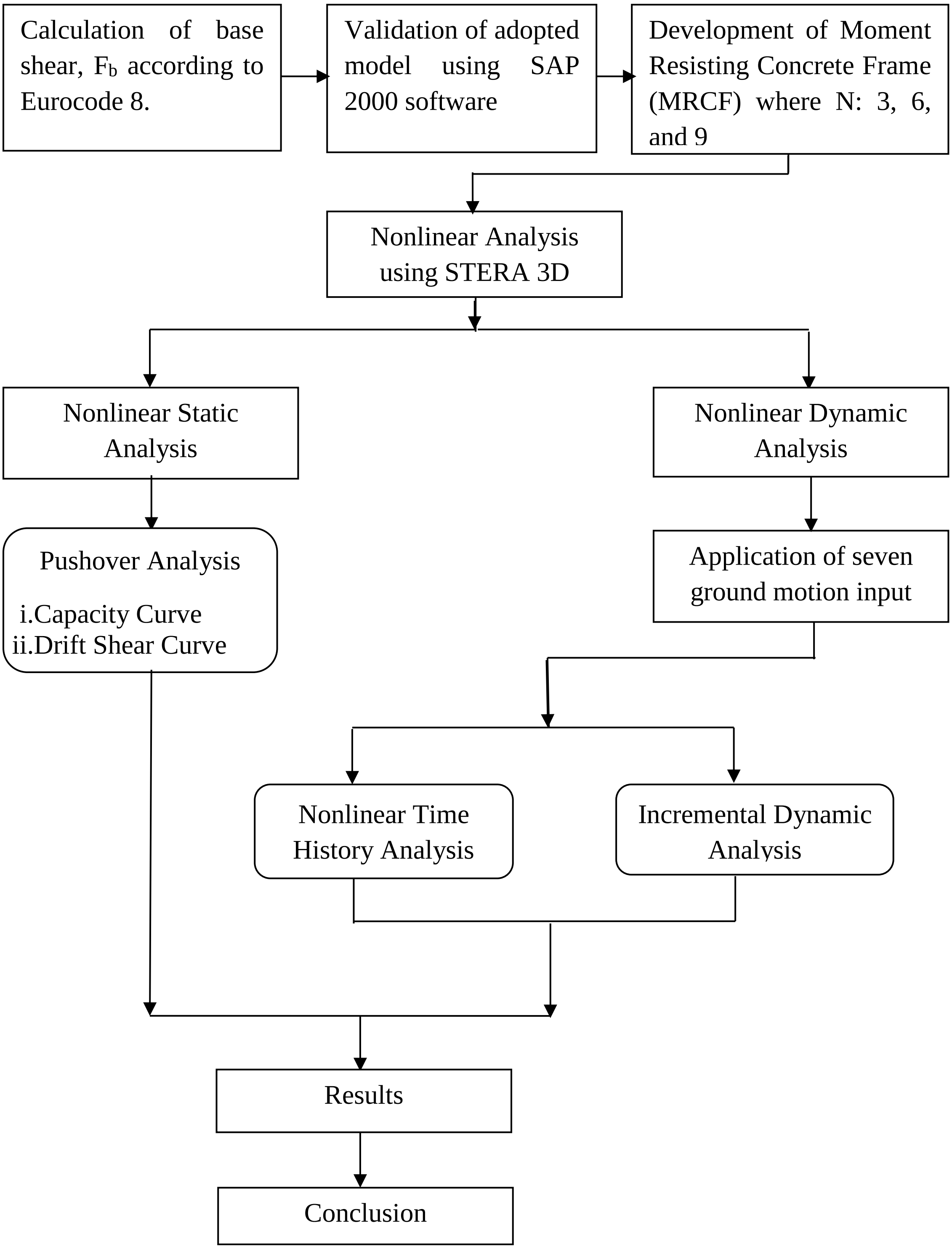


Figure 3.1: Flowchart of the study methodology.

## 3.2 Calculation of Base Shear According to EC8

In this study, parameters of the previous research done by Hatzigeorgiou and Liolios (2010) are 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 is 500 MPa. The load combinations used in this study were referred to Eurocode 8 (EC8):

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

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

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

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 EC8 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;

$\lambda$ 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,

$C_t$ 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 other 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, $q_0$, for systems regular in elevation (EC8, 2004)

| Structural Type | DCM | DCH |
|---|---|---|
| Frame system, dual system, coupled wall system | $3.0\ \alpha_u/\alpha_1$ | $4.5\ \alpha_u/\alpha_1$ |
| Uncoupled wall system | 3.0 | $4.0\ \alpha_u/\alpha_1$ |
| 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 $\alpha_u/\alpha_1$ is used for frames or frame-equivalent dual systems.

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

Ground type B is used for this study which can be referred in Eurocode 8, Clause 3.1.2, Table 3.1 that 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. 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:

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

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 acceleration branch |
| $a_g$ | is the design ground acceleration on type A ground ($ag = \gamma I.a_gR$) |
| $S$ | is the soil factor |

As a result from the calculation, $S_d(T)$ and the behaviour factor, q is 1.54 and 0.85, respectively. The distribution of the lateral forces of three storey model is shown in Table 3.3.

Table 3.3: Seismic lateral forces

| No. of storey | Lateral forces (kN) |
|---|---|
| 3 | 90.06 |
| 2 | 60.04 |
| 1 | 30.02 |

SAP 2000 software is used for computing base shear for three, six and nine storey model. Adopting 2D frames is selected with the number of storey, height, width and bays. For this modelling, only a three storey building is used as a model as shown in Figure 3.2. The unit used for the analysis is kN, m and C. The materials were defined in section properties, load patterns and load cases. The joints were constrained and selected beams and columns were assigned with distributed load and the lateral forces, respectively. Earthquake load cases were selected to run the analysis.

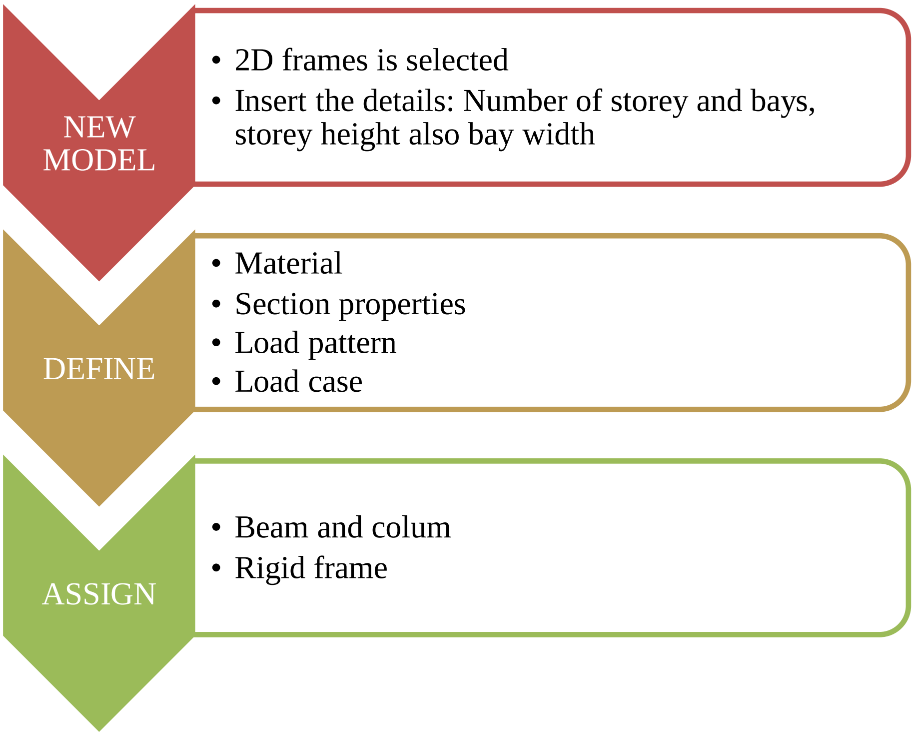


Figure 3.2: Workflow for SAP 2000 modelling

After all the details of the building had been applied, ‘Run Analysis’ is clicked where selected load case which earthquake load were applied to run the analysis. The deformed shape was presented in Figure 3.3 (b).

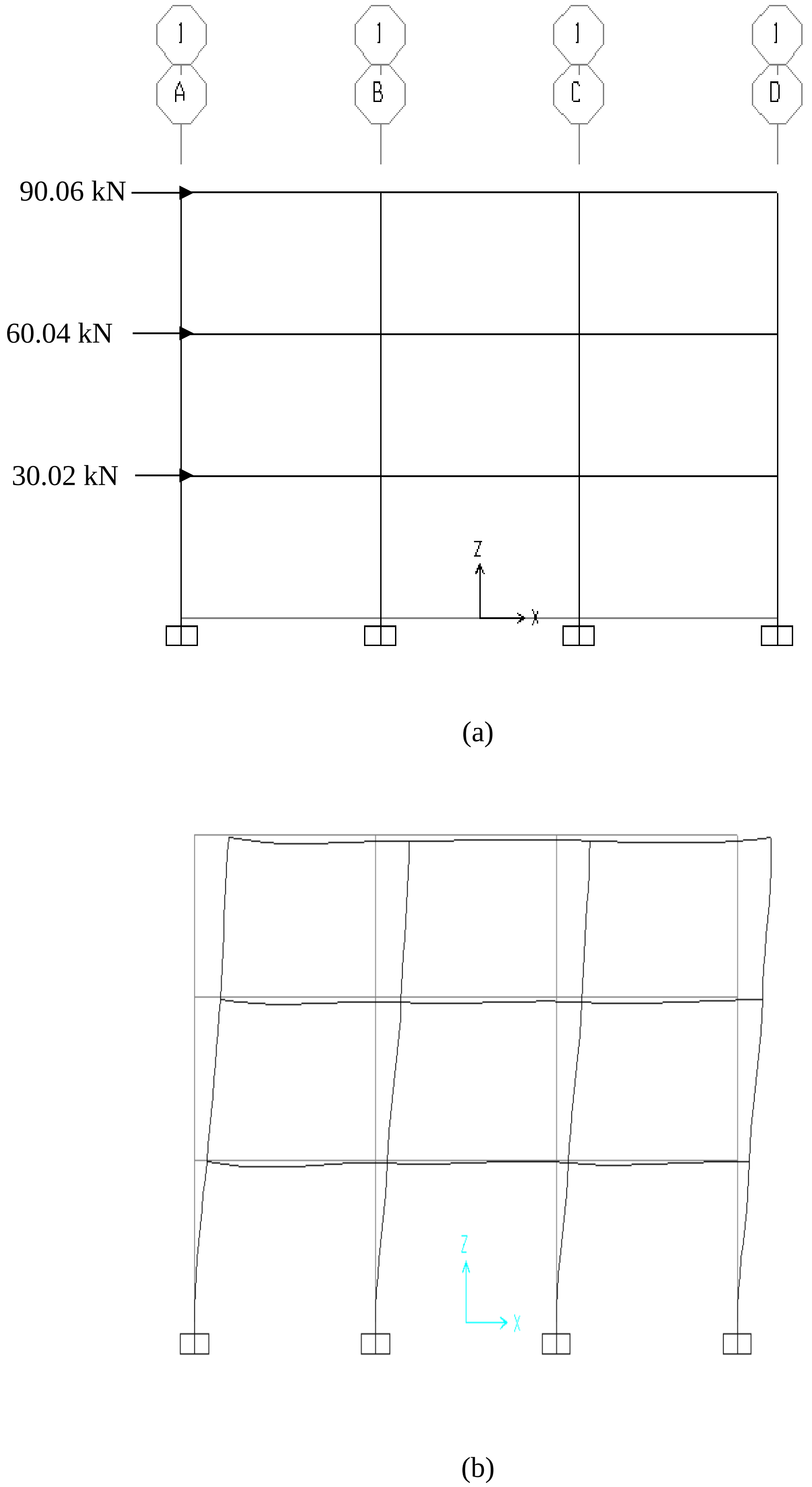
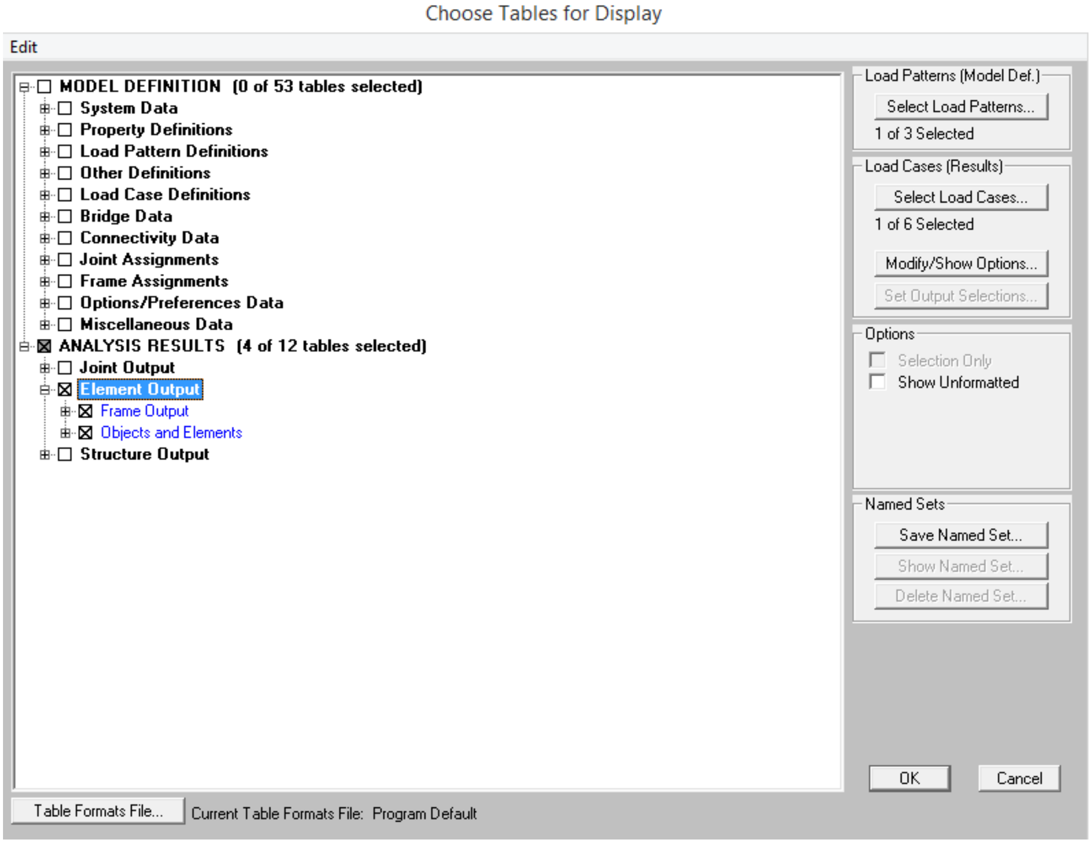


Figure 3.3: (a) Lateral force distribution and (b) Deformed shaped model of 3 storey.

Results can be extracted by choosing Tables and Frame Output were selected. The results were exported to excel files and calculation was done using the value obtained from the analysis.



☐ MODEL DEFINITION (0 of 53 tables selected)
  ☐ System Data
  ☐ Property Definitions
  ☐ Load Pattern Definitions
  ☐ Other Definitions
  ☐ Load Case Definitions
  ☐ Bridge Data
  ☐ Connectivity Data
  ☐ Joint Assignments
  ☐ Frame Assignments
  ☐ Options/Preferences Data
  ☐ Miscellaneous Data
☒ ANALYSIS RESULTS (4 of 12 tables selected)
  ☐ Joint Output
  ☒ Element Output
    ☒ Frame Output
    ☒ Objects and Elements
  ☐ Structure Output

1 of 3 Selected

1 of 6 Selected

☐ Selection Only
☐ Show Unformatted

Current Table Formats File: Program Default

Figure 3.4: Result from the analysis.