STRUCTURAL IMPLICATIONS IN EARTHQUAKE DESIGN OF TALL BUILDINGS IN MALAYSIA

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CERTIFICATION OF APPROVAL

Structural Implications in Earthquake Design of Tall Buildings in Malaysia

by

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Approved by,

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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 has not been undertaken or done by unspecified sources or persons.

Behnam

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ABSTRACT

The impacts of the dynamic properties of wind and earthquake on the response of a newly designed 39-storey reinforced concrete (RC) tall building in Kuala Lumpur, Malaysia are investigated. Samples of several types of structural members were chosen in a lower level to represent the steel to concrete ratio (A_s/A_c) as a technical-economical indication of the project. These are two rectangular columns (one at the side 1.000 ×2.200 m and another near the middle 1.000 ×1.600 m), a beam near the middle 1.000×0.700 m, and a 350 mm shear wall. The commercial structural analysis software, ETABS, was applied to simulate the response of the building to a potential local earthquake. Structural analysis was based on the British Standard BS8110 using Response Spectrum Analysis (RSA). The response of the building to a range of likely wind speeds under ultimate load combination was also simulated using the same software. Representative responses were then monitored: maximum horizontal displacement at the top corner of the building, A_s/A_c, and peak accelerations. As for the wind, equating the maximum roof displacement to that of a hypothetical equivalent cantilever beam, a linear relationship for the equivalent modulus of elasticity of the tall building, E_{eq}, is found. It is shown that such parameter could be used for a quick calculation of maximum roof displacement of various structural systems for tall buildings. Various plots of the response of the structure to earthquake and wind will provide for insight into the sensitivity of the design to seismic and wind loading. They can be used in the conceptual design of the building where quick technical and economical comparison of numerous alternatives is often necessary. The findings could disseminate the recent awareness caused by the Sumatra earthquake (December 2004) among design engineers of high rise buildings.

ACKNOWLEDGEMENT

I owe a debt of gratitude to **Assoc. Prof. Dr. Saied Saiedi** for helping me choose this topic and prepare a sound proposal. I am grateful to him for breaking down what seemed like a formidable research project into manageable tasks. I also benefited from his many years of research experience and paper publication in writing a conference paper.

I would also like to thank my supervisor, **Ms. Nabilah Bt. Abu Bakar** for assigning tasks to me, monitoring my progress and her support in locating relevant literature and information sources. Her feedbacks and thorough assessments of my reports helped me progress in the right path and gave me a clear sense of direction.

Finally, I would like to thank the management of **Web Structures** for providing me with the necessary data and information related to the project and the generous support and supervision I received during my 8 months of industrial internship.

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INTRODUCTION

1.1. BACKGROUND OF STUDY

In line with rapid urbanization in most developing countries, several factors contribute to continuous increase of high-rise buildings. They include

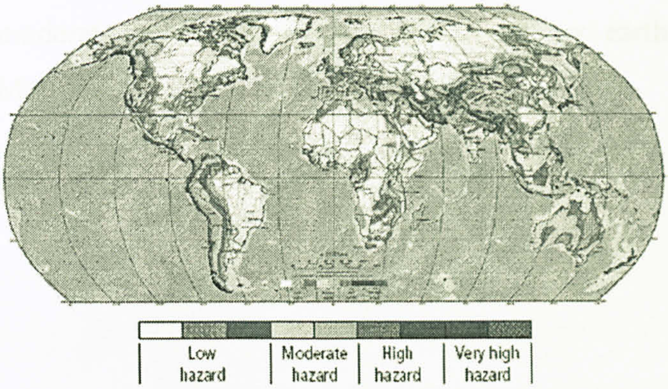
- Growth of urban population and pressure on limited space
- High cost of land
- Desire to avoid continuous urban sprawl
- Need to preserve valuable land
- Restrictions of local topography
- Need for business organizations to be close to each other
- Corporate prestige symbols
- Business and tourist mobility – need for city center hotels
- Need to maintain open areas in city centers

While in many capital cities tall buildings are made of steel, a large majority of tall buildings in Malaysia are made of reinforced concrete (RC). This could be explained by insufficient production of local steel and abundance of cement and aggregates.

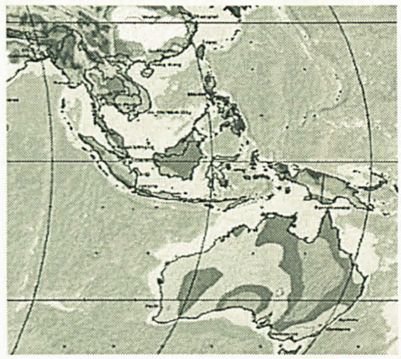
1.2. PROBLEM STATEMENT

Most civil engineering structures in Malaysia have been designed with the assumption of insignificant earthquakes. A huge tsunami attack caused by a big earthquake offshore of Sumatra Island on 26 December 2004 claimed more than 200,000 lives and caused astronomical damages in several countries. Bringing about great alertness, design codes and practices in Malaysia are being revisited.

The detailed history of earthquakes in Malaysia is presented in chapter 2.5. Figure 1.1 shows seismic maps of the world and South-East Asia.



a. Global Seismic Hazard Map



b. Seismic Zone Map of South-East Asia

Figure 1.1. Earthquakes in the world and South-East Asia (GSHAP 2002)

1.3. SCOPE OF STUDY AND OBJECTIVES

The objectives of this project are:

- Summarizing the main features of RC tall buildings
- Outlining the recommendations for earthquake design needed for tall buildings in Malaysia in light of the seismic statistics and zone maps.
- Studying the impacts of various wind loads on the case study building
- The impacts of a moderate earthquake on the design of an RC tall building in terms of
    - Reinforcement requirement (weights to be compared)
    - Concrete consumption
    - Construction cost
- A summary of the results will then be prepared to be used as a reference in the design of high-rise RC buildings subjected to wind and earthquake loadings in Malaysia.

Implications of building against large earthquakes are of two types: socio-economical and technical. Involved in the latter are design aspects, construction techniques, and management requirements. The objectives of this study is to investigate the structural implications of the design of RC tall buildings against a wide range of wind loading and moderate earthquakes (as opposed to no earthquakes traditionally practiced) in Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION TO TALL BUILDINGS

Ever since the dawn of civilization, tall buildings have fascinated humans. The ancient tall buildings were of monumental significance rather than human habitats. However, modern tall buildings are primarily constructed as a response to the commercial demands, often developed as prestige symbols of corporate organizations.

Contemporary tall buildings flourished in the late nineteenth century in the United States of America. North America continued to lead the construction of tall buildings in the world until the late twentieth century. Today, however, Asia has the largest share in the distribution of tall buildings with 29.1%, and North America's at 21% (Table 2.1).

Table 2.1. Tall buildings in regions (2008, reported in *Emporis.com*)

REGION	COUNTRIES (No.)	PERCENT (%)	BUILDINGS (No.)
Asia	20	29.1	35,181
Europe	20	25.7	30,998
South America	10	21.1	25,452
North America	17	20.9	25,187
Oceania	7	2.3	2,753
Africa	20	1.0	1,228
TOTAL	**94**		120,799

2.2. STRUCTURAL SYSTEMS OF TALL BUILDINGS

Buildings are basically divided into three types: steel buildings, reinforced concrete buildings, and composite buildings. As mentioned earlier, most of the tall buildings in the world have steel structural systems mainly due to its high strength-to-weight ratio (Gunel and Ilgin, 2006). However, structural systems of tall buildings in Malaysia are either reinforced concrete or composite.

Numerous methods are available in the literature for classification of structural systems. The focus of this report is the structural systems for RC tall buildings.

Khan (1969) classified structural systems for tall buildings in the form of "Heights for Structural Systems". This brought about a new era of skyscraper revolution in terms of multiple structural systems (Ali and Moon, 2007). Fazlur Khan's classification for concrete buildings is shown is Figure 2.1.

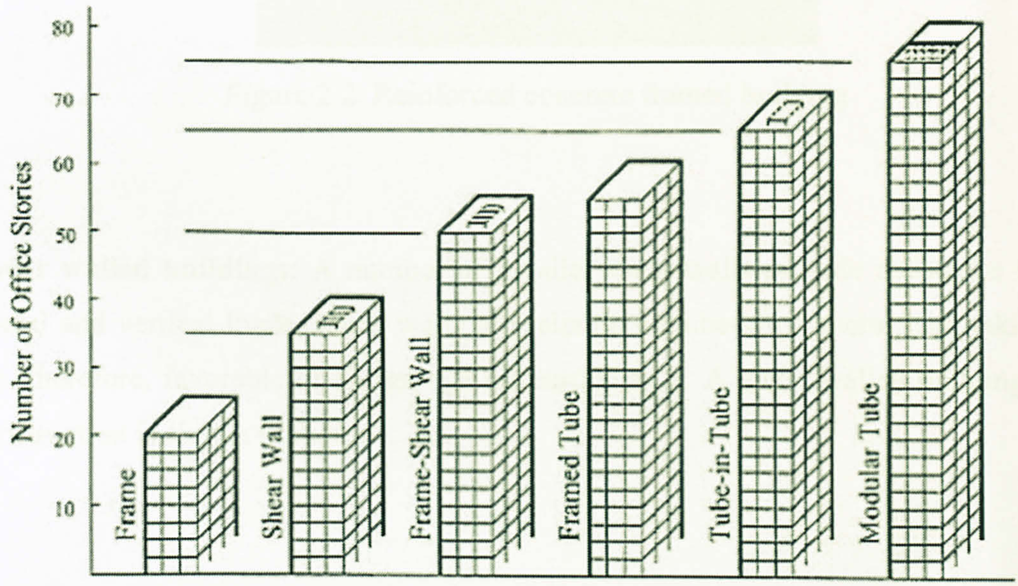


Figure 2.1. Classification of concrete tall building structural systems by Fazlur Khan (Ali and Moon, 2007)

Framed buildings: In this type of structure the weight is carried by a skeleton or framework. Lateral loading is evenly distributed to each of the frames if they are equally stiff. A frame structure must withstand the loads without depending on walls and floors. A picture of a reinforced concrete frame building is shown in Figure 2.2.

Figure 2.2. Reinforced concrete framed building

Shear walled buildings: A number of parallel shear walls provide resistance to both lateral and vertical loads. Shear walls are reliable members for lateral load-taking and are, therefore, favorable in design against earthquakes. A shear walled building under construction is shown in Figure 2.3.

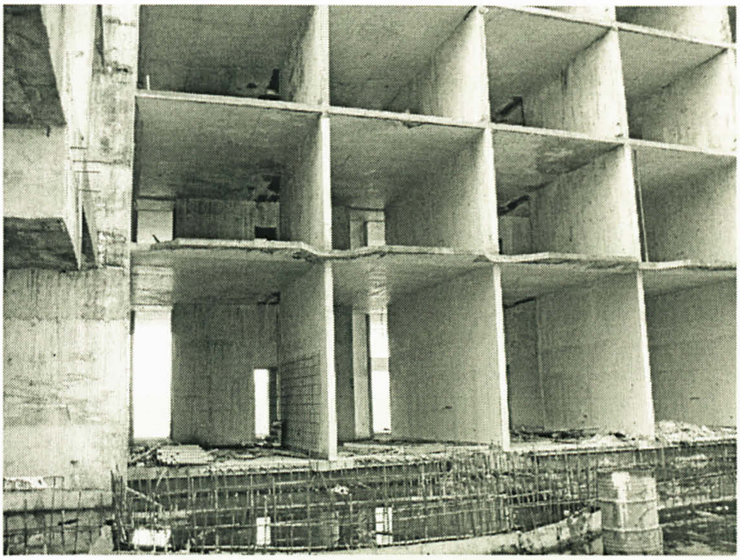


Figure 2.3. A Shear walled building

Shear walls acting with frames: Framed buildings can be strengthened by shear walls. When the occupancy requirements do not favor a pure shear wall system, a combination of frame and shear wall will be a good alternative (Nair, 2007). Figure 2.4 shows a view of a shear wall system combined with frames.

Figure 2.4. Frame and shear wall combination

Framed-tube buildings: In a framed-tube structure, the columns are closely spaced around the perimeter of the building while they are connected by beams at every floor level. The exterior column spacing usually ranges from 1.25 to 3 meters and the depth of the spandrel beams connecting them varies from 60 to 120 cm (Nair, 2006). DeWitt Chestnut Apartments was the first building designed by this system. Figure 2.5 shows a view of this building.

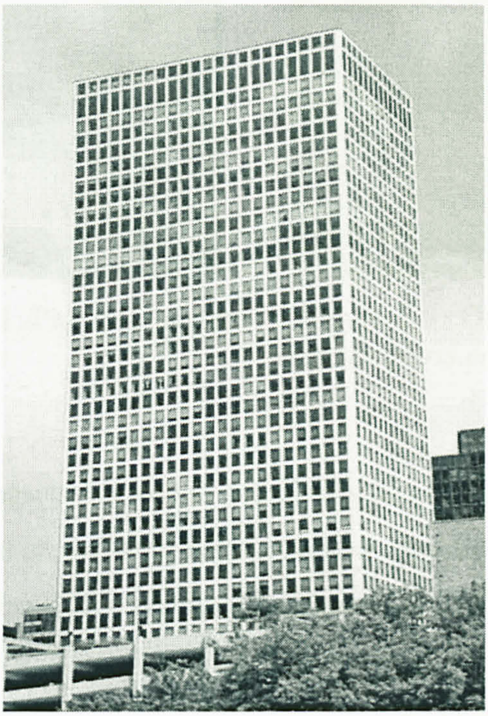


Figure 2.5. DeWitt Chestnut Apartments

Tube-in-tube buildings: This is a system with framed tube combined with an internal and external shear wall core which is helpful in resisting the lateral loads. The inner tube is formed by core walls and the outer tube consists of the closely spaced columns similar to the framed tube system. *One Shell Plaza* in Houston, USA (Figure 2.6) is an example of tube-in-tube system.

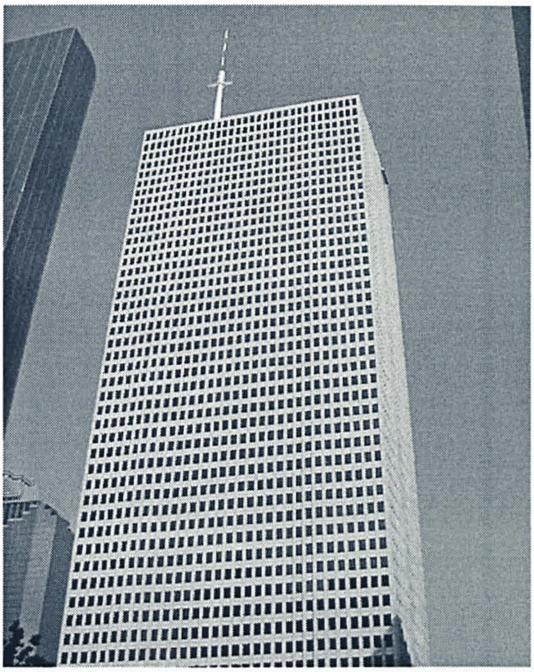


Figure 2.6. One Shell Plaza, Houston, USA from *Emporis.com*

Figure 2.7. One Peachtree Center, USA from *Emporis.com*

Modular tube buildings: Also called bundled tubes, they are used as a means of decreasing the surface area for wind resistance and creating interior space benefits for apartment units. One Peachtree Center in Atlanta, USA is an example of concrete bundled tube design (Ali, 2001). Figure 2.7 shows a view of One Peachtree Center in USA.

2.3. EFFECTS OF WIND ON TALL BUILDINGS

Wind is a complex phenomenon because of the various flow situations caused by interaction of wind with structures. As the building goes higher, the wind analysis becomes more crucial for the overall design of the building. Several wind characteristics and design aspects are presented in this section of the report.

2.3.1. Wind Speed

At great heights above the earth's surface, winds are caused by variable solar heating of the earth. This upper level wind speed is called *the gradient wind velocity*. Closer to the surface, friction of the air stream over the terrain affects the wind speed. In the latter case the wind speed varies from almost zero, at the surface, to the gradient wind speed at a height called the gradient height. The gradient height may vary from 500 to 3000 m according to Mendis P. *et al* (2007).

2.3.2. Design Wind Loads

The characteristics of wind pressures on a building are a function of (i) the characteristics of the approaching wind, (ii) the geometry of the building, and (iii) the proximity and length of the upwind terrain (Mendis P. *et al*, 2007).

Designing a structure for lateral wind loads takes into account the following criteria (Mendis, 2007).

- **Stability** against overturning, sliding, and lifting of the building as a whole.
- **Strength** of the structural members should be sufficient to avoid failure throughout the design life.
- **Serviceability** for buildings, where internal and overall deflections should fall within the acceptable limits specified in the building codes.

2.3.3. Along and Transverse Wind Loading

The flow pattern generated around a building as a result of wind loading is complicated by several factors such as changing speed of the wind and formation of vortices. The along-wind loading can be assumed to be the combination of the action of the mean wind speed and a variant component caused by wind speed fluctuations. This is the basic for the "gust-factor" approach explained in different building codes (Mendis).

Transverse-wind (cross-wind) loading is caused by the dynamic motion perpendicular to the direction of the wind. The effect is more significant for the structures with small damping ratios. The most common source of cross-wind vibration is "vortex-shedding". Since buildings are not streamlined, the flow is easily separated from the body contour creating vortices in different directions.

Another factor contributing to the transverse excitation is the "incident turbulence". This is because of the natural wind properties such as the varying speed and directions that induce fluctuating lift and drag forces as well as moments on the building.

2.3.4. Human Comfort Criteria

Guidelines on general human perception levels are presented in Table 2.2.

Table 2.2. Human perception levels (Mendis, *et al.*, 2007)

Range	Acceleration (m/sec^2)	Effects
1	< 0.05	Humans cannot perceive motion.
2	0.05 ~ 0.10	Sensitive people can perceive motion; hanging objects may move slightly.
3	0.1 ~ 0.25	Majority of people will perceive motion; Level of motion may affect desk work: long-term exposure may produce motion sickness
4	0.25 ~ 0.4	Desk work becomes difficult or almost impossible; ambulation still possible
5	0.4 ~ 0.5	People strongly perceive motion; difficult to walk naturally; Standing people may lose balance.
6	0.5 ~ 0.6	Most people cannot tolerate motion and are unable to walk naturally.
7	0.6 ~ 0.7	People cannot walk or tolerate motion.

8	> 0.85	Objects begin to fall and people may be injured.

2.4. EARTHQUAKES AND TALL BUILDINGS

Sudden release of energy in the Earth's crust causes earthquakes followed by seismic waves. During an earthquake, the ground surface moves in all directions. Horizontal forces caused by earthquakes are the most damaging to buildings because structures are normally designed to withstand vertical gravity loads.

In order to investigate the potential damage of an earthquake to a particular building, it is necessary to establish the nature of the movements that could be induced in the building. During an earthquake, buildings behave differently in terms of their own dynamic response natures.

2.4.1. Dynamic Properties of Earthquakes

The following aspects of ground motion should be considered to determine the potential for building damage:

1. The **direction** of the motion because movements in different directions produce varying effects on a building.
2. The **displacement** from the original position.
3. The **acceleration** of the motion because it is directly related to the magnitude of the imposed load.
4. The general form of the motion in terms of its **duration** and **frequency**.

Typically, maximum accelerations are the most critical as evident from Newton's equation for dynamic force: $F = m \times a$ (Force equals mass times acceleration).

A primary consideration in earthquake design is the magnitude of the earthquake. It may be measured by the level of the actual observed damage which is the basis for

Mercalli method. The levels of damage are reported by drawing a contour map around the epicenter in this method.

Richter scale is used to measure the earthquake intensity at its epicenter. This is a log-based scale that assigns a number to each earthquake. Because of the log base, the magnitude rises much more rapidly than the numbers indicate (Ambrose and Vergun, 1999).

2.4.2. General Design Considerations

The location of the building is a major consideration in seismic design. The weight of the building, the building size, and its natural response to dynamic loading are among important considerations.

Dead load is a stabilizing factor against wind load. It can also be advantageous for increasing the damping ratio during an earthquake, but it is mostly disadvantageous as the actual force induced by the earthquake are proportional to the mass (weight) of the building.

The **building shape** should also be considered. Unsymmetrical buildings may need extensive bracing to transfer the seismic loads. **Stiffness** of **structural** and **non-structural** elements is among the various considerations. Non-structural walls of rigid construction connected to bracing structures can be of great concern.

2.5. EARTHQUAKE HISTORY AND RECORD IN MALAYSIA

Malaysia is relatively far away from any seismic source zone. The nearest faults are about 300 km away from Peninsular Malaysia (Lubukraya, Indonesia to Pulau Ketam, Malaysia according to ***Google Earth***) and are located in Sumatra. However, in the past 170 years, 13 earthquakes of magnitudes between 5.6 and 9.0 on the Richter scale originated from Sumatra have been felt in West Malaysia (Rosaidi, 2001).

In May 1994, residents of Kuala Lumpur felt the tremors caused by an earthquake of a magnitude 6.2 on the Richter scale that had its epicenter 570 km away, near Siberut Islands (Jichun and Pan, 1995).

In October 1995, high-rise buildings in Johor Bahru were shaken by a 7.0 Richter earthquake that killed 100 people in Sumatra, Indonesia. The maximum observed intensity in Johor was estimated at about **VI** (Strong) on the **MM** (Modified Mercalli) scale (Mansor, Selvanayagam, Adnan, & Suradi, 2007).

The 1996 earthquake of 5.4 magnitude on the Richter scale which had its epicenter about 300 km west of Perak alerted occupants of many high-rise buildings in Penang, Perak, Kuala Lumpur and Selangor. The maximum reported intensity was about **VI** on **MM** scale (Mansor *et al.*, 2007).

On June 5, 2000, occupants of several tall buildings were alarmed by a 7.5 Richter earthquake based in Sumatra. According to local newspapers, many people felt the tremors and rushed out of their houses. In Johor Bahru, the tremors caused panic among residents of Larkin Flats, Lumba Kuda Flats, Bukit Kagar Flats, Sujana Flats and Dwi Mahkota Condominium and minor cracks occurred in those buildings (Mansor).

On November 2, 2002, another Sumatran earthquake caused tremors in several cities in Peninsular Malaysia such as Penang, Port Klang and Selangor. It put the residents of tall buildings in a state of panic and thousands ran away from the buildings (Mansor).
A year later, on January 22, 2003, citizens of Penang, Kuala Lumpur and Kota Bahru felt tremors caused by an earthquake of magnitude, M_w 5.8, local newspapers reported (Mansor).

An earthquake having a magnitude of M_w 7.3 occurred on July 25, 2004 and caused cracks in one apartment in Gelang Patah. The epicenter was located in South Sumatra at the longitude of 103.98°E and latitude of 2.41°S. It was more than 400 km away from Johor Bahru and 576 km below surface (Mansor).

The tremendous 9.3 magnitude undersea earthquake that occurred on December 26, 2004, with an epicenter off the west coast of Sumatra triggered a series of powerful tsunamis along the coasts bordering the Indian Ocean. The earthquake was the second largest earthquake ever recorded on a seismograph and the waves caused by the tsunamis were up to 30 meters high. Killing more than 200,000 people, it was one of the deadliest natural disasters in history. Officials described the tsunami as the worst natural disaster in Malaysia's history (Star Online, 2004). Penang and Kedah were the worst affected areas, where 68 people were killed and more than 100 were injured (WHO, 2005).

In the year 2005, there was a significant increase in the number of earthquake incidences with 10 major earthquakes ranging from 6.5 to 8.6 on the Richter scale. A total of 5 earthquakes with intensities ranging from 6.3 to 7.7 on the Richter scale were reported in 2006 (Mansor).

On March 6, 2007, tremors of an earthquake of the magnitude 6.3 which was followed by powerful aftershocks and left 70 people dead in Sumatra were felt in Malaysia and Singapore, where some office buildings were evacuated. (Star Online, 2007)

East Malaysia is moderately active in seismicity. Rosaiedi (2001) reported earthquakes of local origin with magnitudes up to 5.8 on the Richter scale. East Malaysia is also affected by earthquakes of Southern Philippine, the Straits of Macassar, Sulu Sea and Celebes Sea.

In September 1897, two tremors occurred in Sandakan, Labuan, Kinabatangan, Labuk, Sugut and Kudat of Sabah state. It caused fissures on roads and under government offices in Sandakan. In May, 1976, minor cracks in at least three buildings were observed as a result of weak tremors in Sandakan. Another earthquake of 5.8 magnitude on the Richter scale occurred in the same year. In May 1991 an earthquake with a magnitude of 5.1 on the Richter scale in Ranau area caused extensive damages to buildings and roads. In November, 1994, an earthquake of 5.3 Richter scale hit Tawau, Sandakan and Kota Kinabalu and frightened residents of high-rise buildings (Mansor).

Adnan (2008) developed a microzonation map of Kuala Lumpur City Centre for seismic design of buildings. He analyzed the ground response using one-dimensional shear wave propagation method using program **NERA** (Bardet and Tobita, 2001). The results of site response analysis at several points were used to develop a contour map of surface acceleration and amplification factor for the 500-year and 2500-year return periods.
The accelerations at the surface of KL city center range between 9% g (90 gal) to 19% g (190 gal) for the 500-year return period and between 18 % g to 34 % g for the 2500-year return period. Generally the acceleration and amplification factors decrease from the west to the east of KL city center (Adnan, 2008).
Mansor *et al* (2007) classified ground types of west and east Malaysia according to *Eurocode 8*. Horizontal and vertical design response spectra were then proposed for east and west Malaysia. The proposed horizontal design response spectra for East and West Malaysia are presented in Figures 2.8 and 2.9.

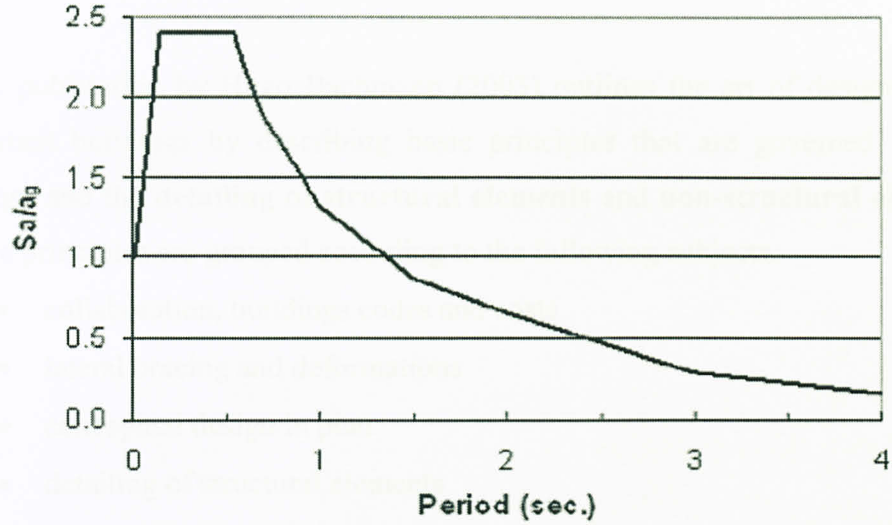


Figure 2.8. Proposed horizontal design response spectra of ground type A for West Malaysia (5% Damping)

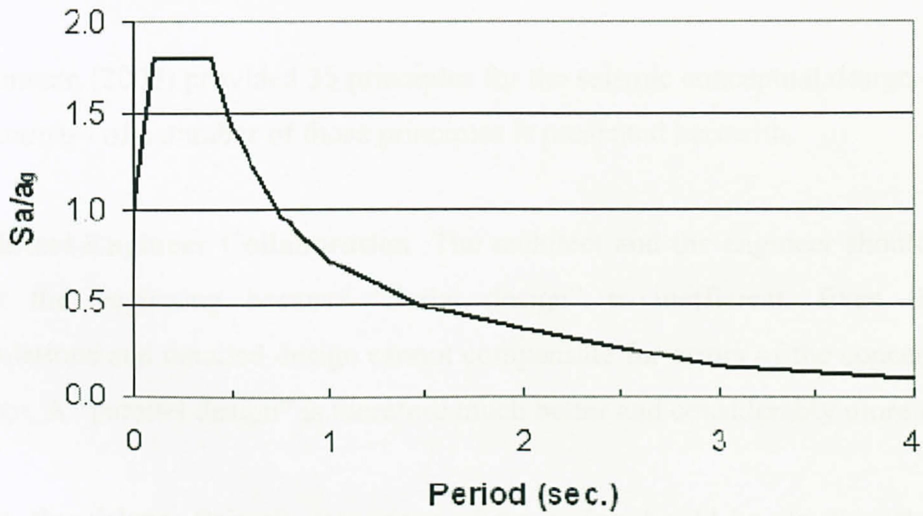


Figure 2.9. Proposed horizontal design response spectra of ground type A for East Malaysia (5% Damping)

2.6. CONCEPTUAL SEISMIC DESIGN OF BUILDINGS

This publication by Hugo Bachmann (2003) outlines the art of designing earthquake resistant buildings by describing basic principles that are governed by **conceptual design** and the **detailing** of **structural elements** and **non-structural elements**. These basic principles are grouped according to the following subjects:

- collaboration, buildings codes and costs
- lateral bracing and deformations
- conceptual design in plan
- detailing of structural elements
- foundations and soils
- non-structural elements and installations

2.6.1. Basic Principles

Bachmann (2003) provided 35 principles for the seismic conceptual design of buildings. A summary of a number of those principles is presented herewith.

Architect-Engineer Collaboration: The architect and the engineer should collaborate from the beginning because "Serial design" is inefficient. Even the cleverest calculations and detailed design cannot compensate for errors of the conceptual seismic design. A "parallel design" is therefore much better and considerably more economical.

Code Provisions: Seismic provisions of the codes should be strictly adhered to. The disregard of the seismic provisions of the building codes may result in an inferior building.

Avoid Soft-Story Ground Floors: The fact that bracing elements such as walls which are available in the upper floors are substituted by columns in the ground floor attributes to collapse of many buildings during earthquakes. This could cause a dangerous sway mechanism with plastic deformation at the column ends (Figure 2.10).

Figure 2.10. Soft-story ground floors

Avoid Soft-Story Upper Floors: The lateral bracing should not be weakened or omitted in an upper story. This may again cause a dangerous sway mechanism.

Avoid Asymmetric Bracing: Center of mass of the building must coincide, or be close to, its center of resistance. This is to avoid eccentricity and twisting. The bracing members should be placed, if possible, along the edges of the building, sufficiently far from the center of mass (Figure 2.11).

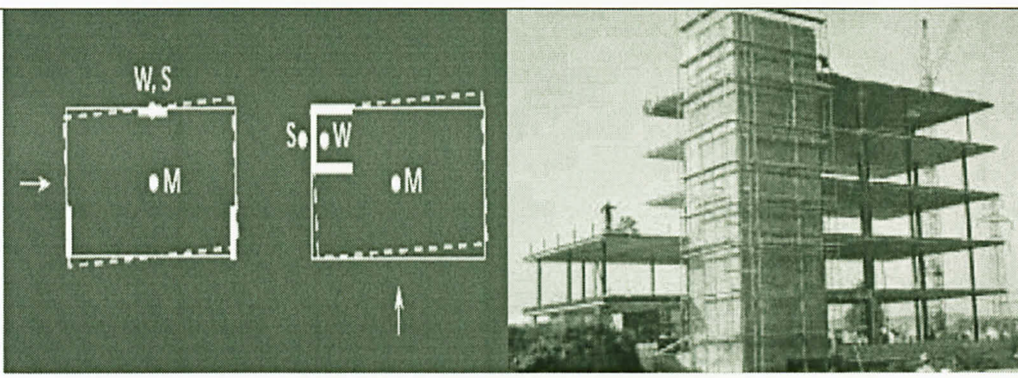


Figure 2.11. Asymmetric bracing

Avoid Bracing Offsets: The offsets disturb the direct flow of forces, reduce the ductility of the bracing and weaken the resistance. This noticeably reduces seismic resistance of the building (Figure 2.12).

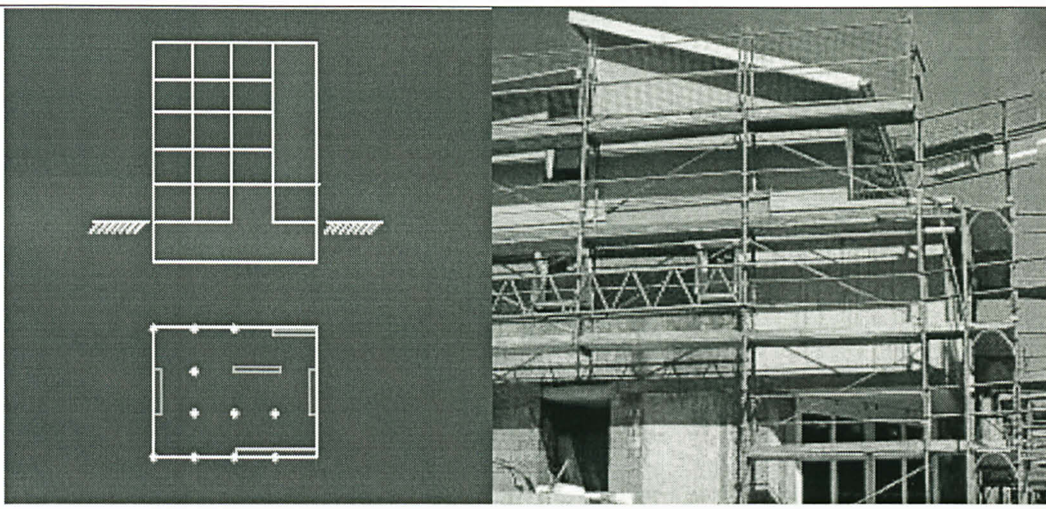


Figure 2.12. Bracing offset

Avoid Discontinuities in Stiffness: Sudden variations in stiffness and resistance of the buildings cause irregularities in the dynamic behavior and distribution of the forces (Figure 2.13).

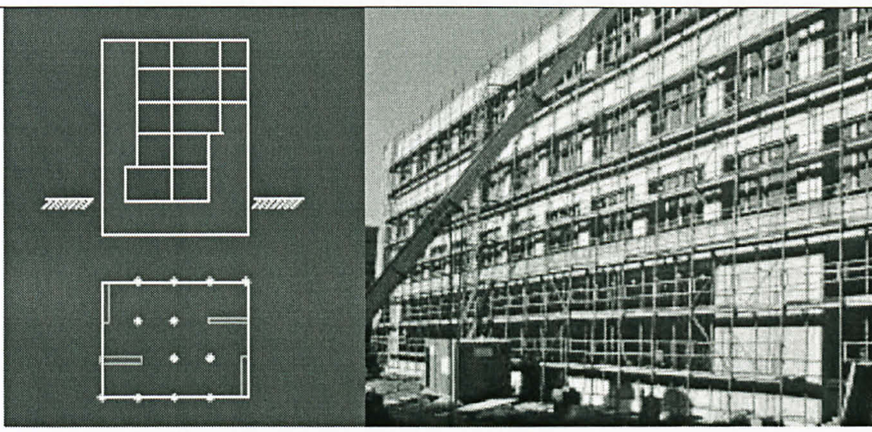


Figure 2.13. Discontinuities in stiffness

Avoid Mixture of Columns and Structural Masonry Walls: Reinforce concrete frame (combination of slab, column and beam) has a substantially smaller horizontal stiffness than the masonry walls. Therefore, the earthquake actions are carried to a great extent by the masonry walls (Figure 2.14).

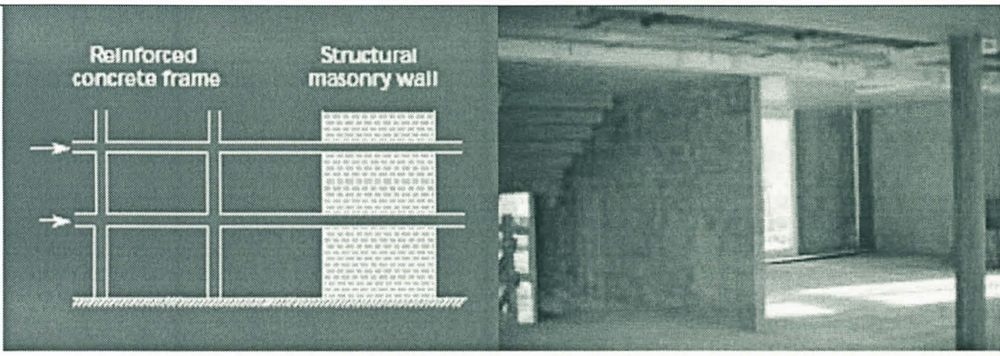


Figure 2.14. Mixture of columns and masonry walls

Match Structural and Non-structural Elements: If the non-structural portions of the building are deformation sensitive and are attached to a horizontally soft structure, without using joints, any horizontal movement caused by an earthquake may cause substantial damages.

Avoid Short Columns: The shear failure of "short columns" is a frequent cause of collapse during earthquakes. Columns under horizontal loads are designed to be stressed up to their plastic moment capacity. In case of a short column with a huge moment gradient and thus a larger shear force, shear failure often occurs before reaching plastic moment capacity (Figure 2.15).

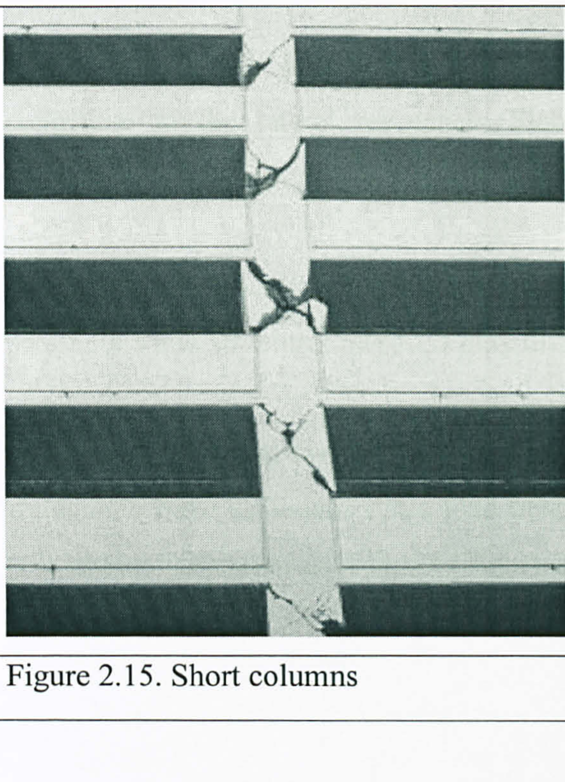


Figure 2.15. Short columns

Avoid Partially Infilled Frames: When parapet walls are infilled into frame structure without the addition of joints, the short column phenomenon may occur. This can cause shear failure, or – in case of sufficient shear strength – a sway mechanism may develop with second order effects (P-Δ Effect). Figure 2.16 shows a sketch of a partially infilled frame.

Favor Compact Plan Configuration: The dynamic behavior of the building must be visualized on plan. In an L-shaped building, the stiffness of two wings may be very different. While oscillating differently, the two wings tend to hinder each other. This produces a large additional stress on the corners of the wings. The problem can be avoided by separating the two wings using joints and making them "dynamically independent" (Figure 2.17).

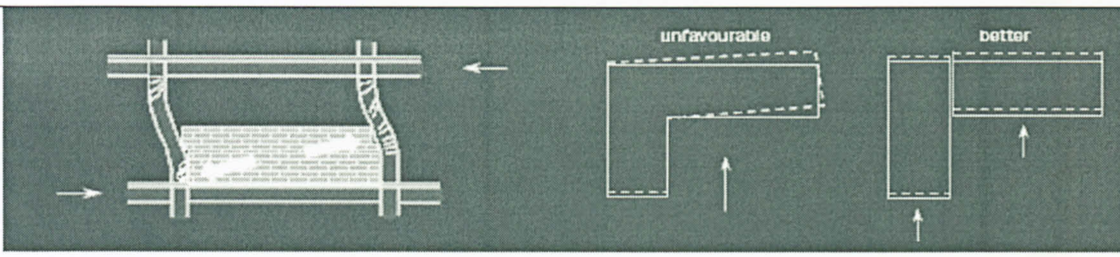


Figure 2.16. Partially infilled frame	Figure 2.17. Compact plan configuration

Make Floor Slabs Rigid: The slabs have to ensure that all the vertical elements contribute to the lateral resistance. Slabs made of prefabricated material are not recommended in this case.

Develop a Site Specific Response Spectrum: In certain soils, the local ground motion parameters and structural response may differ from values specified by the codes.

Assess the Potential for Soil Liquefaction: Certain sandy or silty soils saturated with water may have sufficient static load bearing capacity. However, when vibrated, they will suddenly behave like a liquid (Figure 2.18).

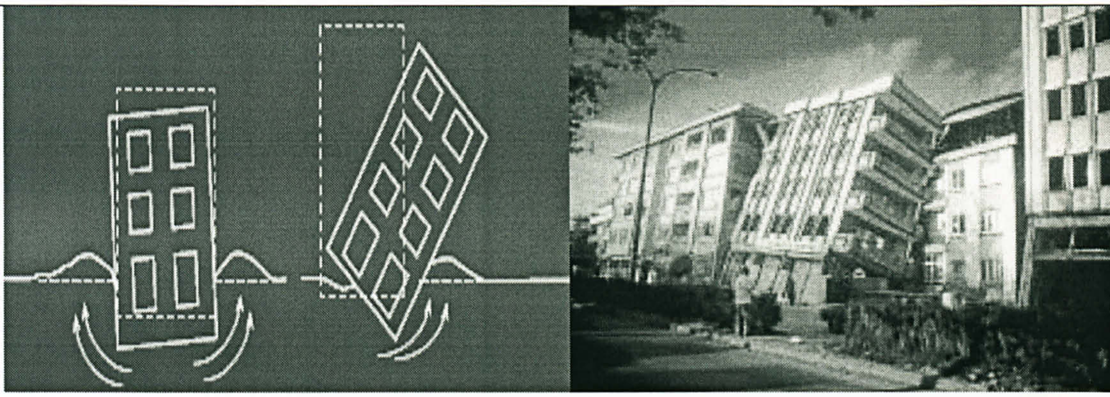


Figure 2.18. Soil liquefaction

CHAPTER 3

METHODOLOGY

In order to accomplish the project objectives, the following steps are taken.

3.1. LITERATURE

The literature was explored to get an overview of the existing tall buildings, outline the main features of earthquake resistant RC tall buildings, and find an appropriate response spectrum for a likely earthquake, given the building classification and site soil's condition, from the available databases or seismic zone maps in Malaysia (Uniform Building Code, 1997).

Structural systems of tall buildings are investigated and are included in chapter 2 of this report. While a brief introduction to tall buildings in general is given in chapter 2, the main focus of this report is on RC tall buildings as explained in the introduction.

3.2. CASE STUDY

A 39-story high-rise building under construction in Kuala Lumpur is adopted. The building is analyzed under different load combinations. Logical combinations of basic load cases are constructed using **dead**, **live**, **wind** and **earthquake** loads.

Jalan Ampang Building (JA) is a 39-story commercial (office) building with an approximate height of 160 meters. The weight of the structure is about 20,000 metric tons. The site is located in Ampang Park, Kuala Lumpur and construction started in May 2008.

The structural frame of the building is made of reinforced concrete. All floor levels are designed as RC flat slab with RC walls and columns to transfer the vertical loads onto the foundation. The lateral stability of the building is taken care of by the lift core walls, staircase core walls and structural frames. A 3D view of the model is shown in Figure 3.1.

Figure 3.1. The JA model in ETABS

The soil investigation carried out consisted of 9 numbers of 75.3mm boreholes advanced by rotary boring machine. The spacing between boreholes varies from 12m to 30m, which is reasonable, considering that the site lies close to the boundary of possible Limestone formation. No bedrock was encountered in the drilling throughout the soil investigation works. The cross section of soil profile along four boreholes is shown in **Figure 3.2**.

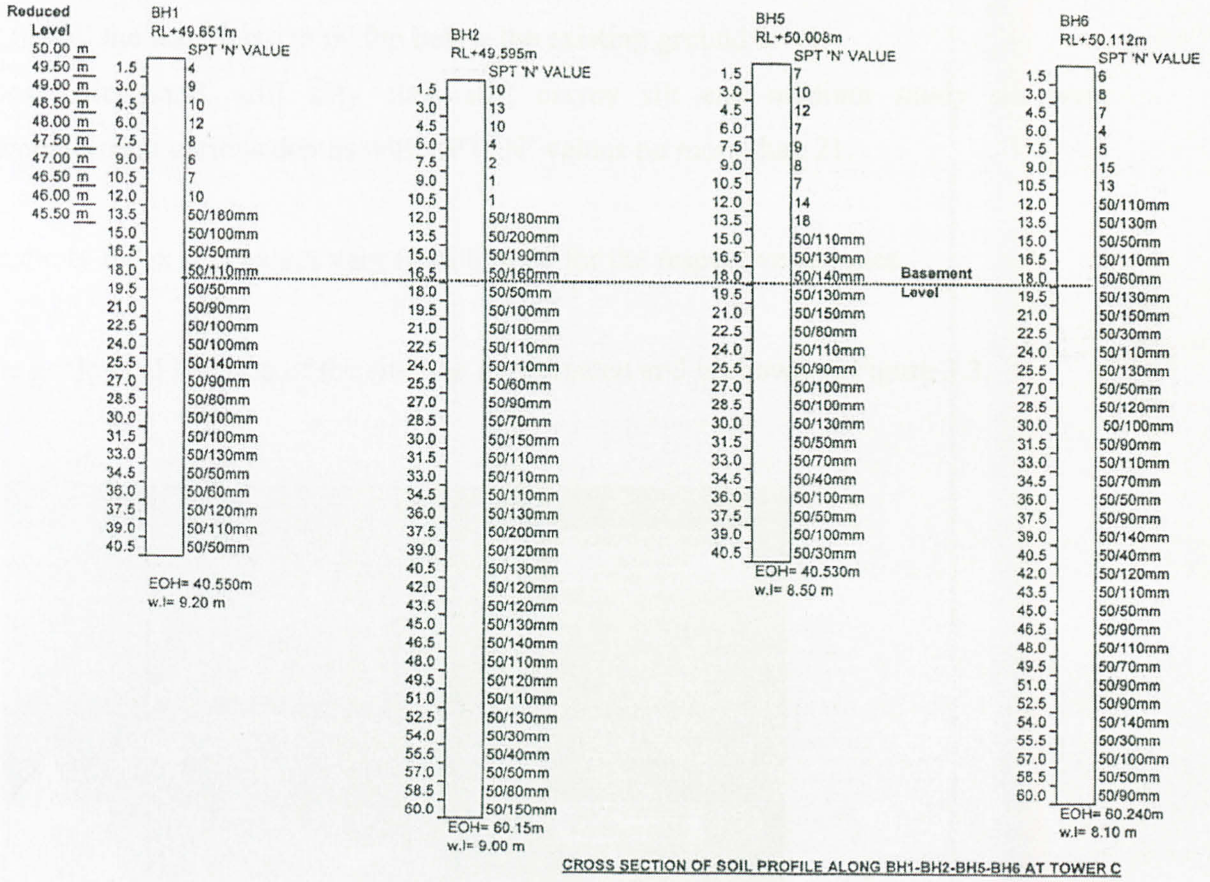


Figure 3.2. Cross Section of Soil Profile along Boreholes

Standard Penetration Test (SPT) was carried out at 1.5m intervals and the value of N was reported together with the number of blow counts for each 75mm penetration. Selected disturbed and undisturbed samples of soils at various depths were scheduled for laboratory tests to determine the engineering characteristics of the soils and several laboratory tests were carried out such as: <u>Natural Moisture Content</u>, <u>Atterberg Limits</u>, <u>Particle Size Distribution</u>, <u>One Dimensional Consolidation Test</u>, <u>Direct Shear Box Test</u>, *etc.*

Soft to medium dense silty sand or sandy silt having SPT 'N' varying from 7 to 21 was encountered at a depth varying from 1.5m to 12.0m below the existing ground level.

Very hard sandy silt having SPT 'N' value more than 50 was encountered at a depth of 12.0m all the way down to 60.0m below the existing ground level.
Loose silty sand, stiff silty clay, stiff clayey silt and medium sandy silt were encountered at various depths with SPT 'N' values no more than 21.

Plasticity Index (PI) values vary from 8 to 24 for the respective samples.

The geological location of the site was investigated and is shown in Figure 3.3.

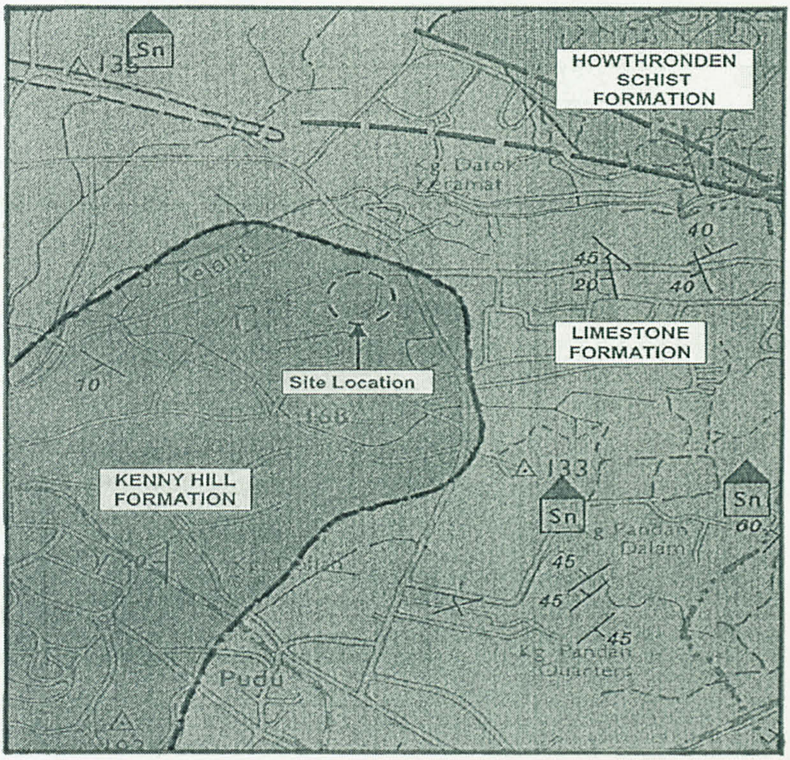


Figure 3.3. Geological Map of Selangor

3.2.1. Design Loadings and Additional Information

All structural codes suggest guidelines for live loads on buildings. The following assumptions are taken in compliance with British Standards.

Table 3.1. Substructure

USAGE/LOCATION	Live Load (kN/m^2)
Parking	2.5
Driveway / Ramp	2.5
Lift Lobby / Staircases / Landing	3.0
M&E Rooms	7.5

Table 3.2. Super Structure

USAGE/LOCATION	Live Load (kN/m^2)
Parking	2.5
Driveway	2.5
Chamber Room	7.5
Transformer Room	16.0
Guardhouse	2.5
Management Room/ Office	2.5

3.2.1.1. Reinforcement Cover

Nominal cover is the design depth of concrete cover to all steel reinforcement, including links (BS 8110 : Part 1, 1997, p.14). The nominal cover should:

a) be in accordance with bar size and aggregate size for concrete cast against uneven surfaces (BS 8110 : Part 1, 1997, p.14);

b) protect the steel against corrosion (BS 8110 : Part 1, 1997, p.16);
c) protect the steel against fire (BS 8110 : Part 1, 1997, p.17);
d) allow the surface treatment such as bush hammering (BS 8110 : Part 1, 1997, p.14).

In order to comply with the BS requirements the following nominal covers are considered.

Cover for reinforced concrete columns = 30mm
Cover for reinforced concrete beams = 35mm
Cover for reinforced concrete slabs = 20mm
Cover for reinforced concrete walls = 25mm
All concrete faces in contact with water or soil = 35mm
All other concrete faces = 20mm

3.2.1.2. Water Proofing

The open terrace and wet areas shall be protected from leakage by appropriate waterproofing system.
RC retaining walls, wherever required, will be protected from moisture penetration by providing an adequate waterproofing system.
The ground floor slab shall be protected against moisture penetration by providing a polyethylene sheet at the base of the slab.

3.3. SOFTWARE APPLICATION

A commercial structural analysis and design program called ETABS (Computers & Structures, Inc., 2007) is employed for the analysis and design of the case study building under two loading conditions: against no earthquake and against moderate earthquake. Figure 3.4 presents a view of a simulation attempt for the dynamic test on a prototype tall building using ETABS.

a. Prototype test of an RC tall building **b.** Elastic ETABS model

Figure 3.4. Software simulation of the response of an RC tall building using ETABS (Maffei J., 2007)

3.3.1. Introduction to ETABS

ETABS is a special purpose analysis and design program developed specifically for building systems. ETABS can handle large and complex building models, including a wide range of nonlinear behaviors. The following list represents a portion of the types of systems and analyses that ETABS can handle:

- Multi-story commercial, government and health care facilities
- Parking garages with circular and linear ramps
- Buildings with steel, concrete, composite or joist floor framing

- Buildings subjected to any number of vertical and lateral load cases and combinations, including automated wind and seismic loads
- Multiple response spectrum load cases, with built-in input curves
- Automated transfer of vertical loads on floors to beams and walls
- P-Delta analysis with static or dynamic analysis
- Multiple linear and nonlinear time history load cases in any direction
- Automated vertical live load reductions, etc.

Models are created using the graphical user interface. The program offers a few options for input and output files such as text, tables and access database files. An example of graphical input file is shown in Figure 3.5.

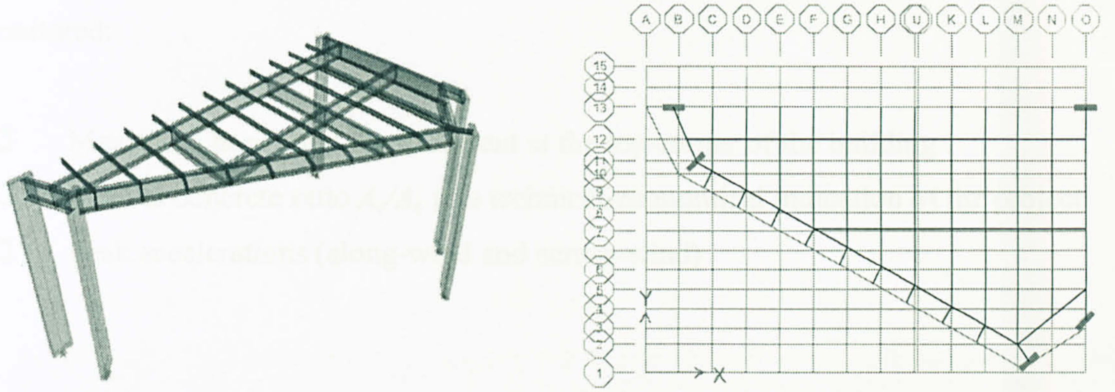


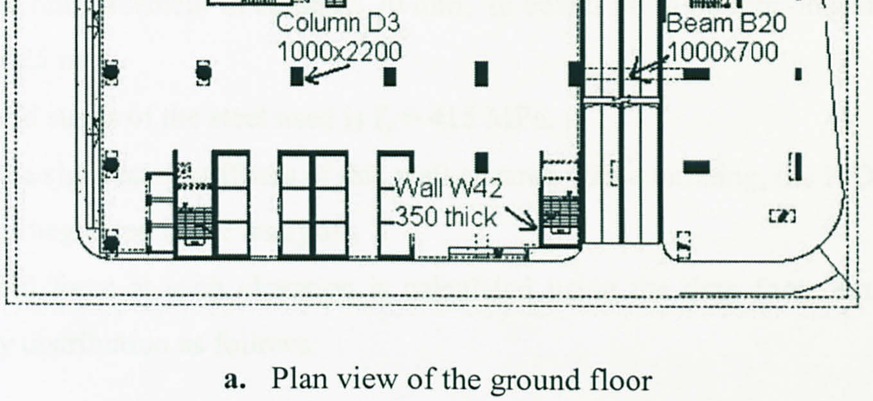
Figure 3.5. Graphical input file (Plan view and 3-D)

CHAPTER 4
RESULTS AND DISCUSSIONS

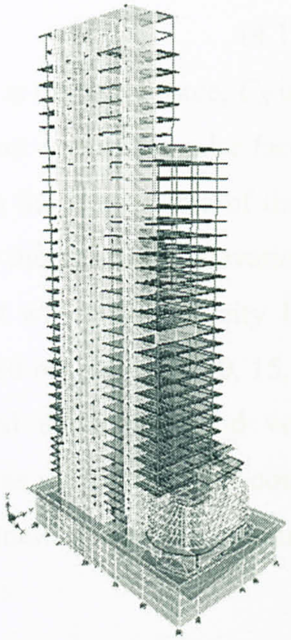
4.1. RESPONSE OF THE BUILDING TO WIND LOADING

Samples of three structural members are chosen on the ground floor where the responses are typically larger: two rectangular columns (one at the side 1.000 ×2.200 m and another near the middle 1.000 ×1.600 m), a beam near the middle 1.000×0.700 m, and a 350 mm shear wall at the side that is exposed to the wind. These members are shown in Figure 4.1.a. For the ease of reference, Column D1 is called side column and Column D3 is referred to as middle column. Three representative responses are then monitored:

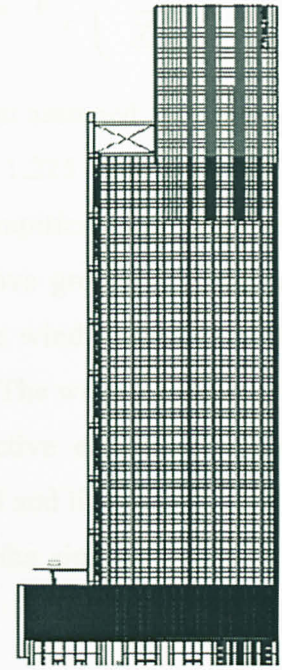
- Maximum horizontal displacement at the top corner of the building
- Steel to concrete ratio A_s/A_c as a technical-economical indication of the project
- Peak accelerations (along-wind and across-wind)



a. Plan view of the ground floor



b. 3D view



c. Elevation view

Figure 4.1. Views of the case study RC tall building in Kuala Lumpur, Malaysia

The commercial structural analysis and design software ETABS (Computers & Structures, Inc. 2007) is utilized to simulate the response of the building under the ultimate load condition. In the simulations, the following assumptions are adopted:

- Ultimate load combination: 1.2 Dead load + 1.2 Live load + 1.2 Wind load
- Concrete used is grade 50 concrete (f_{cu} = 50 MPa) with the modulus of elasticity 32 GPa.
- Cover to reinforcement in columns 70 mm, in beams 30 to 60 mm, in slabs 20 mm, in walls 25 mm
- The Yield stress of the steel used is f_y = 415 MPa.
- Given the significant stiffness of this wall-sheared frame building, the P-Delta effect has been neglected in the analysis.
- The wind force at each elevation is calculated using the drag force equation and velocity distribution as follows:

$$F = 0.5 C_S \rho V^2 A \qquad (4.1)$$

$$V = V_r \left(\frac{Z}{Z_r} \right)^{\alpha} \qquad (4.2)$$

in which F is the wind force, C_S is the shape coefficient assumed 1.23 for this particular configuration of a rectangular face, ρ is density of air 1.225 kg/m^3, V is the wind speed in m/s, A is the frontal area of the building, α is an empirical coefficient assumed 0.35 here, Z_r is the reference elevation usually 10 m above ground surface, and Z is the elevation at which the velocity V is sought. Various wind velocities at the reference elevation (10 m) are tried: 10, 15, 20, 25 and 30 m/s. The wind force at each floor level is computed using the wind velocity at the respective elevation. The forces are introduced as the lateral loads combined with the dead and live loads under the ultimate load combination. Table 1 contains the summary of the simulation results for various wind speeds.

Table 4.1. Summary of the simulation results for various wind speed

Wind Speed (m/s)	**10**	**15**	**20**	**25**	**30**
Max displacement (mm)	389	472	589	737	920
Middle Column, Axial Load (MN)	47.4	48.1	49.1	50.4	51.9
Middle Column, Moment (MN.m)	2.7	3.4	4.8	6.1	8
Middle Column, A_S (mm^2)	10600	14810	20660	30870	39977
Side Column Axial Load (MN)	7.80	7.84	7.89	7.96	8.04
Side Column Moment (MN.m)	0.97	1.3	1.78	2.21	2.86
Side Column A_S (mm^2)	6400 *	6400 *	6400 *	6400 *	6400 *
Top Beam, A_S (mm^2)	1970	1990	2012	2041	2077
Bottom Beam, A_S (mm^2)	1563	1570	1581	1594	1611
Wall, Shear Force (MN)	2.9	2.8	2.7	2.5	2.3
Wall, Moment (MN.m)	72	91	117	150	191
Wall, Axial load (MN)	127.3	124.5	120.6	115.5	109.3
Wall, A_S/A_C	0. 25%	0.25%	0.25%	0.54%	1.5%
Along Wind Acceleration (m/s^2)	0.075	0.094	0.12	0.151	0.184
Across Wind Acceleration (m/s^2)	0.002	0.007	0.022	0.035	0.055

*Minimum A_S is provided

4.1.1. Preliminary Observations

From a comparison of the results with increasing wind speed, a few quick observations can be made:

1. The magnitude of moments for both middle and side columns grows up to three times (from 2.7 to 8 for the middle and from 0.97 to 2.86 for the side)
2. The change in the axial forces of the columns is insignificant as the lateral wind forces are not expected to cause serious vertical forces.
3. Lateral sway of the building has no significant impact on moment and shear force of the beam, therefore A_S shows little change for different wind speeds.
4. The wall minimum reinforcement for wind speeds as high as 20 m/s at 10 m (52 m/s at the top floor) shows sufficiency of the minimum steel for the shear walls except for extreme wind speeds.

4.1.2. Maximum Deflections and Story Drifts

Maximum deflection of the building for various wind speeds, reported in Table 4.1, shows a smooth change. Figure 4.2 shows the drift (defined as the ratio of roof deflection to the storey height) for all the floors as given directly by the software. As the wind forces increase upward, the drift increases with height. The irregularities in the curve can be explained by the sudden change in the cross-section at some elevations. For example level 6 is the last floor of the podium and represents a jump.

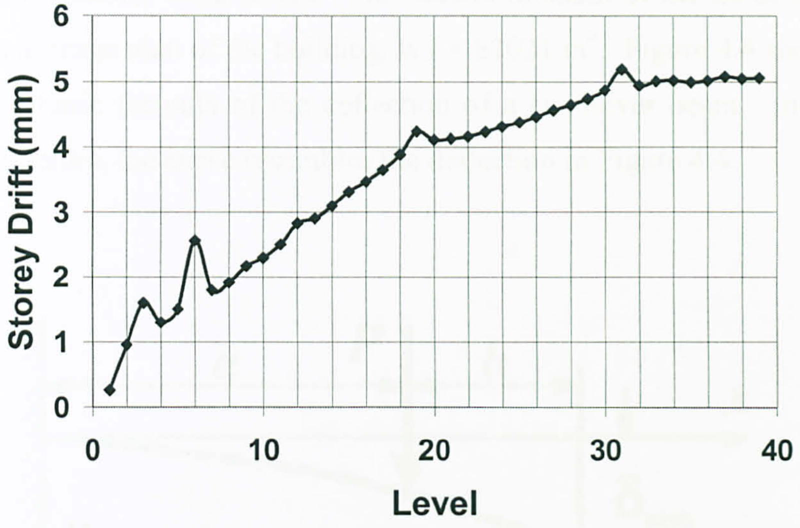


Figure 4.2. Drift at each floor when V=20 m/s

These drifts can be converted accumulatively to show the absolute deflection at each level as depicted in Figure 4.3.

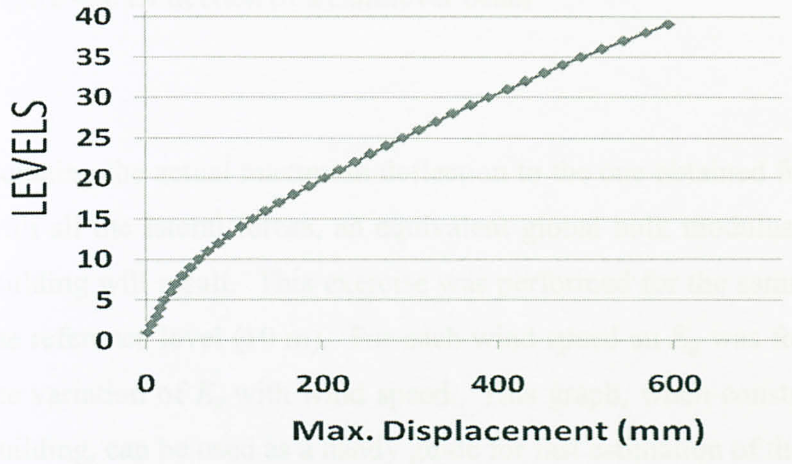
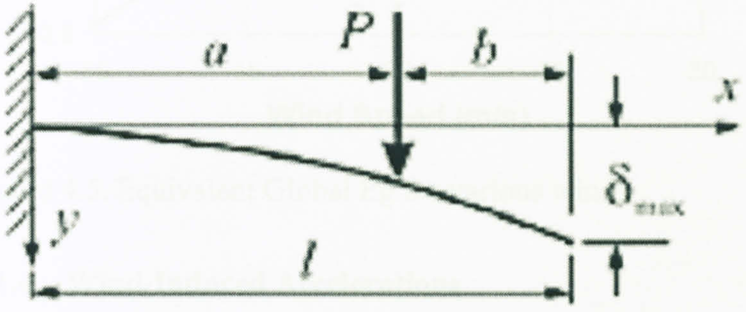


Figure 4.3. Deflection at each floor when V=20 m/s

4.1.3. Equivalent Global Eg of the Building

As a useful exercise, let us regard the building as a cantilever rectangular beam with a box shape cross-section 56 m long and 28 m wide under the simultaneous influence of all the lateral wind forces. The second moment of inertia of this section, representing an average plan of the building, is $I = 82021$ m^4. Figure 4.4 shows the definition sketch and basic formula of the deflection of a cantilever beam. In terms of the shape and curvature, the curve resembles the deflection in Figure 4.4.



$$\delta_{max} = \frac{Pa^2}{6EI}(3l - a)$$

Figure 4.4. Deflection of a cantilever beam

Equating the actual maximum deflection to the one obtained from a detailed calculation with all the lateral forces, an equivalent global bulk modulus of elasticity (E_g) for the building will result. This exercise was performed for the same range of wind speeds at the reference level (10 m). For each wind speed an E_g was found. Figure 4.5 presents the variation of E_g with wind speed. This graph, when constructed for each particular building, can be used as a handy guide for fast estimation of the maximum displacement of the same building under different wind speed. Extending the same exercise for various buildings with different classes of structural systems, generalized similar handy guides (curves, tables …) could be introduced.

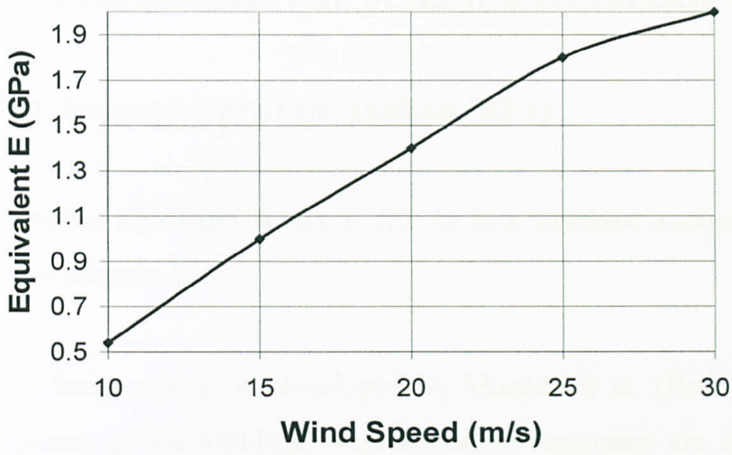


Figure 4.5. Equivalent Global Eg for various winds

4.1.4. Wind-Induced Accelerations

Due to the dynamic nature of wind forces, even if assumed unidirectional and steady, the building will experience accelerations, both along the wind and across the wind (Mendis *et al.*, 2007). Figure 4.6 depicts these accelerations as calculated using empirical formulas, such as those introduced by Taranath (2005). Given the categorization of magnitude of the acceleration based on the human perception levels (Mendis *et al.*, 2007), the results lie in Class 3 implying '*majority of people will perceive motion; Level of motion may affect desk work; long-term exposure may produce motion sickness.*'

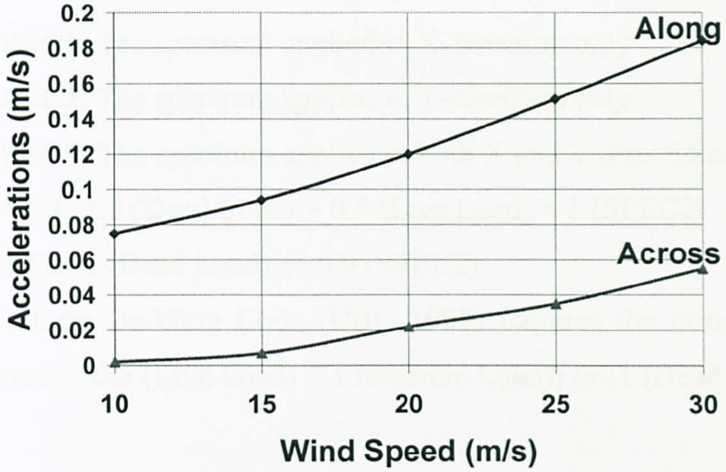


Figure 4.6. Wind induced accelerations

4.2. RESPONSE OF THE BUILDING TO SEISMIC FORCES

4.2.1. Response Spectrum Analysis (RSA)

Response Spectrum Analysis (RSA) is a standard analysis tool in design of structures under seismic loads.

The design spectrum developed by Mansor et al. (Ref. 2.5) was used to monitor the response of the building. Representative responses are summarized in Table 3.4. The detailed report of the results is given in Appendix.

Table 3.4. Summary of the results

Load code	SPEC1	SPEC2	SPEC3	UBC1	UBC2
Max displacement X-direction (mm)	780	120	400	160	140
Max displacement Y-direction (mm)	240	800	420	1080	1017
Middle Column, Axial Load (MN)	1.72	8.15	4.16	44.9	32.18
Middle Column, Moment (MN.m)	3.32	10.7	5.4	7.8	7.5
Side Column Axial Load (MN)	0.4	0.17	0.9	8.2	6.2
Side Column Moment (MN.m)	1.98	3.8	1.94	4.6	4.3
Wall, Axial Load (MN)	21.4	31.3	18.9	149.3	113.5
Wall, Moment (MN.m)	81.2	243	124	296	281

In the simulations, the following assumptions are adopted:

SPEC1: The spectrum applied in X-direction only
SPEC2: The spectrum applied in Y-direction only
SPEC3: The spectrum applied in both X and Y directions with half intensity
UBC1: 1.2 (Dead Load) + 0.5 (Live Load) + 1 (SPEC2)
UBC2: 1 (Dead Load) +- 0.9 (SPEC2)
Uniform Building Code (UBC 1997) requires the designer to use either [1.2 (Dead Load) + 0.5 (Live Load) + 1 (Seismic Load)] or [1 (Dead Load) +- 0.9 (Seismic Load)]

SPEC2 is the most critical for this particular building and is used to construct the representative load combinations introduced above. The analysis results show that UBC1 is the most critical load combination and is therefore used for design purposes.

Figure 4.7 shows the story drifts in X-direction using UBC1 load combination.

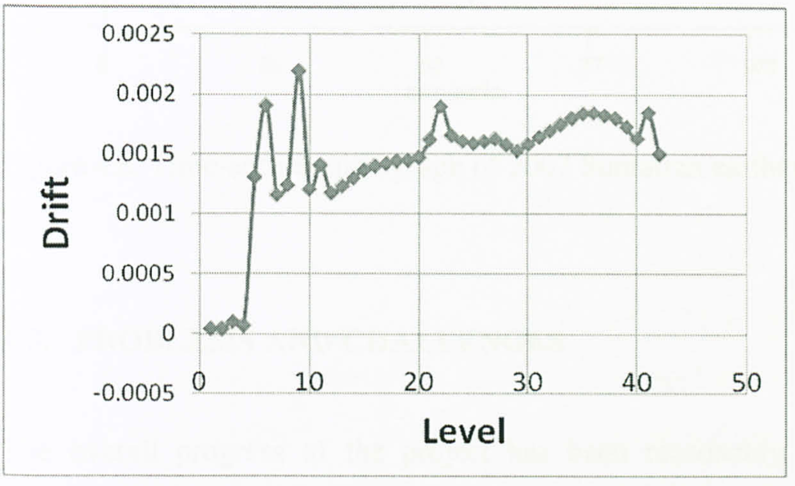


Figure 4.7. Story drifts due to UBC1 load combination

The area of still required for the middle column is $A_S = 38000\ mm^2$ and that of the side column is $9000\ mm^2$. Comparing the results with those of the original design (with consideration of no earthquake), A_S is about 40 % higher. However by enlarging the sections this amount could well be reduced.

4.2.2. Time History Analysis (THA)

Time History Analysis (THA) is being conducted on the case study building. The 8.5 M_w (Moment Magnitude Scale) earthquake in Southern Sumatra on 12 September 2007 is scaled down and used to monitor the responses of the building using ETABS.

The graph shown in Figure 4.8 is being manually digitized. The points obtained from the graph will then be given to ETABS to run the analysis. The author hopes to finish the analysis before the presentation of this dissertation.

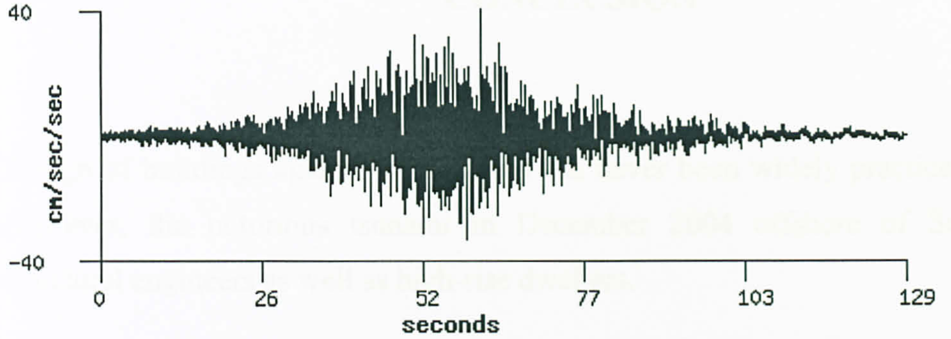


Figure 4.8. Time-acceleration graph of 2007 Sumatran earthquake

4.3. PROBLEMS AND CHALLENGES

The overall progress of the project has been reasonably smooth. However, a few challenges and problems have been encountered and the measures to rectify them were taken.

Since the model is huge and complicated, the **processing time** required is too long (8 to 12 hours per single run). In addition to that, the output files are gigantic (7 Gigabytes altogether per single run).

Browsing through literature met minor difficulties in several occasions. Since the earthquake records in Malaysia are not widely available, most of the records presented in this report are obtained indirectly from the works of other researchers.

CHAPTER 5
CONCLUSION

Design of buildings against earthquakes has never been widely practiced in Malaysia. However, the notorious tsunami in December 2004 offshore of Sumatra alerted structural engineers as well as high-rise dwellers.

An RC tall building near the city centre of Kuala Lumpur, Malaysia, was adopted to investigate the impacts of wind and earthquake on such buildings. The structure is a framed shear-walled 39-story RC tall office building with 160 m height weighing about 20,000 metric tons. Commercial structural software, ETABS, was employed to monitor responses of a few selected structural members under several loading combinations. A series of wind speeds from 10 to 30 m/s at a reference level of 10 m were assumed to blow to the face of the building with maximum frontal area and a published response spectrum was used to monitor the response of the building to seismic forces. The following conclusions can be made from the present study:

The overall design of the building is considered safe against wide range of wind speeds up to 30 m/s at an elevation 10 m above the ground. Maximum deflection at the top, forces in representative structural members (two columns, a beam and a shear wall), wind-induced accelerations, and the required reinforcement were monitored. Given the variation of wind velocity along the vertical, the building can withstand winds of 150 km/hr. However, accelerations for high wind speeds are undesirable for serviceability purposes.

Equating the top deflection with that obtained from a hypothetical equivalent cantilever beam, an equivalent bulk modulus of elasticity has been introduced for the whole building corresponding to each wind speed. The values could be used for a quick estimation of the maximum lateral deflection of the building for various wind speeds through application of simple formulas of beam deflection.

The analysis of the response of the structure to seismic forces was done using a response spectrum developed for West Malaysia. The critical direction of the building was subject to the loading and several load combinations were introduced to the software. Two representative columns were designed to determine the area of steel required. It is concluded that a 40 % increase is expected if the member sizes are to remain the same. However, the representative shear wall has to be redesigned using a bigger section.

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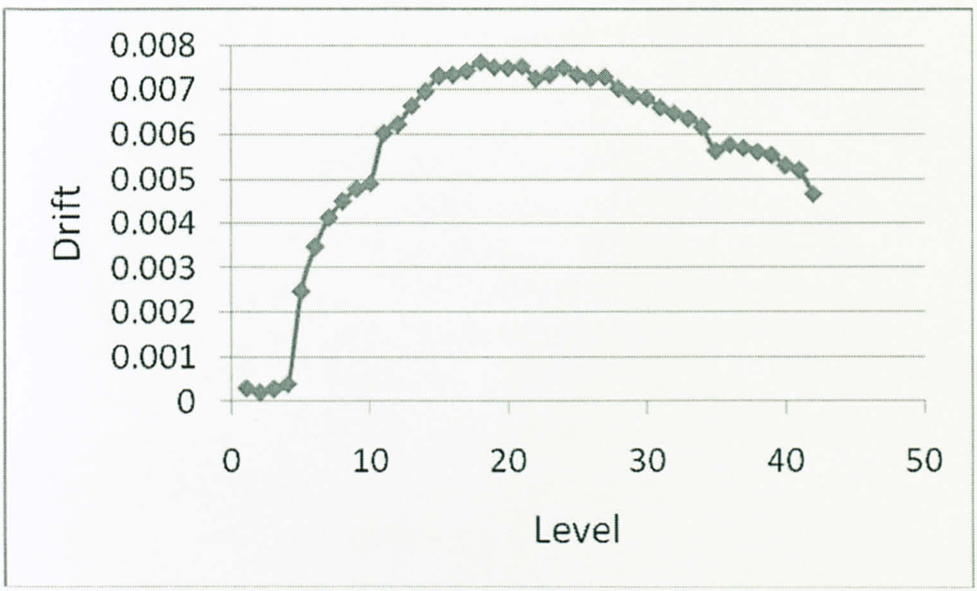
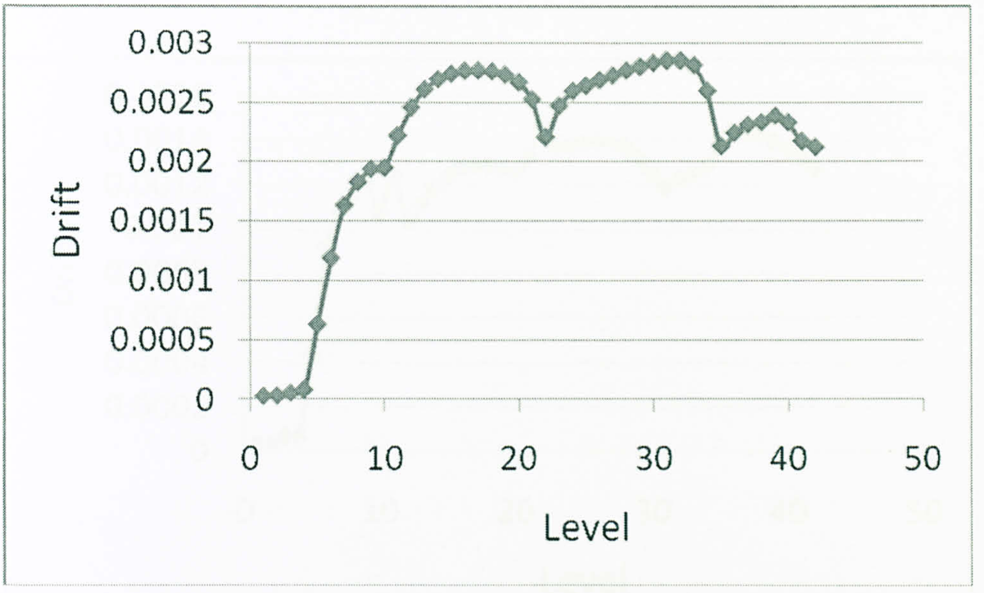
APPENDICES

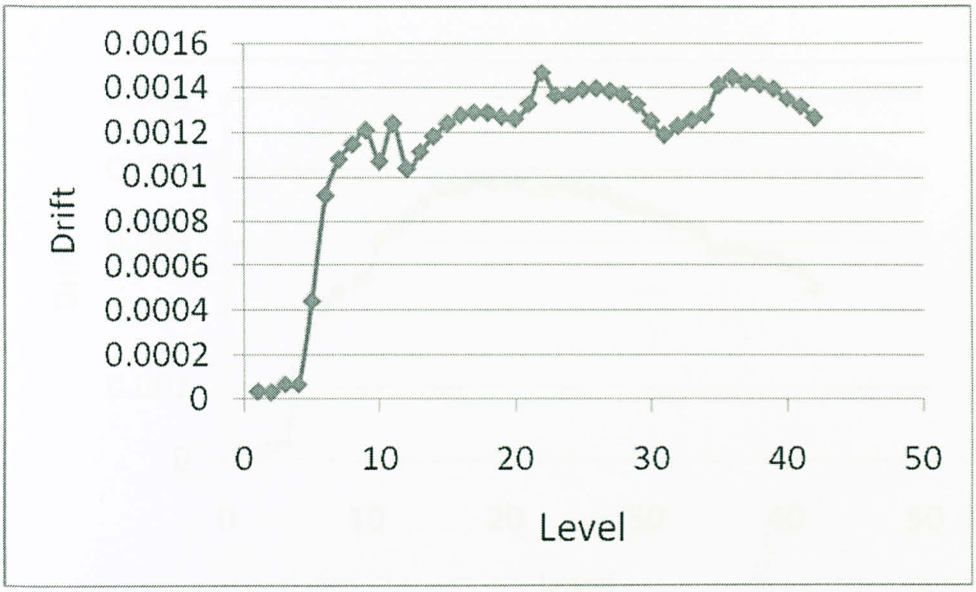
Load Combination	Dead Load	Live Load	Seismic Load
SERV	1	1	0
1UBC1	1.2	0.5	1 x SPEC1
1UBC2	1.2	0.5	1 x SPEC2
1UBC3	1.2	0.5	1 x SPEC3
2UBC1	+- 0.9	0	1 x SPEC1
2UBC2	+- 0.9	0	1 x SPEC2
2UBC3	+- 0.9	0	1 x SPEC3
EQDL1	1	0	1 x SPEC1
EQDL2	1	0	1 x SPEC2
EQDL3	1	0	1 x SPEC3



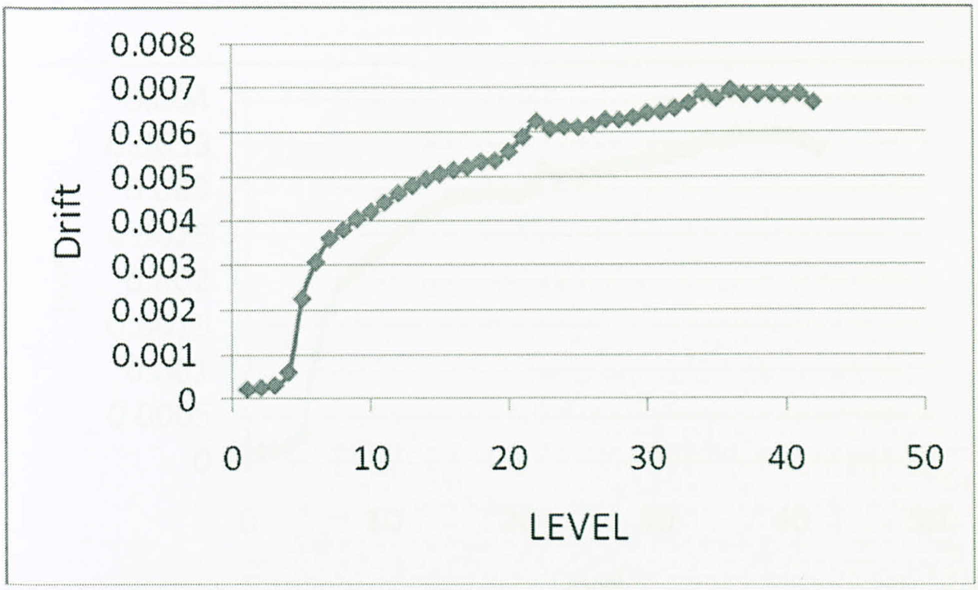
SPEC1 (Story Drifts) in X-direction



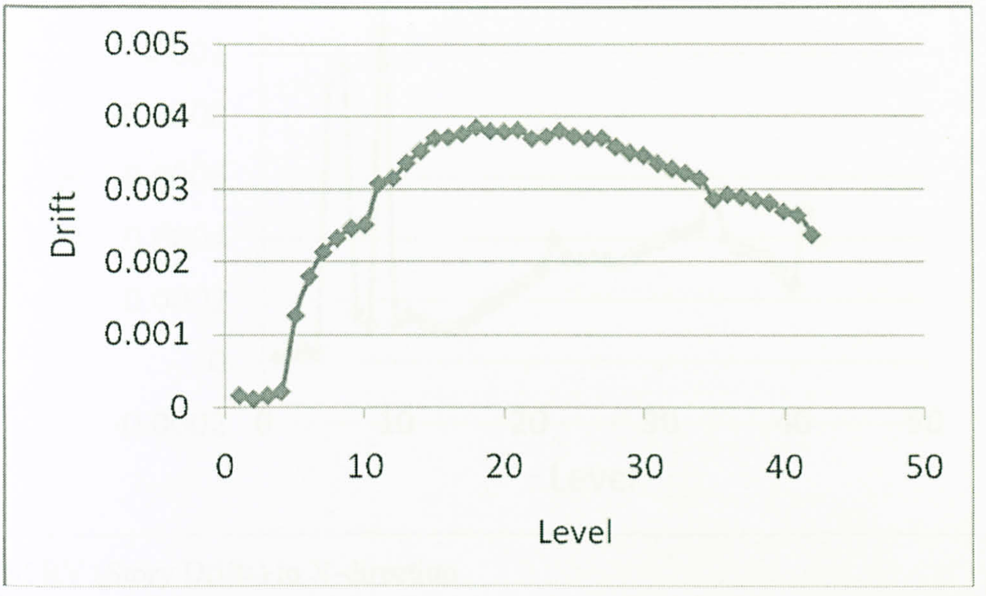
SPEC1 (Story Drifts) in Y-direction



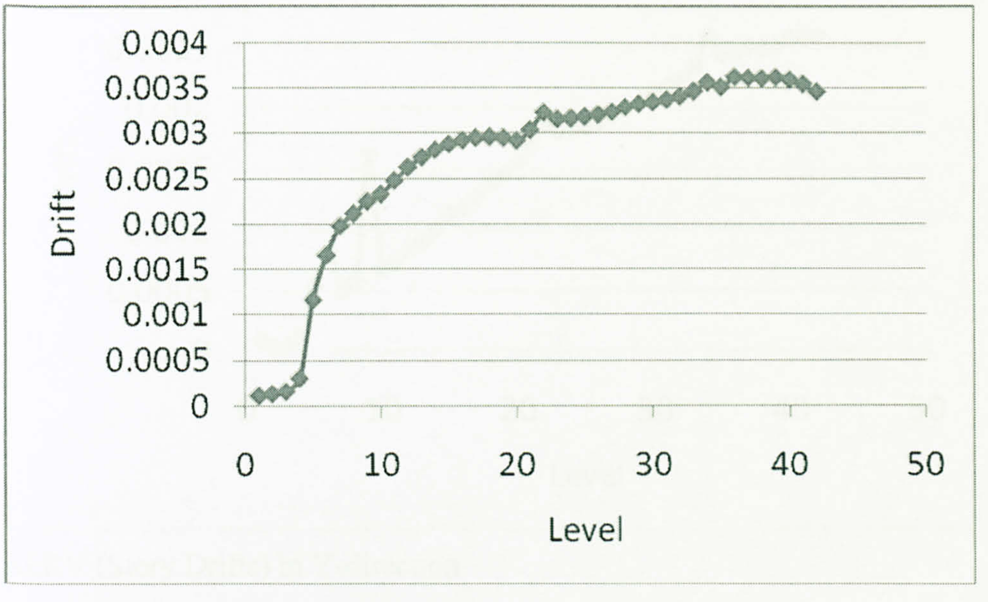
SPEC2 (Story Drifts) in X-direction



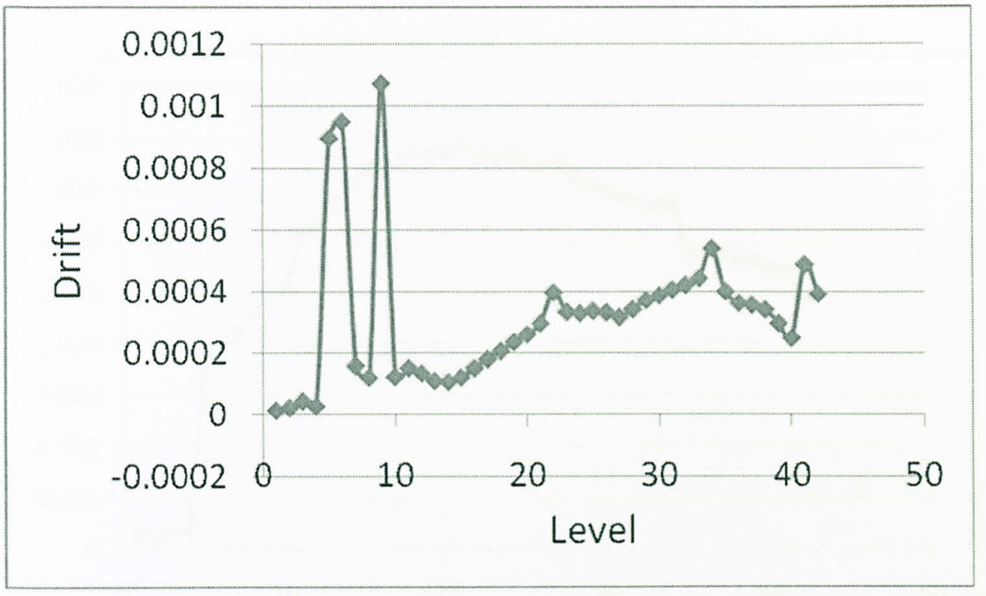
SPEC2 (Story Drifts) in Y-direction



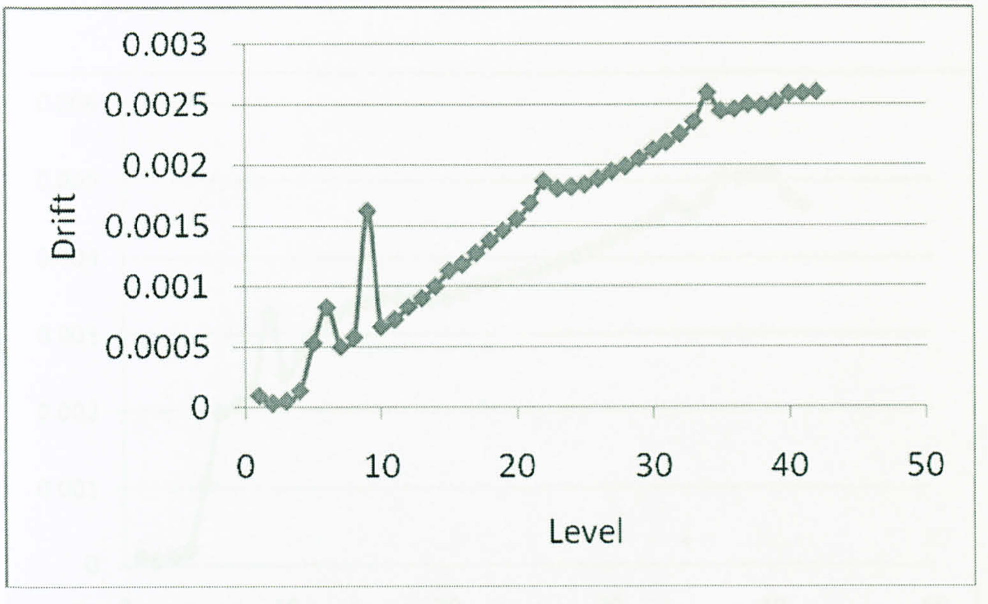
SPEC3 (Story Drifts) in X-direction



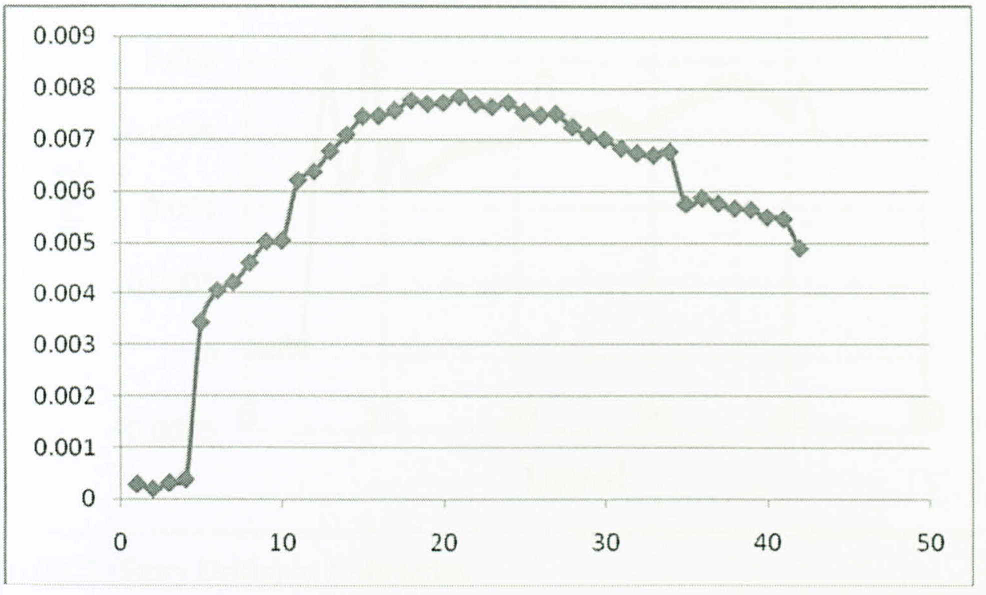
SPEC3 (Story Drifts) in Y-direction



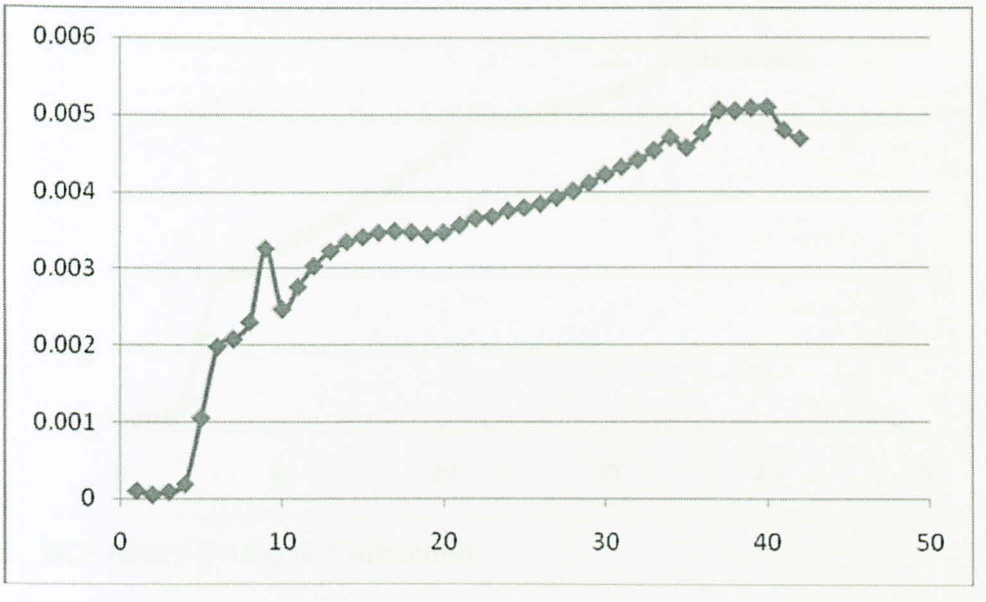
SERV (Story Drifts) in X-direction



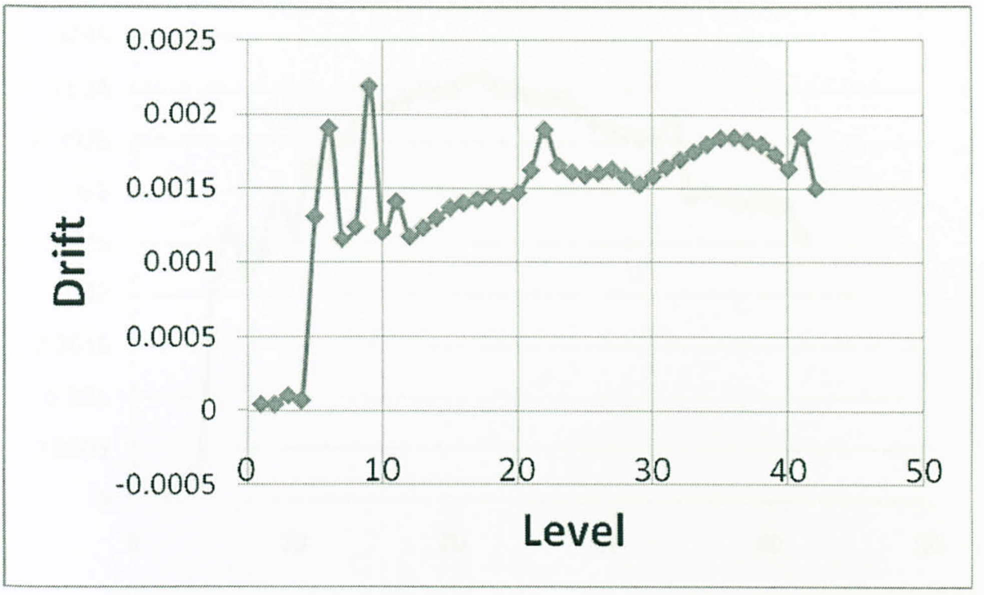
SERV (Story Drifts) in Y-direction



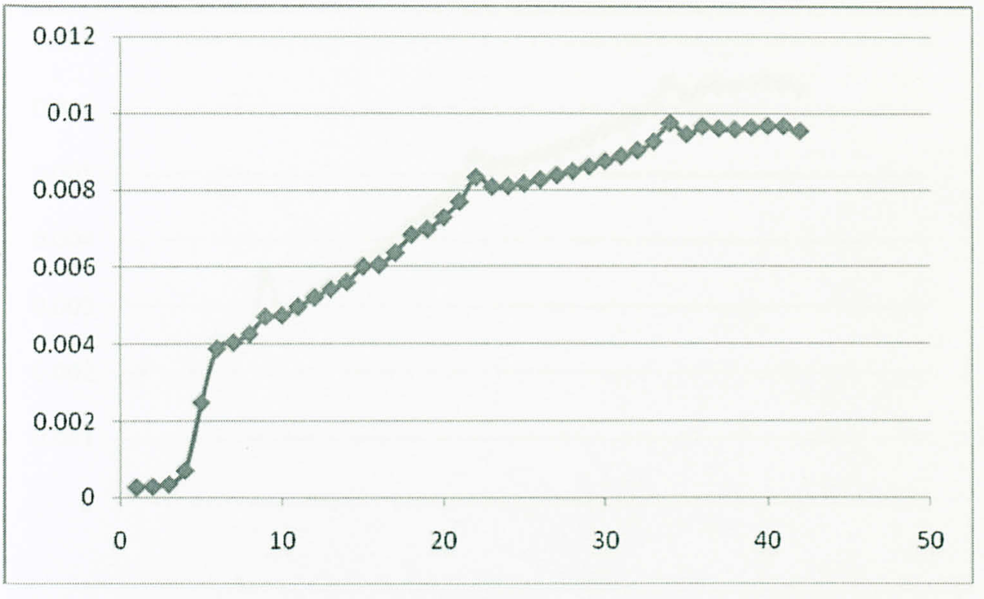
1UBC1 (Story Drifts) in X-direction



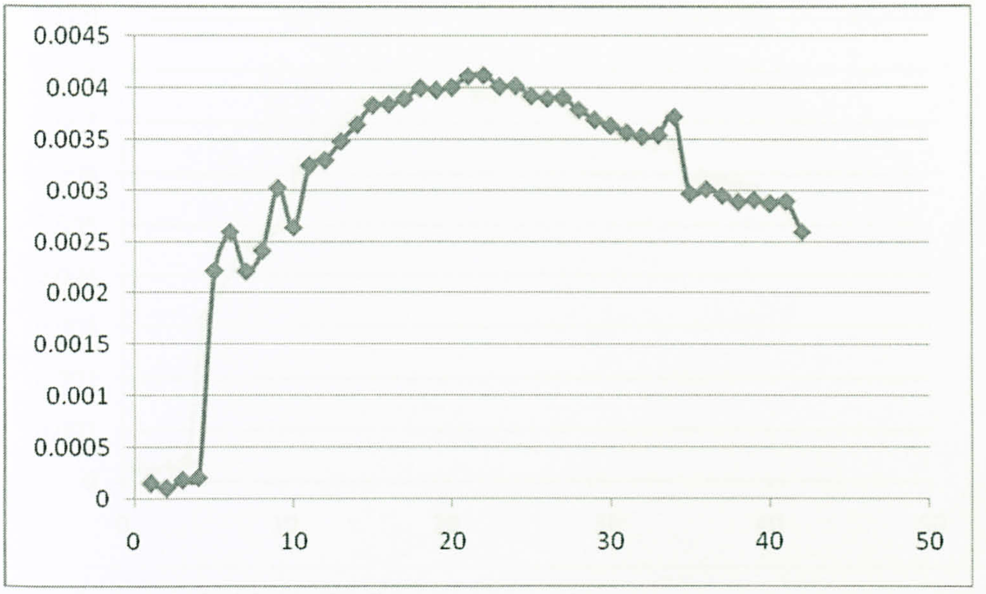
1UBC1 (Story Drifts) in Y-direction



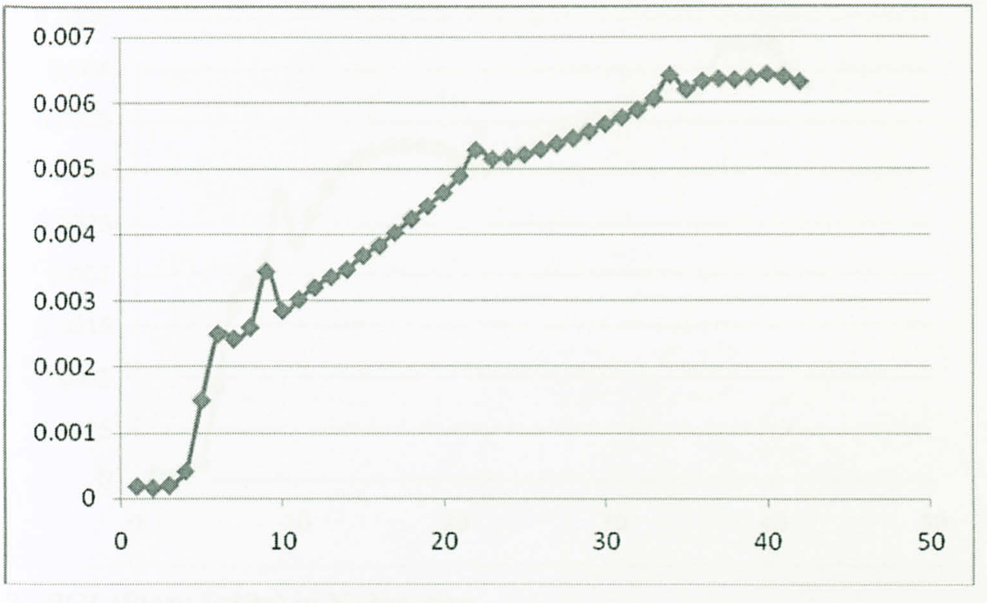
1UBC2 (Story Drifts) in X-direction



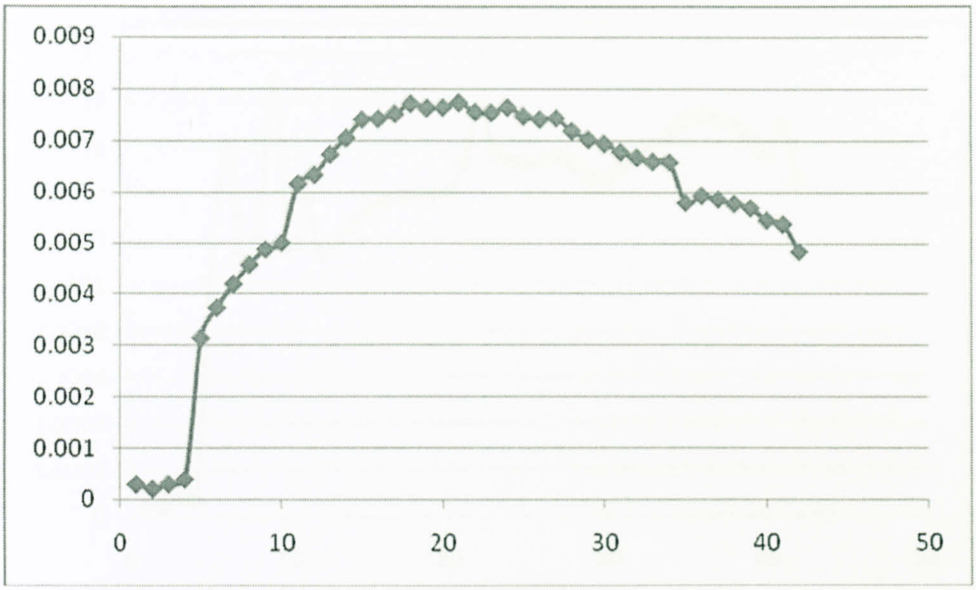
1UBC2 (Story Drifts) in Y-direction



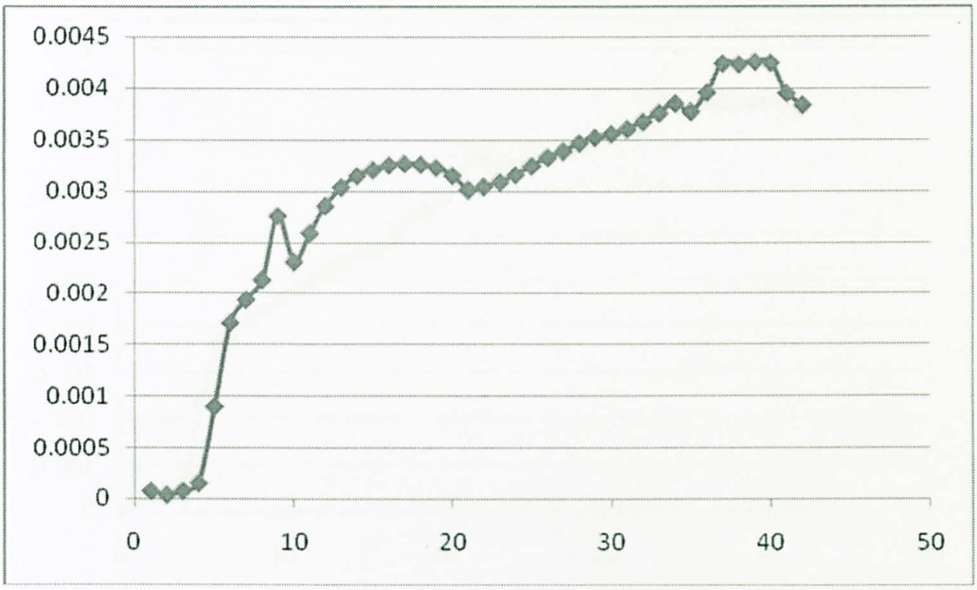
1UBC3 (Story Drifts) in X-direction



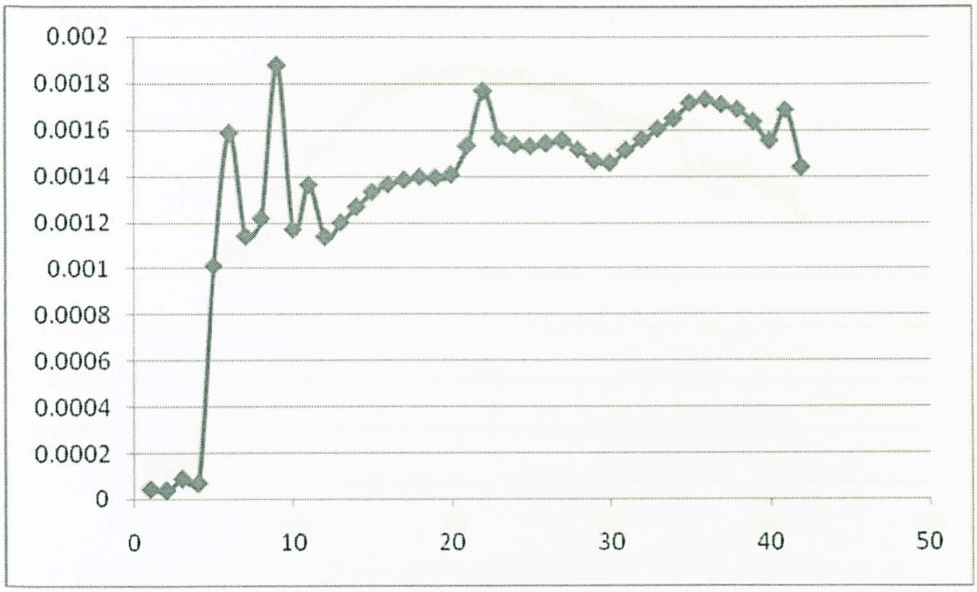
1UBC3 (Story Drifts) in Y-direction



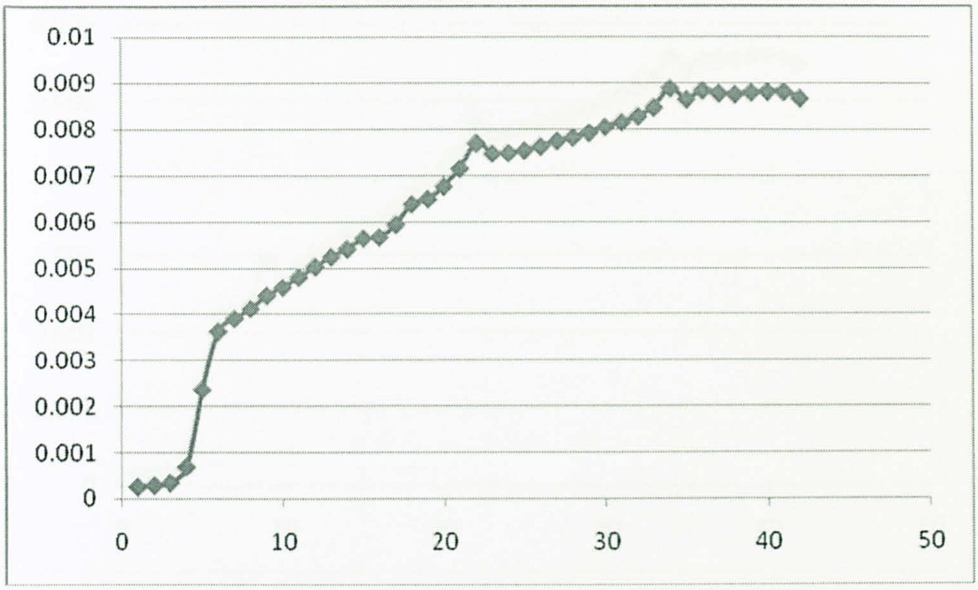
2UBC1 (Story Drifts) in X-direction



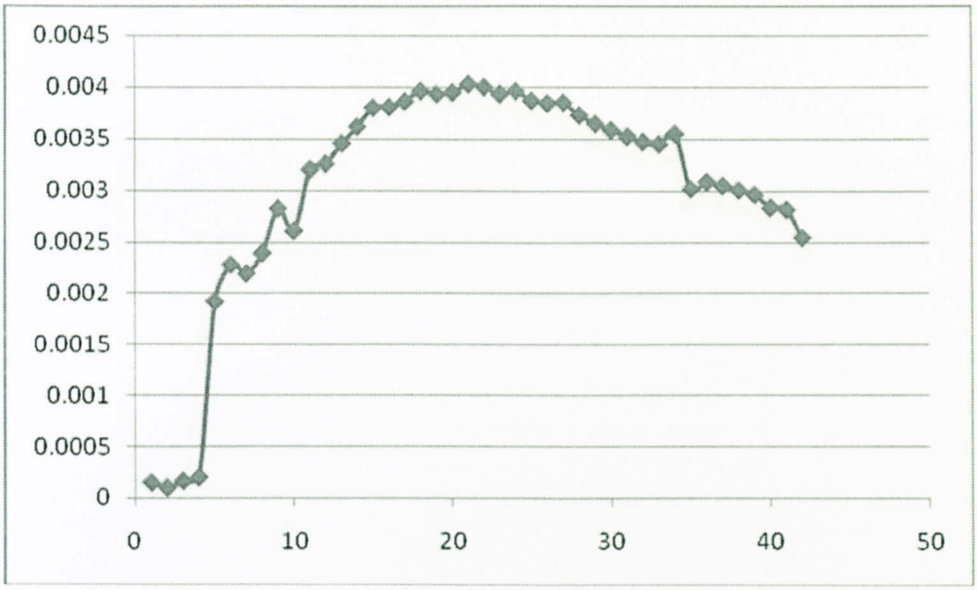
2UBC1 (Story Drifts) in Y-direction



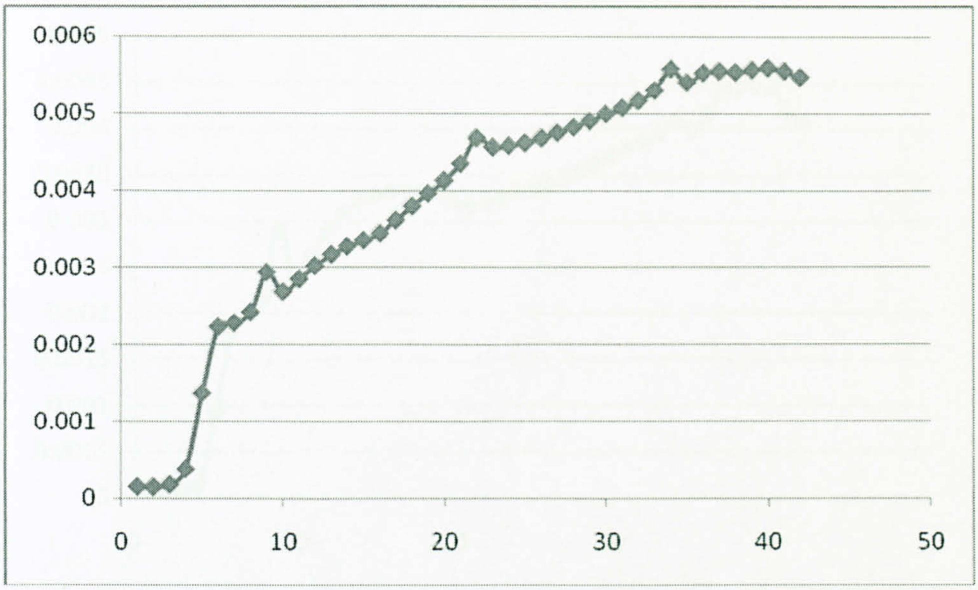
2UBC2 (Story Drifts) in X-direction



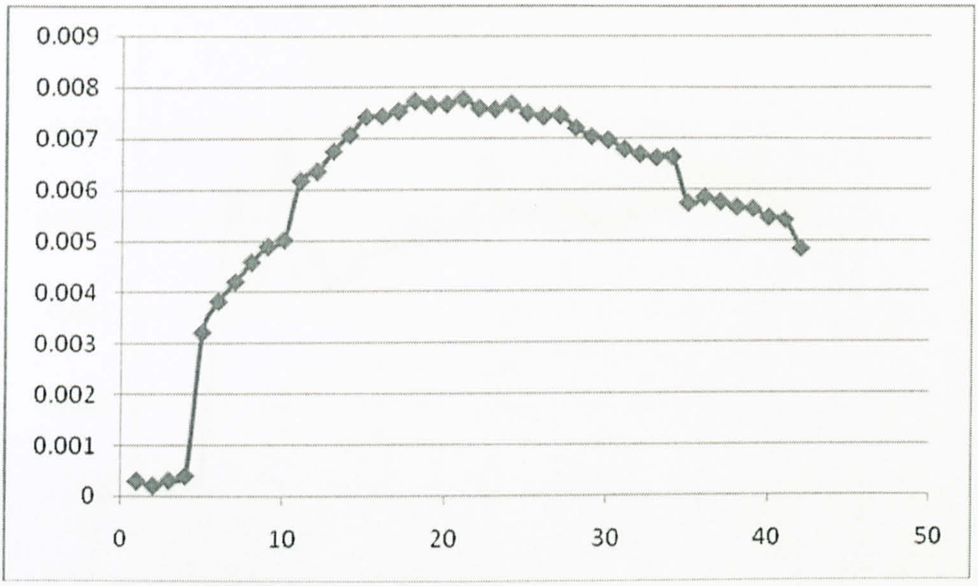
2UBC2 (Story Drifts) in Y-direction



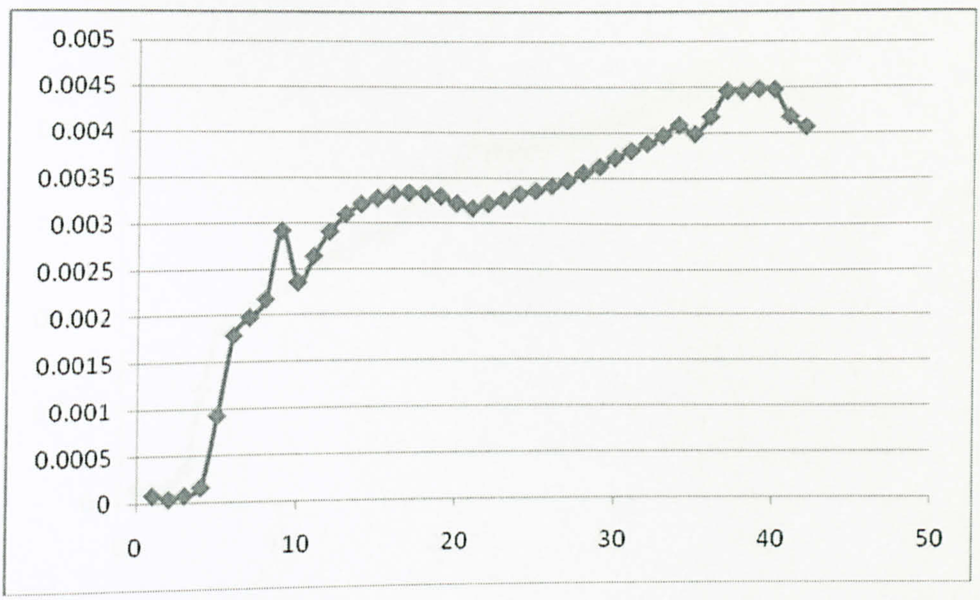
2UBC3 (Story Drifts) in X-direction



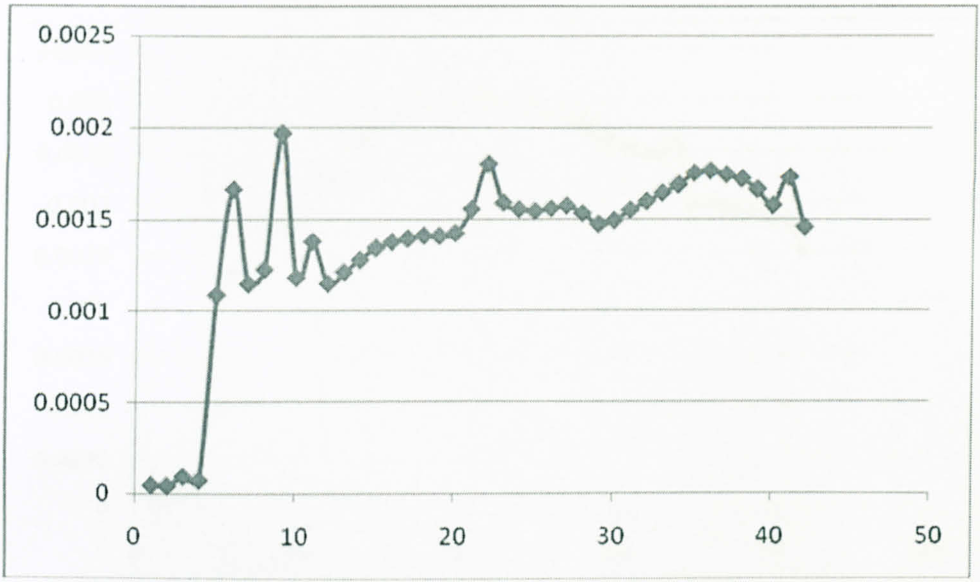
2UBC3 (Story Drifts) in Y-direction



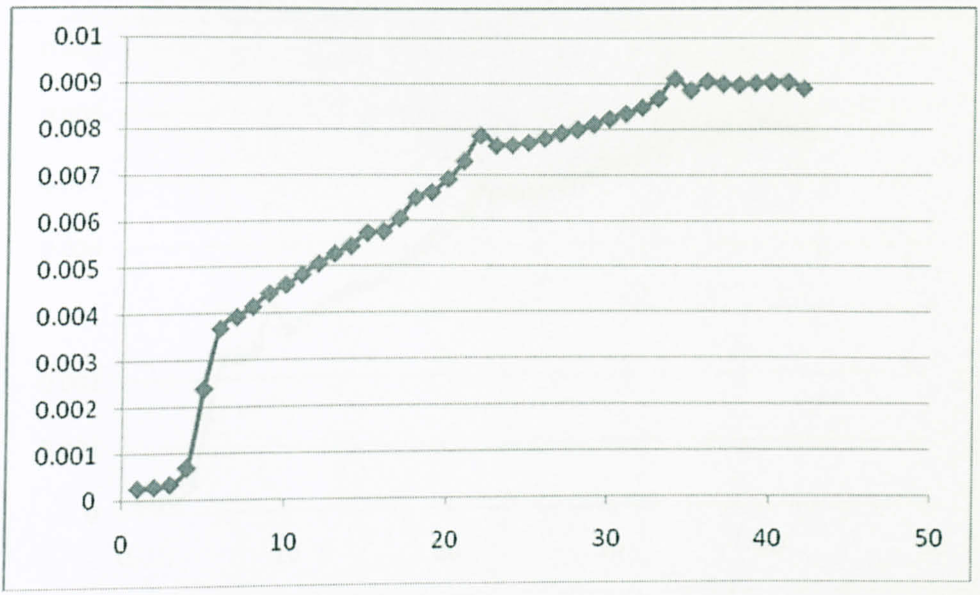
EQDL1 (Story Drifts) in X-direction



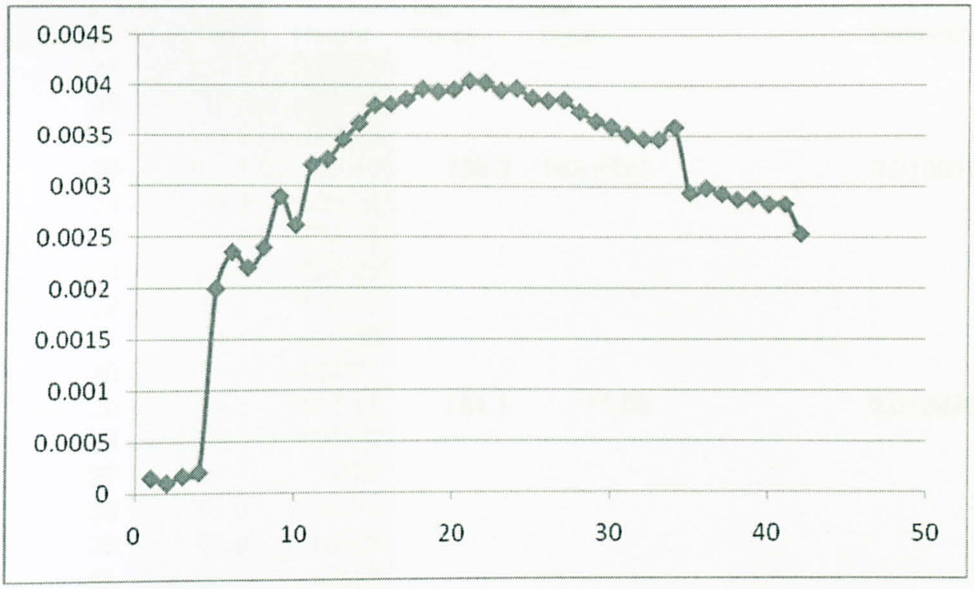
EQDL1 (Story Drifts) in Y-direction



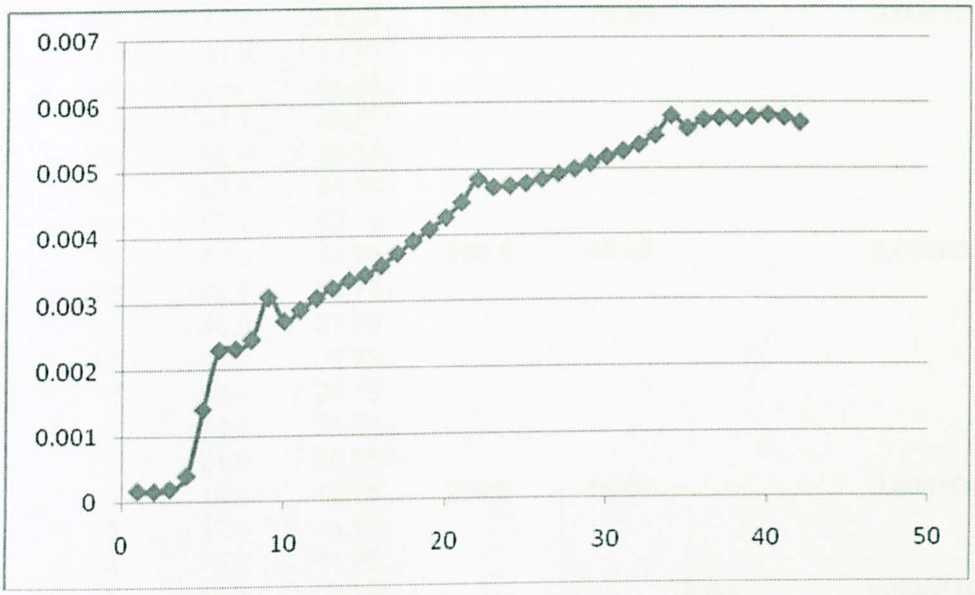
EQDL2 (Story Drifts) in X-direction



EQDL2 (Story Drifts) in Y-direction



EQDL3 (Story Drifts) in X-direction



EQDL3 (Story Drifts) in Y-direction

Story	Force	Height	Eq. Force	Eq. height	Deflection
39	122.0	157.95			
38	119.3	152.95			
37	111.9	147.95			
36	109.4	143.15	736.9	143.4929	0.0190465
35	93.4	138.35			0
34	91.4	134.15			0
33	89.4	129.95			0
32	87.4	125.75			0
31	104.4	121.55			0
30	101.9	117.35			0
29	99.3	113.15	764.1	111.05	0.0129904
28	96.7	108.95			0
27	94.1	104.75			0
26	91.5	100.55			0
25	88.8	96.35			0
24	86.0	92.15			0
23	83.3	87.95			0
22	80.5	83.75			0
21	77.6	79.55			0
20	74.7	75.35	671.1	75.35	0.0057692
19	71.8	71.15			0
18	68.8	66.95			0
17	65.7	62.75			0
16	62.6	58.55			0
15	59.5	54.35			0
14	56.2	50.15			0
13	52.9	45.95	263.8	45.95	0.0009057
12	49.4	41.75			0
11	45.9	37.55			0
10	42.2	33.35			0
9	38.4	29.15			0
8	34.5	24.95			0
7	21.6	20.75			0
6	19.4	17.75	216.8	16.67	0.0001046
5	17.0	14.75			
4	14.5	11.75			
3	15.4	8.75		Total	0.0388164
2	11.0	4.85			
1	2.7	0.65			

Sample spreadsheet to calculate Eg for different wind loads

Story	Force	Height	Eq. Force	Eq. height		Deflection
39	122.0	157.95				
38	119.3	152.95				
37	111.9	147.95				
36	109.4	143.15	736.9	143.4929		0.0190465
35	93.4	138.35				0
34	91.4	134.15				0
33	89.4	129.95				0
32	87.4	125.75				0
31	104.4	121.55				0
30	101.9	117.35				0
29	99.3	113.15	764.1	111.05		0.0129904
28	96.7	108.95				0
27	94.1	104.75				0
26	91.5	100.55				0
25	88.8	96.35				0
24	86.0	92.15				0
23	83.3	87.95				0
22	80.5	83.75				0
21	77.6	79.55				0
20	74.7	75.35	671.1	75.35		0.0057692
19	71.8	71.15				0
18	68.8	66.95				0
17	65.7	62.75				0
16	62.6	58.55				0
15	59.5	54.35				0
14	56.2	50.15				0
13	52.9	45.95	263.8	45.95		0.0009057
12	49.4	41.75				0
11	45.9	37.55				0
10	42.2	33.35				0
9	38.4	29.15				0
8	34.5	24.95				0
7	21.6	20.75				0
6	19.4	17.75	216.8	16.67		0.0001046
5	17.0	14.75				
4	14.5	11.75				
3	15.4	8.75			Total	0.0388164
2	11.0	4.85				
1	2.7	0.65				

Sample spreadsheet to calculate Eg for different wind loads