# SEISMIC DESIGN AND ANALYSIS OF MULTI STORY REINFORCED CONCRETE BUILDINGS IN MALAYSIA


By

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FINAL PROJECT REPORT

Submitted to the Department of Civil Engineering
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Civil Engineering)


Universiti Teknologi PETRONAS

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# CERTIFICATION OF APPROVAL

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Approved:

______________________________

Assoc. Prof. Dr Narayanan Sambupotty
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2013

## CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

______________________________

Djibrillah Oumarou Djibrillah

# ABSTRACT

Buildings in Malaysia are usually designed and analysed without provisions and considerations for earthquake loadings and seismic effects on the structures especially for high rise structures. This disregard for seismic activities comes from the fact that Malaysia is not located nearby the Pacific Ring of Fire which is known as a region where a lot of volcanic eruptions and seismic activities are happening; it is then easily derived and established in practice that severe earthquakes are unlikely to take place and minor ones can be discarded or considered to have negligible effects on compromising the integrity of the structures. Recently however, the occurrences of several earthquakes in neighbouring countries like Indonesia, and the Philippines, even though relatively situated far away, have triggered a series of vibrations which were felt on some of the structures of the high rise buildings. As a measure to prevent or ensure those buildings from being structurally compromised or from failure by collapsing, seismic analyses will have to be considered by being incorporated in the structural design process philosophy of these structures. This paper will involve a dynamic analysis of existing structures of different heights subjected to the nominal or Design Basis Earthquake using provisions of the Eurocode 8 or the Indian Standard IS 1893-1: 2002 Criteria for Earthquake Resistant Design of Structures. The buildings will also be tested to ground motion records scaled up appropriately. Suitable recommendations will be made based on the studies.

# ACKNOWLEDGEMENTS

First of all, I would like to thank Allah s.w.t for his blessings in making all this possible and allow me to finish this report in order to complete my undergraduate studies. I would also like to extend my gratitude to my supervisor, Assoc. Prof. Dr Narayanan Sambupotty, for all his patience, generous help, encouragement and guidance throughout this project when encountering difficulties and successfully completing it.

My parents, family and friends are not to be forgotten as they have continuously never failed to show their support and encouragement.

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# LIST OF ABBREVIATIONS

BS:  British Standard

IS: Indian Standard

ETABS: Extended Three-Dimensional Analysis of Building System

FYP: Final Year Project

SRSS: Square Roots of the Sum of Squares

CQC: Complete quadratic combination

DL: Dead Load

LL: Live Load

WL: Wind Load

EN: European Norm

RC: Reinforced Concrete

# CHAPTER 1
# INTRODUCTION

## 1.1 BACKGROUND

Malaysia is considered as a non-seismic zone because of the fact that its location is relatively far away from the Pacific Ring of Fire which is an active seismic zone. However, Malaysia has recently begun to experience truly significant tremors generated by earthquakes from neighbouring countries even though geographically theses earthquake epicentres are relatively situated far away. In urban area, the effects were quite felt strongly towards high rise buildings which have caused fear and panicking to some of the occupants living in them. For instance, on 11th April 2012 in Shah Alam, the earthquake of magnitude 8.9 on the Richter scale that occurred in Indonesia was strong enough to make the Persanda apartment shake vigorously. Due to these situations, occupants and designers might begin to question themselves about the safety of these structures and whether they are deemed fit to resist these unforeseen and unpredictable events of occurrence since it is beyond human control. Malaysia which has always been considered immune to earthquakes is now no longer invulnerable to them. Therefore, there is an urgent and important need to ensure that the structures provided or yet to be designed to be safe and reliable in order to fulfil their functions in case of occurrence of a worst case earthquakes scenario.

## 1.2 PROBLEM STATEMENT

In Malaysia usually, in their design philosophy, consideration are not given to earthquakes loadings. However recently, frequent tremors of earthquakes from neighboring countries have been felt on buildings especially high rise in Malaysia. This situation has increased concerns among people and also designers as most of these existing buildings have been designed with no provision to withstand earthquake loadings. Consequently, to ensure safety and structural integrity of these structures, earthquakes need to be taken into account in the design process and their behavior needs to be investigated as well to determine its effects. To conduct seismic analysis on structures, various methods are available but not all of them might be suitable for analysis. Choosing the appropriate method is crucial for a better estimation and significant evaluation of the effects.

## 1.3 OBJECTIVES

The objectives of this study are:

- To determine the behaviour of reinforced concrete buildings in Malaysia under earthquake loadings (to obtain natural frequencies, mode shapes),
- To analyse the structural integrity of these buildings in withstanding nominal earthquake loadings.
- To determine the inter-story drift of these reinforced concrete buildings and evaluate these inter-story drifts.

## 1.4 SCOPE OF STUDY

This study is limited only to the incorporation of seismic analysis into the design focus of existing buildings reinforced concrete type of structures in Malaysia using provisions of IS 1893-1: 2002 or the EN 1998-1: 2004. The static analysis, response spectrum analysis or linear time history analysis will be utilized alongside ETABS to conduct and facilitate the study.

## 1.5 RELEVANCY & FEASIBILITY OF PROJECT

Occurrences of earthquakes are quite unknown and unpredictable. As a structural engineer or an occupant, we need to realize its possibility of occurrences at any time by taking into consideration earthquake loadings in the design philosophy for new structures. However, existing structures also need to be taken into consideration as they have a higher unknown level of structural integrity to withstand earthquakes. Therefore, they must be analysed to estimate their level of integrity and safety.

This project is feasible as it mainly involves the use of software to perform the structural analysis. The study is divided in two parts (FYP 1 and FYP 2) and 28 weeks period is allocated to conduct the whole study. It might be considered enough time to complete this project.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 INTRODUCTION

Literature review is an important part of the study as it helps into the understanding of the processes and analysis of the research. The basic intention of our literature review is to give a comprehensive review of previous works on the area of seismic design and analysis of reinforced concrete. In this review, we will focus on the experience from different places around the world but Special consideration will be given to the Malaysian experience. The literature review will try to establish the link between past research, work done on this topic and this study to determine its relevancy and thorough understanding. There are four sections in this review that will help the readers in giving him an overview of the study. The first section is about earthquakes that have been experienced in Malaysia along with their magnitude, location and effects. Then the next section elaborates about types of earthquakes analysis which can be used to carry out the study. Next, the section discusses the Indian seismic code and the Eurocode for seismic design. Finally, the section involves past research conducted in Malaysia on earthquake design.

## 2.2 EARTHQUAKES EXPERIENCED IN MALAYSIA

Even though in the 1980s, the dam-induced Kenyir earthquake occurred, the first earthquake with epicentres in Peninsular in Malaysia took place in Bukit Tinggi in November 2007 and in May 2008. From 1973 to present days, more than forty four earthquakes have been reported in East Malaysia with Ranau, Kudat and Lahad Datu being the most active seismic zone with the strongest earthquake ever registered in Lahad Datu in 1976 with a magnitude of 6.2 (Lat, Che Noorliza, Ibrahim, 2009).

Earthquakes that occur in the Sumatran Region often have affected Peninsular Malaysia in the past by means of vibrations that have been felt on some of the buildings. In fact, between the year 2002 and year 2003, two earthquakes, respectively, of intensity Mw = 7.4 and Mw = 5.8 took place near the Sumatran Field have caused intense vibrations on some of the buildings that has resulted in public concerns in many cities. In Penang, the first earthquake caused even cracks on some buildings (Adnan, Hendriyawan, Marto, 2004)

Malaysians were significantly surprised by the Sumatra (Andaman) earthquake in November 26, 2004. The earthquake generated the most critical and direct impact with an intensity of 9.15 on the Richter scale. Consequently, a tsunami occurred and made more damages. Tremors were highly experienced especially by people in high-rise building in western states of Peninsular Malaysia (Koong, Won, 2005).

## 2.3 TYPES OF EARTHQUAKES ANALYSIS

There are many types of analysis techniques to take seismic effects into consideration when analysing and designing structures. And depending on certain parameters such as number of stories, ground conditions, importance factor and risk and consequences associated with its construction and failure, many of the codes of practices incorporate dynamic analyses on top of static analyses for more accurate simulation and results. Static analysis or equivalent static procedure to compute equivalent lateral force of the earthquake is easier and require less computation as compared to the dynamic analyses. Because of this it carries a great amount of uncertainties during analyses because of so many oversimplifications. However dynamic analyses in earthquake analyses are divided in parts: time history analysis and response spectrum analysis. Time history dynamic analysis consist of recording a range of earthquake accelerations with respect to time in the form of a plot called response history and evaluate the response of the structure over time. It has the advantage of being utilized for nonlinear and linear analysis. Additionally for dynamic analyses, there is another method called response spectrum method which is a plot of peak periods of an earthquake to accelerations which are used to obtain the acceleration to be applied on the structure.

### *2.3.1 STATIC ANALYSIS*

In this method of seismic analysis, the total base shear is distributed alongside the height of the building to describe the effects of seismic ground motion on the structure. The base shear is first computed based on simple formulas which depend on the codes used alongside some empirical multiplier. It takes into consideration the seismic weight of the building and the design horizontal seismic coefficient of the structure which depends on the seismic hazard exposure of that particular zone. Albeit, it is a static method, somehow it includes some dynamic factors of the building such as the fundamental period **T** and the response reduction factor **R**.

According to the Clause 7.5 of IS 1893 (Part 1): 2002, the design base shear along any principal direction can be determined by the following formula:

$$\mathbf{V_B = A_h W}$$

Where,

$\mathbf{A_h}$ = Design horizontal seismic coefficient of the structure

**W** = Seismic weight of the building

### *2.3.2 TIME HISTORY ANALYSIS*

The Time history analysis involves a time-step by step integration of dynamic equilibrium equation. The general Equation for a dynamic response of a multi-degree of-freedom system subjected to ground motion is given by the D'Alembert principle by the following equation as:

$$\mathbf{M \ddot{X} + C \dot{X} + KX = F}$$

Where,

**C** = Damping Matrix

**M** = Mass matrices

**K** = Stiffness matrices

$\mathbf{\ddot{X}}$ = Acceleration

$\mathbf{\dot{X}}$ = Velocity

**X** = Displacement

**F** = Inertial force of the earthquake

**F** = Force vectors

The same equation can be used for response spectrum analyses with the only differences in input as for time history will make use of response history and for response spectrum analyses will be using response spectra graphs.

### *2.3.3 RESPONSE SPECTRUM ANALYSIS*

This is a very useful method for analysing the performance of structures during earthquakes. It makes use of the peak period obtained from a dynamic analysis of a single degree-of-freedom-system. Peak ground accelerations are recorded for different periods of the structure and then these accelerations are plotted against their equivalent periods to come up with a graph called dynamic response spectrum. It is strongly recommended in practices that the curves obtained be smoothened out as they might be very rough. As per Clause 7.8.4.5 of the IS 1893 (Part 1): 2002, to obtain the peak story shear force, use of statistical method called modal combination techniques such as ABS (Sum of the Absolute values) or Maximum Absolute Response, SRSS (square roots of the sum of squares) and CQC (Complete quadratic combination).

Here below is a representation of a response spectrum graph:

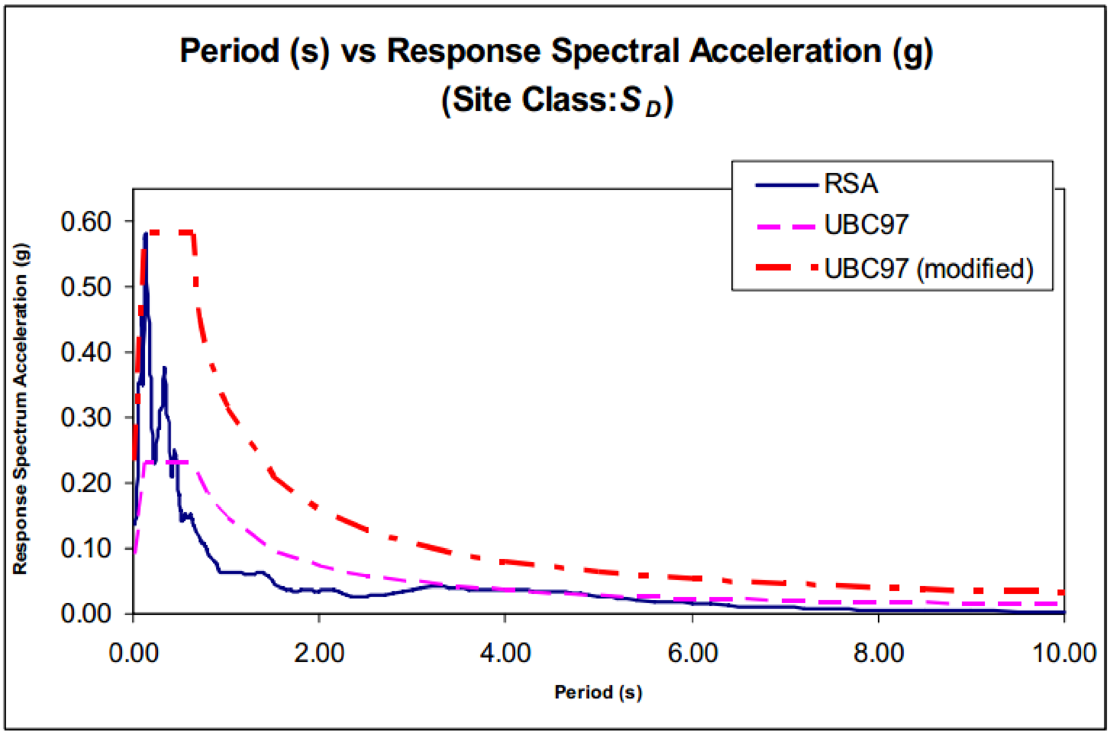


**Figure 1 Response Spectrum Accelerations**

In order to make this graph above useful and use it for our analysis, values will have to be extracted and put in a tabulated form as in the table below:

**Table 1 Tabulated Response Spectrum Accelerations**

| Period (s) | RSA (g) |
|---|---|
| 0.01 | 0.2331 |
| 0.1271 | 0.5828 |
| 0.6356 | 0.5828 |
| 0.70 | 0.4500 |
| 0.80 | 0.3938 |
| 0.90 | 0.3500 |
| 1.00 | 0.3150 |
| 1.50 | 0.2100 |
| 2.00 | 0.1575 |
| 2.50 | 0.1260 |
| 3.00 | 0.1050 |
| 3.50 | 0.0900 |
| 4.00 | 0.0788 |
| 4.50 | 0.0700 |
| 5.00 | 0.0630 |
| 5.50 | 0.0573 |
| 6.00 | 0.0525 |
| 6.50 | 0.0485 |
| 7.00 | 0.0450 |
| 7.50 | 0.0420 |
| 8.00 | 0.0394 |
| 8.50 | 0.0371 |
| 9.00 | 0.0350 |
| 9.50 | 0.0332 |
| 10.00 | 0.0315 |

## 2.4 DESIGN PHILOSOPHY OF EARTHQUAKES

According to Pankaj A. & Manish S. (2006) the philosophy of seismic design is to guarantee that the structures possess at least a minimum capacity to withstand without any damage minor earthquake, Design Basis Earthquake DBE without significant structural damage and Maximum Considered Earthquake MCE without complete failure. the IS 1893 (Part 1): 2002 defines the Design Basis Earthquake (DBE) as the maximum earthquake that is more likely to happen during the design life of the structure and the Maximum Considered Earthquake (MCE) as the most critical earthquake effects considered. The MCE is usually the double of the DBE. Since complete protection against earthquakes of all sizes is impossible and uneconomical, the basic criteria of seismic design should be established on lateral strength, deformability, ductility and stiffness of the structure.

## 2.5 STUDIES IN MALAYSIA

Malaysia has always been classified among regions with low or inexistent seismic activity. As a result, earthquake resisting design philosophy was never taken into account. Malaysia recognize the possibility and threat of seismic hazard to perpetrate human casualties and properties damages only after being touched by a series of earthquake waves which have been materialized by buildings swaying and cracks. Since less than one per cent of structures in Malaysia are not designed with provisions to resist earthquakes, a great deal of attention to that matter has begun to rise (Madjid, 2009). But in 2002, when the Gujarat earthquake occurred in India, its waves travelled more than 600 km from the epicentre and caused damages to several cities; the MMD (Malaysian Meteorological Department) took that matter to the government to take measures in adopting Seismic Design philosophy into buildings design as no law before was adopted to deal with this issue ( Bendick et al., 2001).

Repeated near field earthquakes are generally discarded even though their effects on reinforced concrete buildings are recognized. An investigation was conducted to obtain the response of high rise buildings under single near field earthquake and repeated near field earthquake and derive a comparison between the responses. It was found out that a repeated near field earthquake has more impacts than a single near field earthquake (Zulham, Madjid. and Faisal, 2012).

To analyze the performances of a structural and the soil response in the presence of an earthquake loading, by time history methods, ground motion acceleration of the earthquake will have to be identified. However, in Malaysia, to produce acceleration ground motion, Uniform Hazard Spectra (UHS) was carried out in two ways since there is a lack of data registered. Even though, the ground acceleration for Kuala Lumpur can be determined through this method, a variation of up to 35% can be expected from the origin to the surface (Adnan, Hendriyawan, Marto, Irshyam, 2006). In recent years, Malaysia is more aware of the seismic effect on their structures because of the tremors were repeatedly felt over the centuries from the earthquake events around Malaysia. Most bridges in Malaysia do not take earthquake loadings into structural design consideration. A case study conducted by Tan (2002) on the behaviour of high-rise building under seismic effect for PETRONAS Twin Tower (KLCC) used Finite Element Analysis. The studies on performance of high rise buildings in Malaysia with various intensity of earthquake using Finite Element Modelling have been conducted by Noor Aishah (2002) and Yew (2000). Therefore the assessment due to seismic is very important in order to recognize the performance of the buildings. A seismic risk analysis addressed to earthquake emergency management and protection strategies planning, requires vulnerability and damage evaluation performed at territorial scale (Giovinazzi, 2005). IDARC-2D dynamic non-linear analysis software is used to analyse the structures with different intensities load to know the maximum allowable earthquake load intensity for the buildings.

Suradi (2007) also adopted the performance base seismic engineering in her study. The intent of earthquake resistance design therefore has become one of attempting to limit the damage experience by a building to levels, which are considered acceptable by structural engineers. Historically, damage that would not result in loss of life was deemed acceptable for most structures (Hamburger, 1996). Performance-based seismic engineering (PBSE) is defined as the procedure of design and construction of structures that will resist earthquakes in a predictable manner (Hamburger, 1996). It is to make owners and designers capable of selecting alternative performance goals or objective for the design of different structures. Severe earthquakes are relatively frequent events, which may or may not ever occur within the life of a building.

## 2.6 SUMMARY

Review of various journals, technical papers and other materials show how important study of earthquakes and structural integrity to earthquakes loadings are since these loadings are quite unforeseen and unpredictable. This is to ensure that buildings to fulfil their primary purpose which is to provide safe and reliable shelter for people. The literature discussed about codes and method of analysis. This is to ensure that we understand the basics concepts of design and analysis so that the study can be carried out effectively. However the model should be simple enough to avoid complex situations but representative enough to include major and important details. To conclude, all these literature reviews are precious to conduct the study of our project to its terms.

# CHAPTER 3
# METHODOLOGY

## 3.1 INTRODUCTION

The methodology that is going to be used to evaluate and complete this study will be based on the following subsections. First, the design will be conducted as per current design of code practice (DL + LL + WL) then checked against earthquake loadings. There are three ways to do that:

- Static Analysis,
- Response Spectrum Analysis and,
- Time Series.

However, only Response Spectrum Analysis will be used for our dynamic analysis to check against earthquake loading and to find out the dominant frequencies of the structure and mode shapes.

## 3.2 BUILDING CHARACTERISTICS

For our study purpose structures of 3, 5, 10, 20 and 30 stories level high will be analyzed. To simplify our study, the parameters and variables such as the base area of the structures is assumed to be a square and only one different base area is chosen (24m x 24m). Column to column distance or span is taken 6m and for the beam sizing it is assumed to be respectively 0.2m and 0.45m for thickness and depth. Slabs are assumed to have a thickness of 0.15m. However, column sizes will vary due to height and are summarized in the table below. All columns are assumed to be square and their sizing is given in the table below. The building is considered as residential type and story height will be considered as 3m as per Malaysian practice.

**Table 2 Member Dimension for Modeling**

| Structure | Function | Number of Floors | height (m) | Column Sizing (mm) |
|---|---|---|---|---|
| 1 | mixed | 3 | 9 | 400 |
| 2 | mixed | 5 | 15 | 500 |
| 3 | mixed | 10 | 30 | 1 to 5 floors - 800<br>6 to 10 floors - 500 |
| 4 | mixed | 20 | 60 | 1 to 5 floors - 1200<br>6 to 10 floors - 1000<br>11 to 15 floors - 800<br>16 to 20 floors - 500 |
| 5 | mixed | 30 | 90 | 1 to 5 floors - 1700<br>6 to 10 floors - 1500<br>11 to 15 floors - 1200<br>16 to 20 floors - 1000<br>21 to 25 floors - 800<br>26 to 30 floors - 500 |

## 3.3 LOADINGS

For this analysis, there are only two (2) types of loading which are going to be considered: horizontal loads and vertical loads. Vertical loads comprise of the self-weight of the structure, dead loads, and live loads. These loads have the similar features of being marked by gravity. On the contrary, horizontal loads which are also referred as lateral loads are loads that present perpendicularity to the gravitational forces and comprise in this case only wind load and earthquake load. In the following, as per Malaysian practice, details about loading values and assumptions will be given.

### *3.3.1 DEAD LOAD*

Dead loads are permanent loads which are acting on the structure. The unit weights of the materials that will help in calculations are as follow:

Reinforced Concrete : 24.0 $kN/m^3$

However this will be considered automatically in the software. As for super dead load to account for finishes cladding and any additional dead load, we will take it to be 2 kN/m$^2$ and will be the same for all floors throughout.

### *3.3.2 LIVE LOAD*

Live load is the load that accounts for the intended use or occupancy. As per BS6399 and current Malaysian practice, the value of live load shall be taken as 1.5 kN/m2 and will be the same for all floors from top to bottom.

### *3.3.3 WIND LOAD*

Wind load is part of horizontal loadings acting on the building structure. We suppose it acts on the wall areas along the side of the building with higher effect as we go up. The basic wind speed is taken to be 35 m/s.

### *3.3.4 SEISMIC LOAD*

Seismic loads are loads generated and induced by an earthquake in form of acceleration of the ground motion. From the studies of response spectrum conducted by Taksiah A. M. (2007) in one of the paragraphs above, the acceleration for the range of higher peaks is within 0.04g which will be considered for the analyses with soil class taken as D.

## 3.4 ETABS SOFTWARE

ETABS software is an integrated building design software developed and released by Computers and Structures, Inc. to analyze and design building systems. Even though, it might seem sophisticated, it is very user-friendly. With the capacity of taking care of the most complex and largest model, it has become software of choice of structural engineer in the construction industry. However, the advantages of using ETABS are (Computers & Structures, 2005):

- With ETABS, any building configuration is possible even though most buildings are straightforward in geometry with horizontal beams and vertical columns. Then, a grid system can be established defined by horizontal floors and vertical column geometry with almost no effort.

- The similarity of the floor levels in a building can be used to significantly reduce the time for modelling and designing.
- The structural definition is simple, to the point and representative. The input and output conventions used correspond to common building terminology. In ETABS, the definition of the models is done logically floor-by-floor, column-by-column, bay-by-bay and wall-by-wall.
- ETABS corrects effects on the stiffness of the frame because of large member dimensions in relation to story heights and bay widths in the formulation of the member stiffness.
- The results produced by the program does not need additional processing before being used in structural design it is already in a form that is directly usable as compared to some general-purpose computer program results which may need additional processing.

## 3.5 FLOWCHART

The figure below shows the course of the project, in order words it means the steps that will be used to evaluate and complete this study.

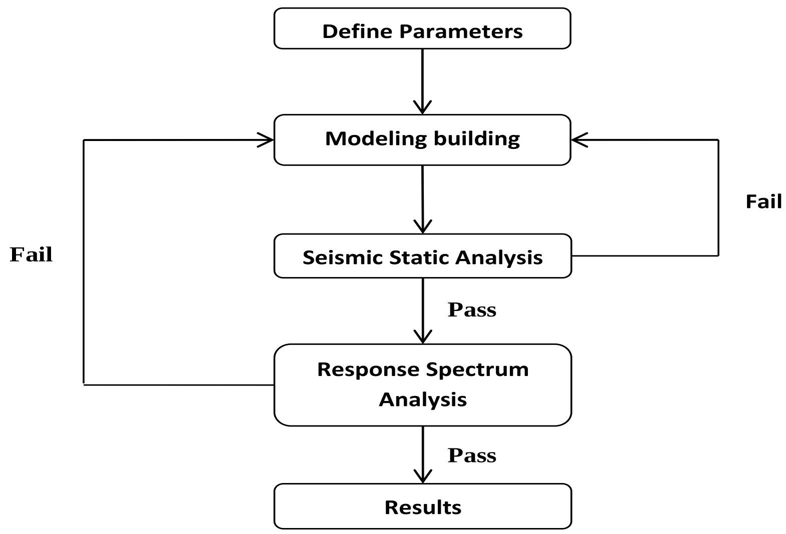


**Figure 2 Research Methodology Flow Chart**

For the First part of the seismic static analysis in ETABS, these steps shall be followed:

- First establish the structure size and dimensions (such as height of the stories, distances between columns and overall dimensions)
- Define code(s) to be used alongside material properties (in our case concrete)
- Then we need to define and assign section properties (beams and columns) and also draw the others elements if applicable (floor, walls, piers and spandrels)
- define and assign all the loads that are applicable (dead, live, and wind) and set up the load combination of static load cases.
- The last step is to run the analysis and the design to view the outputs

For the second part including response spectrum analysis in ETABS, follow the steps below:

- First open any of the models which has been previously analysed statistically in the first part of the analysis
- Next define and assign any response spectrum input
- Finally run the analysis and the design to get the outputs

The above are just outlines which try to give an insight and clarification on how the study was carried out using ETABS. To be actually done an implemented one needs to be very familiar with the software through learning by reading and exercising.

## 3.6 PROJECTS ACTIVITIES

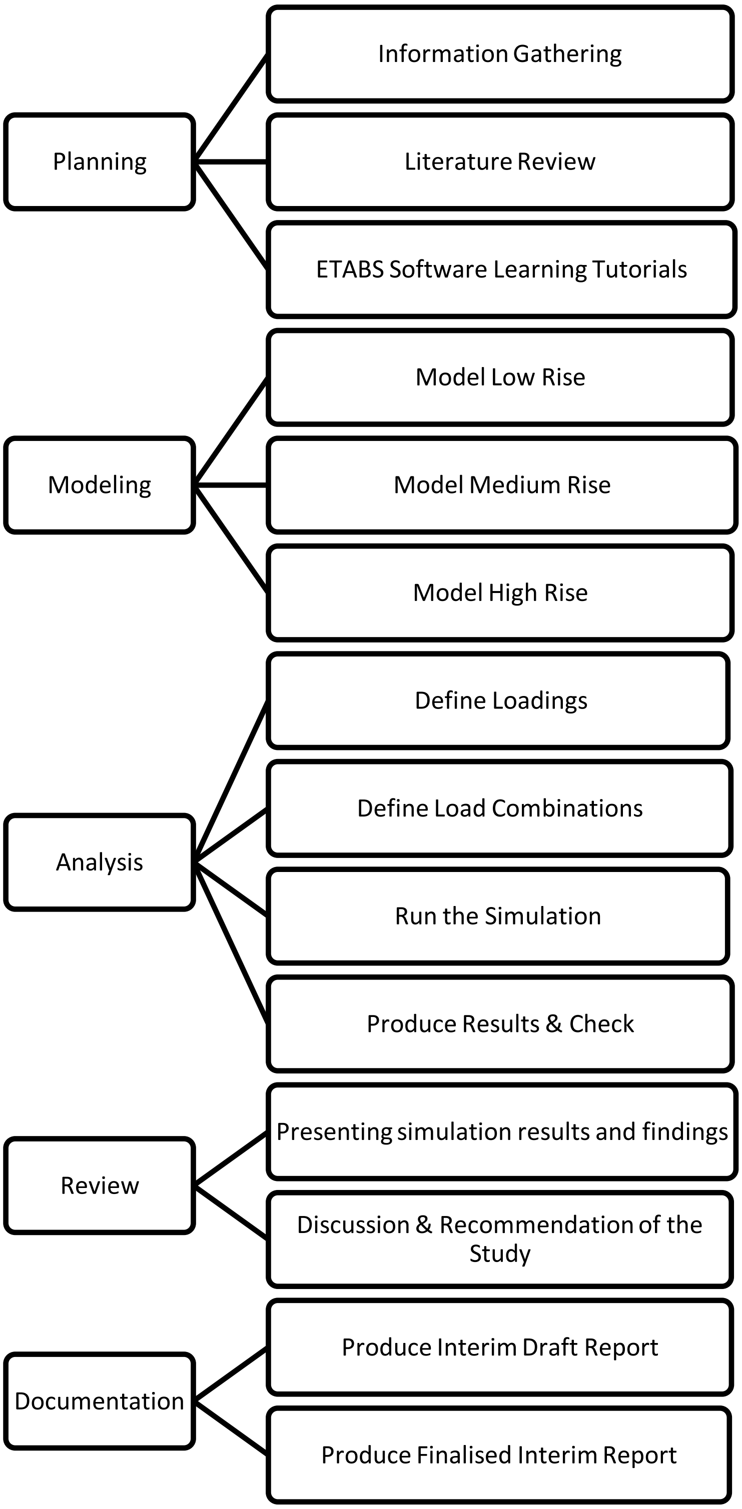


**Figure 3 Project Activities**

## 3.7 MAPPING OUT RESEARCH TIMELINE

The following key milestones and Gantt chart present all the activities that are involved in our project with their framework and timeline as in table 3.1 and table 3.2 respectively.

**Table 3 Key Milestones for FYP 1**

| Week | Activities | Person Involved | Documentation Progress |
|---|---|---|---|
| End of Week 2 | Topics To be Selected | Student | |
| End of Week 3 | Supervisor Assignment | Coordinator | |
| | Topic Confirmation | Student | |
| | Finding & Analysing Litterature | Student | Litterature Review |
| End of Week 4 | Planning & Structuring | Student | Methodology |
| End of Week 5 | Extended Proposal Defence Draft Preparation | Student | Extended Proposal |
| | To be Checked | Supervisor | Draft |
| End of Week 6 | Submission of Extended Proposal Defence | Student | Extended Proposal |
| | | Supervisor | |
| | | Coordinator | |
| End of Week 9 | Project Defence | Student | Slides |
| | | Supervisor | |
| | | Examinor | |
| End of Week 11 | Spreadsheets & Models | Student | |
| End of Week 12 | Testing Models | Student | |
| End of Week 13 | Submission of Interim Draft Report | Student | Interim draft Report |
| | | Supervisor | |
| End of Week 14 | Submission of Interim report | Student | Interim Report |
| | | Supervisor | |
| | | Examinor | |

**Table 4 Key Milestones for FYP 2**

| Week | Activities | Person Involved | Documentation Progress |
|---|---|---|---|
| Week 1 - 5 | Finalizing Modelling & Static Analysis | Student | |
| End of Week 6 | Run Response Spectrum Analysis | Student | |
| End of Week 7 | Output of Response Spectrum Analysis | Student | |
| End of Week 8 | Sbmission of Progress Report | Student | Progress Report |
| End of Week 9 | Interpret all the Outputs | Supervisor | Results Sections |
| | | Student | |
| End of Week 10 | Pre-Sedex and Submission of Dissertation Draft | Student | Poster |
| | | Supervisor | |
| | | Examinor | |
| End of Week 11 | Amendments of Dissertation | Student | Dissertation |
| End of Week 13 | Oral presentation & Technical Paper | Student | Poster |
| | | Supervisor | |
| | | Examinor | |
| End of Week 14 | Submission of Project Dissertation | Student | Dissertation |
| | | Supervisor | |
| | | Examinor | |

**Table 5 Gantt Chart for FYP 1**

| No. | Detail/Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Topic Selection | | X | | | | | | | | | | | | |
| 2 | Meeting Project Supervisor | | | X | X | X | X | X | X | X | X | X | X | X | X |
| 3 | Preliminary Studies | | | | | | | | | | | | | | |
| | 1. Finding & Analysing Litterature | | | X | X | X | X | | | | | | | | |
| | 2. Preliminary planning & structuring | | | | X | | | | | | | | | | |
| | 3. Extended Proposal Defence Preparation | | | | | X | X | | | | | | | | |
| 4 | Extended Proposal Defence Submission | | | | | | X | | | | | | | | |
| 5 | Proposal Defence | | | | | | | | X | X | | | | | |
| 6 | Project Flow | | | | | | | | | | | | | | |
| | 1. Spreadsheets to Calculate Lateral Forces | | | | | | X | X | | | | | | | |
| | 2. Modelling the Structures to be analysed | | | | | | X | X | X | X | X | X | | | |
| | 3. Testing the Models | | | | | | | | | | | X | X | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 7 | Submission of Interim Draft Report | | | | | | | | | | | | | X | |
| 8 | Submission of Interim Report | | | | | | | | | | | | | | X |

**Table 6 Gantt Chart for FYP 2**

| No. | Detail/Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Model Simulations** | X | X | X | X | X | | | | | | | | | |
| 2 | **Meeting Project Supervisor** | X | X | | | X | | | X | X | X | X | X | X | X |
| 3 | **Project Continuation** | | | | | | | | | | | | | | |
| | Interpretation | | | | | X | X | X | | | | | | | |
| | Amendments | | | | | | | | X | X | X | X | X | X | |
| 4 | **Submission of Progress Report** | | | | | | | | X | | | | | | |
| | **Pre-Sedex** | | | | | | | | | | X | | | | |
| | **Submission of Dissertation Draft** | | | | | | | | | | X | | | | |
| | **Submission of Technical Paper** | | | | | | | | | | | | | X | |
| 5 | **Oral Presentation** | | | | | | | | | | | | | X | |
| 6 | **Submission of Dissertation** | | | | | | | | | | | | | | X |

## 3.8 TOOLS

- ETABS software
- Excel Spreadsheets

## 3.9 SUMMARY

There are several steps to follow in order to complete this project within the allocated timeframe but the very first step to follow will be to acquire an understanding in depth of the subject matter through literature review and analysis and also by regularly meeting one's supervisor. This can be accomplished through extensive reading of articles, journals, technical papers, web pages from the internet and related books. It helps in getting background information on the subject as well as in building technical knowledge which will allow in making the right assumptions and concepts to be applied to complete the project.

# CHAPTER 4
# RESULTS & DISCUSSION

## 4.1 INTRODUCTION

This section mostly presents and interprets the results obtained from the software ETABS after running the analysis and the design check for all the reinforced concrete building frames subjected to dead, live, wind, earthquake loads and response spectrum analyses . We will then divide the results into two parts; first all the results will be tabulated and displayed in a way for simplification and clarification of presentation purpose. Last the results presented will be discussed in accordance to the objectives of the study and subjected to various interpretations in accordance with theories and code of practices.

## 4.2 RESULTS

All the tables below will summarise the inter-story drifts, periods and modes of each building which has been analysed and all the figures below show their column P-M-M interaction ration.

- **3-Story building of height 9m**

**Table 7 3-Story Building Inter-Story Drift**

| Story | Drift X | Drift Y |
|---|---|---|
| STORY3 | 0.00092 | |
| STORY3 | | 0.00092 |
| STORY2 | 0.0018 | |
| STORY2 | | 0.0018 |

| | | |
|---|---|---|
| STORY1 | 0.00368 | |
| STORY1 | | 0.00368 |

**Table 8 3-Story Building Periods and Modes**

| Mode | Period | Modal Mass | Modal Stiff |
|---|---|---|---|
| 1 | 0.87996 | 112.98484 | 5760.45 |
| 2 | 0.87996 | 112.98484 | 5760.45 |
| 3 | 0.77293 | 112.98484 | 7466.25 |

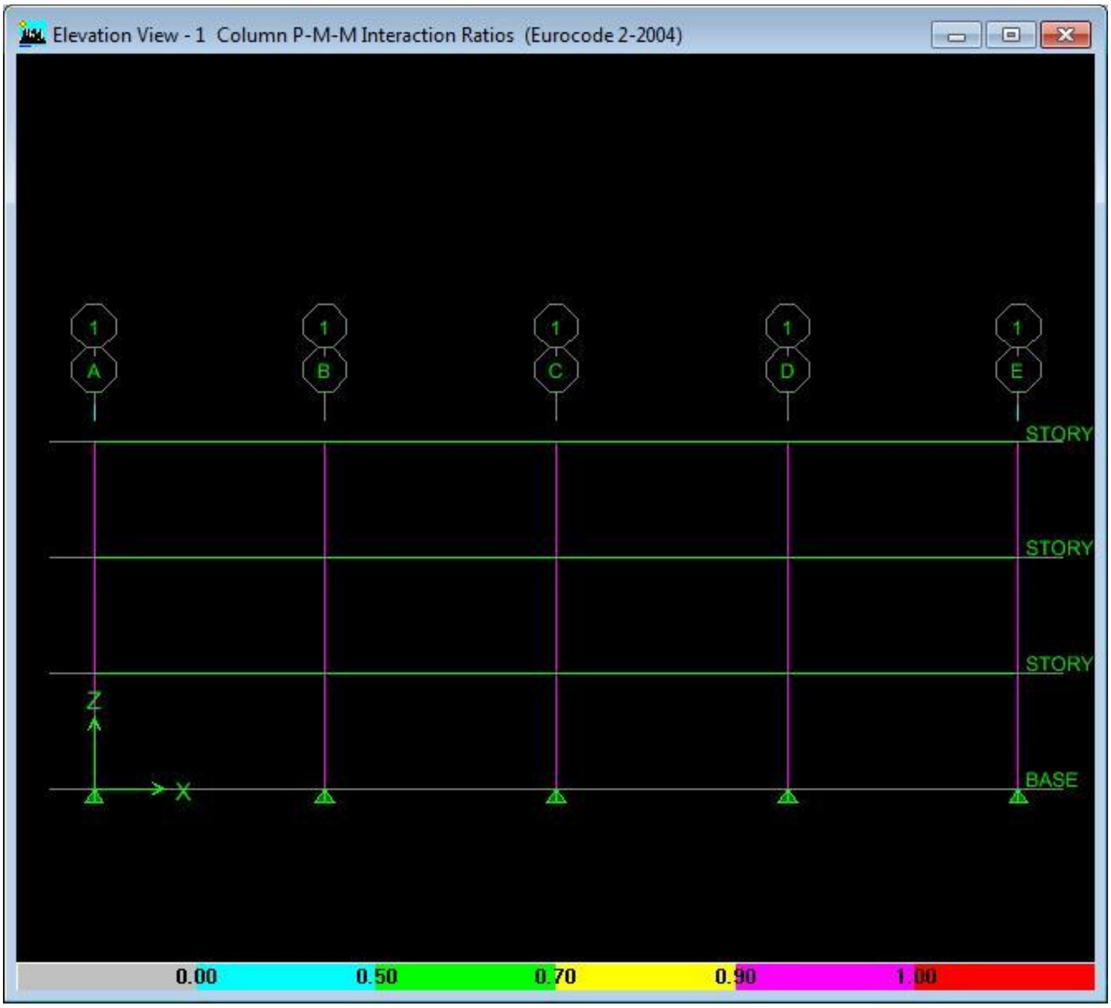


**Figure 4 Column P-M-M Interaction Ratio of 3-Story Building**

- **5-Story building of height 15m**

**Table 9 5-Story Building Inter-Story Drift**

| Story | Drift X | Drift Y |
|---|---|---|
| STORY5 | 0.000749 | |
| STORY5 | | 0.000749 |
| STORY4 | 0.001178 | |
| STORY4 | | 0.001178 |
| STORY3 | 0.001665 | |
| STORY3 | | 0.001665 |
| STORY2 | 0.002261 | |
| STORY2 | | 0.002261 |
| STORY1 | 0.003276 | |
| STORY1 | | 0.003276 |

**Table 10 5-Story Building Periods and Modes**

| Mode | Period | Modal Mass | Modal Stiff |
|---|---|---|---|
| 1 | 1.159091 | 112.9848 | 3320.053 |
| 2 | 1.159091 | 112.9848 | 3320.053 |
| 3 | 1.019144 | 112.9848 | 4294.465 |
| 4 | 0.31039 | 112.9848 | 46298.27 |
| 5 | 0.31039 | 112.9848 | 46298.27 |

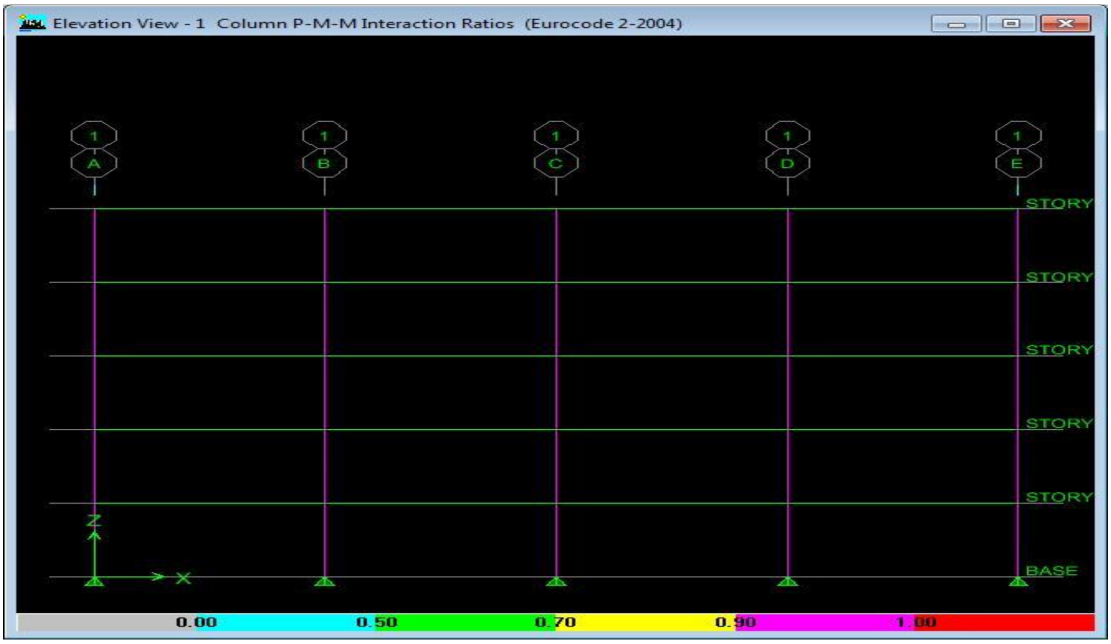


**Figure 5 Column P-M-M Interaction Ratio of 5-Story Building**

- **10-Story building of height 30m**

**Table 11 10-Story Building Inter-Story Drift**

| Story | Drift X | Drift Y |
|---|---|---|
| STORY10 | 0.000572 | |
| STORY10 | | 0.000573 |
| STORY9 | 0.00087 | |
| STORY9 | | 0.00087 |
| STORY8 | 0.001169 | |
| STORY8 | | 0.001169 |
| STORY7 | 0.00146 | |
| STORY7 | | 0.00146 |
| STORY6 | 0.001803 | |
| STORY6 | | 0.001803 |
| STORY5 | 0.001913 | |
| STORY5 | | 0.001913 |
| STORY4 | 0.002052 | |
| STORY4 | | 0.002053 |
| STORY3 | 0.002226 | |
| STORY3 | | 0.002226 |
| STORY2 | 0.002429 | |
| STORY2 | | 0.002429 |
| STORY1 | 0.00266 | |
| STORY1 | | 0.00266 |

**Table 12 10-Story Periods and Modes**

| Mode | Period | Modal Mass | Modal Stiff |
|---|---|---|---|
| 1 | 2.075403 | 112.9848 | 1035.559 |
| 2 | 2.075403 | 112.9848 | 1035.559 |
| 3 | 1.722495 | 112.9848 | 1503.363 |
| 4 | 0.600905 | 112.9848 | 12352.88 |
| 5 | 0.600905 | 112.9848 | 12352.88 |
| 6 | 0.527975 | 112.9848 | 16001.19 |
| 7 | 0.293608 | 112.9848 | 51742.2 |
| 8 | 0.293608 | 112.9848 | 51742.2 |
| 9 | 0.258643 | 112.9848 | 66677.5 |
| 10 | 0.181634 | 112.9848 | 135202.7 |

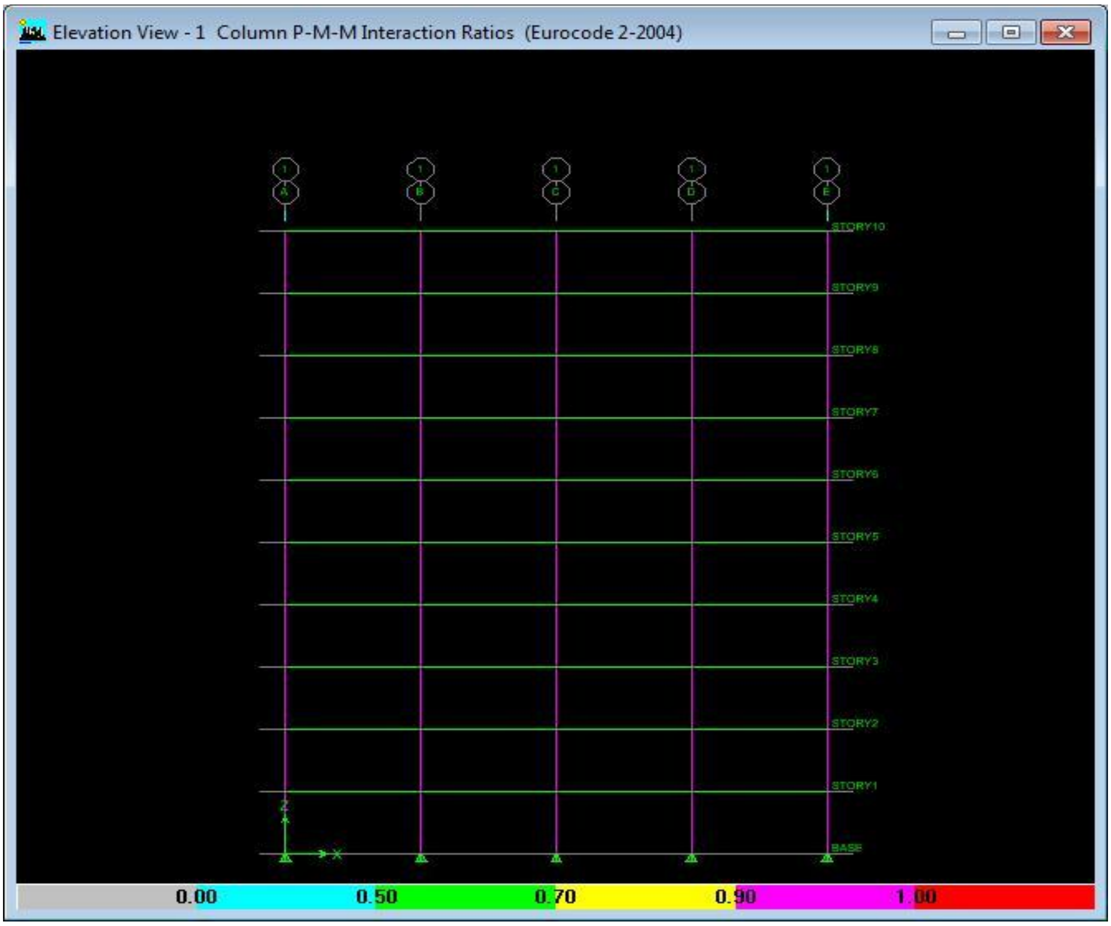


**Figure 6 Column P-M-M Interaction Ratio of 10-Story Building**

- **20-Story building of height 60m**

**Table 13 20-Story Building Inter-Story Drift**

| Story | Drift X | Drift Y |
|---|---|---|
| STORY20 | 0.000553 | |
| STORY20 | | 0.000553 |
| STORY19 | 0.000819 | |
| STORY19 | | 0.000819 |
| STORY18 | 0.001073 | |
| STORY18 | | 0.001073 |
| STORY17 | 0.001281 | |
| STORY17 | | 0.001281 |
| STORY16 | 0.001443 | |
| STORY16 | | 0.001443 |
| STORY15 | 0.001399 | |
| STORY15 | | 0.001399 |
| STORY14 | 0.001411 | |
| STORY14 | | 0.001411 |
| STORY13 | 0.001386 | |
| STORY13 | | 0.001386 |
| STORY12 | 0.001371 | |
| STORY12 | | 0.001371 |
| STORY11 | 0.001413 | |
| STORY11 | | 0.001413 |
| STORY10 | 0.001453 | |
| STORY10 | | 0.001453 |
| STORY9 | 0.00151 | |
| STORY9 | | 0.00151 |
| STORY8 | 0.001583 | |
| STORY8 | | 0.001583 |
| STORY7 | 0.001672 | |
| STORY7 | | 0.001672 |
| STORY6 | 0.001778 | |
| STORY6 | | 0.001778 |
| STORY5 | 0.001858 | |
| STORY5 | | 0.001858 |
| STORY4 | 0.001924 | |
| STORY4 | | 0.001924 |
| STORY3 | 0.001993 | |
| STORY3 | | 0.001993 |
| STORY2 | 0.002063 | |
| STORY2 | | 0.002063 |
| STORY1 | 0.00213 | |
| STORY1 | | 0.00213 |

**Table 14 20-Story Building Periods and Modes**

| Mode | Period | Modal Mass | Modal Stiff |
|---|---|---|---|
| 1 | 3.523839 | 112.9848 | 359.2095 |
| 2 | 3.523839 | 112.9848 | 359.2095 |
| 3 | 2.636534 | 112.9848 | 641.6721 |
| 4 | 1.178147 | 112.9848 | 3213.519 |
| 5 | 1.178147 | 112.9848 | 3213.519 |
| 6 | 0.980086 | 112.9848 | 4643.567 |
| 7 | 0.600198 | 112.9848 | 12382.01 |
| 8 | 0.600198 | 112.9848 | 12382.01 |
| 9 | 0.518505 | 112.9848 | 16591.03 |
| 10 | 0.380089 | 112.9848 | 30875.16 |
| 11 | 0.380089 | 112.9848 | 30875.16 |
| 12 | 0.331086 | 112.9848 | 40691.06 |
| 13 | 0.248179 | 112.9848 | 72418.8 |
| 14 | 0.248179 | 112.9848 | 72418.8 |
| 15 | 0.220607 | 112.9848 | 91651.54 |
| 16 | 0.18697 | 112.9848 | 127595.8 |
| 17 | 0.18697 | 112.9848 | 127595.8 |
| 18 | 0.166373 | 112.9848 | 161144.9 |
| 19 | 0.138714 | 112.9848 | 231813.2 |
| 20 | 0.138714 | 112.9848 | 231813.2 |

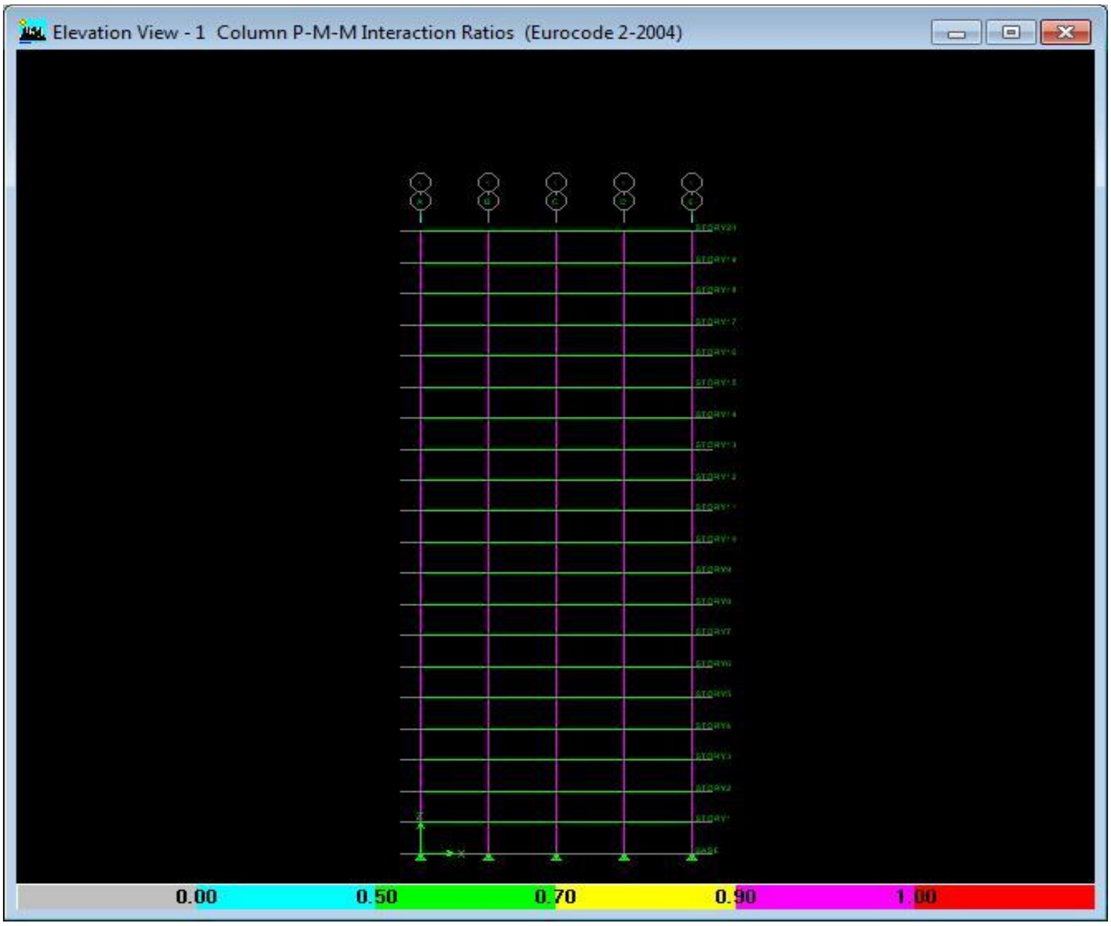


**Figure 7 Column P-M-M Interaction Ration of 20-Story Building**

- 30-Story Building of height 90m

**Table 15 30-Story Building Inter-Story Drift**

| Story | Drift X | Drift Y |
|---|---|---|
| STORY30 | 0.000565 | |
| STORY30 | | 0.000565 |
| STORY29 | 0.000823 | |
| STORY29 | | 0.000823 |
| STORY28 | 0.001048 | |
| STORY28 | | 0.001048 |
| STORY27 | 0.001206 | |
| STORY27 | | 0.001206 |
| STORY26 | 0.001282 | |
| STORY26 | | 0.001282 |
| STORY25 | 0.001176 | |
| STORY25 | | 0.001176 |
| STORY24 | 0.001144 | |
| STORY24 | | 0.001144 |

| | | |
|---|---|---|
| STORY23 | 0.001061 | |
| STORY23 | | 0.001061 |
| STORY22 | 0.000981 | |
| STORY22 | | 0.000981 |
| STORY21 | 0.000954 | |
| STORY21 | | 0.000954 |
| STORY20 | 0.000942 | |
| STORY20 | | 0.000942 |
| STORY19 | 0.000954 | |
| STORY19 | | 0.000954 |
| STORY18 | 0.000971 | |
| STORY18 | | 0.000971 |
| STORY17 | 0.000991 | |
| STORY17 | | 0.000991 |
| STORY16 | 0.001017 | |
| STORY16 | | 0.001017 |
| STORY15 | 0.001035 | |
| STORY15 | | 0.001035 |
| STORY14 | 0.001055 | |
| STORY14 | | 0.001055 |
| STORY13 | 0.001079 | |
| STORY13 | | 0.001079 |
| STORY12 | 0.001111 | |
| STORY12 | | 0.001111 |
| STORY11 | 0.001156 | |
| STORY11 | | 0.001156 |
| STORY10 | 0.001194 | |
| STORY10 | | 0.001194 |
| STORY9 | 0.001225 | |
| STORY9 | | 0.001225 |
| STORY8 | 0.001261 | |
| STORY8 | | 0.001261 |
| STORY7 | 0.001301 | |
| STORY7 | | 0.001301 |
| STORY6 | 0.001346 | |
| STORY6 | | 0.001346 |
| STORY5 | 0.001381 | |
| STORY5 | | 0.001381 |
| STORY4 | 0.001409 | |
| STORY4 | | 0.001409 |
| STORY3 | 0.001435 | |
| STORY3 | | 0.001435 |
| STORY2 | 0.001458 | |
| STORY2 | | 0.001458 |
| STORY1 | 0.001476 | |

| | | |
|---|---|---|
| STORY1 | | 0.001476 |

**Table 16 30-Story Building Periods and Modes**

| Mode | Period | Modal Mass | Modal Stiff |
|---|---|---|---|
| 1 | 5.188276 | 112.9848 | 165.7043 |
| 2 | 5.188276 | 112.9848 | 165.7043 |
| 3 | 3.163683 | 112.9848 | 445.6501 |
| 4 | 1.694617 | 112.9848 | 1553.233 |
| 5 | 1.694617 | 112.9848 | 1553.233 |
| 6 | 1.298256 | 112.9848 | 2646.422 |
| 7 | 0.9058 | 112.9848 | 5436.453 |
| 8 | 0.9058 | 112.9848 | 5436.453 |
| 9 | 0.747158 | 112.9848 | 7990.149 |
| 10 | 0.553394 | 112.9848 | 14565.03 |
| 11 | 0.553394 | 112.9848 | 14565.03 |
| 12 | 0.472462 | 112.9848 | 19982.3 |
| 13 | 0.390115 | 112.9848 | 29308.6 |
| 14 | 0.390115 | 112.9848 | 29308.6 |
| 15 | 0.336733 | 112.9848 | 39337.56 |
| 16 | 0.279995 | 112.9848 | 56895.55 |
| 17 | 0.279995 | 112.9848 | 56895.55 |
| 18 | 0.245361 | 112.9848 | 74091.36 |
| 19 | 0.216273 | 112.9848 | 95362.23 |
| 20 | 0.216273 | 112.9848 | 95362.23 |
| 21 | 0.191832 | 112.9848 | 121209.6 |
| 22 | 0.167186 | 112.9848 | 159580 |
| 23 | 0.167186 | 112.9848 | 159580 |
| 24 | 0.150016 | 112.9848 | 198200.2 |
| 25 | 0.133944 | 112.9848 | 248618.3 |
| 26 | 0.133944 | 112.9848 | 248618.3 |
| 27 | 0.120615 | 112.9848 | 306605.5 |
| 28 | 0.111776 | 112.9848 | 357010.7 |
| 29 | 0.111776 | 112.9848 | 357010.7 |
| 30 | 0.100861 | 112.9848 | 438464.3 |

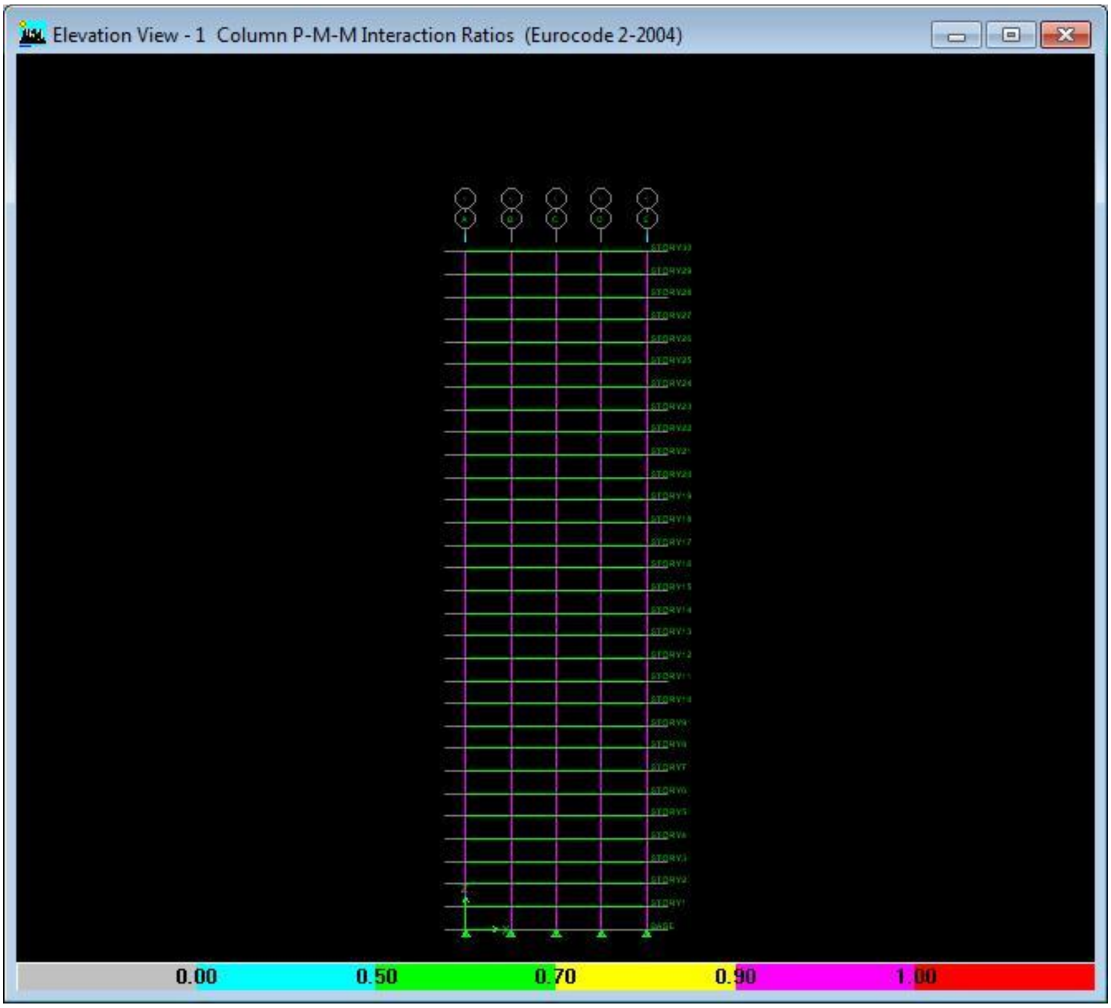


**Figure 8 Column P-M-M Interaction Ratio of 30-Story Building**

## 4.3 INTERPRETATION & DISCUSSIONS

Inter-story drift is an index which measures the localized excessive deformation of each floor of the structure. Generally, there is no exact value determined by any codes for inter-story drift limit. So, it is usually taken and assumed based on the level of displacement comfort. It usually varies between 0.001 and 0.005. For this study, we assume it to be 0.004. All of our buildings inter-story drift indexes are kept well below the limit which means they do not need to be altered to pass the limit stated. However, we shall however consider if possible even lower values as discomfort in buildings may be deemed unacceptable by its occupants.

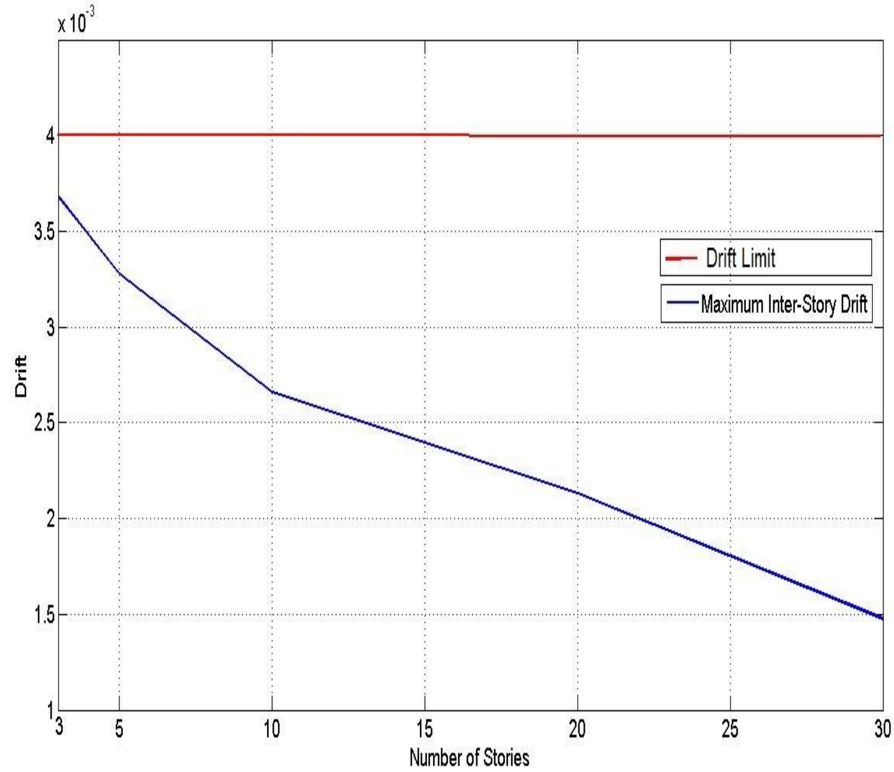


**Figure 9 Drifts Comparisons**

There are many reasons as why drift limitations has to be restricted. Besides from causing discomfort to its dwellers or from influencing sensitive equipment, it can be used to reduce distress in the structure, excessive cracking for serviceability purpose, loss of stiffness and even P-Δ effects.

In case where it is considered higher, it can be reduced to an acceptable level by either modifying the geometric configuration of the building, increasing the bending stiffness of the horizontal members or by inclusion of stiffer wall or core wall or in critical conditions, it might be indispensable to provide dampers to the structure.

From the columns P-M-M interaction ratios of all the structures analyzed statically and then through response spectrum method, according to the stress band color, all of our vertical elements (columns) have their capacity ranging from 0.9 to 1.0. . Since the capacity ratios values are not superior to 1.0, it means that all the vertical elements are not overstressed and structurally resistant to the earthquake dynamic loading. We can easily conclude that our structure is safe for the earthquake design magnitude. However in terms of reserve strength, we have to be careful as the values are all approaching 1.0. .

# CHAPTER 5
# CONCLUSION & RECOMMENDATIONS

From our results obtained from the analyses outputs, the elements are in accordance to our objectives of the study which are:

- By means of response spectrum, frequencies (periods) and mode shapes have been obtained and tabulated for each type of structure as to show the behaviour of the reinforced concrete buildings subjected to earthquake loadings
- The inter story drift indexes of all the buildings were determined and their maximum found to be less than the limit which is 0.004 when evaluated and compared to the limit value and;
- Analysis of the structural integrity of these buildings in withstanding the design earthquake loadings was conducted and was judged to be safe from the column P-M-M Interaction diagrams as for all the buildings columns capacity ratio is below 1. However their vertical elements appear to not present excessive reserve strength as their capacity is closer to 1.

The way forward will be to conduct studies on different shapes and geometrical configurations and to see the variations as the study we conducted only included regular rectangular shape and symmetrical configuration.

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