COMPARATIVE STUDY OF THE SOFTWARE ANALYSIS BETWEEN MIDAS GEN AND SCIA ENGINEER ON THE HIGH-RISE BUILDING ACCORDING TO EC8

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **“COMPARATIVE STUDY OF THE SOFTWARE ANALYSIS BETWEEN MIDAS GEN AND SCIA ENGINEER ON THE HIGH-RISE BUILDING ACCORDING TO EC8”** was prepared by **DESMOND KUEK JIN HUI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Malaysia experienced both local and far field earthquake activities. Malaysia authority had invited professional body to produce a national code of standard for earthquake engineering namely Malaysia National Annex (NA) to Eurocode 8 (EC8). In this study, important parameters in the code of standard are clearly stated such as the national deciding value of response spectrum curve in respective ground type, peak ground acceleration value in different region in Malaysia and etc. The main objective of this study is to model, analyse and compare the effect of high-rise building in different region of Malaysia by using structural analysis software. A 12 storey high-rise building under seismic action of Peninsular Malaysia (PGA = 0.08 g), Sarawak (PGA = 0.09 g) and Sabah (PGA = 0.16 g) on ground type B with the respective horizontal elastic response spectrum acceleration curve according to EC8 Malaysia NA were modelled and analysed by structural analysis software namely Midas Gen and Scia Engineer. The seismic performance of the high-rise building is determined by several indicators such as fundamental period, base and storey shear, storey displacement, interstorey drift and internal forces of members.

In modal analysis, Midas Gen and Scia Engineer require 25 modes and 13 modes respectively to achieve sum of participating mass of 90 %. The base and storey shear, storey and interstorey displacement increase as PGA value increases. The average percentage difference of the analysis output between Midas Gen and Scia Engineer on high-rise building in Sabah region for base and storey shear, storey displacement and interstorey displacement in x direction are 14.0469 %, 4.3761 % and 4.5300 % respectively. In linear analysis, internal forces of members namely beam and column are studied based on its axial force, shear force and bending moment. The bending moment of beam and column for both Midas Gen and Scia Engineer consist totally different trend and are not relevant to compare.

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LIST OF SYMBOLS / ABBREVIATIONS

a_g	design acceleration on type A ground, m/s^2
a_{gR}	reference peak ground acceleration, m/s^2
g	acceleration of gravity, m/s^2
PGA	peak ground acceleration, m/s^2
PGV	peak ground velocity, m/s
PGD	peak ground displacement, m
P_{NCR}	probability of exceedance, %
q	behaviour factor
SWV	shear wave velocity, m/s
T_{NCR}	reference return period, years
T_s	site natural period, s
V_s	shear wave velocity, m/s

BIM	Building Information Modelling
BS	British Standard
DCL	ductility class low
DCM	ductility class medium
DCH	ductility class high
DBKL	Kuala Lumpur City Hall
EC0	Eurocode
EC1	Eurocode 1
EC2	Eurocode 2
EC8	Eurocode 8
ES	elastic response spectrum
GB	Great Britain
Midas IT	Midas Information Technology Co. Ltd.
NA	National Annex
RS	response spectrum
SDOF	single-degree-of-freedom
UAE	United Arab Emirates
US	United States
USGS	United States Geology Survey

α_A	amplification parameter
γ_1	importance factor

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Malaysia experienced both local and far field earthquake activities such as Bukit Tinggi local earthquake, Ranau local earthquake and Northern Sumatera far field earthquake which killed 68 peoples in Penang, Langkawi and Kedah (Marto et al., 2013; Felix Tongkul, 2016). Malaysia authority had realised the seriousness of the effect of the earthquake and therefore invited professional body to create a national code of standard for earthquake engineering for the future building (Bavani, 2015).

In year 2017, Malaysia National Annex (NA) to Eurocode 8 (EC8) had finally been published. EC8 NA is advised to use in conjunction with EC8 where there are some principle clauses must be followed. EC8 NA contains numerous parameters which fit Malaysia ground condition, design earthquake magnitude, importance factor for specific use of building and etc.

Structural analysis and design software have been adopted in the construction industry for a long time. The application of structural analysis and design software may expedite work drastically and complicated design may be analysed and designed effectively (Sturdy Structural, 2016). Biasioli (2018) has suggested a few number of software which comply with Eurocode such as Midas Gen and Scia Engineer. These two structural analysis and design software will be used to model, analyse and design a high-rise building under seismic loading based on the regional area in Malaysia with compliance to the new implemented Malaysia NA to EC8.

1.2 Problem Statement

An Earthquake had been long feared as the one of the most hazardous natural phenomena. In definition, an earthquake can be explained as the sudden movement of the earth's surface that cause from the release of energy in the earth crust (Zaleha Awaludin and Adnan, 2016). Although Peninsular Malaysia is located on a stable part of Eurasian Plate, tremors due to far-field effects of earthquakes in Sumatra could still felt in tall buildings in Kuala Lumpur (Balendra and Li, 2008). Therefore, the implementation of applying seismic loading into high-rise building design with compliance to EC8 NA is a necessary.

After the Sabah earthquake in 2015, The Star Online reported that Kuala Lumpur City Hall (DBKL) started to look into the building of earthquake-resistant structures (Bavani, 2015). In year 2008, professional body was invited by the government to draft a code of standard in earthquake engineering for future buildings in Malaysia. In year 2015, a first draft of EC8 NA has been proposed for public comment. In year 2017, Malaysia National Annex to Eurocode 8 has finalized and ready to apply in building and civil structures in Malaysia including Peninsular Malaysia, Sarawak and Sabah. In EC8 NA, seismic hazard map with different value of peak ground acceleration showed the difference of regional seismic severity and the earthquake parameter with its corresponding recommended ductility class design.

Structural analysis and design software can often expedite engineer's work. According to Biasioli (2018), European Standard Committee has proposed a few number of structural analysis software that comply to both Eurocode 2 (EC2) and EC8 which are design of concrete structures and design of structures for earthquake resistance respectively. In this project, Midas Gen and Scia Engineer are used to analyse and design high-rise building with compliance to the EC8 NA. The features, pros and cons of the software will be investigated in a way that whether they could analyse and design accurately according to EC8.

1.3 Aim and Objectives

The aim of this research is to study the seismic modelling and the analysis of high-rise building according to EC8 by using structural analysis software. The objectives of this study are:

1. To model high-rise building under seismic action in different region in Malaysia using Midas Gen and Scia Engineer.
2. To analyse high-rise building under seismic action in different region in Malaysia using Midas Gen and Scia Engineer.
3. To compare the effect of seismic action on high-rise building in different region in Malaysia using Midas Gen and Scia Engineer.

1.4 Scope and Limitation of the Study

The scope of study includes the application of structural analysis and design software such as Midas Gen and Scia Engineer. The study includes the modelling of high-rise building in software, the application of seismic loading to the high-rise building, and the comparison of results produced by Midas Gen and Scia Engineer.

The limitation of the study is the modelling of high-rise building comes with a number of assumptions such as ground type. As the effect of earthquake to high-rise building will be compared regionally, the collection of site condition data will be not possible.

1.5 Significance of the Study

The outcome of this research served as a reference for further studies of Eurocode compliance software in analysis and design of high-rise building. This study assists young engineers in the application of Midas Gen and Scia Engineer in analysing the seismic resistance high-rise building.

1.6 Outline of the Report

In Chapter 1 Introduction, a brief general introduction, problem statement, aims and objectives, scope and limitation of the study and significance of the study are discussed.

In Chapter 2 Literature Review, a background about the earthquake in Malaysia and some previous earthquake activities are discussed. Next, the basic parameters used in modelling seismic hazard are discussed. Eurocodes are roughly overviewed and Malaysia NA to EC8 is discussed. Structural analysis and design software namely Midas Gen and Scia Engineer are also discussed.

Chapter 3 Methodology describes the workflow of the study. The procedures in modelling and analysing high-rise building including the parameters used and assumptions made are discussed in this chapter.

In Chapter 4 Results and Discussion, the results from software analysis according to different region in Malaysia by Midas Gen and Scia Engineer are displayed and compared appropriately.

Chapter 5 summarized the study with conclusion and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Earthquake in Malaysia

In general, earthquake happens when two blocks of earth crust strike, slip or impact with each other (Wald, 2018). Fortunately, Malaysia is located outside of Ring of Fire which United States Geology Survey (USGS) stated that 90 % of earthquake located there. By referring to Figure 2.1, all the trenches area form a Ring of Fire where earthquake is most likely to be happened. Despite of that, Malaysia cannot escape from natural disaster earthquake.

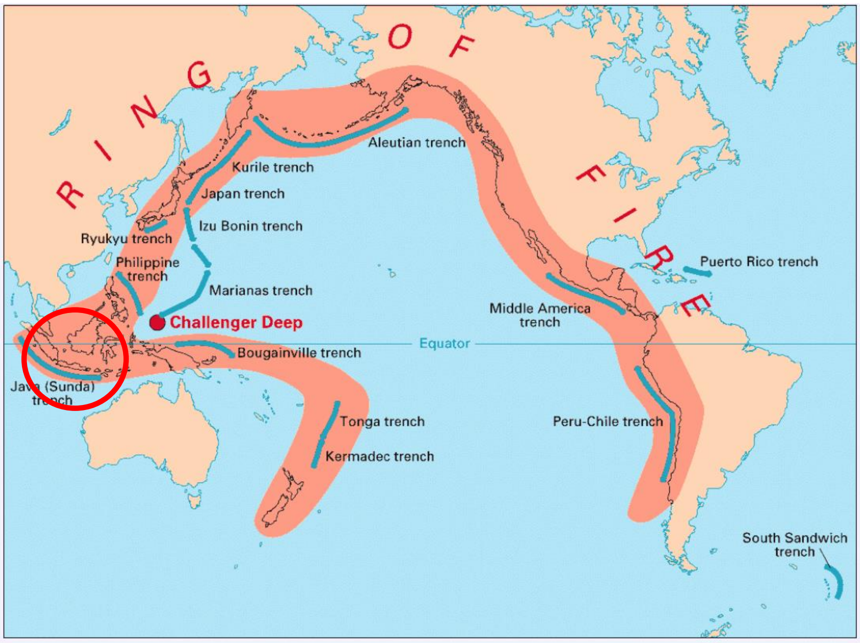

Figure 2.1: Ring of Fire

2.1.1 Earthquake Activities in Peninsular Malaysia

Peninsular Malaysia is located far away from any earthquake epicenter, and the nearest earthquake epicenter is located approximately 350 km away from Peninsular Malaysia. Besides, Peninsular Malaysia has a low to moderate seismicity level due to its location in stable Sunda Shelf (Azlan Adnan et al., 2005). However, buildings built on soft ground may subject to tremors due to far-field effects of earthquake in Sumatra (Balendra and Li, 2008).

Peninsular Malaysia has been affected by both of the tectonic features which are far field earthquakes and near field earthquakes as shown in Table 2.1 (Marto et al., 2013).

Table 2.1: Far Field Earthquake that Affected Peninsular Malaysia (Marto et al., 2013)

Date	Epicenter	Magnitude	Effect on Malaysia
1984-08-27	Northern Sumatera	5.2	Kuala Lumpur, Penang
1994-10-11	Southern Sumatera	6.5	Southern Malaysia and Singapore
1998-04-01	Padang	6.9	Kuala Lumpur
2004-12-26	Northern Sumatera	9.0	68 people killed in Penang, Langkawi, Kedah
2007-09-12	Southern Sumatera	8.4	Setapak, Cheras, Pudu, Langkawi, Johor Bahru, Melacca
2012-07-25	Northern Sumatera	6.6	West coast Peninsular Malaysia

Near field earthquake is locally originated in Peninsular Malaysia. There are some feature seismic activities caused by the near field earthquake such as Bentong Fault Zone which comprises of the Bukit Tinggi Fault and Kuala Lumpur Fault as shown in Table 2.2 (Marto et al., 2013).

Table 2.2: Local Earthquake Occurrences in Peninsular Malaysia (Marto et al., 2013)

Date	Case	Location
2007-2009	24	Bukit Tinggi, Pahang
2009	4	Kuala Pilah, Perak
2009	1	Jerantut, Pahang
2009	1	Manjung Perak
2010	1	Kenyir Dam, Terengganu
2012	1	Mersing, Johor

2.1.2 Earthquake Activities in East Malaysia

East Malaysia consisted of two state which is Sabah and Sarawak. Large earthquake from Southern Philippines and in the Straits of Macassar, Sulu Sea and Celebes Sea may affect Sabah and Sarawak. Despite of that, Sabah and Sarawak had experienced locally originated earthquake (Mohd Rosaidi, 2001).

Sabah and Sarawak were experienced quite a number of locally originated earthquake in the history. Some of the earthquake were critical enough to cause structural damages and injuries to human. A recent locally originated earthquake in Ranau District of Sabah with epicenter located near the peak of mount Kota Kinabalu having a magnitude of 6.0 had killed 18 people and caused structural and infrastructural damages (Felix Tongkul, 2016). Figure 2.2 and Figure 2.3 show the effect of earthquake upon infrastructure and structure.

Figure 2.2: Minor Crack on Ground and Road Produced by the Ranau Earthquake-Generating Fault

Figure 2.3: Broken Glass Pane in Ranau BSN Bank (left), Cracked Wall (centre) and Cracked Pillar of SMK Ranau Teacher's Flat (right)

2.2 Modelling of Seismic Hazard

Seismic analysis is one of the title under structural analysis. The selection of structural analysis method onto a building or any civil structure are depending on the severity of the impact, importance of the structure and the irregularity of the structure.

In order to find out the effect of building structures upon the ground motion, idealisation of structures and loads are carried out. Structures are idealised into single-degree-of-freedom so that the response spectrum accelerograms for different height of building structures may be calculated then lastly idealise the massive data again to become elastic response spectrum curve that is able to apply by engineers.

In EC8 NA, the application of response spectrum in modelling the response of earthquake on building with respect to relevant ground condition is recommended.

2.2.1 Idealisation of Structures and Loads

In order to ease the structural analysis process or to analyse a complex structure under actions and loadings, modelling of complex structural members into a structural model is essential of fundamental structural analysis (Haukaas, 2014). In addition, all real structures are in the existence of three-dimensional space and having extend in all three axis directions, the further idealisation of 3D model to 2D model gives a better insight which allows the model becomes easier to analyse as a first approximation as shown in Figure 2.4 (Haukaas, 2014).

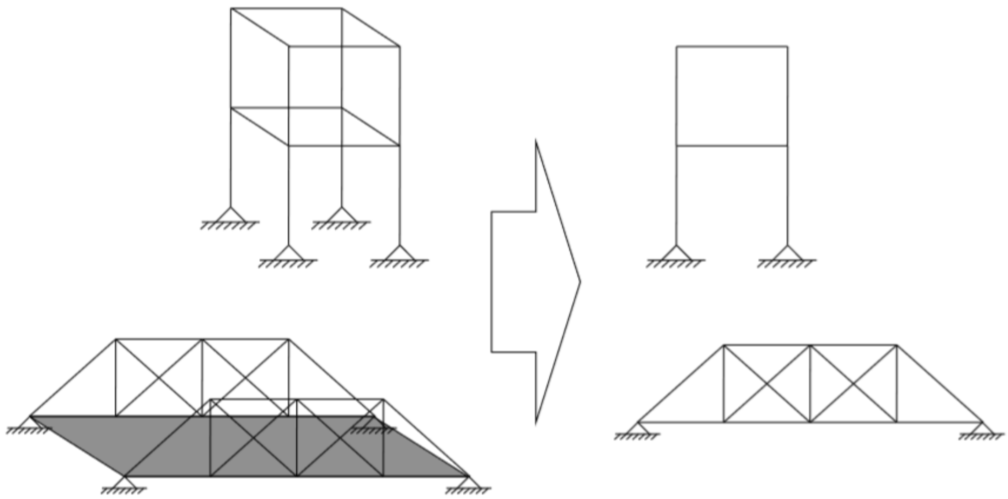

Figure 2.4: Idealisation of 3D Structures to 2D Problems (Haukaas, 2014)

In seismic design, earthquake loadings are in the form of lateral dynamics loading which makes the analysis process complicated. According to Tsang and Lam (2018), a simplified “stick model” can be used to analyse of the lateral resisting behaviour of a multi-storey building structure subject to seismic conditions. Lumped masses are attached to the “stick” at certain intervals of height to indicate the masses of the building floors. Figure 2.5 shows the idealisation of multi-storey buildings into stick models.

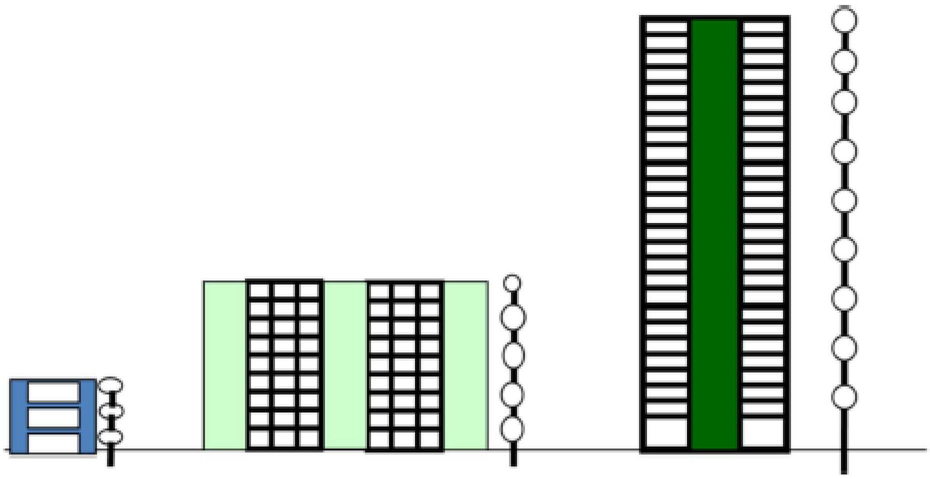

Figure 2.5: Idealisation of Multi-Storey Buildings into Stick Models (Tsang and Lam, 2018)

When a building subjects to seismic actions or dynamics actions, a difference number of vibration modes may allow the lumped masses stick model system also known as single-degree-of-freedom (SDOF) model to demonstrate a simplified dynamics response as illustrated in Figure 2.6 (Tsang and Lam, 2018).

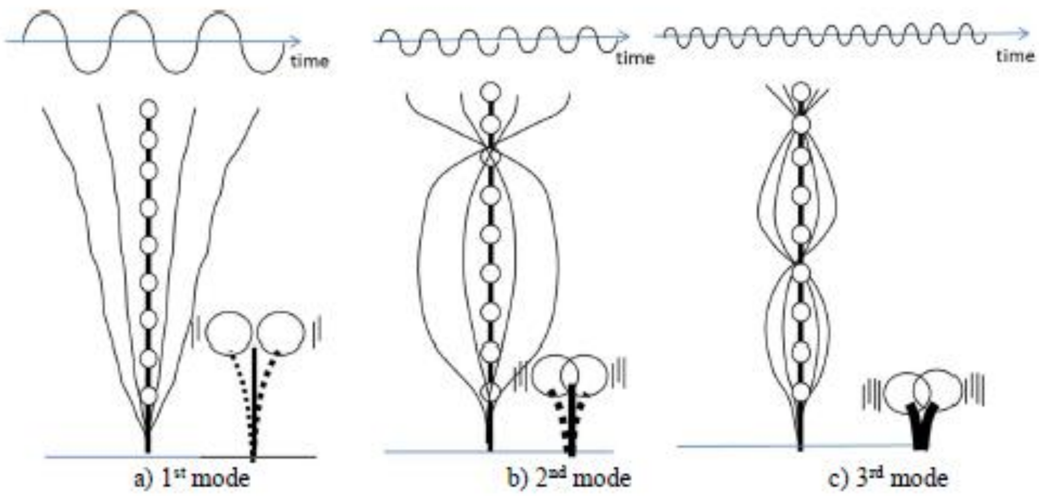

Figure 2.6: SDOF Models under Different Vibration Modes (Tsang and Lam, 2018)

2.2.1.1 Single Degree of Freedom System

A static response of a structure occurs when loads or displacements are applied in a slow motion where the inertia forces are negligible and may be disregarded in the equation of force equilibrium. Whereas, if the loads or displacements are applied quickly, the inertia forces may not be disregarded in the equilibrium equation and structure responds dynamically to those excitations (Fardis et al., 2015).

The above concepts are described by a SDOF system, with constant parameters, that is subjected to a ground displacement and an applied force varying with time. Under this excitation, the system may deform and developed several mechanisms as shown in Table 2.3 (Fardis et al., 2015).

Table 2.3: SDOF System and Forces

Forces	Description
Restoring Force	Proportional to the relative displacement and the stiffness of the system
Damping Force	Proportional to the relative velocity and a damping constant
Inertia Force	Proportional to the absolute acceleration of the mass

The forces stated in Table 2.3 should be in equilibrium as shown in Eq 2.1. For simplicity, the dependence on time of the applied force, acceleration, velocity and displacement are omitted.

$$m\ddot{u}^t + c\dot{u} + ku = p \tag{2.1}$$

where,

m = mass

c = viscous damping constant

k = stiffness of the system

$\ddot{u}^t$ = absolute acceleration

$\dot{u}$ = relative velocity

u = relative displacement

2.2.2 Response Spectrum

An earthquake response spectrum (RS) is a parameter that provides the peak values of structural response with mainly concerned by engineers during the design process. In RS, the responses are expressed in terms of displacements, forces and moments. In response to earthquake ground motion, response spectrum presents an estimated peak values for whole range of linear elastic SDOF systems (Tsang and Lam, 2018).

According to Trombetti et al. (2008), each seismic record can be simplified into the schematized tripartite response spectrum which governed by peak ground motion parameter and amplification parameter.

Peak ground motion parameter refers to peak ground acceleration (PGA), peak ground velocity (PGV) and peak ground displacement (PGD). These parameters are related to the energy released from ground and the values will change with the record scaling. Whereas amplification parameters are correlated with the intensity measures, and do not directly expressed by the earthquake ground motion, therefore amplification parameters do not change with record scaling (Trombetti et al., 2008).

2.2.3 Elastic Response Spectrum

Response Spectrum that calculated from actual accelerograms has a shape of highly irregular, and the spectral values are fluctuated over small changes in the structural period. Therefore, an idealised elastic response spectrum, which can be abbreviated as "Elastic Spectrum" (ES) is developed to allow the analysis and design of structures as illustrated in Figure 2.7 (Tsang and Lam, 2018). EC8 Malaysia NA also recommended a nationally defined parameter of horizontal and vertical elastic response spectra to be used in designing structures.

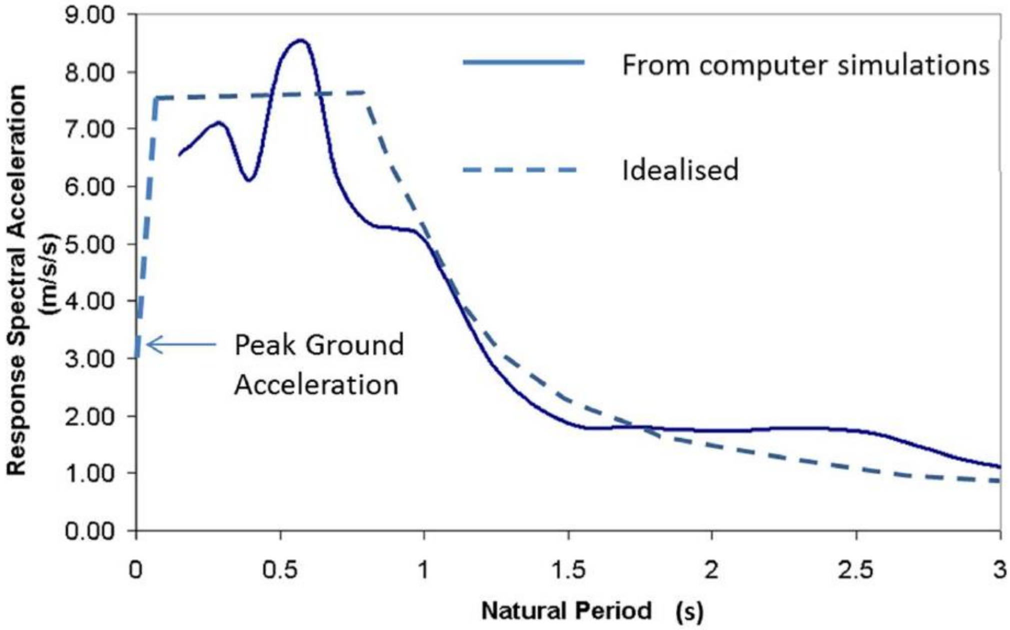

Figure 2.7: Response Spectrum and Idealised Elastic Response Spectrum

At natural period, T = 0, the acceleration of the structure is theoretically identical to acceleration of the ground. With the assumption of the SDOF systems, the mass centre peak acceleration of structural is equal to the peak ground acceleration (PGA) (Tsang and Lam, 2018). As the natural period of the structure increases, the spectral value increases at a great rate until the peak is reached. The spectral value ratio at the peak to PGA value is the amplification parameter, α_A as shown in Eq 2.2. (Trombetti et al., 2008). This amplification parameter α_A has a recommended value of 2.5.

$$\alpha_A = RSA_{max}/PGA \tag{2.2}$$

where,

RSA_{max} = peak point of spectral acceleration

PGA = peak ground acceleration

2.2.4 Peak Ground Acceleration

Peak Ground Acceleration (PGA) is the peak point in a recorded ground acceleration time history, which can be very sensitive to high frequency signals in the record, even frequency has minor effect to the structural response behaviour (Tsang and Lam, 2018).

According to Lorant (2016), to measure the earthquake effect on ground, PGA can be used. 0.001 g is noticeable by people, 0.02 g causes people to lose their stability, and 0.50 g is very high but building may survive under certain circumstances. Fortunately, by referring to the seismic hazard map of Malaysia (Malaysian Standards, 2017), Peninsular Malaysia has PGA value of 0.08 g, Sarawak has PGA value of 0.16 g, Sarawak has PGA value of 0.09 g. These peak ground acceleration value can be stated under low to moderate seismicity level.

Various code of practice including EC8 had been using PGA as scaling parameter for constructing elastic response spectrum (Tsang and Lam, 2018).

2.3 Eurocodes

Eurocodes are the reference design codes and now widely applied by most of the country to achieve a more efficient design in construction of building. According to the research by Nwoji and Ugwu (2017), Eurocode 2 is basically in a good way to replace the British Standard (BS) 8110-97 in term of the difficulty of usage and also the economically of the outcome of design. Eurocodes are ready to be completely replaced the BS with the existence of NA produced by local professors.

The Eurocodes have 10 codes to cover construction subjects which extend from the basis of structural design until the design for earthquake resistance as shown in Table 2.4 (European Commission, 2018e).

Table 2.4: EN Eurocode Contents

EN 1990	Eurocode	Basis of structural design
EN 1991	Eurocode 1	Actions on structures
EN 1992	Eurocode 2	Design of concrete structures
EN 1993	Eurocode 3	Design of steel structures
EN 1994	Eurocode 4	Design of composite steel and concrete structures
EN 1995	Eurocode 5	Design of timber structures
EN 1996	Eurocode 6	Design of masonry structures
EN 1997	Eurocode 7	Geotechnical design
EN 1998	Eurocode 8	Design of structures for earthquake resistance
EN 1999	Eurocode 8	Design of aluminium structures

2.3.1 Overview of Eurocode 0

Eurocode EN 1990: “Basis of structural design” also known as EC0 is intended to be used in conjunction with other codes including EN 1990 to EN 1999 and National Annex for structural building design from geotechnical aspects to situation involving earthquake (European Commission, 2018a). It is an essential code as it introduces the basic principles and requirements for the safety, serviceability and durability of structures.

2.3.2 Overview of Eurocode 1

Eurocode EN 1991: "Actions on structures" also known as EC1 provides a comprehensive loads or actions that should be considered in the building design and other civil engineering works (European Commission, 2018b). Eurocode 1 has 4 main parts covering general actions, traffic loads on bridges, action induced by cranes and machinery and silos and tanks.

EC1 must be used together with National Annex in order to obtain a correct and accurate loads or actions that fit the most in different nation. For example, Malaysia has no winter season and therefore, snow load must not be considered in building design.

2.3.3 Overview of Eurocode 2

Eurocode EN 1992: "Design of concrete structures" also known as EC2 is a code of design for concrete structures that is similar to the commonly used code in Malaysia: BS 8110.

EC2 applies to the building design and other civil engineering structure works in plain, reinforced and prestressed concrete. It is used in conjunction with other Eurocodes with the requirement for resistance, serviceability, durability and fire resistance of concrete structures. EC2 covers 3 parts which are general rules and rules for buildings, concrete bridges and liquid retaining and containment structures (European Commission, 2018c).

EC2 Malaysia NA is ready to replace British Standard 8110 as EC2 has been a better standard concrete design code in term of its cost saving, difficulty of usage and technologically advancement. Nwoji and Ugwu (2017) claimed that EC2 is more flexible, safer and economical to be used compared to the British Standard 8110.

2.3.4 Overview of Eurocode 8

Eurocode EN 1998: "Design of structures for earthquake resistance" also known as EC8 is basically applies to the design and buildings construction and other civil engineering works in seismic region. The use of Eurocode 8 is to ensure that human lives are protected, damage is limited and structures important to civil protection remains operational in the event of earthquakes (European Commission, 2018d). EC8 has 6 parts and there are stated in Table 2.5.

Table 2.5: Eurocode EN 1998 Parts

EN 1998-1:2004	Eurocode 8: Design of structures for earthquake resistance Part 1: General rules, seismic actions and rules for buildings
EN 1998-2:2005	Eurocode 8: Design of structures for earthquake resistance Part 2: Bridges
EN 1998-3:2005	Eurocode 8: Design of structures for earthquake resistance Part 3: Assessment and retrofitting of buildings
EN 1998-4:2006	Eurocode 8: Design of structures for earthquake resistance Part 4: Silos, tanks and pipelines
EN 1998-5:2004	Eurocode 8: Design of structures for earthquake resistance Part 5: Foundations, retaining structures and geotechnical aspects
EN 1998-6:2005	Eurocode 8: Design of structures for earthquake resistance Part 6: Towers, masts and chimneys

In Malaysia NA to MS EN 1998-1: 2015, Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings, there are several differences between Eurocode recommendation and Malaysia decision. The differences mainly based on the local circumstances with its specific parameters such as the defining shape of horizontal elastic response spectra and Seismic Hazard Map of Malaysia provided by Department of Mineral and Geoscience Malaysia (Malaysian Standards, 2017).

2.4 Malaysia National Annex to Eurocode 8

The purposes of EN 1998 EC8 are to ensure human lives and building are either protected or damages are limited during earthquake event. There are 10 sections under EC8 Part 1, extends from basic performance requirements and compliance criteria, general design rules and specific rules for various structural materials and elements where all these are applicable to buildings and civil engineering works in seismic regions.

2.4.1 Elastic Response Spectra

Fardis et al. (2015) summarizes the required parameters to define design seismic action according to EC8 as follows:

i. The reference return period for the design seismic action.
ii. PGA on rock, defined as a material with an equivalent shear wave velocity larger than 800 m/s.
iii. The Importance Class of the building.
iv. The representative ground type.
v. The predominant surface wave magnitude of earthquakes that contribute to the seismic hazard.

The above required parameters are further discussed in the following subsection.

2.4.2 Fundamental Requirements

Under EC8, in seismic region, structures shall be designed and constructed based on the importance of the structures with a suitable degree of reliability (Malaysian Standards, 2017, 2004). The probability of exceedance and reference return period recommended by the EC8 NA is tabulated in Table 2.6.

Table 2.6: Probability of Exceedance and Reference Return Period in EC8 and EC8 Malaysia NA

Requirements	No-collapse Requirement	Damage Limitation Requirement
Probability of Exceedance, P_{NCR}	10% in 50 years	10% in 10 years
Reference Return Period, T_{NCR}	475 years	95 years

The degree of reliability is classified into different building importance class. An importance factor γ_1 is assigned to respective importance class accordance to the national authorities as shown in Table 2.7.

According to EN 1998-1 Clause 4.4.3.1, in order to satisfy the damage limitation requirement and no-collapse requirement, the interstorey drifts are limited in accordance with EN 1998-1 Clause 4.4.3.2 which are stated in Table 2.8.

Table 2.7: Importance Factor γ_1 for Malaysia (Malaysian Standards, 2017)

Building Importance Class	**Importance Factor γ_1**	**Recommended Building Categories**
I	0.8	Minor construction
II	1.0	Common building (low-rise dwellings and shops)
III	1.2	Buildings of large occupancies (high-rise residential and commercial building)
IV	1.5	Lifeline built facilities (buildings that provide important service)

Table 2.8: Limitation of Interstorey Drift

Building Type	**Requirement**
For buildings having non-structural elements of brittle materials attached to the structure.	$d_r v / h \leq 0.005$
For buildings having ductile non-structural elements.	$d_r v / h \leq 0.0075$
For buildings having non-structural elements fixed in a way so as not to interfere with structural deformations, or without non-structural elements.	$d_r v / h \leq 0.01$

where,

d_r is the design interstorey drift;

h is the storey height;

v is the reduction factor accordance with national annex

- MS EN 1998-1:2005 Clause 4.4.3.2 (2)
    - Only Class IV buildings need to be checked for damage limitation limit state based on a return period of 475 years.
    - v = 0.5 is to be adopted.

2.4.3 Ground Type

Ground type can be identified by several appropriate investigations. In Looi, Lim and Hee (2018), a recommendation of Standard Penetration Test (SPT-N) values with shear wave velocity are used to estimate the site natural period (T_s) in order to identify the ground type.

According to Marto, Tan and Leong (2013), shear wave velocity is the basic geotechnical characteristic that acts as the major controller of site response and the major input of quantitative earthquake engineering. The relationship between shear wave velocity (SWV) and SPT-N value were analysed by Imai and Tonouchi (1982) which containing the largest dataset is formulated as Eq 2.3 (Wair, Dejong and Shantz, 2012). Site natural period can be then estimated by Eq 2.4 and Eq 2.5 given in EC8 NA (Malaysian Standards, 2017; Looi, Lim and Hee, 2018). EC8 NA has proposed a ground classification scheme in accordance to site natural period for soil deposit exceeding 30 m in depth as shown in Table 2.9.

$$SWV = V_{s,i} = 97N^{0.31} \tag{2.3}$$

$$V_s = \sum_{i=1}^{n} d_i \, / \, \sum_{i=1}^{n} \frac{d_i}{V_{s,i}} \tag{2.4}$$

$$T_s = \sum_{i=1}^{n} \frac{d_i}{V_{s,i}} \times 4 = \frac{4H_s}{V_s} \tag{2.5}$$

where,

$V_{s,i}$ = SWV, m/s

d_i = thickness of any layer

Table 2.9: Ground Classification Scheme in Accordance to Site Natural Period for Soil Deposit Exceeding 30 m in Depth (Malaysian Standards, 2017)

Ground type	Description	Range of Site Natural Period
A	Rock site, or site with very thin sediments	$T_s < 0.15\ s$
B	A site not classified as Ground Type A, C, D and E	
C	A site with sediments of more than 30 m deep to bedrock	$T_s = 0.5 - 0.7\ s$
D	A site with sediments of more than 30 m deep to bedrock	$T_s = 0.7 - 1.0\ s$
E	A site with sediments of more than 30 m deep to bedrock or deposits consisting of at least 10 m thick of clays/silts with a high plasticity	$T_s > 1.0\ s$

2.4.4 Seismic action

In the application of EC8, the seismic hazard is usually described in terms of the reference PGA on type A ground, a_{gR}. This reference PGA on type A ground can be found in the zonation maps in NA as shown in Figure 2.8 and Figure 2.9.

The design ground acceleration a_g may be calculated with the reference PGA and the importance factor as shown in Eq 2.6.

$$a_g = \gamma_1 \times a_{gR} \tag{2.6}$$

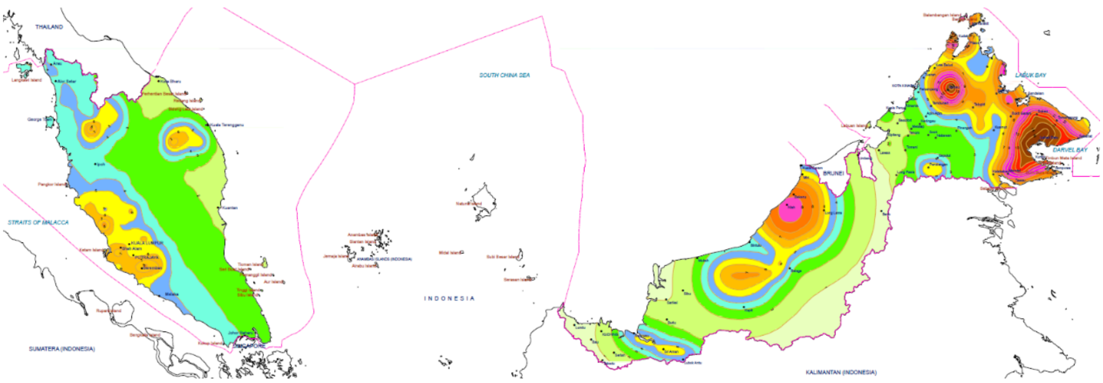

Figure 2.8: Seismic Hazard Map of Malaysia

Figure 2.9: Peak Ground Acceleration Indication

2.4.4.1 Horizontal and vertical elastic response spectrum

Earthquake motion is represented by elastic response spectrum. The shape of elastic response spectrum being taken by EC8 for no-collapse requirement and damage limitation requirement are the same. The horizontal elastic response spectrum for two orthogonal axis is assumed to be same and independent. The general shape of horizontal elastic response spectrum is shown in Figure 2.10.

In Malaysia NA to EC8, the defining shape of horizontal and vertical elastic response spectra have been summarized according ground type, regions and deep soil effects into Table 2.10 and Table 2.11.

For horizontal components of seismic actions, the elastic response spectrum is defined by the following expression:-

$$0 \leq T \leq T_B: S_e(T) = a_g \cdot S \cdot \left[1 + \frac{T}{T_B}(\eta \cdot 2.5 - 1)\right] \tag{2.7}$$

$$T_B \leq T \leq T_C: S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \tag{2.8}$$

$$T_C \leq T \leq T_D: S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \left[\frac{T_C}{T}\right] \tag{2.9}$$

$$T_D \leq T \leq 4s: S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \left[\frac{T_C T_D}{T^2}\right] \tag{2.10}$$

$$S_{De}(T) = S_e(T) \left[\frac{T}{2\pi}\right]^2 \tag{2.11}$$

where,

$S_e(T)$ = elastic acceleration response spectrum (RSA)

$S_{De}(T)$ = elastic displacement response spectrum (RSD)

T = vibration period of a linear single-degree-of-freedom system

a_g = design ground acceleration on type A ground ($a_g = \gamma_1 \cdot a_{gR}$)

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

T_C = upper limit of the period of the constant spectral acceleration branch

T_D = value defining the beginning of the constant displacement response range of the spectrum

S = soil factor

η = damping correction factor with a reference value of $\eta = 1$ for 5% viscous damping

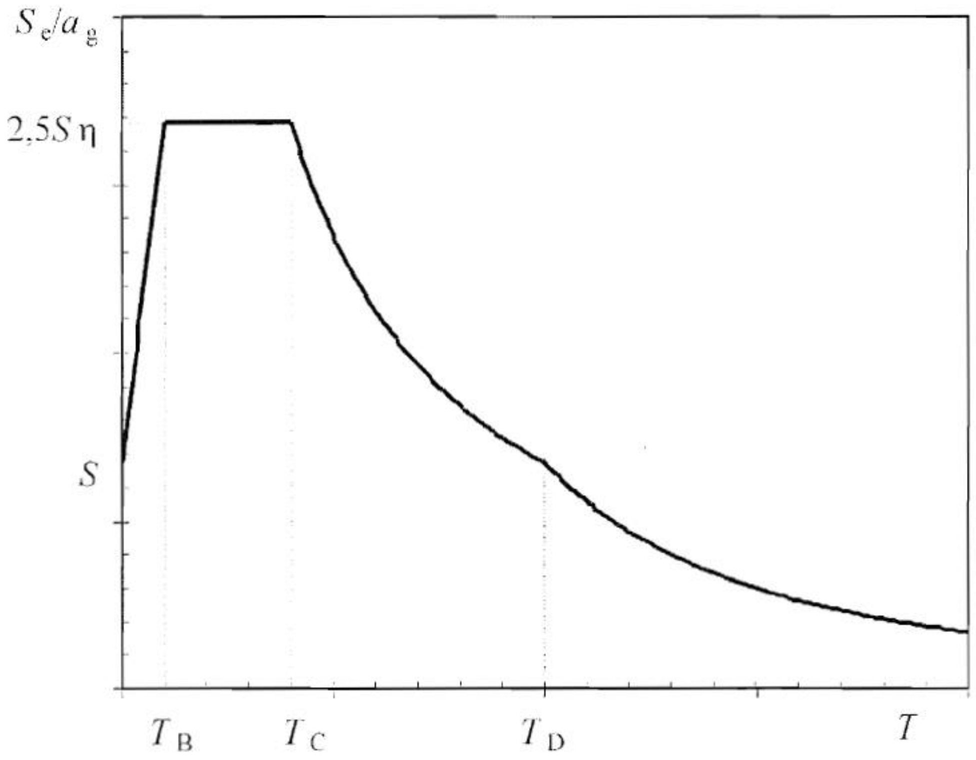

Figure 2.10: General Shape of Horizontal Elastic Response Spectrum

Table 2.10: Parameters S, T_B, T_C, T_D Defining Shape of Horizontal Elastic Response Spectra (In Absence of Deep Soil Effects)

Regions	**Ground Type**	**S (s)**	**T_B (s)**	**T_C (s)**	**T_D (s)**
Peninsular	A	1	0.05	0.2	2.2
	B	1.4	0.05	0.3	2.2
	C	1.15	0.05	0.5	2.2
	D	1.35	0.3	0.8	2.2
	E	1.4	0.15	0.5	2.2
Sabah	A	1	0.1	0.4	2
	B	1.4	0.15	0.4	2
	C	1.35	0.15	0.6	2
	D	1.35	0.2	0.8	2
	E	1.4	0.15	0.5	2
Sarawak	A	1	0.05	0.5	1.2
	B	1.2	0.15	0.5	1.2
	C	1.3	0.2	0.5	1.2
	D	1.35	0.2	0.5	1.2
	E	1.4	0.15	0.5	1.2

Table 2.11: Parameters S, T_B, T_C, T_D Defining Shape of Horizontal Elastic Response Spectra (Site Natural Period T_s Calculation is required for Soil Deposit Exceeding 30m in Depth)

Regions	**Ground Type**	**S (s)**	**T_B (s)**	**T_C (s)**	**T_D (s)**
Peninsular	A	1	0.1	0.3	2.0
	B	1.5	0.1	0.3	1.5
	C	1.8	0.1	0.6	1.0
	D	1.35	0.1	0.8	1.5
	E	1.8	0.1	0.6	2.0
Sabah	A	1	0.1	0.3	4.0
	B	1.5	0.1	0.3	4.0
	C	1.8	0.1	0.6	1.0
	D	1.35	0.1	0.8	1.5
	E	1.8	0.1	0.6	2.0
Sarawak	A	1	0.1	0.3	1.25
	B	1.5	0.1	0.3	1.25
	C	1.8	0.1	0.6	1.0
	D	1.35	0.1	0.8	1.5
	E	1.8	0.1	0.6	2.0

For vertical component of seismic actions, the parameters for defining shape of vertical elastic response spectrum given by EC8 NA is tabulated in Table 2.12. The elastic response spectrum is defined by the following expression:-

$$0 \leq T \leq T_B: S_{ve}(T) = a_{vg} \cdot S \cdot \left[1 + \frac{T}{T_B}(\eta \cdot 3.0 - 1)\right] \tag{2.12}$$

$$T_B \leq T \leq T_C: S_{ve}(T) = a_{vg} \cdot S \cdot \eta \cdot 3.0 \tag{2.13}$$

$$T_C \leq T \leq T_D: S_{ve}(T) = a_{vg} \cdot S \cdot \eta \cdot 3.0 \left[\frac{T_C}{T}\right] \tag{2.14}$$

$$T_D \leq T \leq 4s: S_{ve}(T) = a_{vg} \cdot S \cdot \eta \cdot 3.0 \left[\frac{T_C T_D}{T^2}\right] \tag{2.15}$$

Table 2.12: Parameters a_{vg}, T_B, T_C, T_D Defining Shape of Vertical Elastic Response Spectra in Malaysia National Annex to Eurocode 8

a_{vg}/a_g	T_B (s)	T_C (s)	T_D (s)
0.70	0.05	0.15	1.0

2.4.4.2 Behaviour Factor

The behaviour factor q is an approximation of the ratio of the earthquake forces structures are likely to experience to the earthquake forces that used in the design. The values of behaviour factor q account for the influence of the viscous damping being different from 5 % are given for various material and structural systems according to relative ductility classes.

The upper limit of the behaviour factor q to account for energy dissipation capacity must be derived for each direction as Eq 2.16. The basic factor q_o and factor k_w of the behaviour factor may be obtained from Table 2.13 and Table 2.14 respectively according EC8.

$$q = q_0 k_w \geq 1.5 \tag{2.16}$$

where,

q_0 = basic value of the behaviour factor, dependent on the type of the structural system and on its regularity in elevation

k_w = factor reflecting the prevailing failure mode in structural systems with walls

In Salvitti and Elnashai (1996), the response modification (behaviour) factor plays a main role in earthquake-resistant design. This behaviour factor accounts implicitly for inelastic response, presence of damping and other force reducing effects. For the design of reinforced concrete structures, different ductility class have different behaviour factor q.

In Králik and Králik (2009), a set of behaviour factor with their respective ductility class, structure material and structure system have been summarized according to several standards. The behaviour factor used in EC8 is summarized according to ductility class as shown in Table 2.15.

Table 2.13: Basic Factor of the Behaviour Factor q_0

Structural Type	DCM	DCH
Frame system, dual system, coupled wall system	$3.0\alpha_u/\alpha_1$	$4.5\alpha_u/\alpha_1$
Uncoupled wall system	3.0	$4.0\alpha_u/\alpha_1$
Torsional flexible system	2.0	3.0
Inverted pendulum system	1.5	2.0

- For buildings not in regular elevation, the value q_0 decreases 20 %
- Value for α_u/α_1
  - Frames or frame-equivalent dual system
    - One-storey building: 1.1
    - Multistorey, one-bay frames: 1.2
    - Multistorey, multi-bay frames or frame-equivalent dual system: 1.3
  - Wall or wall-equivalent dual system
    - Wall systems with only two uncoupled walls per horizontal direction: 1.0
    - Other uncoupled wall systems: 1.1
    - Wall-equivalent dual or coupled wall systems: 1.2
  - Buildings that are not regular in plan
    - Average value: 1.0

Table 2.14: Factor k_w

Type of System	Value of Factor k_w
Frame or frame-equivalent dual systems	1.0
Wall or wall-equivalent dual systems	$\frac{1+\alpha_0}{3} \leq 1, \mathit{but\ not\ less\ than}\ 0.5$

i. Prevailing aspect ratio, $\boldsymbol{\alpha_0}$
  - $\boldsymbol{\alpha_0 = \sum h_{wi} / \sum l_{wi}}$
  - Where

    $\boldsymbol{h_{wi}}$ is the height of the wall *i;*

    $\boldsymbol{l_{wi}}$ is the length of the section of wall *i.*

Table 2.15: Behaviour Factor q in Eurocode 8

Level	Frames multi-storey regulatory	Shear walls	Frames and shear walls
DCL	1.00	1.00	1.00
DCM	3.90	3.00	3.90
DCH	5.85	4.40	5.85

2.4.4.3 Combinations of Seismic Actions with Other Actions

With reference to MS EN1998-1 Clause 3.2.4 (1) P, the design value of E_d of the effect of actions in seismic design situation shall be determined in accordance with EN1990:2002, 6.4.3.4 where it can also be expressed as:

$$\sum_{j\geq 1} G_{k,j} + P + A_{Ed} + \sum_{i\geq 1} \psi_{2,i} \cdot Q_{k,i} \tag{2.17}$$

In order to include the effects of horizontal components of seismic action usually described by two orthogonal components independent same response spectrum, the combination may be computed as follow accordance to MS EN1998-1 Clause 4.3.3.5.1 (3):

$$E_{Edx} + 0.3\, E_{Edy} \tag{2.18}$$

$$0.3\, E_{Edx} + E_{Edy} \tag{2.19}$$

where,

E_{Edx} = the action effects due to the application of the seismic action along the chosen horizontal axis x of the structure

E_{Edy} = represents the action effects due to the same seismic action along the orthogonal horizontal axis y of the structure

According to MS EN 1998-1 Clause 3.2.4 (2) P, the storey mass with the inertial effects of the design seismic action shall be considered with associated with the gravity load as in Eq 2.20 to be used together with Eq 2.21 and the φ and ψ value given in EC8 and EC1 are shown in Table 2.16 and Table 2.17 respectively.

$$\sum G_{k,j} + \sum \psi_{E,j} \cdot Q_{k,i} \tag{2.20}$$

where,

$G_{k,j}$ = gravity actions

$Q_{k,i}$ = variable actions

$\psi_{E,j}$ = combination coefficient for variable actions i

$$\psi_{E,j} = \varphi \cdot \psi_{2,i} \tag{2.21}$$

Table 2.16: Value for φ

Type of variable action	Storey	φ
Categories A-C*	Roof	1.0
	Storeys with correlated occupancies	0.8
	Independently occupied storeys	0.5
Categories D-F *		1.0

Note: * = Categories as defined in MS EN 1991-1-1

Table 2.17: Value for ψ Factors

Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, (see MS EN 1991-1-1)			
Category A: domestic, residential areas	0.7	0.5	0.3
Wind loads on buildings (see MS 1553:2002)	0.5	0.2	0

2.4.5 Ductility Class

In earthquake-resistance reinforced concrete design, the capacity of dissipation of energy and the strength of the structures are both important (Olteanu et al., 2009). The earthquake-resisting structure must have both resistance and ductility, non-linear response analysis should be carried out in order to identify the ductility class and therefore code and standards may provide guidelines for each design cases (Carvalho, Coelho and Fardis, 1996).

Olteanu et al. (2009) has summarized the meaning of ductility for reinforced structure. An indeterminate structure’s ability to re-distribute internal forces, and the ability to reduce internal forces due to restraint, most importantly the ability of structures to withstand dynamics forces such as earthquake, dynamic impact or explosion.

According to EC8, there are three classes of ductility namely DCL, DCM and DCH which are low ductility class, medium ductility class and high ductility class respectively. In DCL, structural design, dimensioning and detailing are based on EC2 and a few additional rules for enhancing the ductility. In DCM, structures should achieve inelastic range without brittle failure. In DCH, structures have to be ensured to have large capacity of energy dissipation. In different ductility class, there are different value of behaviour factor that has been stated earlier.

Malaysia NA to EC8 has given a recommended value for classifying ductility class according to value of peak ground acceleration as shown in Table 2.18.

Table 2.18: Governing Parameter for Threshold of Seismicity by Malaysia National Annex to Eurocode 8

Seismicity	**Ductility Class**	**Peak Ground Acceleration**
Very Low	Low (DCL)	$\leq 0.39\ m/s^2$
Low	Low (DCL)	$\leq 0.78\ m/s^2$
Medium	Medium (DCM)	$> 0.78\ m/s^2$

2.4.6 Capacity Design

Capacity design of a building is to control the ductility behaviour of structure in order for building to withstand earthquake of design-level. The dissipation of earthquake energy occurs generally in a ductile structure, ductile elements can withstand repeated displacement without significantly strength loss, ductile elements may bend or deform but do not break easily (Kappos, 1997).

Brittle failure must be prevented in earthquake action structures. The application of Eurocode in assigning ductility class medium or high (DCM, DCH) enables the structure to develop stable mechanisms without suffering undesired failure.

In frame system, the condition as per Eq 2.22 must be fulfilled by all joints between beams and columns.

$$\sum M_{Rc} \geq 1.3 \sum M_{Rb} \tag{2.22}$$

where,

M_{Rc} = design values of moments of resistance of the column

M_{Rb} = design values of moments of resistance of the beam

A factor accounting for overstrength γ_{Rd} is introduced in shear design forces for structural members according to their ductility class shown in Table 2.19.

Table 2.19: Overstrength Factor γ_{Rd}

$\boldsymbol{\gamma_{Rd}}$	**Ductility Class**	
	DCM	**DCH**
Beam	1.0	1.2
Column	1.1	1.3
Joint	-	1.2
Wall	-	1.2

2.5 Output from Model for Structural Assessment

The evaluation of seismic performance requires the selection of appropriate output quantities or response indicators. In general, the commonly used indicators are divided into actions (stresses and their resultants) and deformations (strains and their resultants). Local and global indicators are used for accurate and reliable assessment of seismic response. Local output parameters are required primarily to detect potential damage localisation and to evaluate the attainment level of threshold values of stress and strain in fibres at different performance level. Global response indicators are used to estimate the fundamental structural characteristics (Elnashai and Sarno, 2015). Figure 2.11: Typical Response Indicators Used for Structural Assessment (Elnashai and Sarno, 2015).

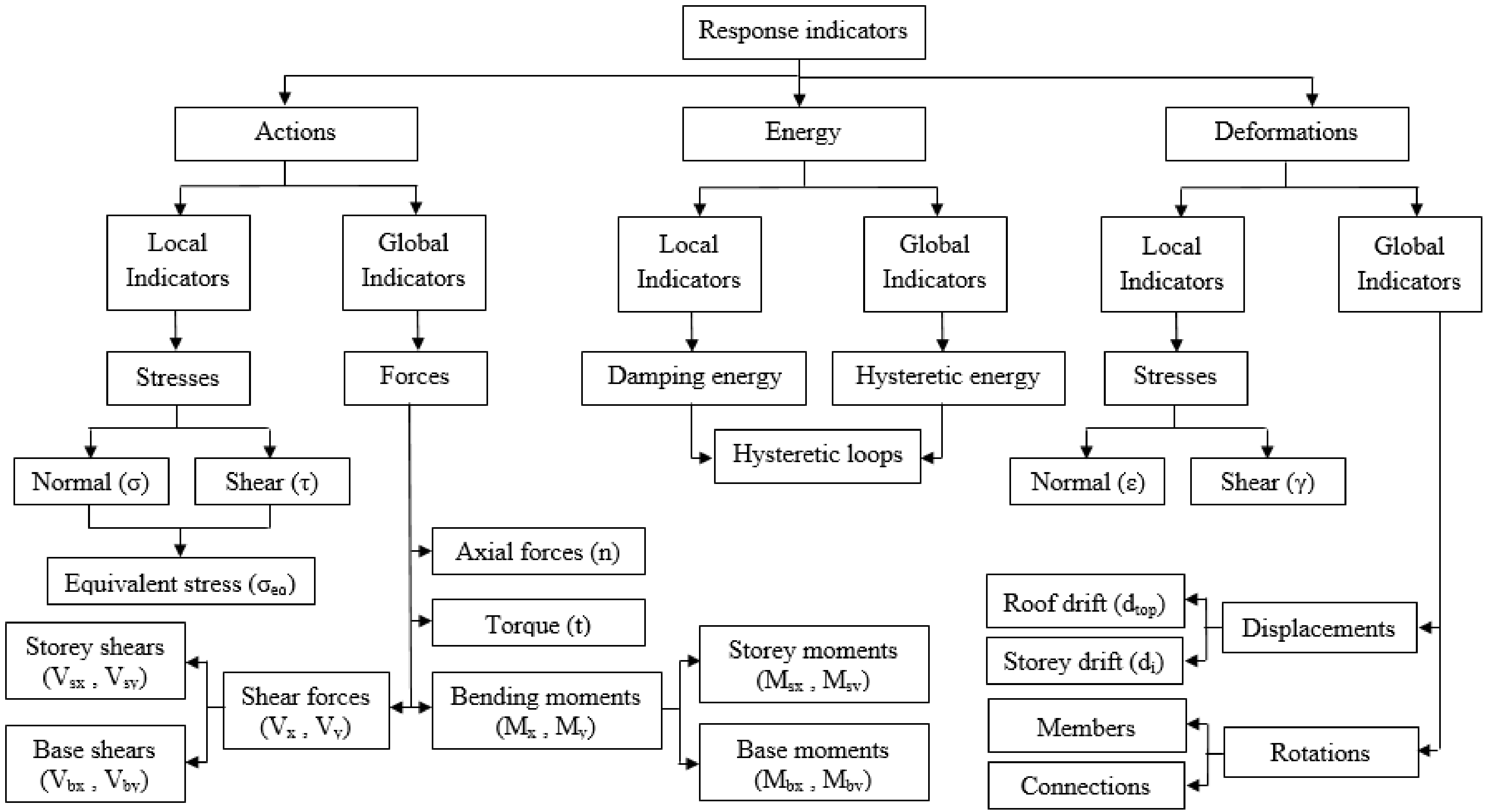

Figure 2.11: Typical Response Indicators Used for Structural Assessment (Elnashai and Sarno, 2015)

2.5.1 Actions

Actions output may be presented by both local and global indicators. Local actions emphasis stress and strain, whereas global actions correspond to internal actions. In framed structures, moments and shears are frequently observed at base and each storey level which are often known as base and storey shear forces and moments respectively (Elnashai and Sarno, 2015).

2.5.2 Deformations

Deformation parameters provide a more graphical way to indicate the damage of structures under earthquake than actions do. System assessment may be analysed by both local and global indicators. A detailed finite element analysis of a structure may produce normal and shear strains, ε and τ respectively. Global response deformational parameters for example inter-storey drift may be used to determine the occurrence of different damage states (Elnashai and Sarno, 2015).

2.6 Structural Analysis and Design Software

Nowadays, structural analysis software is being widely used by the engineers in their daily work to model geometries of structures and analyse the structures, and hence reduce the time needed for model, analyse and design structures (Sturdy Structural, 2016).

Eurocode Joint Research Centre had tabulated a list of Eurocode design software that consists of the code of design – Eurocode in February 2018. There are both free and commercial Eurocode design software recognized by the European Commission, the concern of this project is of concrete structures (EC2) and seismic design (EC8), therefore, Table 2.20 and Table 2.21 show some structural software that consists of the mentioned elements (EC2 and EC8).

Table 2.20: Free Eurocode Design Software (Biasioli, 2018)

Software Name	Software House	Country	Language
Freelem	Freelem	France	Country language only
Jasp	IngegneriaNet	Italy	Country language only

Table 2.21: Commercial Eurocode Design Software (Biasioli, 2018)

Software Name	Software House	Country	Language
SOFiSTiK	SOFiSTiK	Germany	Multiple language available
Scia Engineer	Nemetchek	Belgium	Multiple language available
RFEM	Dlubal	Germany	Multiple language available
RSTAB	Dlubal	Germany	Multiple language available
FRILO	Nemetchek	Germany	Multiple language available
STAAD	Bentley	US/GB	Multiple language available
Midas Gen	Midas	Korea	Multiple language available
ETABS	CSI	US	Multiple language available

In Universiti Tunku Abdul Rahman, Nemetchek and Midas had provided educational licenses for Scia Engineer and Midas Gen respectively for educational purpose. Hence, in this comparative study of structural analysis and design software, Scia Engineer and Midas Gen are chosen to be studied especially in their seismic analysis and seismic design with accordance to EC8.

2.6.1 Midas Gen

Midas Information Technology Co. Ltd. (Midas IT) has a main focus in developing analysis and design software in the field of civil, structure and mechanical engineering field (Overview of Company, 2018).

Midas has a well-known history as they were developed in 1989 and commercialised in 1996, Midas programs have been widely used previously in various project and they claimed themselves to be chosen by more than ten thousands customers and projects. As one of the product from Midas, Midas Gen had been proudly used to analyse and design high-rise building such as Burj Khalifa (UAE), Guangzhou Twin Tower (China), Gate of the Orient (China) and etc.

According to the catalogue, Midas Gen have advantages in their intuitive user interface, advanced analysis features, accurate and practical results and design capabilities (midas Gen: Integrated Design system for Buildings and General Structures, 2015).

Figure 2.12: Burj Khalifa, Guangzhou Twin Tower and Gate of the Orient

2.6.1.1 Seismic Analysis in Midas Gen

Midas Gen offers various seismic assessment of structure such as dynamic analyses (eigenvalue, response spectrum and time history), pushover analysis, inelastic time history analysis, nonlinear time history analysis and etc.

The analysis results provided by Midas Gen are verified by a series of verification example provided in their manual. Each verification example are compared with theoretical results and similar programs results.

In a case study of dynamic response spectrum analysis of a 2-D, 3 storey plane frame as shown in Figure 2.13, and the results are almost identical to the theoretical results and totally identical to ETABS by CSI as shown in Table 2.22 (midas Gen: Verification Examples RS-1, 2015).

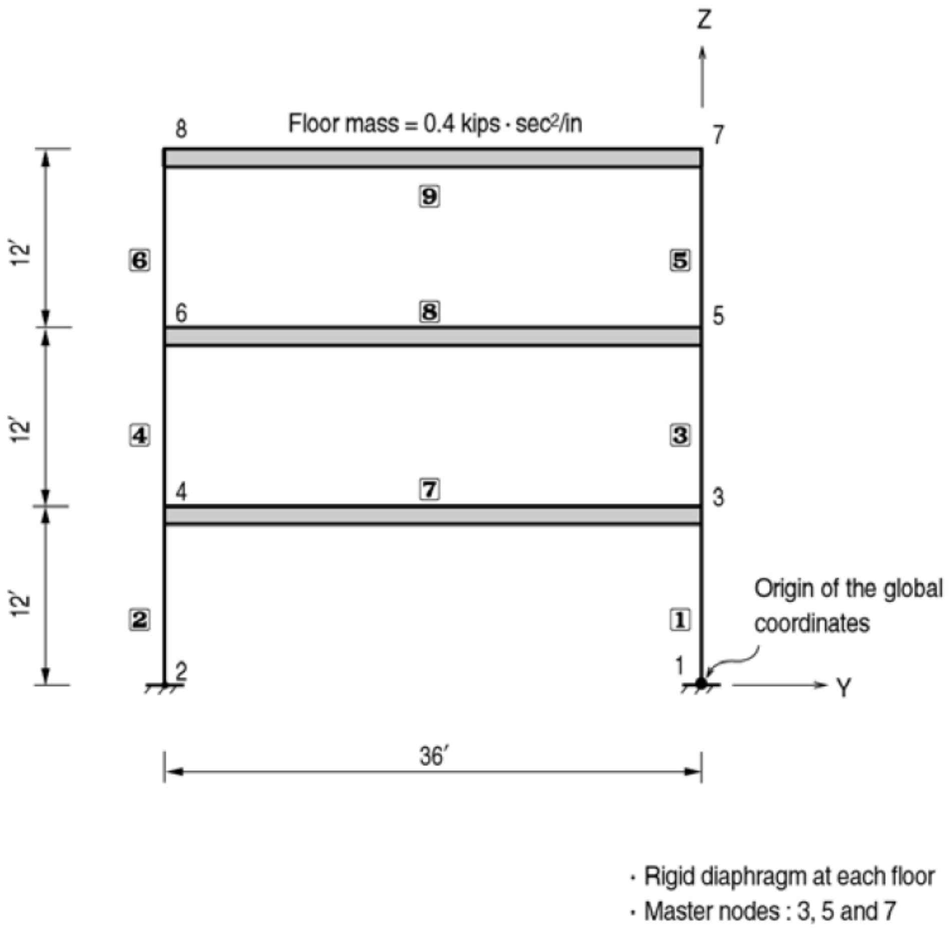

Figure 2.13: Case Study 1: Dynamic Response Spectrum Analysis of a 2-D, 3 Storey Plane Frame

Table 2.22: Case Study 1: Dynamic Response Spectrum Analysis of a 2-D, 3 Storey Plane Frame

Results	**Theoretical**	**ETABS**	**Midas Gen**
Natural Period Mode (s)			
1^{st}	0.4414	0.4414	0.4414
2^{nd}	0.1575	0.1575	0.1575
3^{rd}	0.1090	0.1090	0.1090
Displacement (in)			
3F	2.139	2.139	2.139
2F	1.719	1.716	1.716
1F	0.955	0.955	0.955
Reaction Moment at Node 1 (kip-in)	11730	11730	11730

In a case study of response spectrum analysis of 3-D, 2 storey frame structure obtained from Elastic Analysis for Structural Engineering, Example Problem Manual is shown in Figure 2.14, the results generated by Midas Gen was totally identical to the results by the writer and results generated by SAP2000 as shown in Table 2.23 (Peterson, 1981; midas Gen: Verification Examples RS-4, 2015).

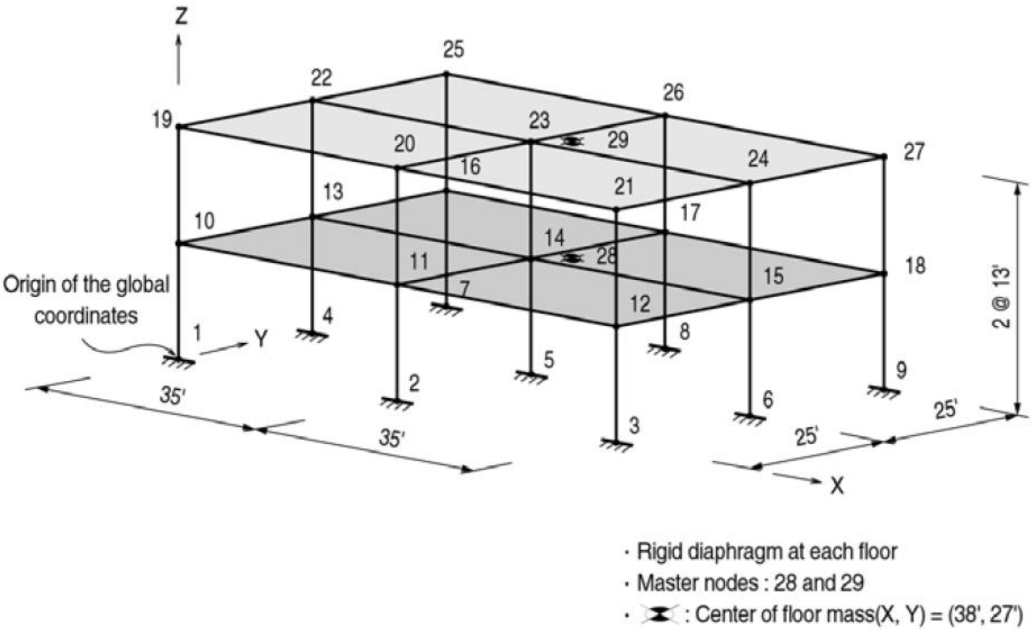

Figure 2.14: Case Study 2: Response Spectrum Analysis of 3-D, 2 Storey Frame Structure

Table 2.23: Case Study 2: Response Spectrum Analysis of 3-D, 2 Storey Frame Structure

Results	**Calculation by Writer (Peterson, 1981)**	**ETABS**	**Midas Gen**
Natural Period Mode (s)			
1st	0.2271	0.2271	0.2271
2nd	0.2156	0.2156	0.2156
3rd	0.0733	0.0733	0.0733
4th	0.0720	0.0720	0.0720
Global X-displacement at Node 29 (ft)	0.0201	0.0201	0.0201

The above two case studies in verification of response spectrum analysis proved Midas Gen is capable to analyse building in Malaysia according to Malaysia NA to EC8 which encouraged the seismic analysis by using response spectrum.

2.6.1.2 Seismic Design in Midas Gen

Midas Gen offers automatic capacity design capability for concrete structures to provide the appropriate amount of ductility in the corresponding ductility class (midas Gen: Integrated Design system for Buildings and General Structures, 2015).

The capacity design in Midas Gen follows code of practice (EC8) in ductility class medium and ductility class high. The design action effects are calculated in accordance with the capacity design rule. Special provision for ductile primary seismic walls is considered. The detailing for local ductility in reinforcement ratio, spacing of hoops, mechanical volumetric ratio of confining hoops and others are considered as well (midas Gen: Integrated Design system for Buildings and General Structures, 2015).

2.6.2 Scia Engineer

Scia has been developing, distributing and supporting structural engineering and construction related software since year 1974. Scia software is a globalised software which possesses 13 languages and supports 20 national standards including EC8 Malaysia NA (SCIA company profile, 2018).

Scia Engineer is an integrated, multi-material structural analysis and design software for all types of civil and building structures such as office buildings, industrial plants, bridges and any other project. There are some examples of high-rise building structures analysed and designed by Scia Engineer such as Pontsteiger, Amsterdam and TBR Brussels Tower, Belgium.

Scia Engineer has advantages in integrated design in single process, advanced generators, comprehensive code-coverage and a plug-in to BIM workflow.

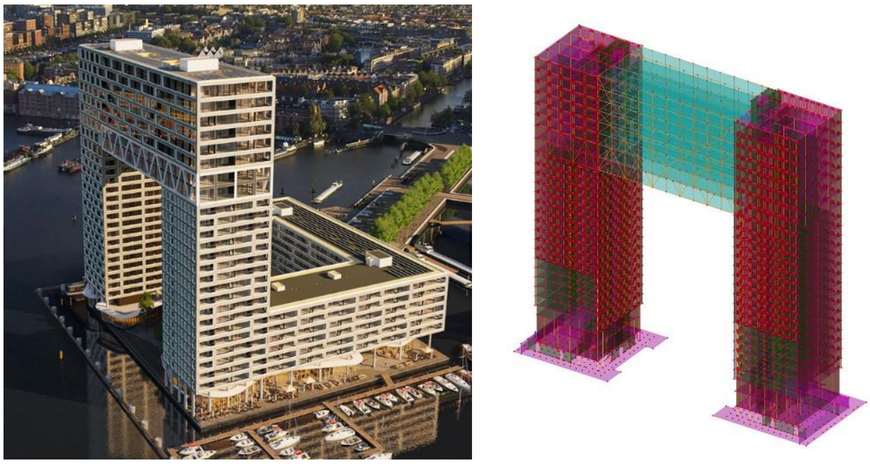

Figure 2.15: Pontsteiger, the New Spectacular Landmark of Amsterdam

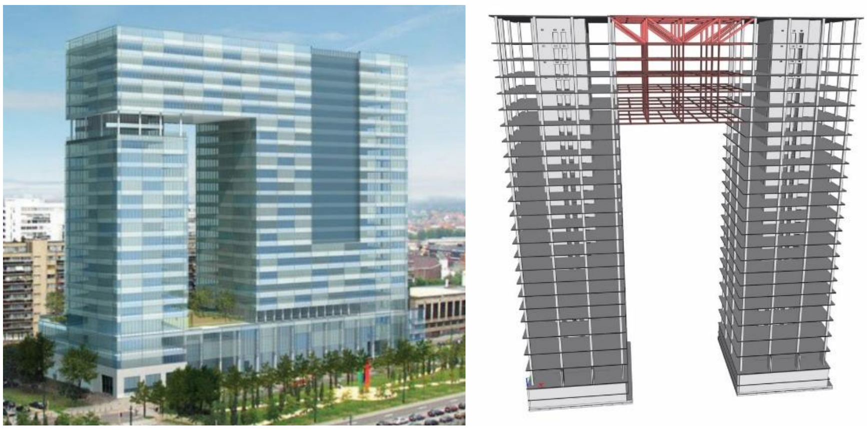

Figure 2.16: TBR Brussels Tower – Brussels, Belgium

2.6.2.1 Seismic Analysis in Scia Engineer

Scia Engineer offers several dynamic analysis method:

i. Free Vibration: Eigen Frequencies
ii. Forced Vibration: Harmonic Load
iii. Spectral Analysis: Seismic Load
iv. Damping
v. Reduced Analysis Model
vi. Vortex Shedding: Karman Vibration
vii. Direct Time Integration

The spectral analysis and influence of damping on seismic action will be more relevant to the seismic analysis. In Scia Engineer, the seismic load can be entered after creating combination of mass group (Scia Engineer Advanced Professional Training: Dynamics, 2015).

When defining a spectrum in Scia Engineer, the spectrum can be defined either by combination of frequencies and accelerations, periods and accelerations or inputting the parameters given by EC8 or NA.

A case study of design verification of Athens Opera House has been carried out in (Nemetchek Scia Engineer & ECtools Verification Document for ACI 318-11 & ASCE/SEI 7-10, 2014). The superstructure was modelled by Scia Engineer see Figure 2.17 and ETABS see Figure 2.18, all the load and spectra assumptions are taken identically.

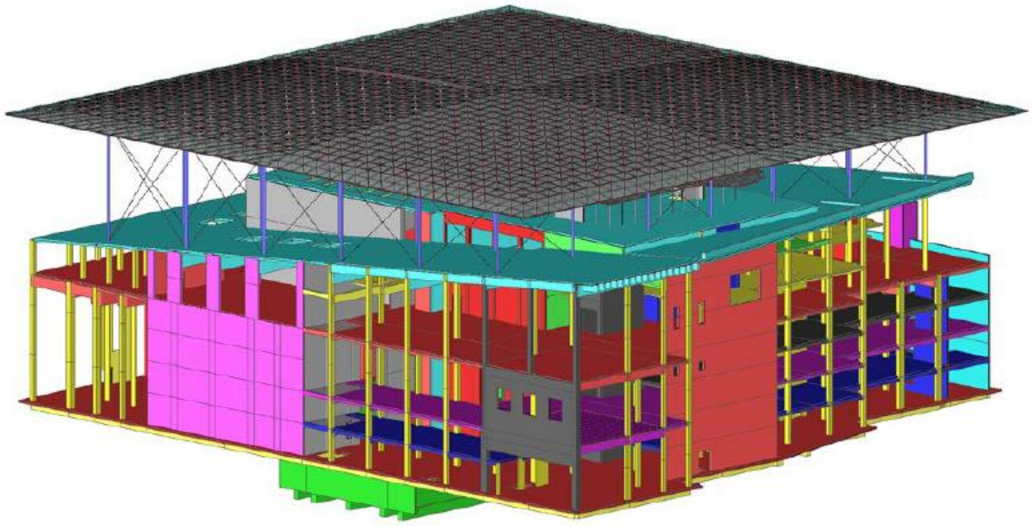

Figure 2.17: Athens Opera House Model by Scia Engineer

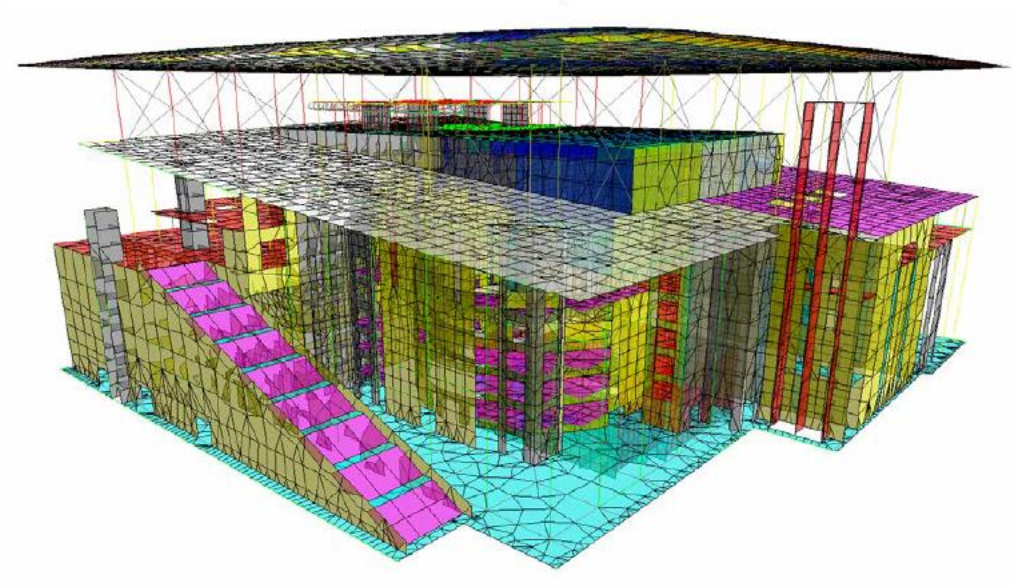

Figure 2.18: Athens Opera House Model by ETABS

A comparison between the summations of loads at base with load combination of $1.35G_k + 1.50Q_k$ has a difference less than 0.5 %.

Table 2.24: Comparison of Summations of Base Reactions in Athens Opera House

Scia Engineer	ETABS
1771693 kN	1772505 kN

Although the sum of total reactions are very close, their distribution of load in each structures show some variance. Global force balance and global assembled masses are identical in both software. The dynamics characteristics of the two models are identical with a deviation less than 4 %. Modelling of column and wall in both software are in a close match. However in modelling of beam, (Nemetchek Scia Engineer & ECtools Verification Document for ACI 318-11 & ASCE/SEI 7-10, 2014) commented that Scia Engineer is more accurate than ETABS as ETABS ignores the moment and shear force that clashed with T-flanges, the difference has no significant effect to the building.

2.6.2.2 Seismic Design in Scia Engineer

Scia Engineer does not consists function for capacity design to correspond ductility classes. However, Scia Engineer often used with ECtools as an add-in.

ECtools is a design software for Reinforced Concrete using several codes of design including Eurocode. ECtools is one of the most efficient design tools in application of the capacity design concept, it has the capability to design structural members for ductile behaviour.

2.7 Previous Research

According to Hu et al. (2012), structural system becomes complicated and progressively consummate earthquake-resistant theories, some conventional software can no longer meet the needs of calculation and analysis. In the research Hu et al. (2012), they modelled a 29 storey building by ETABS, SAP 2000, Midas Gen and SATWE as shown in Figure 2.19 to analyse the effect of earthquake towards high-rise building. They performed response spectrum analysis and elastic time history analysis on their structural analytical model. In response spectrum analysis, 60 eigenvalues modes with effective mass participation factor larger than 90 % improved the reliability of the analysis results and interstorey displacement angle is shown in Figure 2.20.

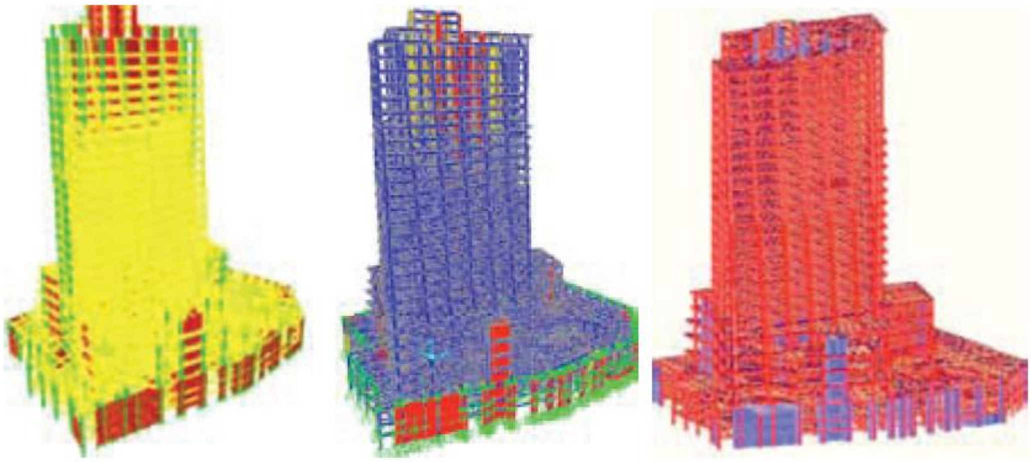

Fig. 2. Structural analytic models (a) ETABS; (b) SAP2000; (c) MIDAS

Figure 2.19: Structural Analytic Models (Hu et al., 2012)

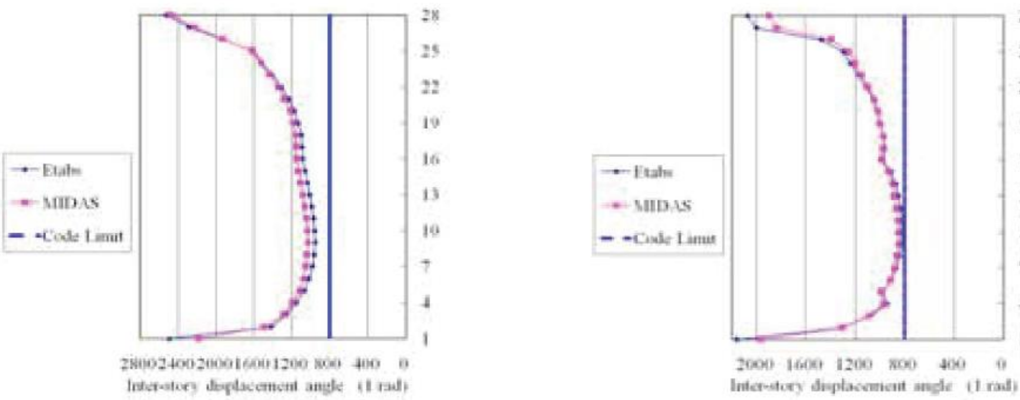

Fig. 4. Inter-story displacement angle (a) X Direction; (b) Y Direction

Figure 2.20: Interstorey Displacement Angle (Hu et al., 2012)

2.8 Summary

In summary, the literature review had studied the phenomenon of Malaysia historical earthquake activities and the importance of constructing seismic resistance building. Next, the modelling of seismic hazard and some of the important parameters used to measure earthquake and structure behaviour on earthquake such as response spectrum and peak ground acceleration. Eurocodes have been reviewed and a further investigation into Malaysia NA to EC8 have been carried out. Malaysia NA to EC8 is a guideline for seismic resistance building, it has proposed some recommended seismic action parameters for earthquake resistance building design such as importance factor of building categories, reference peak ground acceleration at different region, elastic response spectrum to respective ground type and etc. Lastly, structural analysis and design software have been studied and discussed. Both software to be used in this study namely Midas Gen and Scia Engineer are recommended by Eurocode Joint Research Centre to analysis and design according to EC8.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

In research of comparison of structural analysis and design software in investigating the high-rise building under seismic loading with compliance to Malaysia National Annex to Eurocode 8, a realistic high-rise building was selected to be modelled and analysed using Midas Gen and Scia Engineer.

The high-rise building was imposed to assumed action and load with compliance to Malaysia National Annex to Eurocode 1, and subjected to seismic loading with compliance to Malaysia National Annex to Eurocode 8 in several region of Malaysia.

3.2 Modelling of High-rise Building

According to Emporis Standards, high-rise building having an architectural height between 35 meter to 100 meter, or having a minimum of 12 floors (high-rise building | Emporis Standards | EMPORIS, 2018). A building slenderness is measured by the aspect ratio where it is a ratio between height and structural lateral system footprint (Zils and Viise, 2003). In this study, a high-rise building of 12 floors with height of 42 meter and aspect ratio of 1:1.4 was modelled and analysed by Midas Gen and Scia Engineer.

The simplified structural layout of the high-rise building is as shown in Figure 3.1. The floor height of the building is 3.5 meter. In this study, the modelling of the high-rise building includes beam, column, shear wall and floor, appropriate assumptions had been made. The structural model produced by Midas Gen and Scia Engineer are as shown in Figure 3.2 and Figure 3.3 respectively.

The material used in this structural model was concrete C30/37. The section size of elements used were referred to the original structural drawing with appropriate assumptions and simplification.

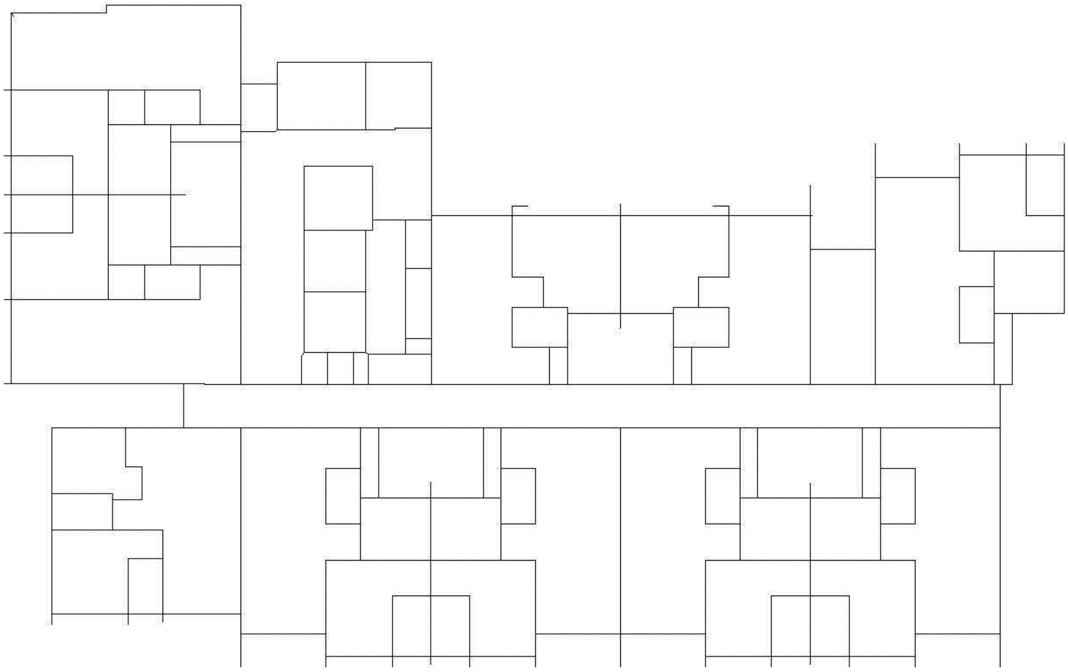

Figure 3.1: Simplified Structural Layout Plan

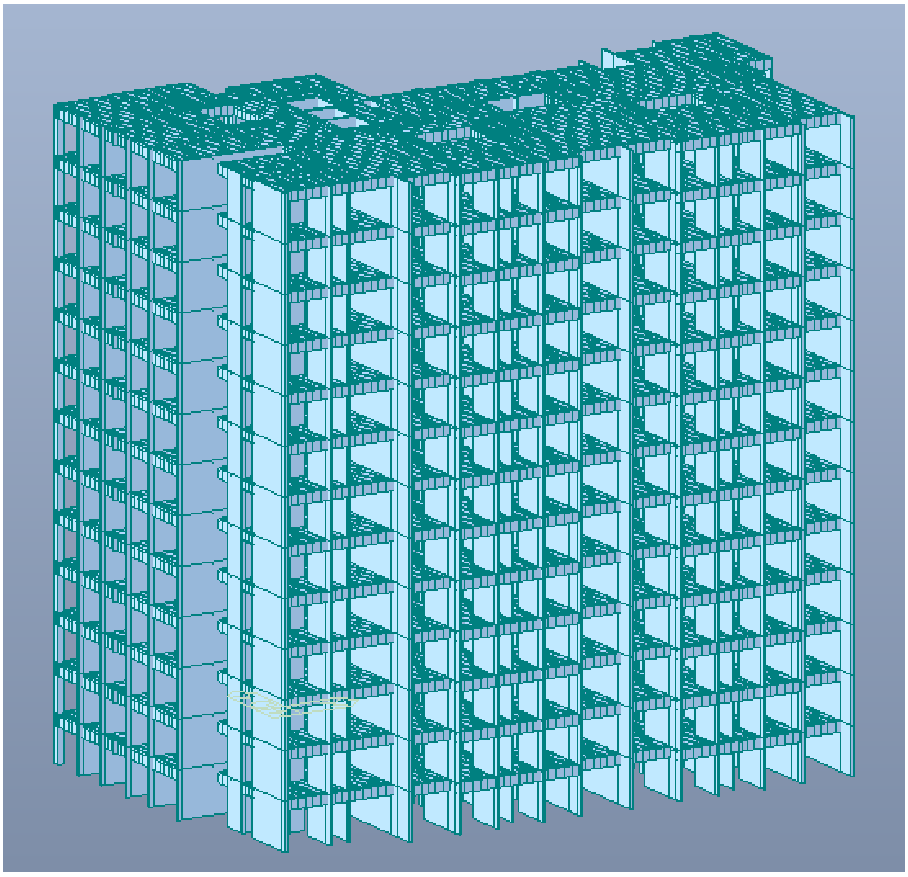

Figure 3.2: Structural Model Produced by Midas Gen

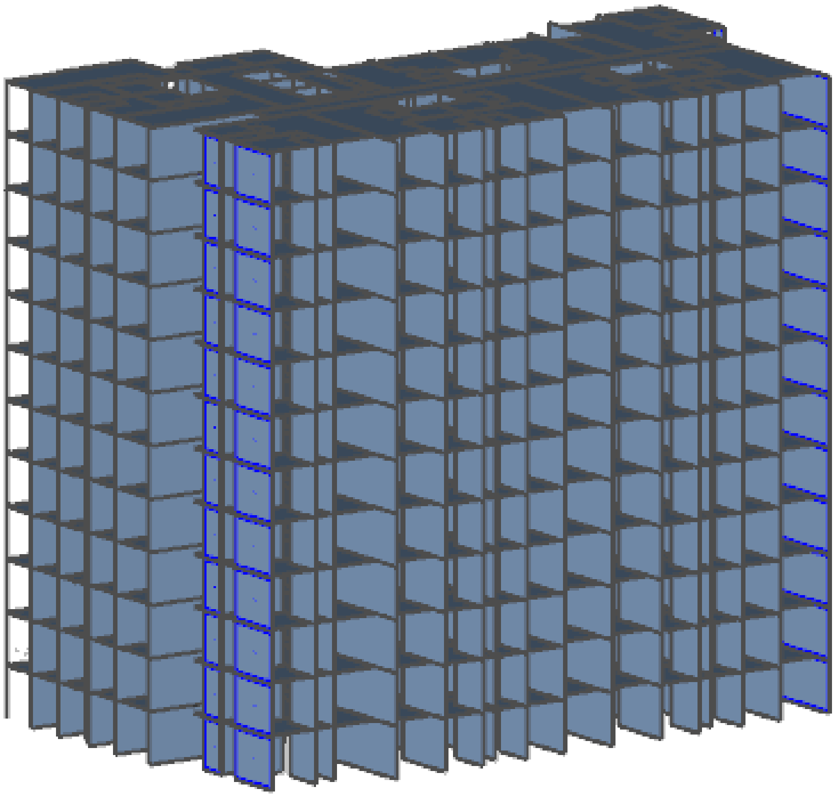

Figure 3.3: Structural Model Produced by Scia Engineer

3.3 Assignation of Action and Load

According to MS EN 1991-1-1:2002 Eurocode 1 Section 3: Design situations, relevant loads (permanent and imposed loads) shall be determined for each design criteria identified in accordance to MS EN 1990 Clause 3.2.

The assignation of permanent loads are based on common assumptions as the information of the architecture elements given are not sufficient. The brick wall assumed to be used is common brick wall with G_k = 2.6 kN/m^2 multiply by storey height. Floor finishing including tiles and etc. The assumed values are tabulated in Table 3.1: Permanent Loads.

Table 3.1: Permanent Loads

Elements	G_k (kN/m)	G_k (kN/m^2)
Brick wall	9.1	-
Floor finishing	-	2

The assignation of imposed action and load were accordance to Malaysia National Annex to Eurocode 1. Table NA2 and Table NA3 are to use together to identify the relationship between specific use of loaded area with corresponding sub-category and the recommended imposed loads (Q_k) to be applied in building. Some applicable imposed load values are tabulated in Table 3.2. The assigned imposed load onto the plan layout is shown in Figure 3.4: Assigned Imposed Load According to Specific Use.

The loads and actions are converted into masses in order for eigenvalues analysis to be carried out in the later stage. The masses are of 1.0 permanent action (including self-weight) + 0.15 variable action which comply to MS EN 1998-1 Clause 3.2.4 (2) P and Clause 4.2.4 (2) P.

Table 3.2: Specific Use of Loaded Area and Imposed Loads

Specific use	**Sub-category**	**Examples**	**Q_k (kN/m^2)**
Areas for domestic and residential activities	A1	Normal dwelling units	1.5
	A3	Toilet areas	2.0
Areas where people may congregate (except residential and shopping areas)	C38	Walkways – high density (including escape routes)	7.5

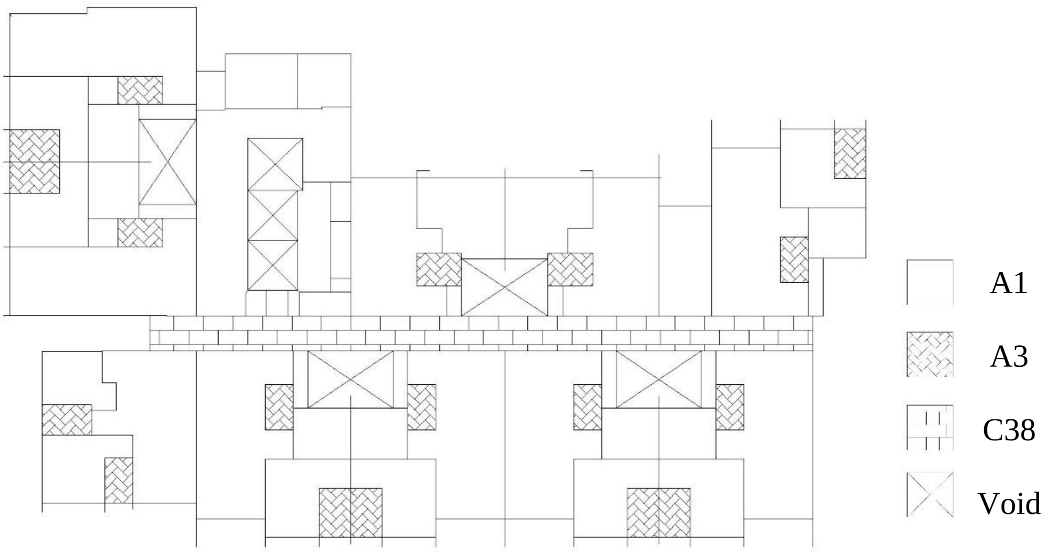

Figure 3.4: Assigned Imposed Load According to Specific Use

3.4 Assignation of Seismic Loading

One of the objectives in this research is to compare the effect of seismic loading in different region in Malaysia. In order to see the significant difference of seismic effect on high-rise building, the regions which possess the highest peak ground acceleration were chosen.

According to Malaysia National Annex to Eurocode 8 Table NA1 Clause 3.2.1(4), peak ground acceleration less than equal 0.78 m/s^2 is considered to be low seismicity and shall be designed to ductility class low (DCL) which is designed to Eurocode 2 requirements. In this case, only the location with the highest value of peak ground acceleration in 3 regions of Malaysia were studied which are Peninsular Malaysia, Sabah and Sarawak region. The PGA value of the stated regions can be referred in Table 3.3.

Table 3.3: Location of Malaysia and Peak Ground Acceleration (Malaysian Standards, 2017)

Malaysia	**Location**	**Peak Ground Acceleration**	
		(g)	**(m/s^2)**
Peninsular	Seremban	0.08	0.7848
Sabah	Lahad Datu	0.16	1.5696
Sarawak	Niah	0.09	0.8829

There are some important parameters shall be determined and assumed in this research as some of the information in designing high-rise building are impossible to be obtained.

The high-rise building is a service apartment which may contain large number of occupancies, the building importance class shall be class III and importance factor shall be 1.2 according to Malaysia National Annex to Eurocode 8: Annex E Table E1.

Since the information of ground condition is not possible to be obtained, an assumption of ground type of type B (a site not classified as Ground Type A, C, D or E) will be used in the entire research. Under Table NA1 clause 3.2.2.1(4) and 3.2.2.2(1)P of Malaysia National Annex to Eurocode 8, in absence of deep soil effects, and for site specific information Malaysia spectra, Table 3.4 shows the horizontal elastic response spectrum parameters in its corresponding region for ground type B.

The behaviour factor is assumed to be q = 3.0. Lower boundary factor is applied as default where β = 0.2. Structural fundamental period is approximated according to EN1998-1 Clause 4.3.3.2.2 (3) where $T_1 = 0.05\ H^{3/4}$.

Table 3.4: Horizontal Elastic Response Spectrum Parameters of Ground Type B

Malaysia	S	T_B (s)	T_C (s)	T_D (s)
Peninsular	1.4	0.05	0.3	2.2
Sabah	1.4	0.15	0.4	2.0
Sarawak	1.2	0.15	0.5	1.2

The design response spectrum acceleration graph of the above stated parameters in Peninsular Malaysia, Sabah and Sarawak to be analysed in Midas Gen and Scia Engineer are summarized as shown in Figure 3.5.

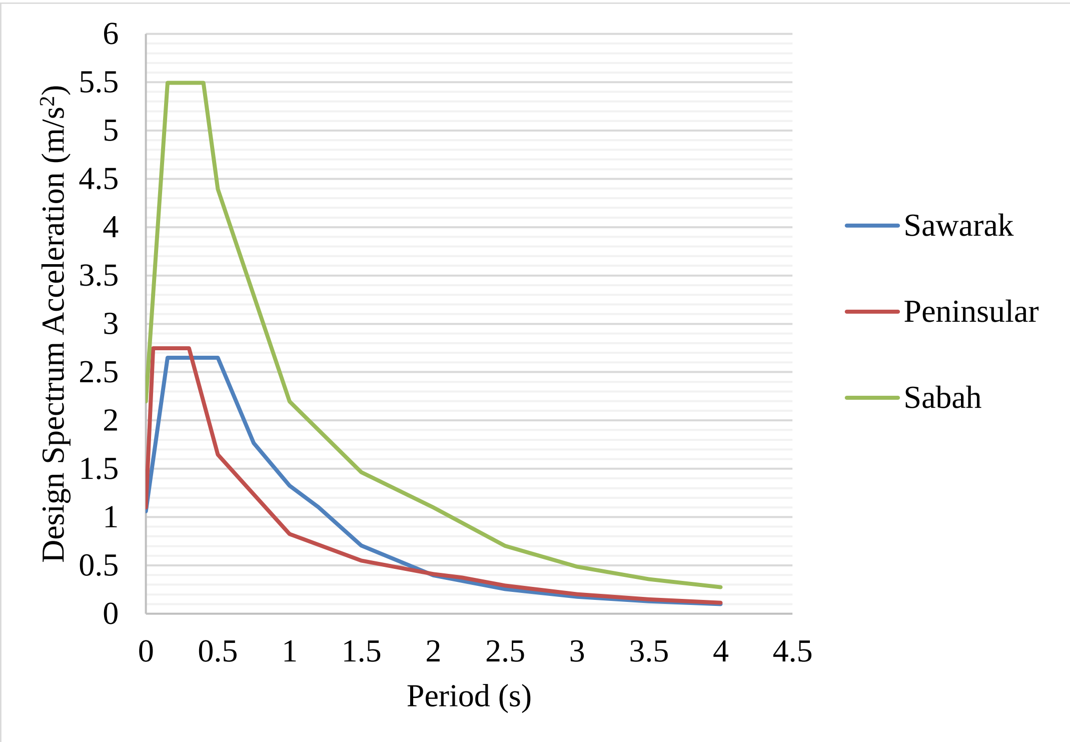

Figure 3.5: Design Response Spectrum Curve in Peninsular Malaysia, Sabah and Sarawak

There are some minor differences between Midas Gen and Scia Engineer during assignation of seismic loading. The seismic loading assignation process for both software are demonstrated in the following subsection.

3.4.1 Midas Gen Seismic Loads Assignation

In Midas Gen, there are two type of seismic loads required to be assigned namely static lateral seismic loads and dynamics response spectrum.

In static seismic loads, static load cases have to be firstly defined in Load – Static Loads – Create Load Cases – Static Loads Cases as shown in Figure 3.6. Next, static lateral seismic loads in 4 direction are inputted respectively in Load – Static Loads – Lateral – Seismic Loads as shown in Figure 3.7.

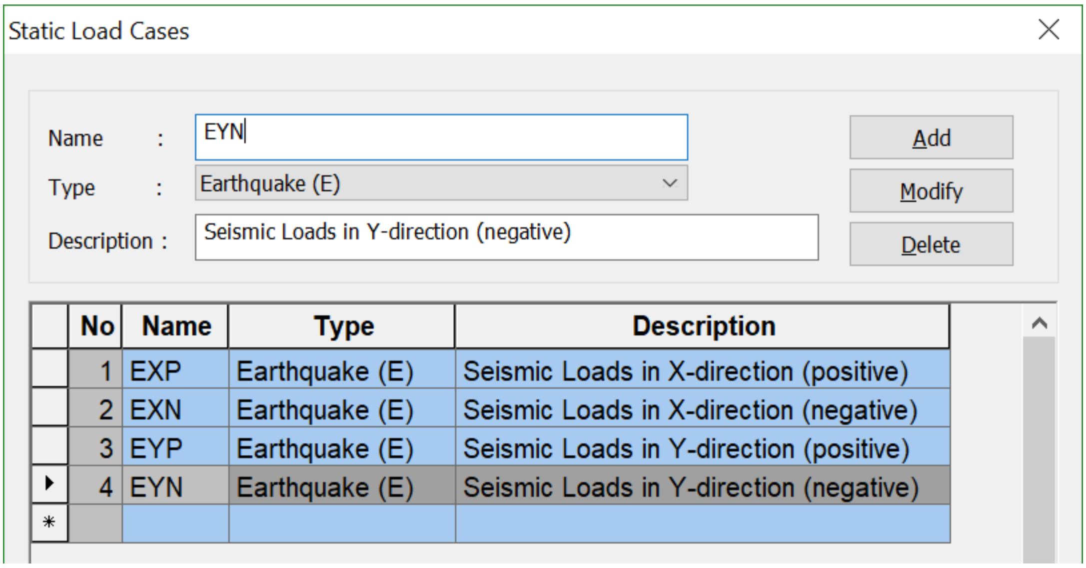

Figure 3.6: Define Static Seismic Load Cases

Secondly, dynamic response spectrum functions and load cases have to be define in order for eigenvalue modal analysis. Response spectrum functions are to be added in Load – Seismic – Response Spectrum Data – RS Functions as shown in Figure 3.8. Then, apply the created response spectrum functions to create response spectrum load cases in Load – Seismic – Response Spectrum Data – RS Load Cases as shown in Figure 3.9. It may be noticeable that the response spectrum scale factor was assigned as 0.333, this is due to Midas Gen does not include q-factor in dynamics response spectrum analysis where q-factor = 3 shall be included in the spectrum curve.

Modal combination has to be set to SRSS type as shown in Figure 3.10. Type of analysis is assigned to be Eigen Vectors Lanczos method and the frequency number of eigenvectors are assigned to comply with the requirement in EN1998-1 Clause 4.3.3.3(3) – “the sum of effective modal masses amounts to at least 90 % of the total masses” in Analysis – Analysis Control – Eigenvalue.

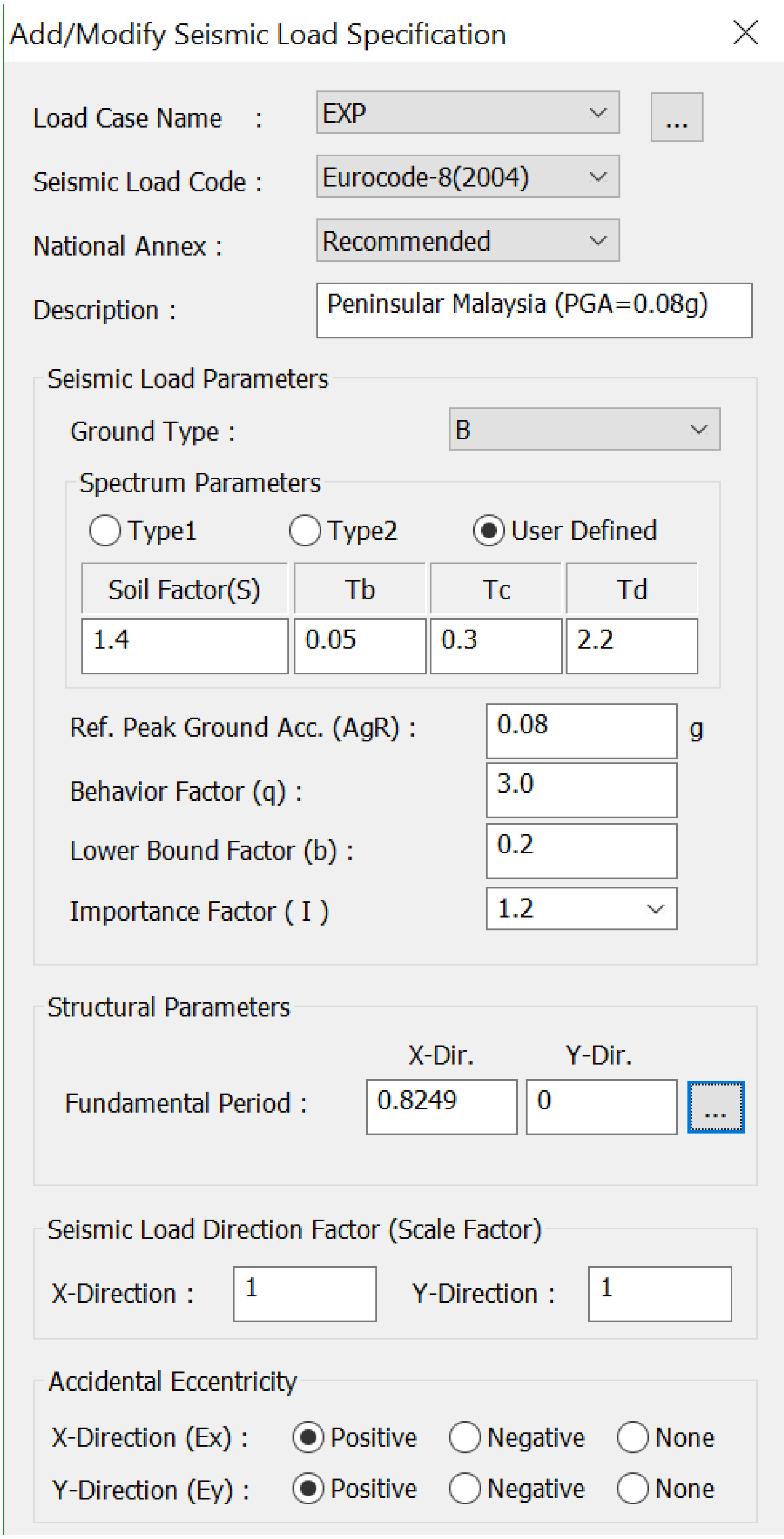

Figure 3.7: Static Seismic Loads

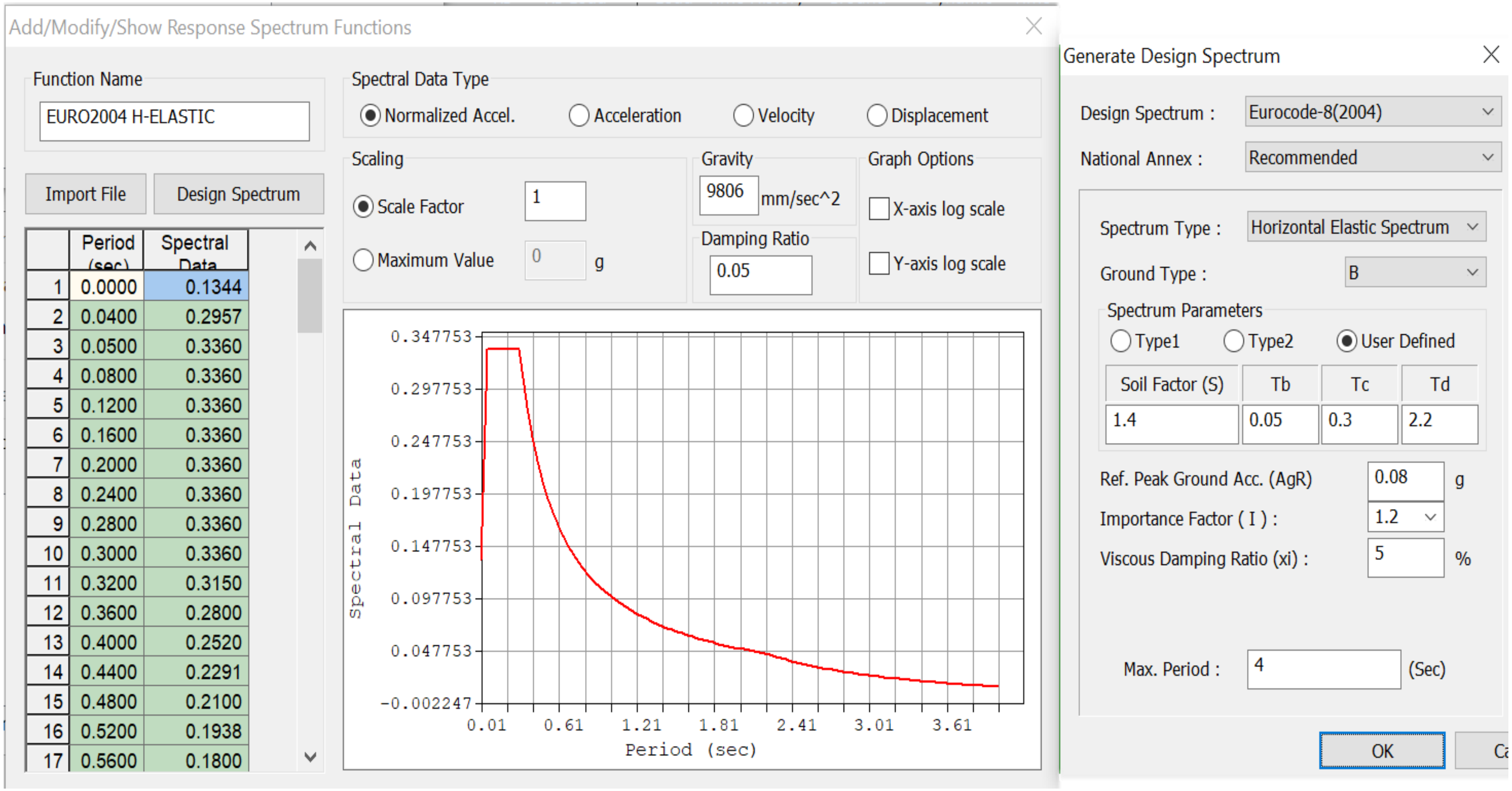

Figure 3.8: Response Spectrum Function

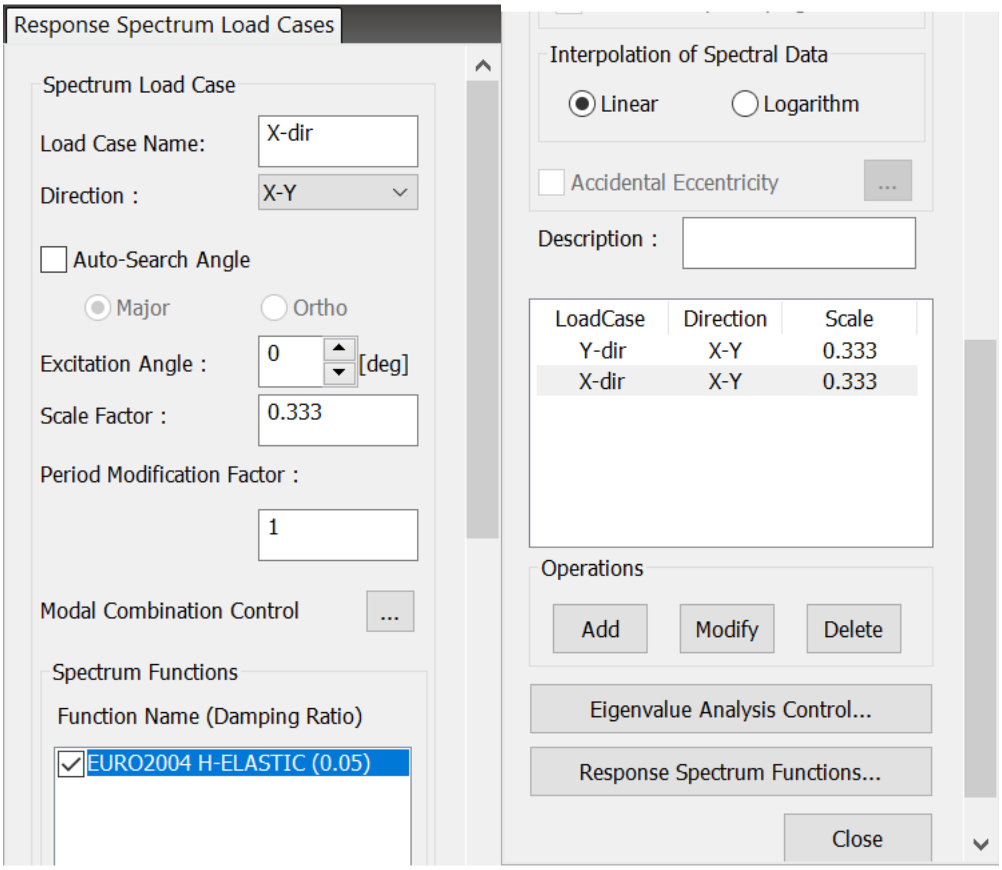

Figure 3.9: Response Spectrum Load Cases

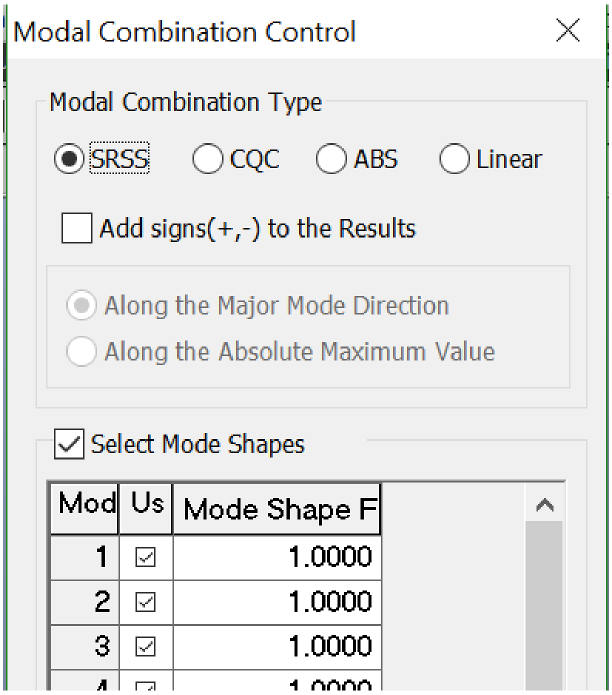

Figure 3.10: Modal Combination Control

3.4.2 Scia Engineer Seismic Loads Assignation

In Scia Engineer, seismic analysis function has to be activated in the project data while creating the file as shown in Figure 3.11. Next, seismic spectrum has to be defined in Library – Loads – Seismic Spectrum as shown in Figure 3.12, drawing type has to be set as period and input type as Eurocode, then the spectrum data can be inputted as shown in Figure 3.13. After the masses have been defined, seismic load cases are ready to define in Main Tree – Load cases, Combinations – Load Cases as shown in Figure 3.14. Lastly, the solving method of the seismic analysis may be adjusted in Main Tree – Calculation, mesh – Solver setup – Advanced solver setting as shown in Figure 3.15.

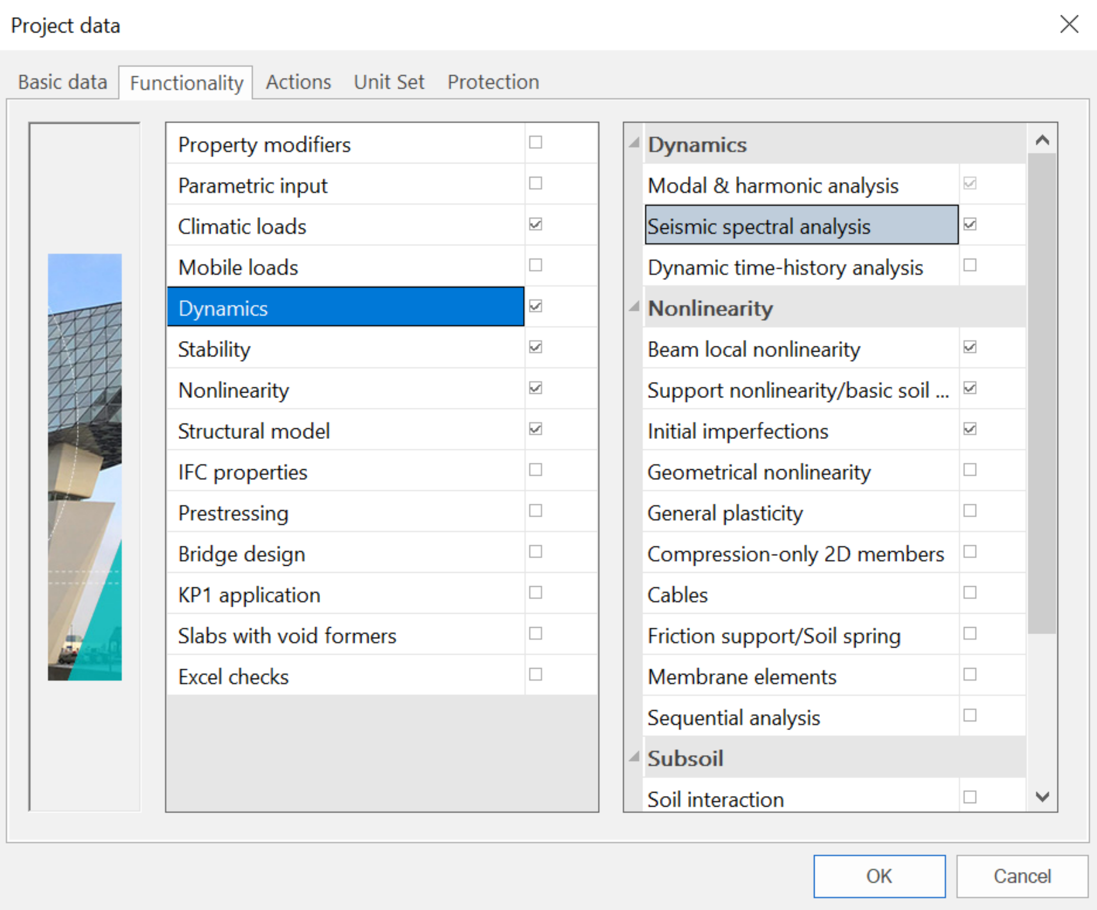

Figure 3.11: Activation of Seismic Spectral Analysis

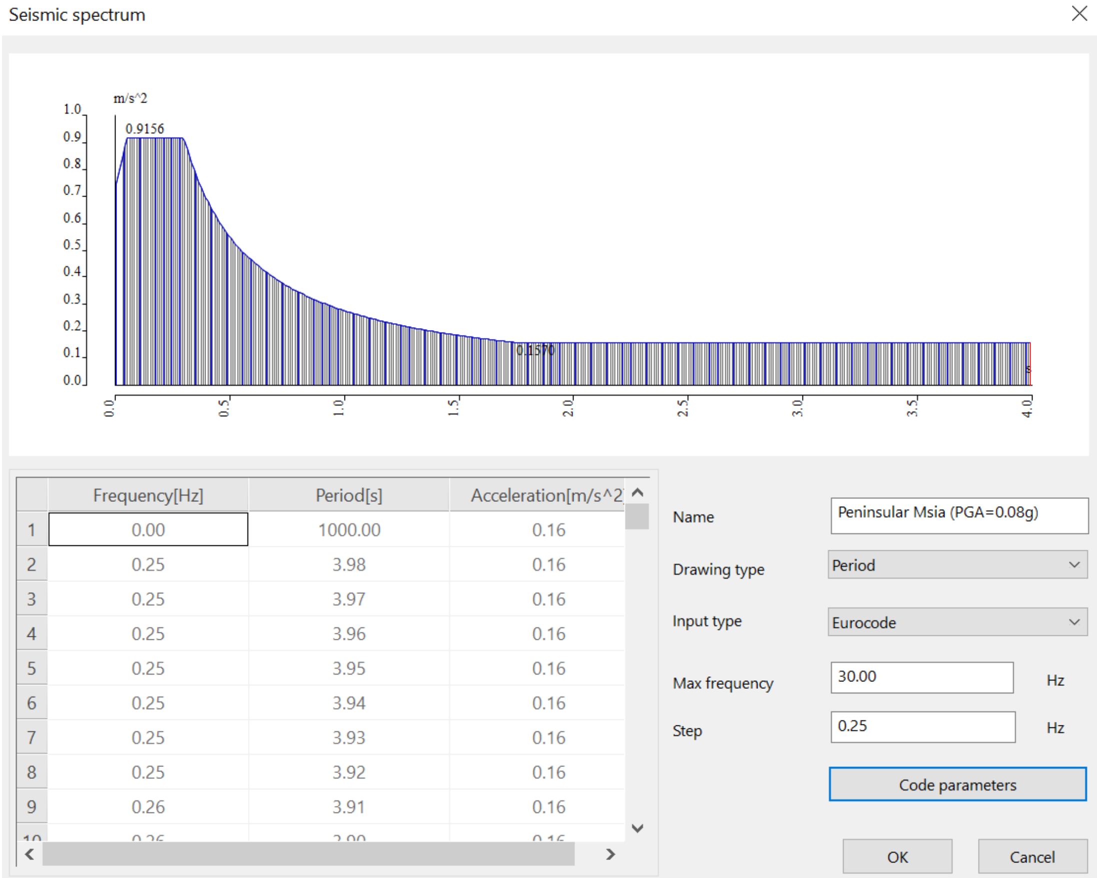

Figure 3.12: Spectrum Analysis

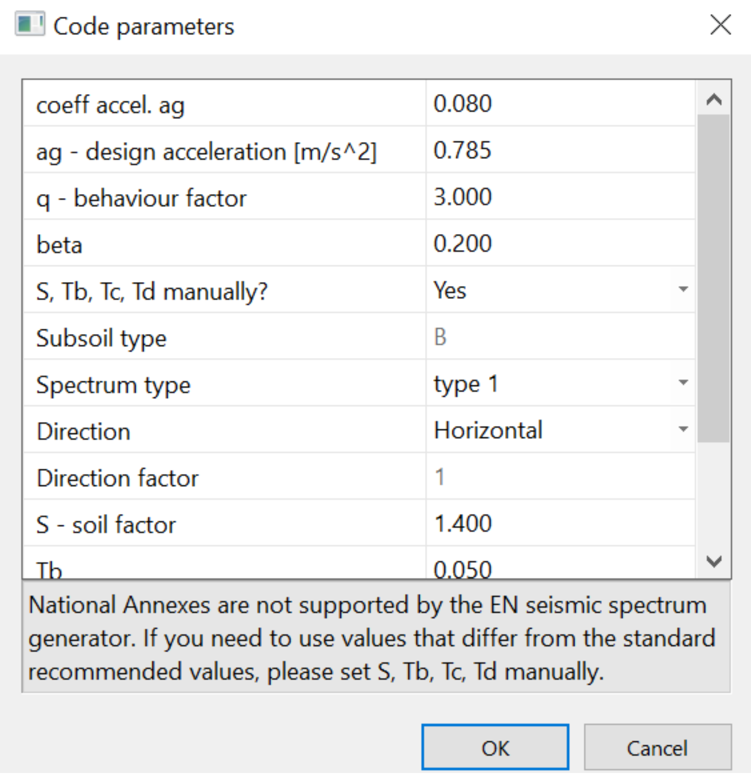

Figure 3.13: Spectrum Data

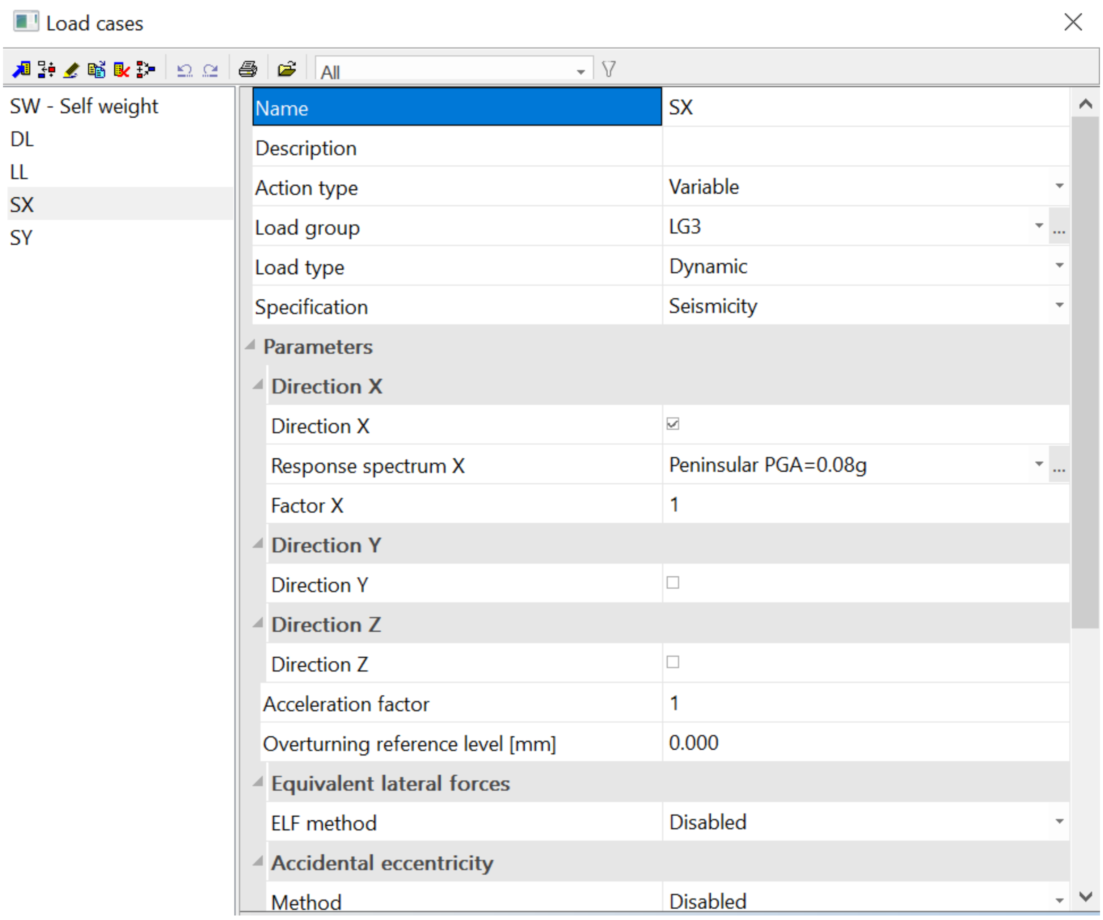

Figure 3.14: Seismic Load Cases

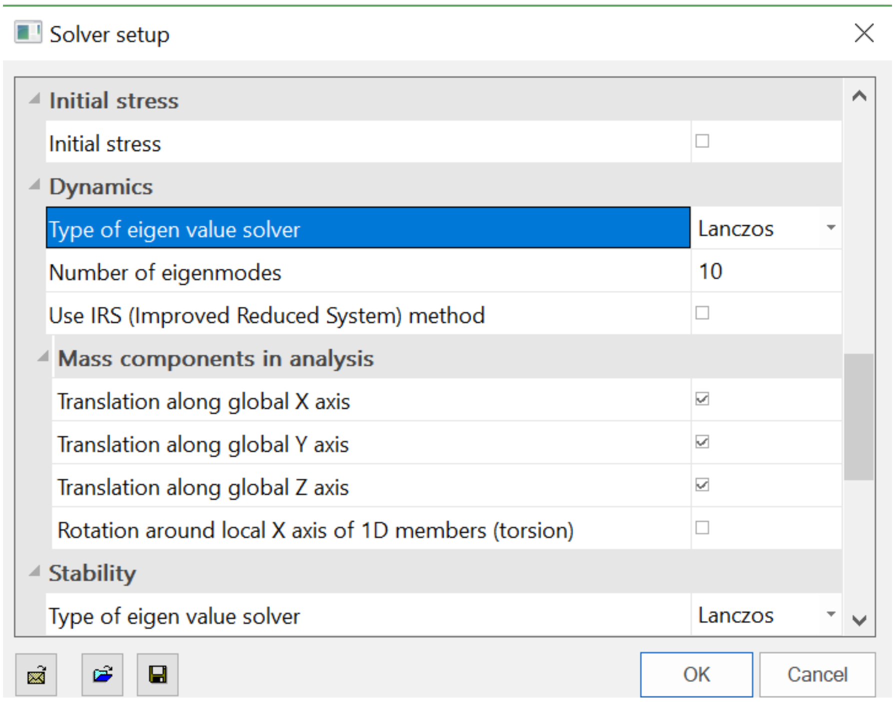

Figure 3.15: Dynamics Solver Setup

3.5 Loads Combination

According to MS EN 1990 Clause 6.4.3.1 (1) P, the effects of the actions E_d shall be determined by combining the values of actions that are considered to occur simultaneously. In this case, there are some important clauses in Eurocode 0, 1 and 8 are used as reference to determine the appropriate loads combination of actions for seismic design situations.

Fundamental combination of actions for seismic design situations can be found out in MS EN 1990 Clause 6.4.3.4 (2), and its coefficients can be found in MS EN 1990 Annex A1 Table A1.1 where category defined in MS EN 1991-1-1 Table NA2. The combination of horizontal components of the seismic action in two orthogonal response spectrum is described in MS EN 1998-1 Clause 4.3.3.5.1 (3). With complying with all the clauses stated at the above, the load combination being applied in this study are shown in the following equation:

$$1.0\ G_k + 0.3\ Q_k + 1.0\ E_{Edx} + 0.3\ E_{Edy} \tag{3.1}$$

$$1.0\ G_k + 0.3\ Q_k + 0.3\ E_{Edx} + 1.0\ E_{Edy} \tag{3.2}$$

3.6 Analyse High-rise Building

Midas Gen and Scia Engineer were used to analyse the high-rise building in several regions (Peninsular Malaysia, Sabah and Sarawak) using Modal Analysis and Linear Analysis. Some important results were extracted from both software namely mode of vibration, mode shape, storey shear, storey displacement and member internal forces.

3.7 Flowchart of Work

In this study, the methodology started with the modelling of high-rise building on ground type B by using structural analysis software namely Midas Gen and Scia Engineer. After the modelling of nodes, lines and plates element, the loads are assigned. The loads that are assigned included self-weight, permanent loads and imposed loads according to EC1 and NA to EC1, seismic loads are assigned according to EC8 and NA to EC8. The structure was analysed in modal analysis to ensure the number of modes are sufficient for the summation of participating mass exceed 90 %. Next, linear analysis was performed. Important results were filtered, collected and compared accordingly.

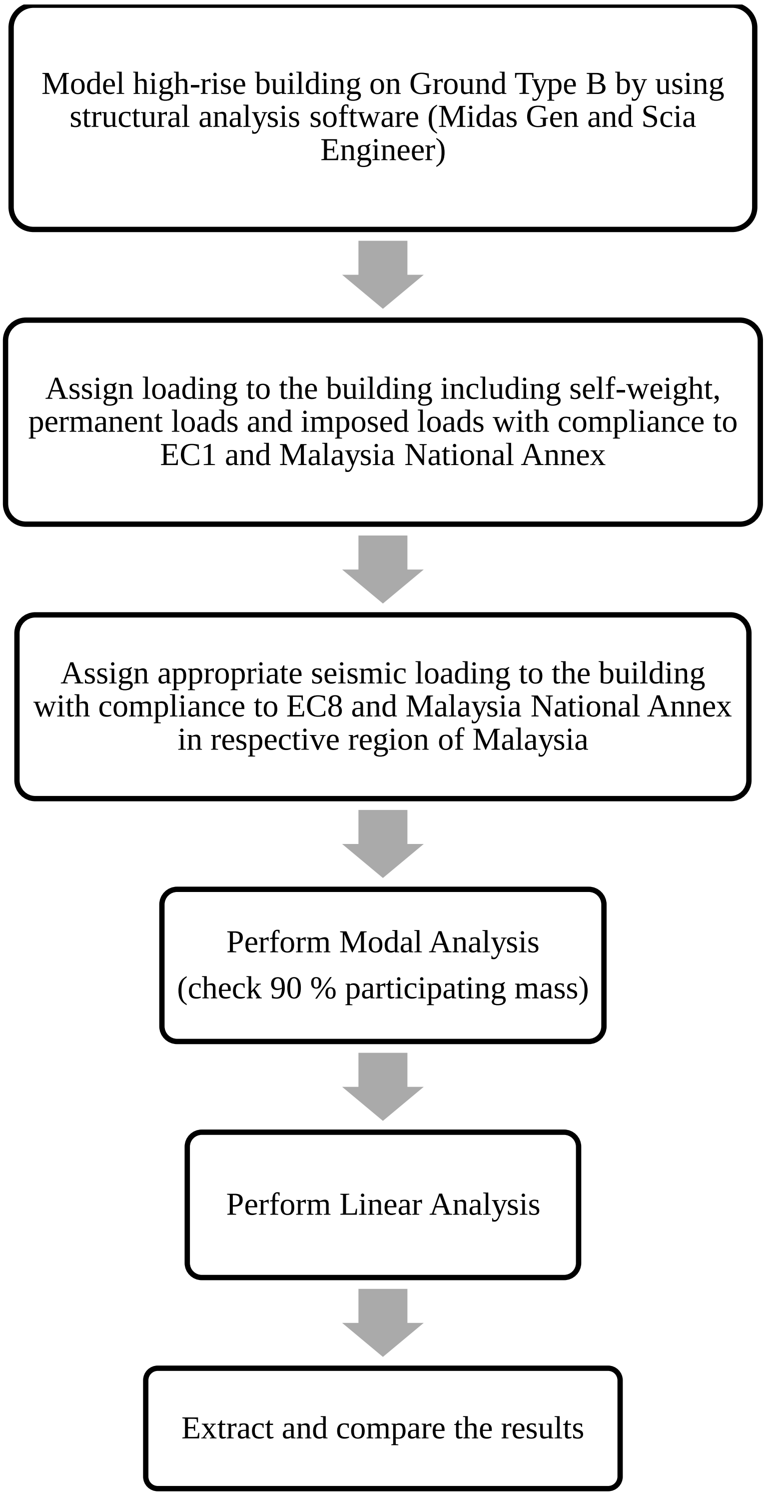

Figure 3.16: Flowchart of Work

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discussed and compared about the results obtained from both Midas Gen and Scia Engineer on an identically modelled high-rise building which include fundamental period, base and storey shear, base and storey displacement and internal forces (axial load, shear force and bending moment) of specific members.

4.2 Fundamental Period and Deformed Structure

According to MS EN 1998-1 Clause 4.3.3.3.1 (3), the sum of the effective modal masses for the modes taken into account amounts to at least 90 % of total mass of the structure. Therefore, both Midas Gen and Scia Engineer undergo trial and error in simulation to determine the number of eigenvalue modes required to achieve a participating mass of 90 %.

The eigenvalue modes requires in Midas Gen and Scia Engineer to achieve a summation of participating mass of 90 % are 25 modes and 13 modes respectively. Both software are having major participating mass at first mode and third mode for x-direction and y-direction respectively. The fundamental period in x-direction for Midas Gen and Scia Engineer are 0.7719 seconds with 60.06 % participating mass and 0.8002 seconds with 60.05 % participating mass respectively, whereas in y-direction for Midas Gen and Scia Engineer are 0.5175 seconds with 48.10 % participating mass and 0.5448 seconds with 54.28 % respectively. Figure 4.1 and Figure 4.2 show the vibration modes results which is a graph of cumulative participating mass versus frequency for Midas Gen and Scia Engineer in both x-direction masses and y-direction masses.

By referring to Figure 4.1 and Figure 4.2, the results are considered uniform as they are having a similar trend even though there are some minor fluctuations. Midas Gen has slightly higher cumulative participating mass in both x and y-direction compared to Scia Engineer. By looking into the detailed results, the number of mode which controlling the participating mass in x-direction are mode 1, 4, 9 and mode 1, 4, 10 in Midas Gen and Scia Engineer respectively. Whereas the number of mode which controlling the participating mass in y-direction are mode 3, 6, 25 and 3, 6, 13 in Midas Gen and Scia Engineer respectively. Basically the last controlling number of mode affects the fundamental period needed for the structure to achieve a cumulative of 90 % of structure's mass.

Since the vibration modes in both software are almost identical, the number of modes to generate results in order to obtain an achieving participating mass of 90 % is comparable in this case. Scia Engineer uses 13 modes to achieve a satisfying results whereas Midas Gen requires 25 modes to achieve a satisfying results, therefore, Scia Engineer is said to be more efficient in performing modal analysis. According to Scia Resource Centre, Scia Engineer possesses a powerful Improved Reduced System (IRS) to efficiently compute eigenmodes of structure. IRS significantly reduces the number of degree of freedom of a large finite element meshes and notably reduce the required analysis time (Rossier, Bastiaens and Broz, 2013).

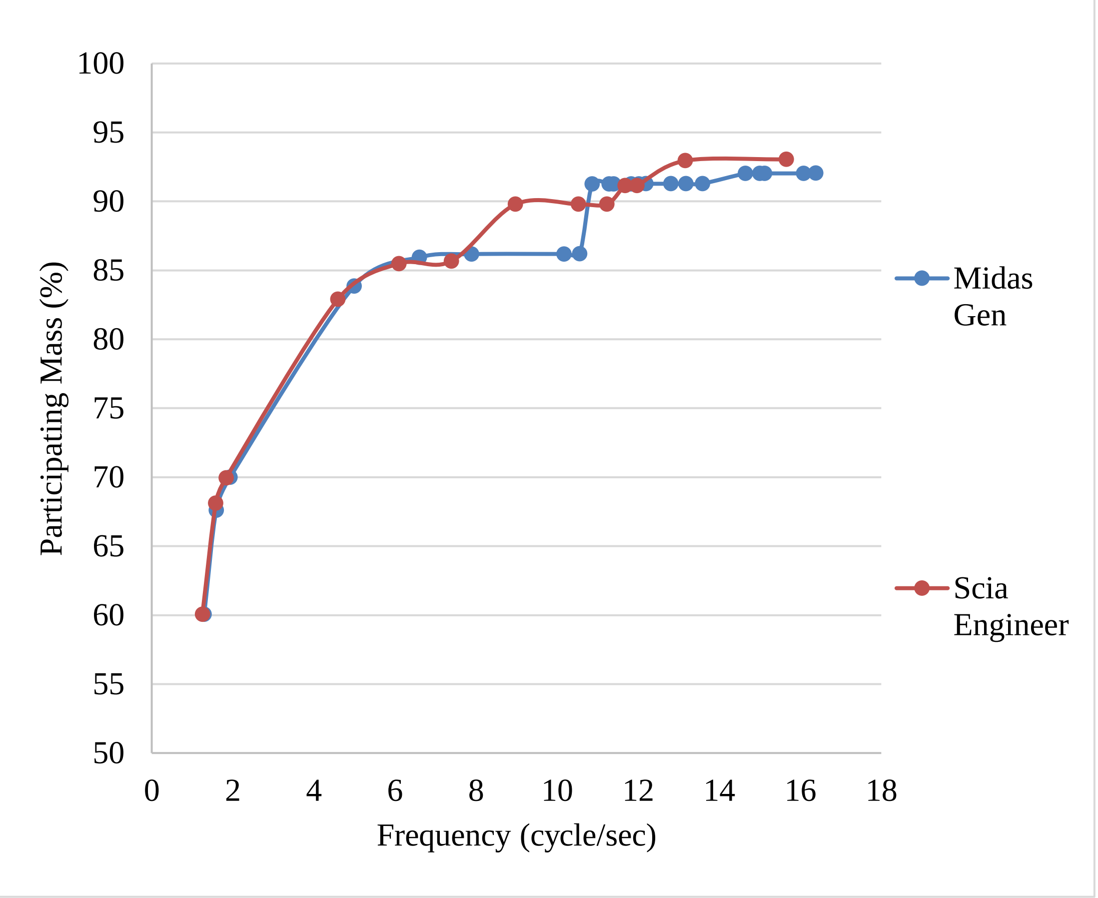

Figure 4.1: Graph of Cumulative Participating Masses in X-direction vs Frequency

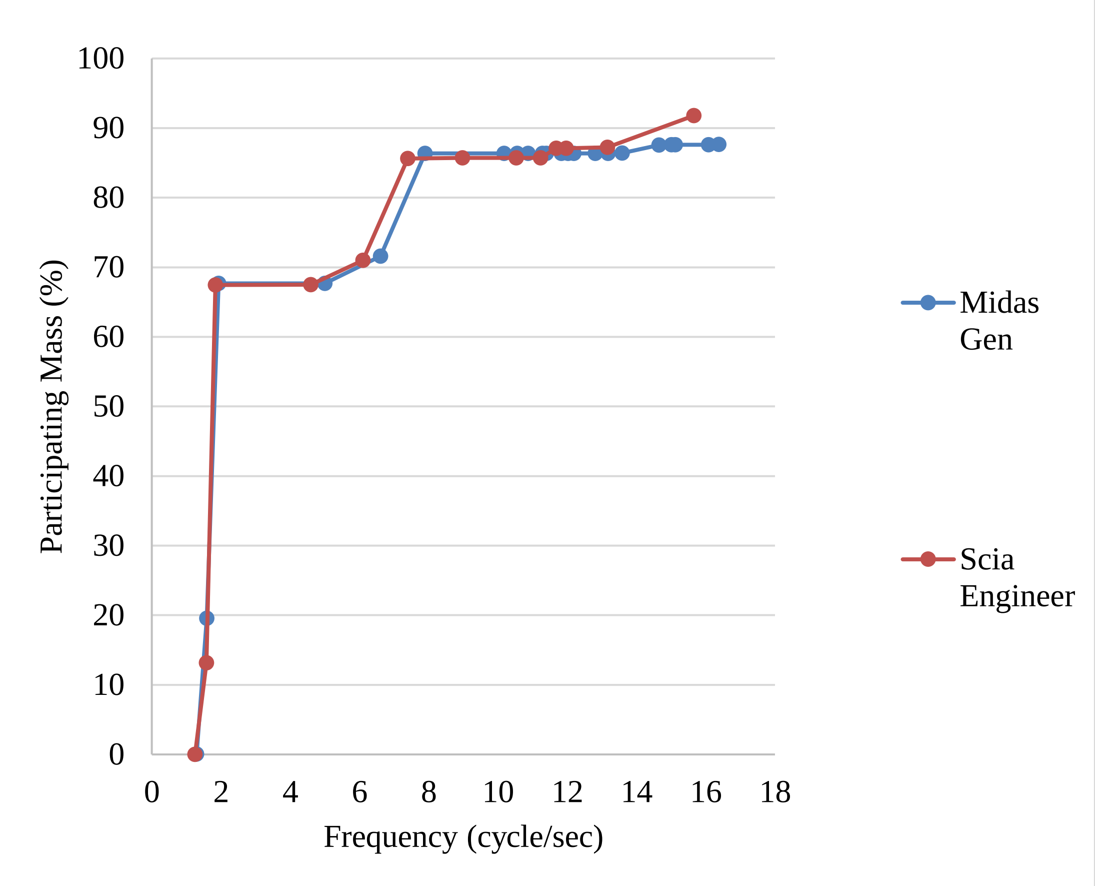

Figure 4.2: Graph of Cumulative Participating Masses in Y-direction vs Frequency

Vibration mode shape of the modelled high-rise building were also generated by Midas Gen and Scia Engineer. Major vibration shape in both x and y direction are identified by participating masses. In Midas Gen and Scia Engineer, mode 1 has major x-direction participating mass and the deformed shape are shown in Figure 4.3 and Figure 4.4 respectively. Both software show a similar deformed shape in vibration mode 1. Similarly in y-direction, Midas Gen and Scia Engineer have major participating mass in mode 3 where the deformed shape are shown in Figure 4.5 and Figure 4.6 respecctively. Deformed shapes of y-direction major participating mass are similar in Midas Gen and Scia Engineer.

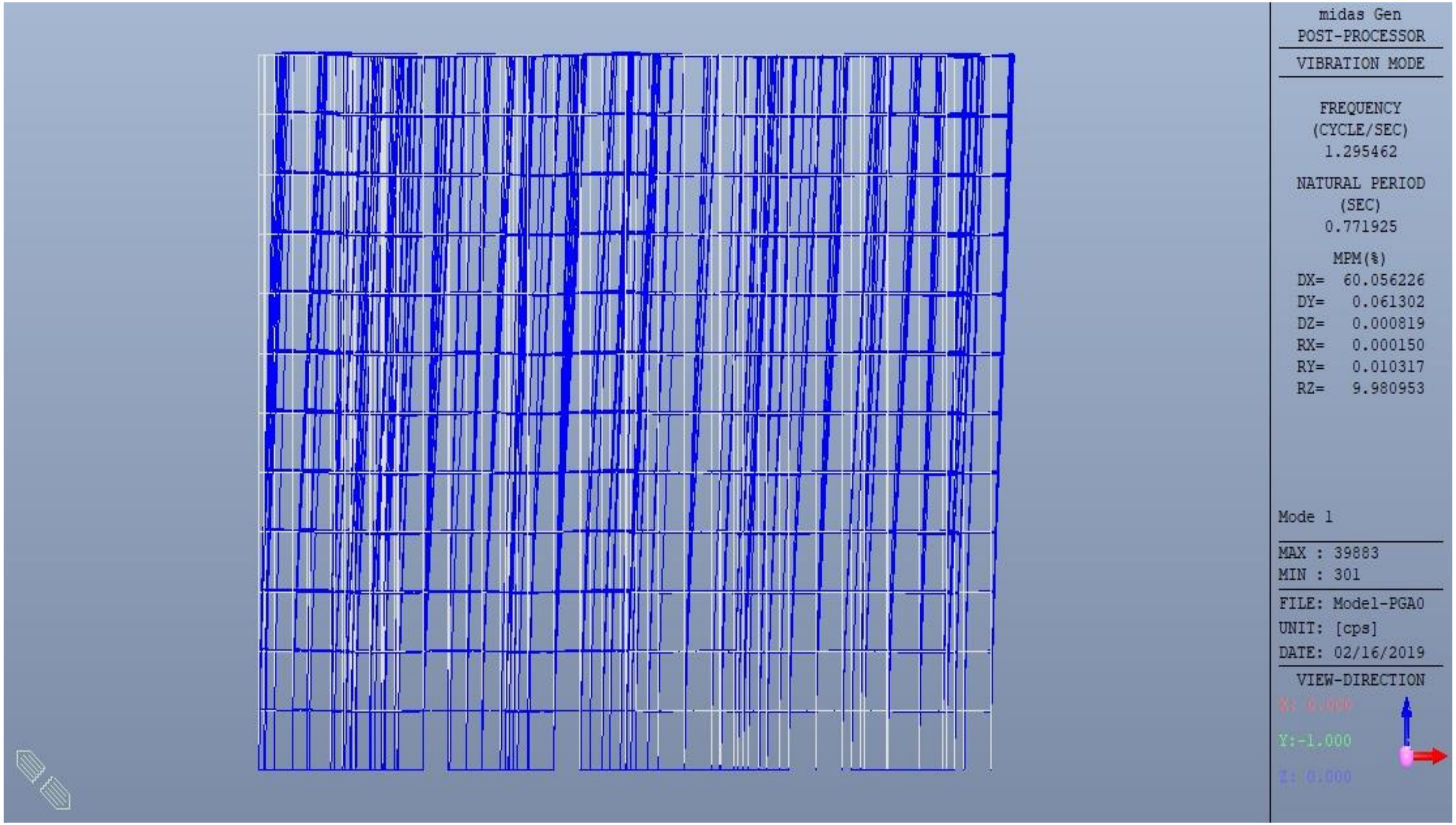

Figure 4.3: Vibration Mode Shape 1 by Midas Gen

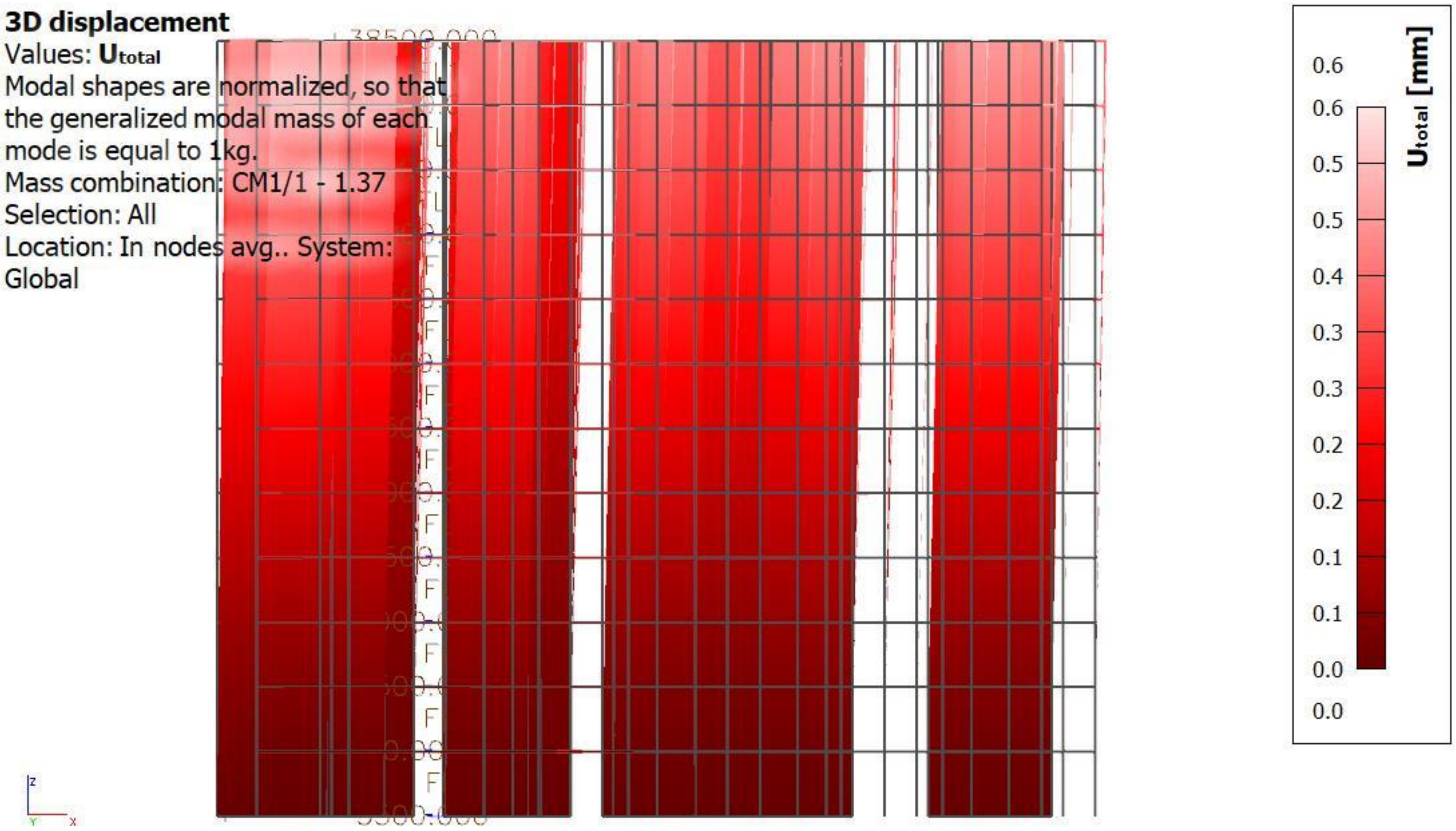

Figure 4.4: Vibration Mode Shape 1 by Scia Engineer

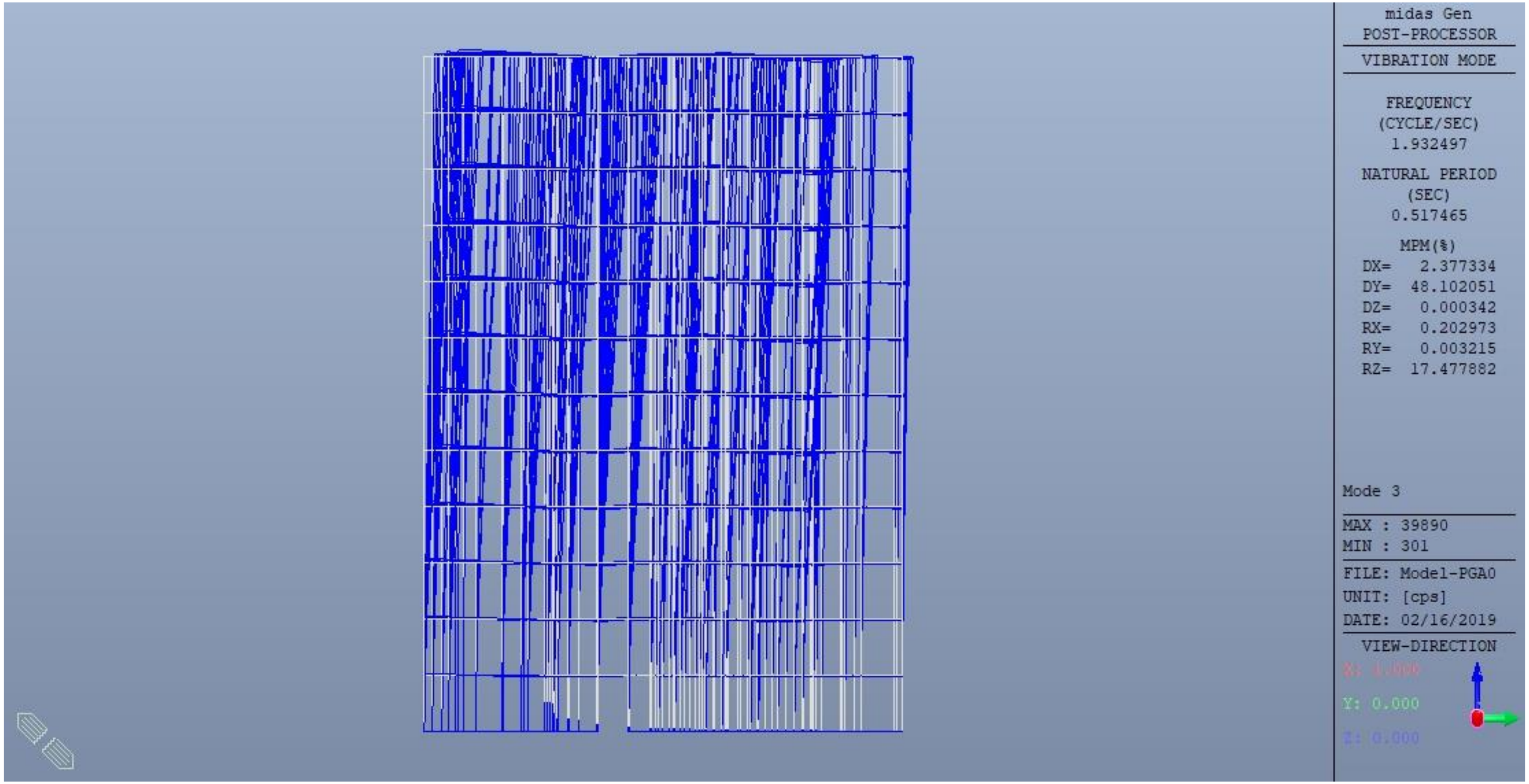

Figure 4.5: Vibration Mode Shape 3 by Midas Gen

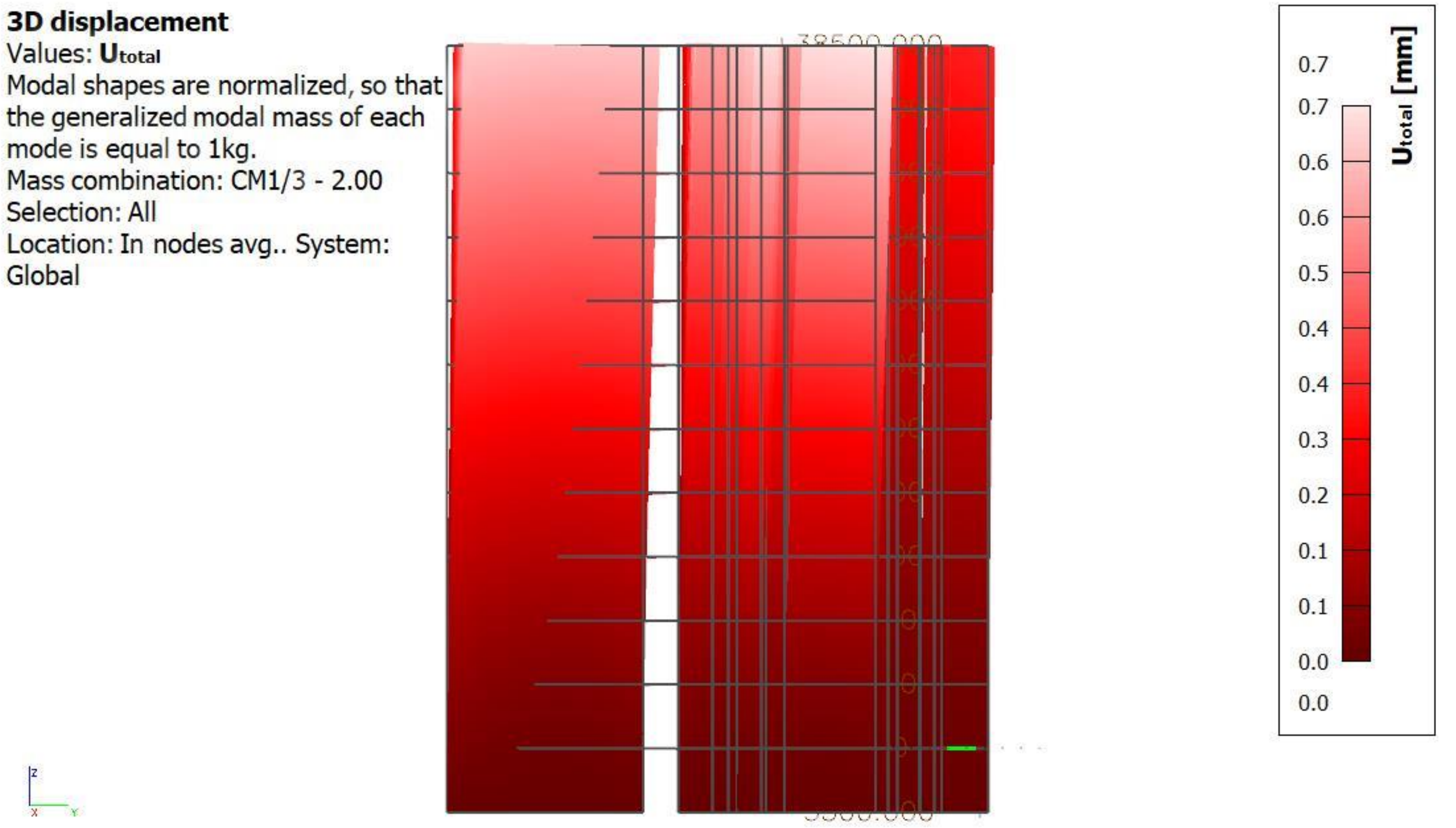

Figure 4.6: Vibration Mode Shape 3 by Scia Engineer

4.3 Base and Storey Shear

Base shear is the shear force at the base level and storey shear is the shear force at respective storey height. Base and storey shear of the modelled high-rise building by Midas Gen are shown in Figure 4.7 and Figure 4.8 for x and y direction respectively, whereas base and storey shear of modelled high-rise building by Scia Engineer are shown in Figure 4.9 and Figure 4.10 for x and y direction respectively. The base and storey shear basically decreases over height in both x and y direction. The base and storey shear increases as the PGA value increases where Peninsular Malaysia possesses the lowest base shear and Sabah possesses the highest base shear. In short, PGA value directly affected the base and storey shear of high-rise building. The higher the PGA value, the higher the base and storey shear.

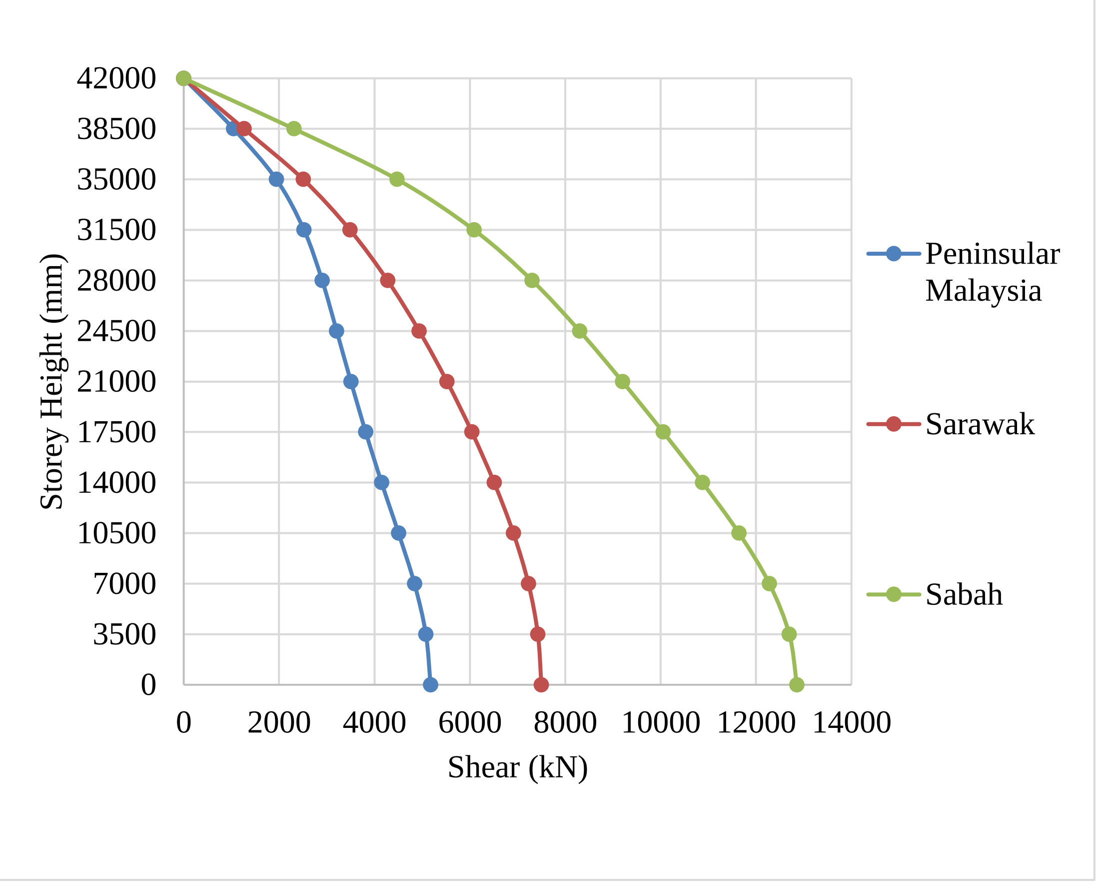

Figure 4.7: Graph of Base and Storey of X-direction by Midas Gen

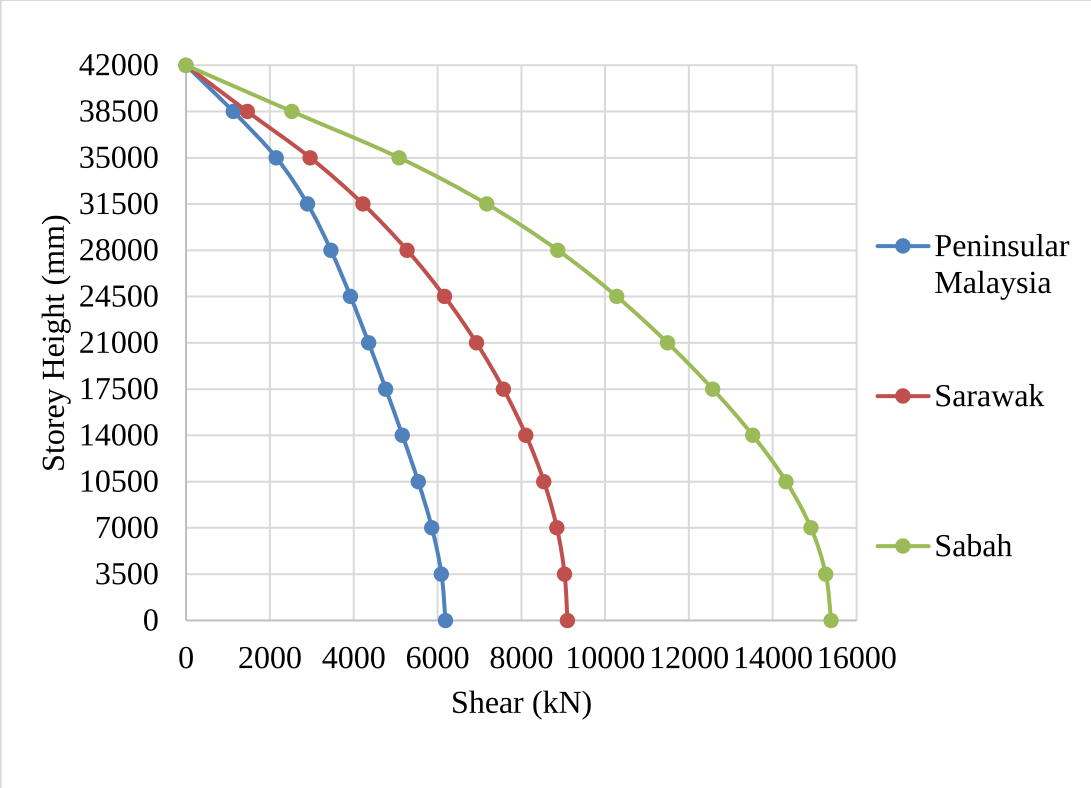

Figure 4.8: Graph of Base and Storey of Y-direction by Midas Gen

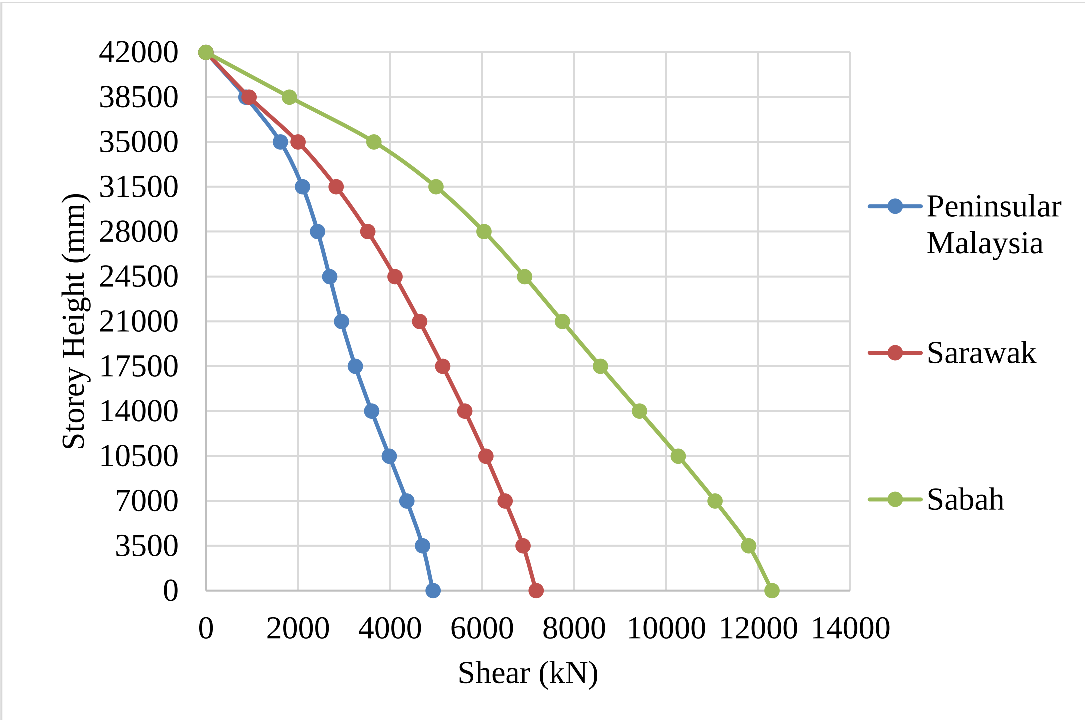

Figure 4.9: Graph of Base and Storey of X-direction by Scia Engineer

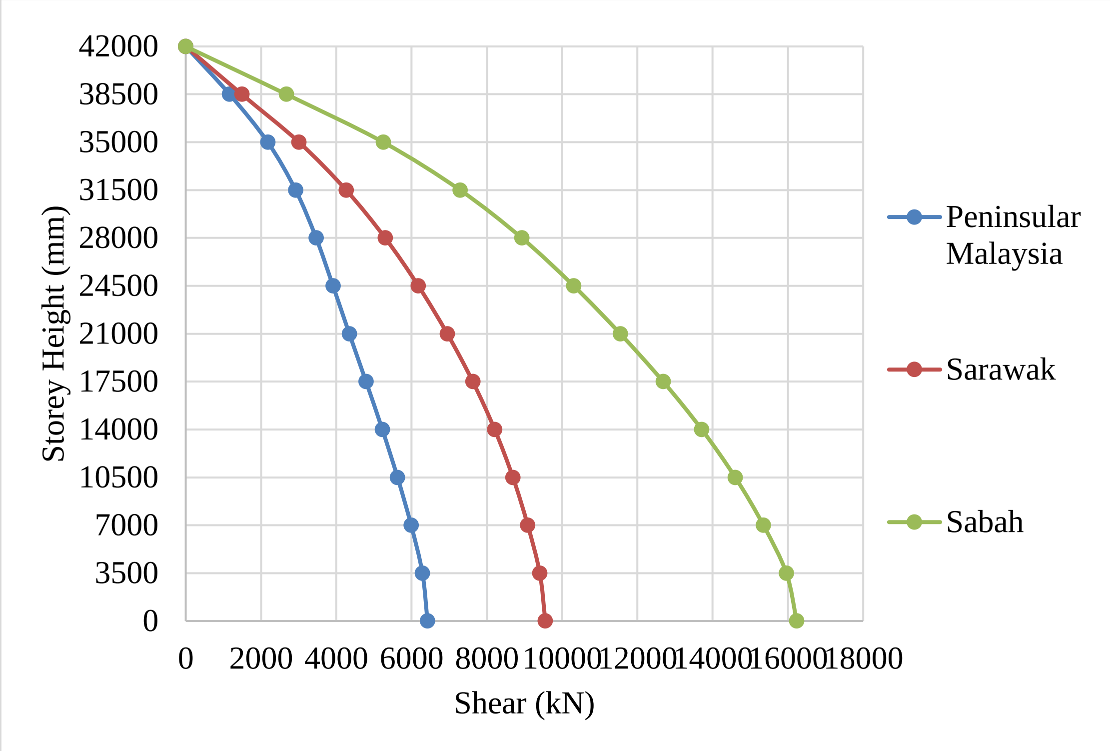

Figure 4.10: Graph of Base and Storey of Y-direction by Scia Engineer

4.3.1 Comparison between Software

The PGA value of 0.16 g in Sabah region has been taken to analyse the difference of the base and storey shear on an identically modelled high-rise building between Midas Gen and Scia Engineer. Seismicity from x and y direction are analysed separately as shown in Figure 4.11 and Figure 4.12 respectively. Under seismic action from x-direction, Midas Gen provided a slightly higher base and storey shear whereas under seismic action from y-direction, Scia Engineer provided a slightly higher base and storey shear. The average percentage difference of base and storey shear of x and y direction in Sabah is tabulated in Table 4.1.

Table 4.1: Average Percentage Difference of Base and Storey Shear in Sabah Region

Average Percentage Difference between Midas Gen and Scia Engineer	
X-direction	14.0469 %
Y-direction	2.4101 %

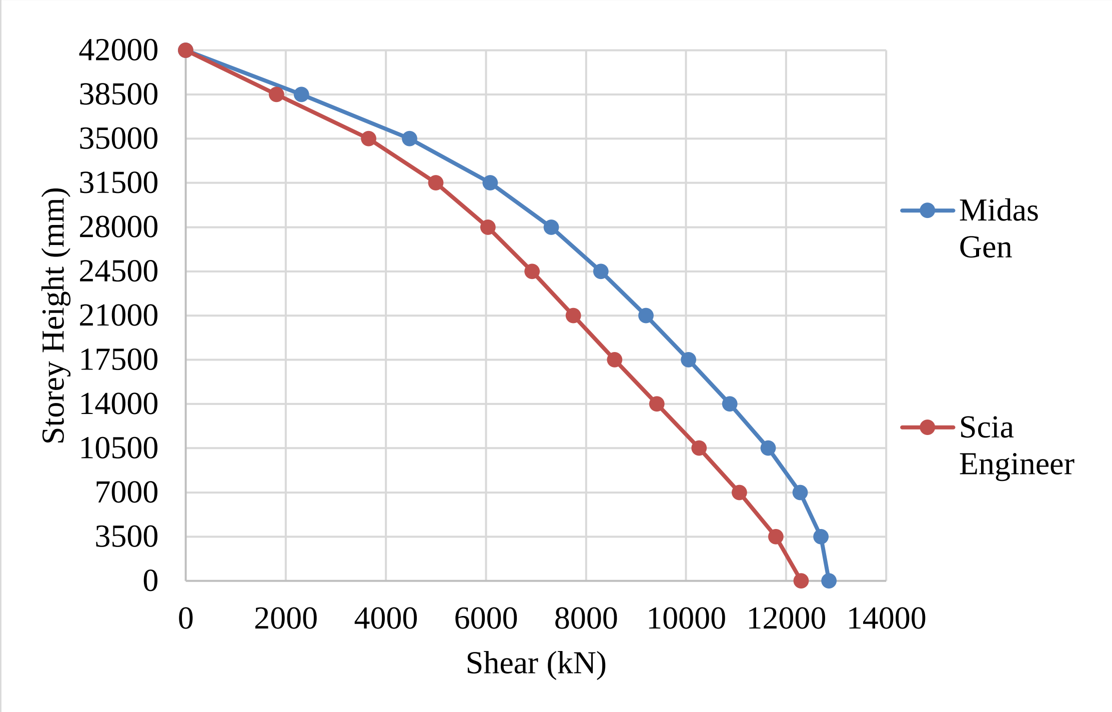

Figure 4.11: Comparison of Base and Storey Shear of X-direction Seismicity in Sabah between Midas Gen and Scia Engineer

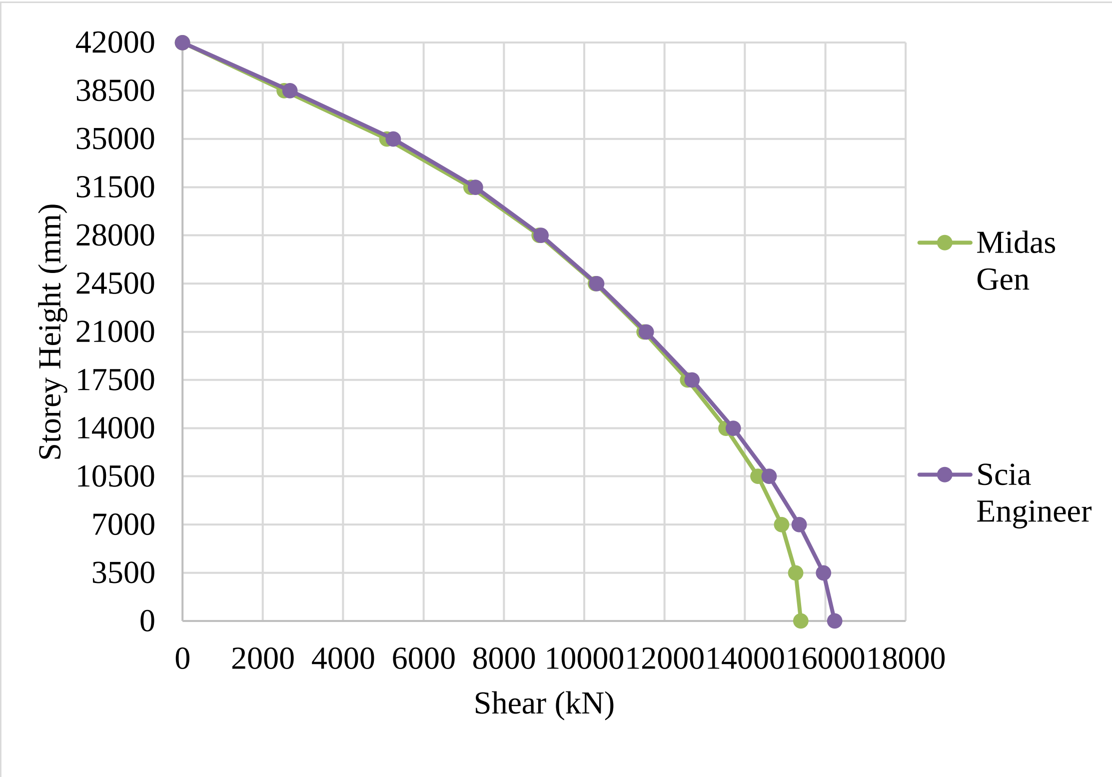

Figure 4.12: Comparison of Base and Storey Shear of Y-direction Seismicity in Sabah between Midas Gen and Scia Engineer

4.4 Storey Displacement

Structure undergoes deformation when applied with loads or action. In earthquake resistance structure, structures are designed to withstand horizontal loads and are designed to minimize the horizontal displacement. In this section, storey displacements are analysed in term of maximum displacement of each storey in both x and y-direction of earthquake action.

Storey Displacement of high-rise building in different region modelled by Midas Gen are shown in Figure 4.13 and Figure 4.14 for x and y direction respectively. Storey Displacement of high-rise building in different region modelled by Scia Engineer are shown in Figure 4.15 and Figure 4.16 for x and y direction respectively. In general, storey displacement increases over storey height. Storey displacement also affected by PGA value based on region in Malaysia generated by both software in which Sabah (PGA = 0.16 g) has the highest storey displacement and Peninsular Malaysia (PGA = 0.08 g) undergoes a comparable lower storey displacement as shown. Hence, it can be concluded that the higher the PGA value, the higher the storey displacement.

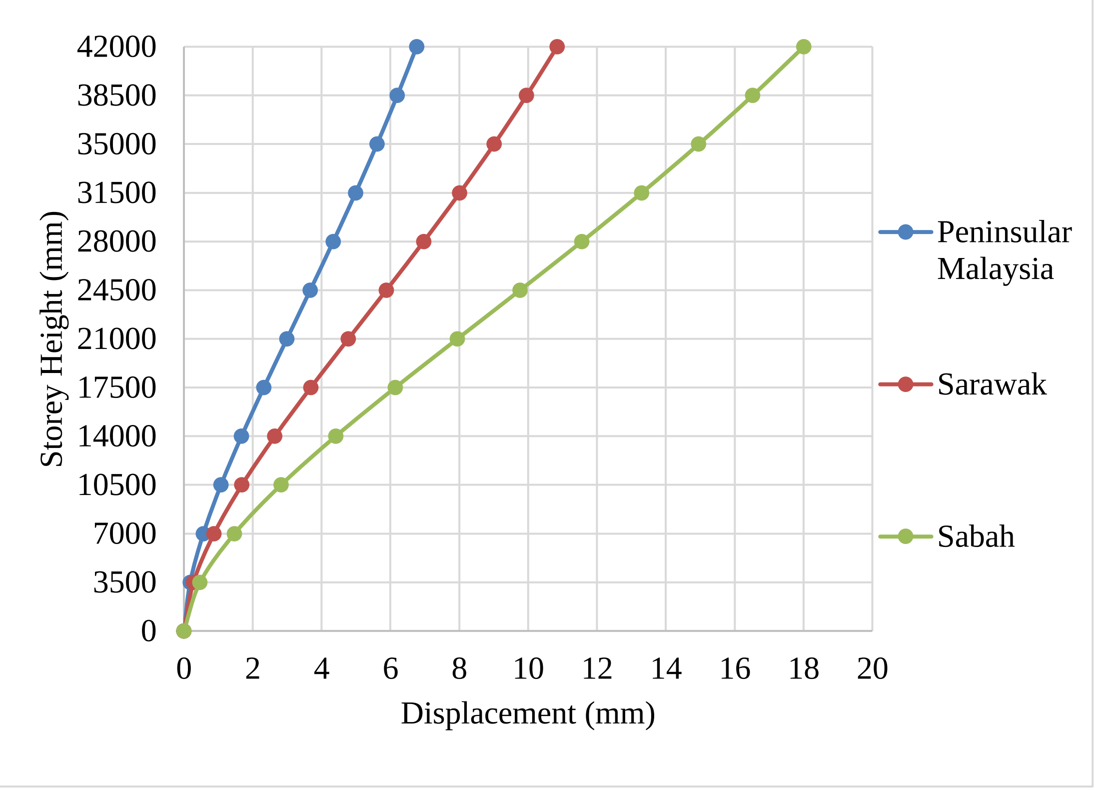

Figure 4.13: Graph of Storey Height vs Displacement due to X-direction Seismicity by Midas Gen

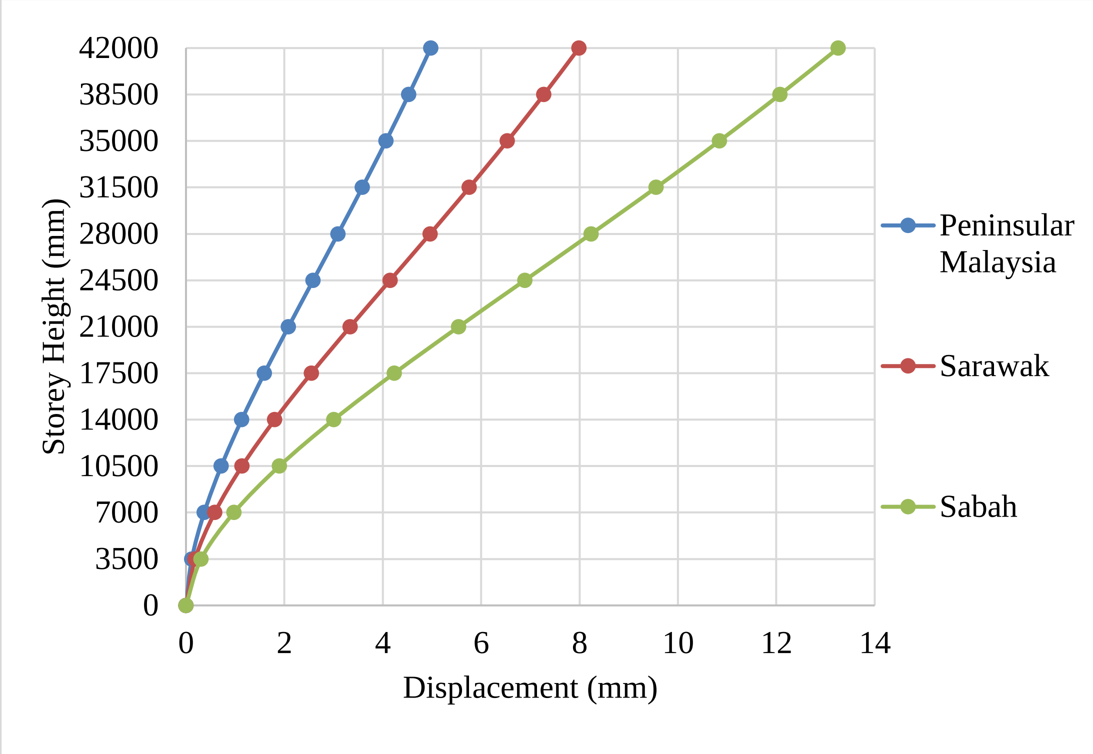

Figure 4.14: Graph of Storey Height vs Displacement due to Y-direction Seismicity by Midas Gen

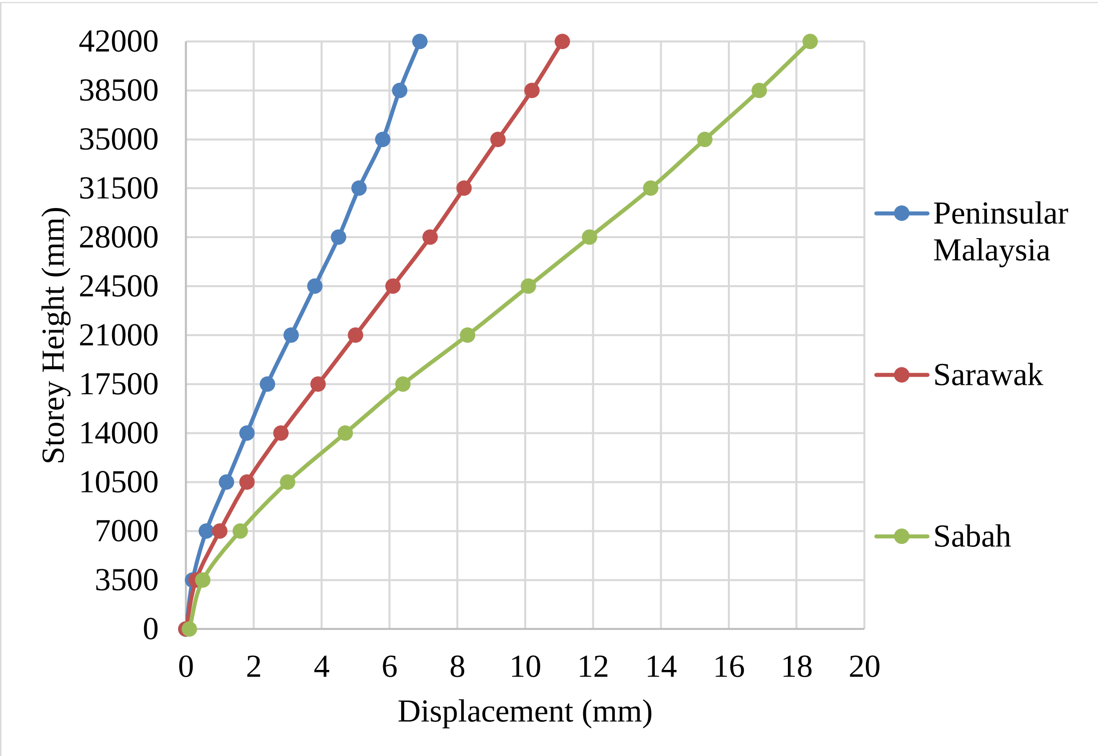

Figure 4.15: Graph of Storey Height vs Displacement due to X-direction Seismicity by Scia Engineer

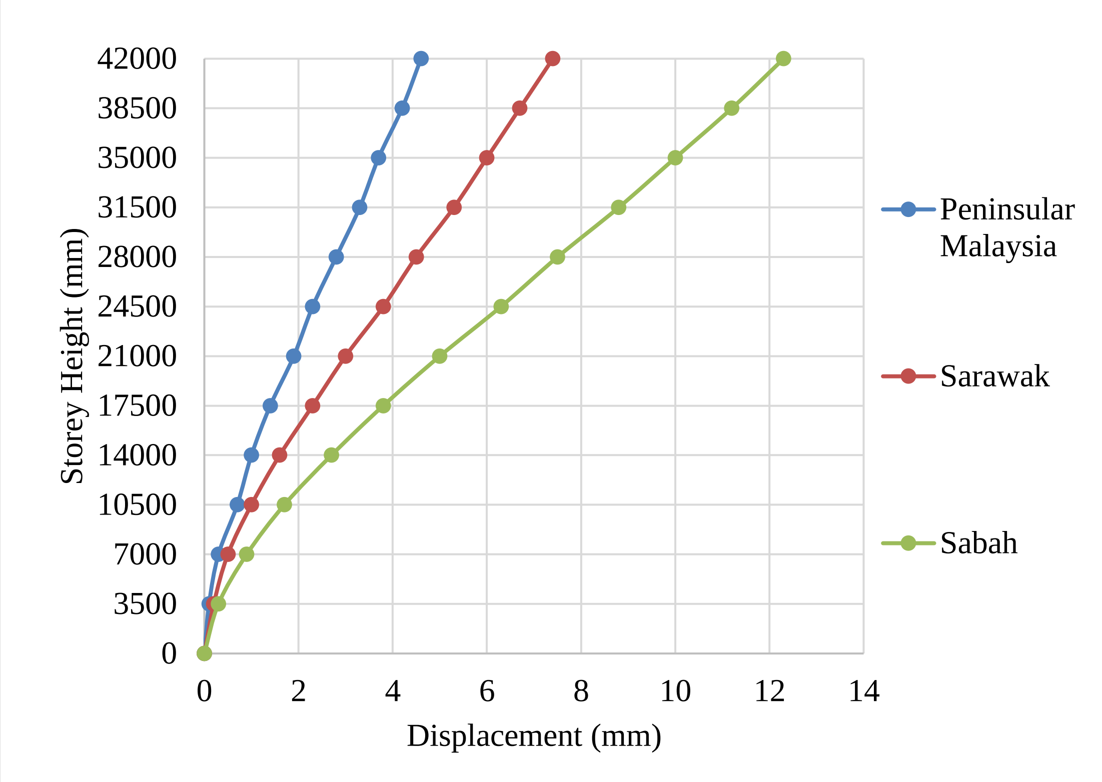

Figure 4.16: Graph of Storey Height vs Displacement due to Y-direction Seismicity by Scia Engineer

4.4.1 Comparison between Software

The PGA value of 0.16 g in Sabah region has been taken to analyse the difference of the storey displacement on an identically modelled high-rise building between Midas Gen and Scia Engineer. Seismicity from x-direction and y-direction are analysed separately as shown in Figure 4.17 and Figure 4.18 respectively. Midas Gen has a higher storey displacement under seismic action from y-direction, whereas Scia Engineer has a higher storey displacement under seismic action from x-direction. The average percentage difference of storey displacement of x and y direction in Sabah is tabulated in Table 4.2.

Table 4.2: Average Percentage Difference of Storey Displacement in Sabah Region

Average Percentage Difference between Midas Gen and Scia Engineer	
X-direction	4.3761 %
Y-direction	8.2481 %

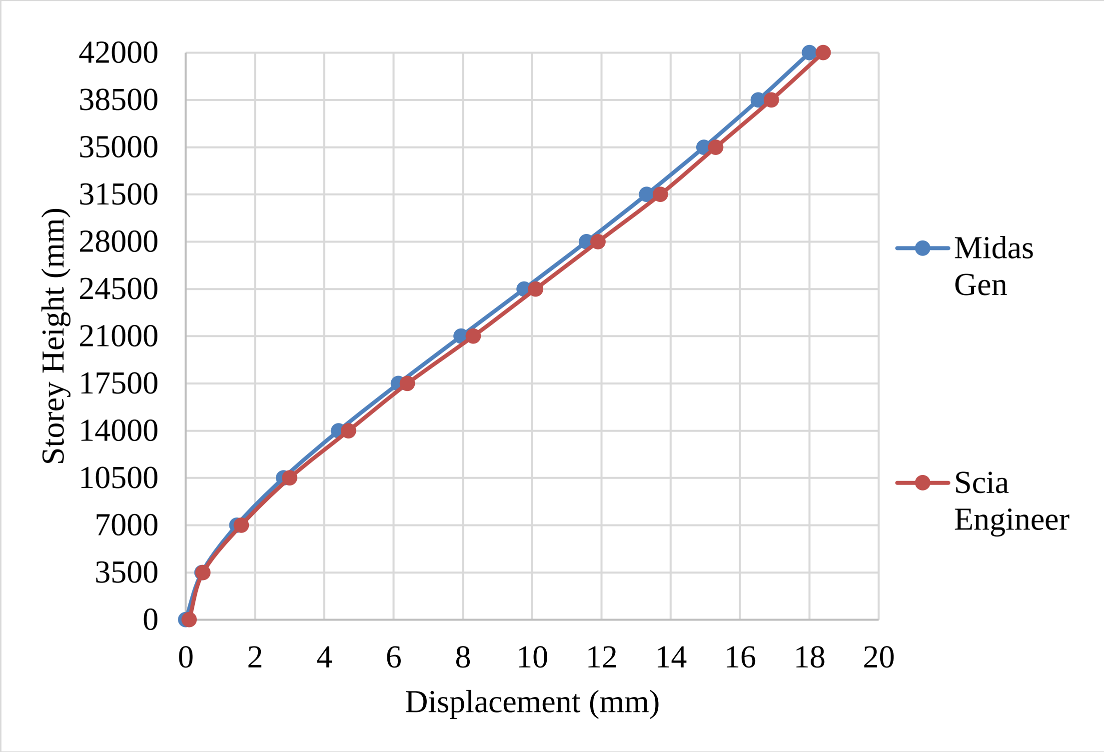

Figure 4.17: Comparison of Storey Displacement of X-direction Seismicity in Sabah between Midas Gen and Scia Engineer

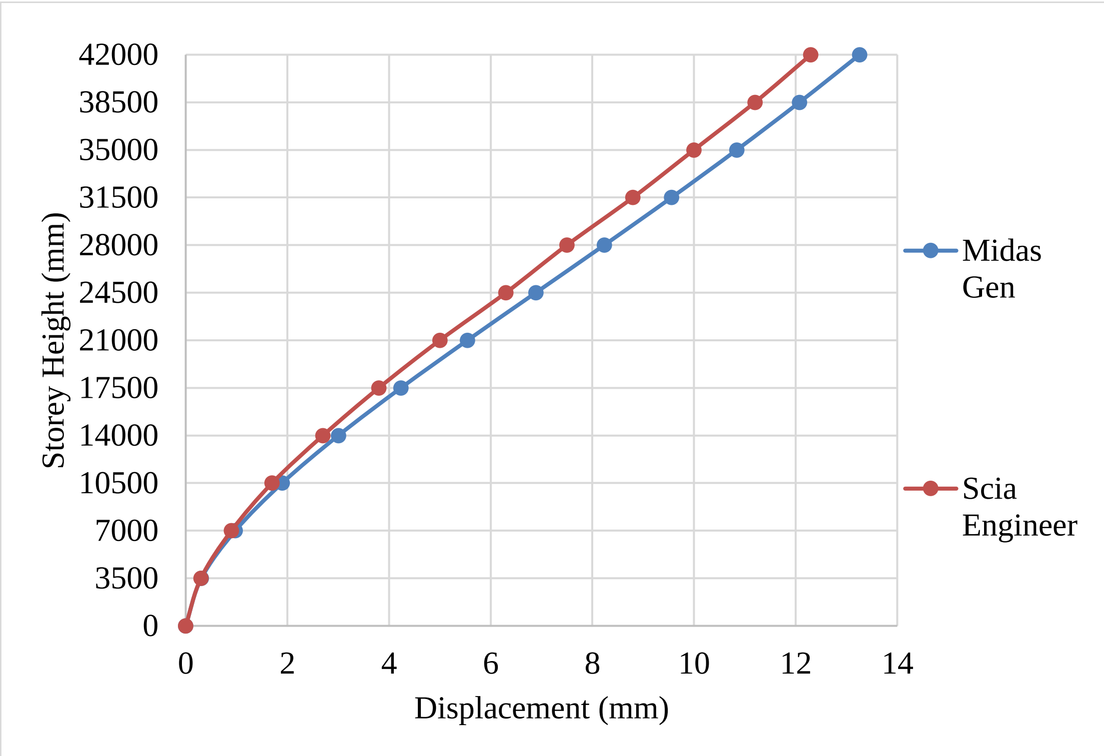

Figure 4.18: Comparison of Storey Displacement of Y-direction Seismicity in Sabah between Midas Gen and Scia Engineer

4.5 Interstorey Drift

Interstorey drift is a useful engineering response and important parameter for high-rise buildings structural performance, it is defined as relative translational displacement between two consecutive floor in China's code namely GB50011, 2010 (Zhou and Bu, 2012). According to MS EN 1998-1:2005 Clause 4.4.3.2 (2), NA to EC8 recommended that only class IV building needed to be checked with damage limitation and the reduction factor to be adopted equal to $v = 0.5$. In this study, interstorey drift is still being analysed even though residential buildings are classified as class II, the reduction factor remained as $v = 0.5$. The interstorey drift for Peninsular Malaysia, Sarawak and Sabah analysed by Midas Gen and Scia Engineer are shown in Figure 4.19, Figure 4.20, Figure 4.21 and Figure 4.22.

In general, Sabah undergoes the highest interstorey drift due to it possesses the highest PGA value among the other region. Same goes to Sarawak and Peninsular Malaysia. The PGA value is directly affected the interstorey drift, the higher the PGA value, the higher the interstorey drift. Although Sabah region has the highest interstorey drift which are 0.00026 and 0.00019 in x and y direction respectively generated by Midas Gen, the interstorey drift is still considered as acceptable by assessing with the limitation of interstorey drift under MS EN 1998-1:2005 Clause 4.4.3.2.

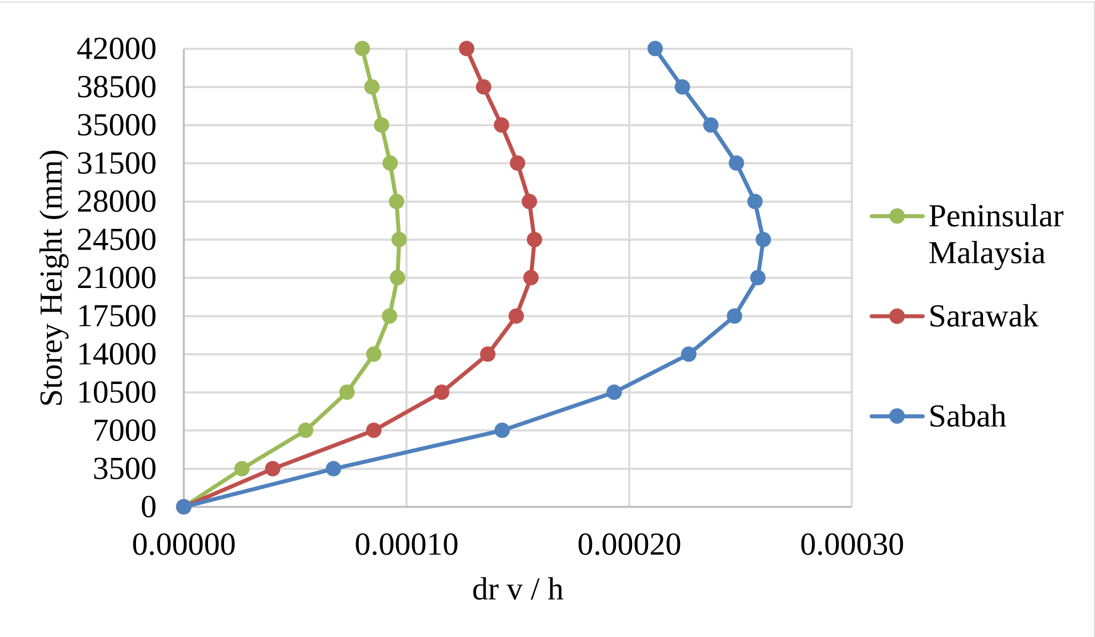

Figure 4.19: Graph of Interstorey Drift of High-rise Building due to X-direction Seismicity by Midas Gen

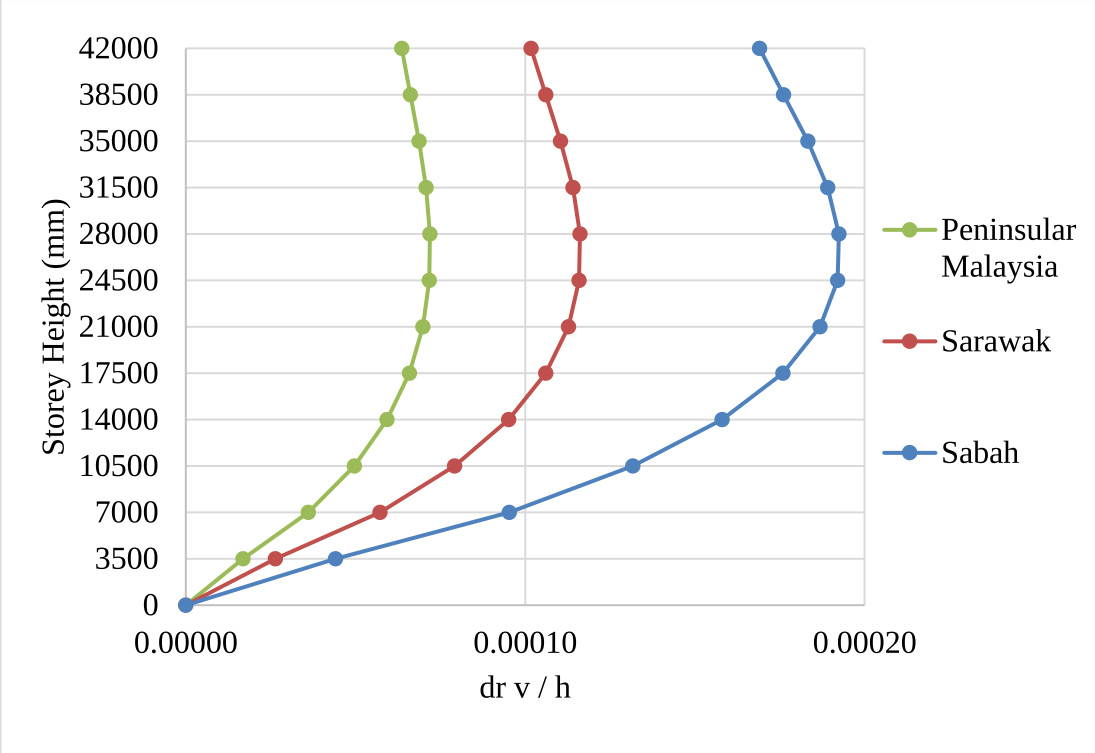

Figure 4.20: Graph of Interstorey Drift of High-rise Building due to Y-direction Seismicity by Midas Gen

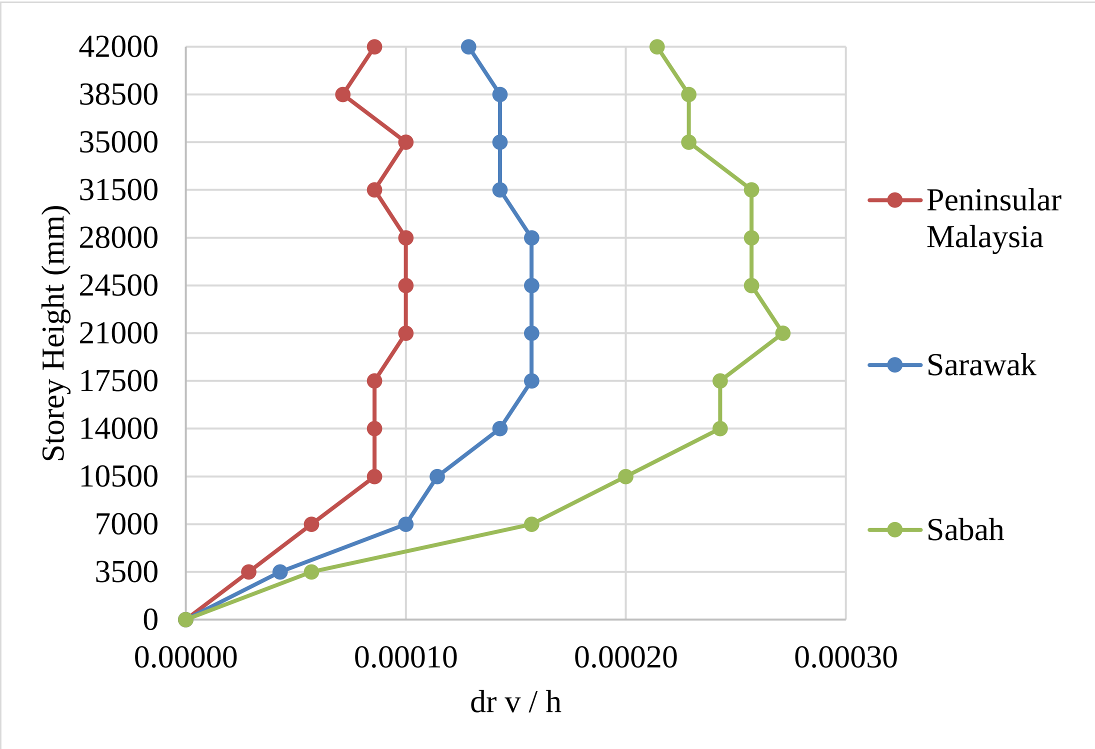

Figure 4.21: Graph of Interstorey Drift of High-rise Building due to X-direction Seismicity by Scia Engineer

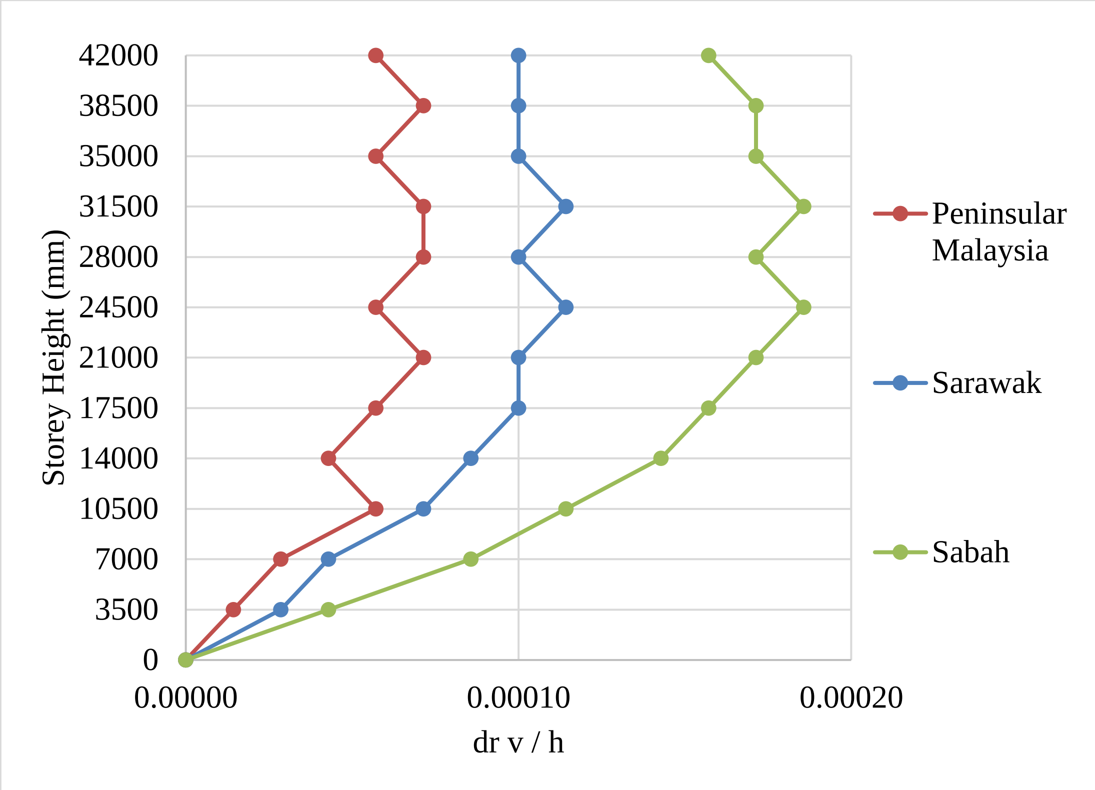

Figure 4.22: Graph of Interstorey Drift of High-rise Building due to Y-direction Seismicity by Scia Engineer

4.5.1 Comparison between Software

The PGA value of 0.16 g in Sabah region has been taken to analyse the difference of the interstorey drift on an identically modelled high-rise building between Midas Gen and Scia Engineer which are shown in Figure 4.23 and Figure 4.24 for x and y direction respectively.

Both Midas Gen and Scia Engineer are having a similar graph trend in which the interstorey drift increases from base storey to storey height of 24500 mm then decreases when it reaches the top level. Midas Gen generated a smoother curve but Scia Engineer generated a slightly fluctuated curve.

The percentage difference of interstorey drift between Midas Gen and Scia Engineer are 4.53 % and 7.25 % in x and y direction respectively as shown in Table 4.3. This differences are mainly due to the non-uniform curve of interstorey drift generated by Scia Engineer.

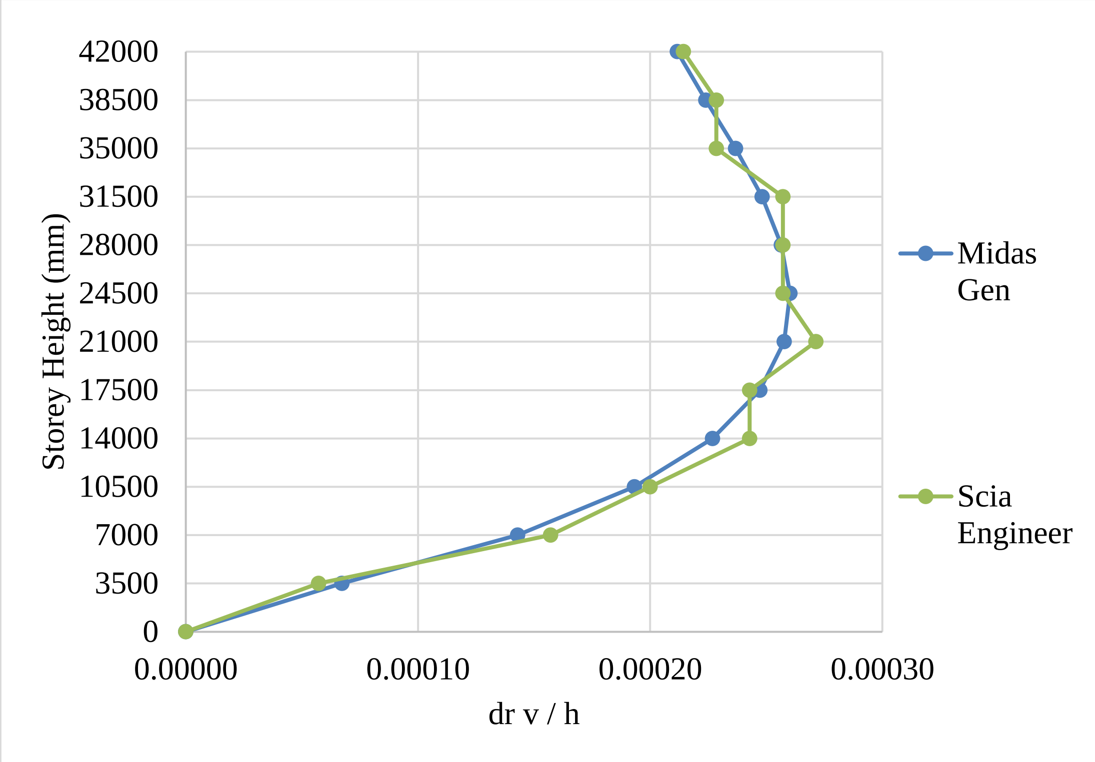

Figure 4.23: Comparison of Interstorey Drift of X-direction Seismicity in Sabah between Midas Gen and Scia Engineer

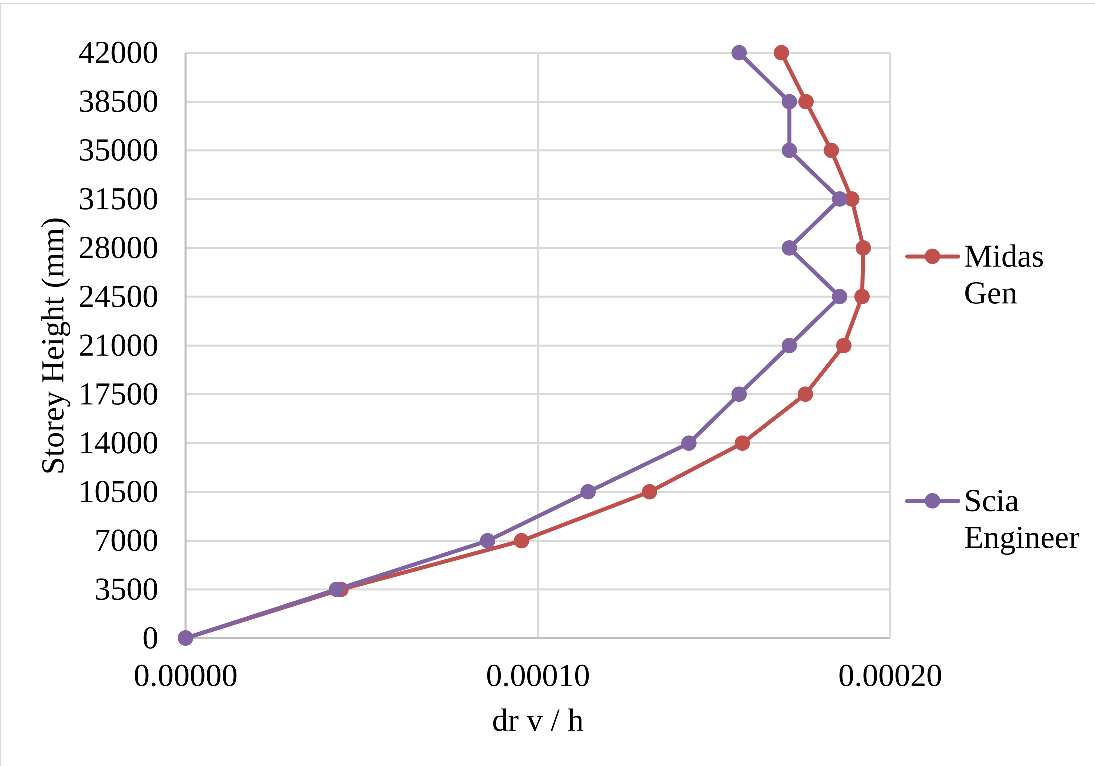

Figure 4.24: Comparison of Interstorey Drift of Y-direction Seismicity in Sabah between Midas Gen and Scia Engineer

Table 4.3: Average Percentage Difference of Interstorey Drift in Sabah Region

Average Percentage Difference between Midas Gen and Scia Engineer	
X-direction	4.5300 %
Y-direction	7.2475 %

4.6 Internal Forces of Members

In this project, the internal forces of specific beam and column are analysed. There are some important internal forces must be analysed before proceeding to the design of reinforced steel for the members such as axial force (N) (particularly for column) bending moment (M) and shear force (F).

The members that are selected for analysis are highlighted and shown in Figure 4.25. In this residential building, there is only one column which has been circled in red colour in the diagram and the selected beam is highlighted in purple colour.

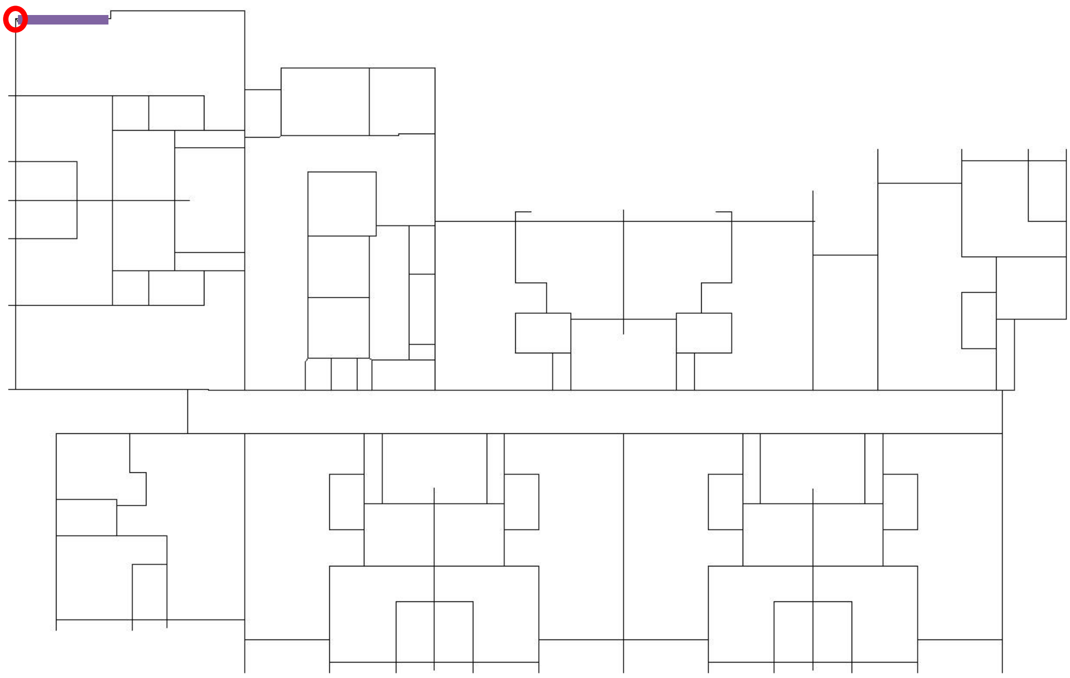

Figure 4.25: Illustration of Selected Beam and Column in the Structural Layout

4.6.1 Beam

As shown in Figure 4.25, the selected beam is consisting only one span with two supports. In both Midas Gen and Scia Engineer, the beam is assigned to have both end fixed. Shear force diagram under Ultimate Limit State (1.35 G_k + 1.5 Q_k) of every storey of the specific beam generated by Midas Gen and Scia Engineer are shown in Figure 4.26 and Figure 4.27 respectively. Bending moment diagram under Ultimate Limit State of every storey of the specific beam generated by Midas Gen and Scia Engineer are shown in Figure 4.28 and Figure 4.29 respectively.

Under Ultimate Limit State, the beam reacts similarly where having a similar trend in both Midas Gen and Scia Engineer with some minor differences. Both Midas Gen and Scia Engineer are considering the effect of support settlement and produced different shear and moment in different level, the effect in both software are similar where shear force decreases as storey height increases, bending moment decreases at dx = 0, nearly constant at maximum and increases at dx = 4250 mm along with increasing of storey height.

By referring to Figure 4.29, it is noticeable that Scia Engineer provided an odd curve for level 8 to level 12, this is due to the collection of data from Scia Engineer software, Scia Engineer did not provide enough information in order to plot a smooth curve however it only provided critical point of the results. Whereas in Midas Gen, it produces a consistently curve as per meshed and modelled previously.

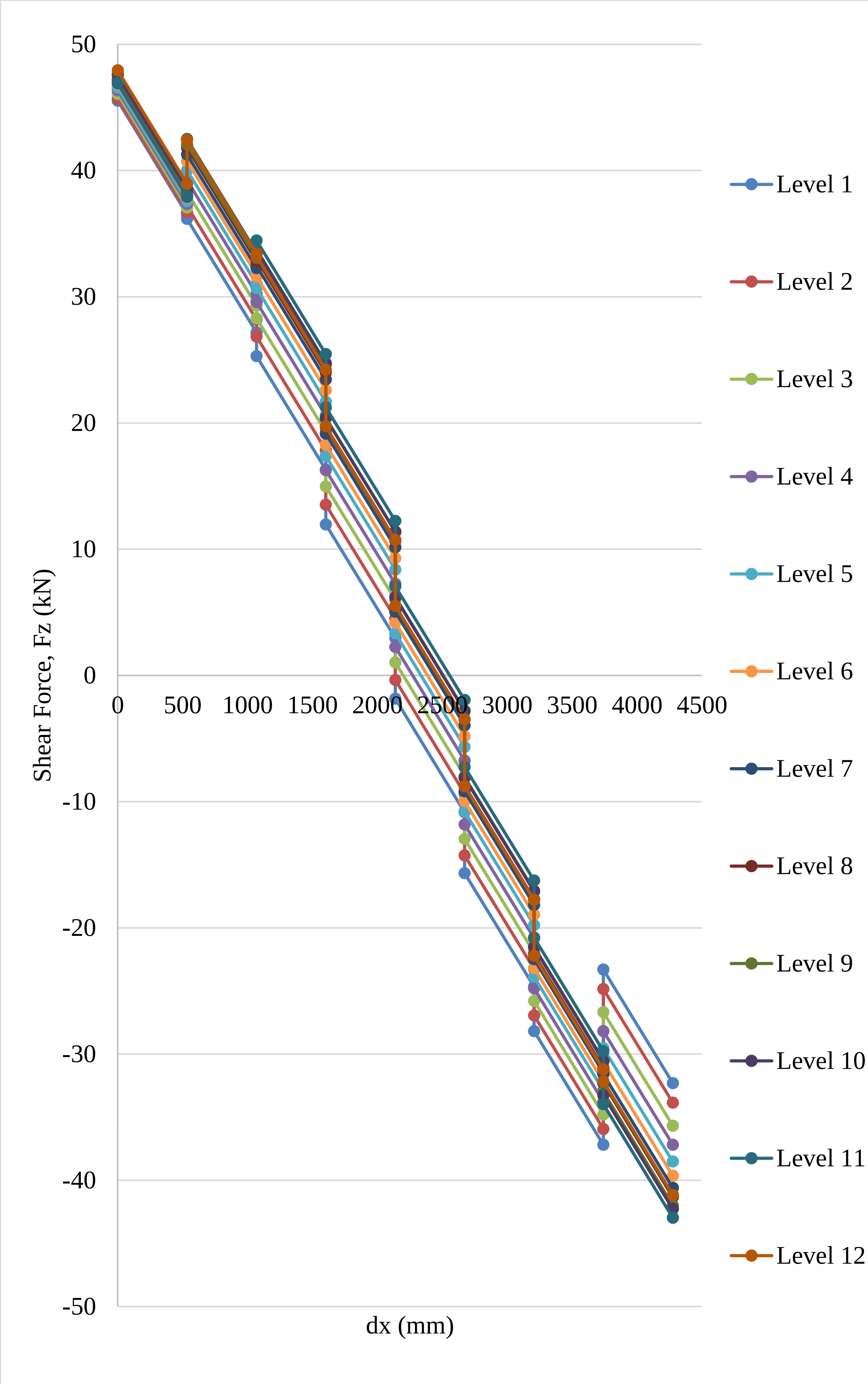

Figure 4.26: Beam Shear Force Diagram under ULS at Different Floor Level by Midas Gen

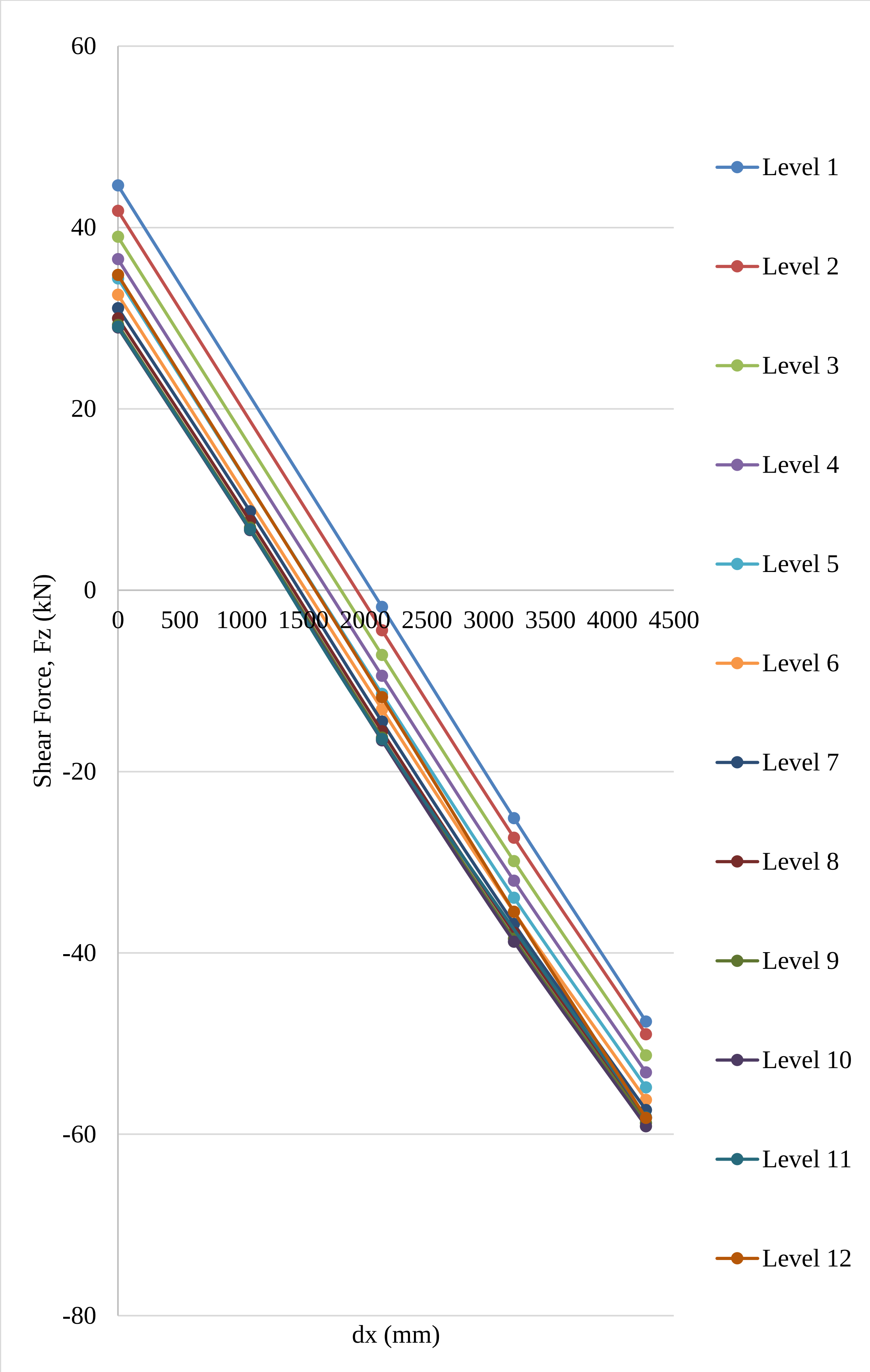

Figure 4.27: Beam Shear Force Diagram under ULS at Different Floor Level by Scia Engineer

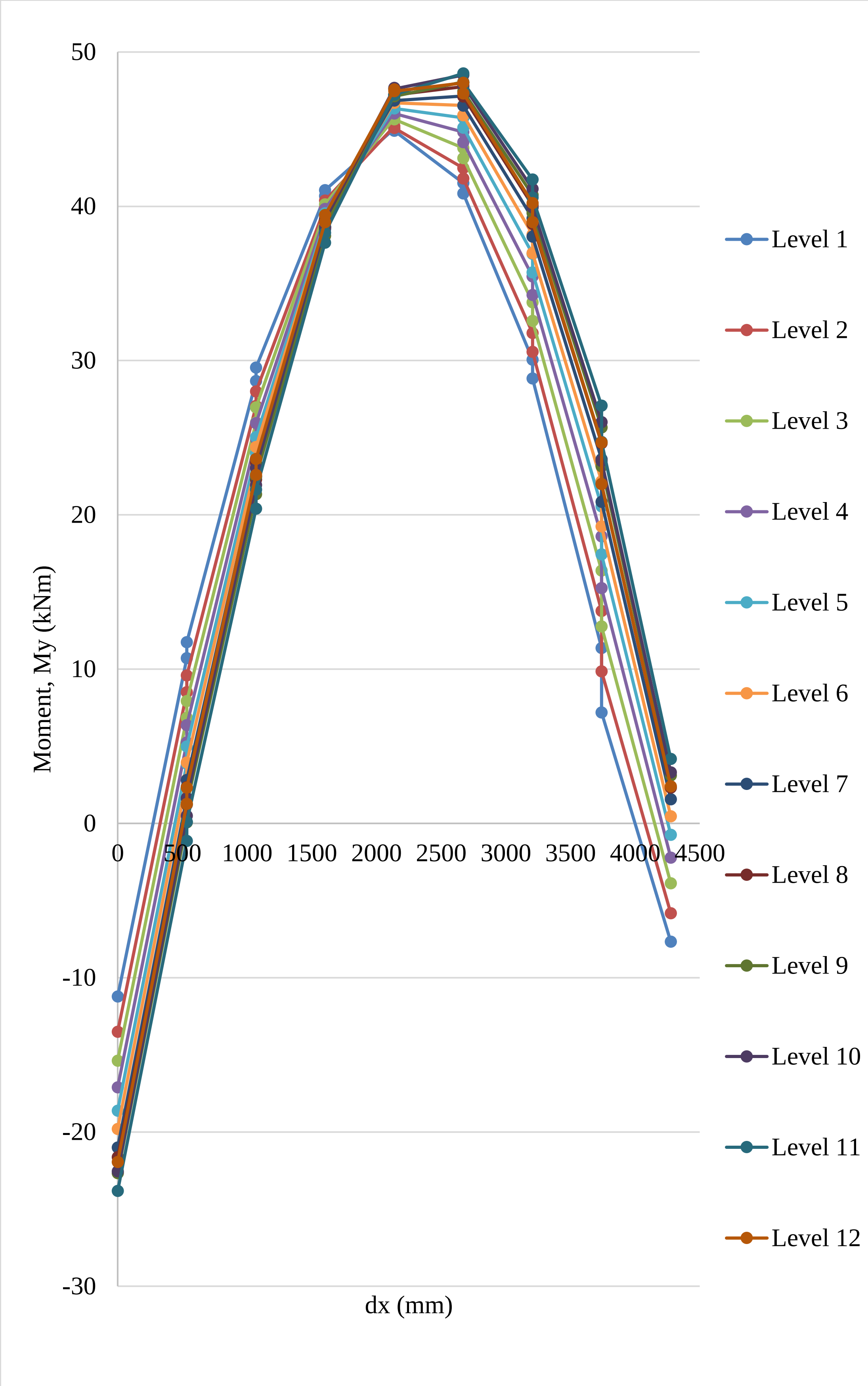

Figure 4.28: Beam Bending Moment Diagram under ULS at Different Floor Level by Midas Gen

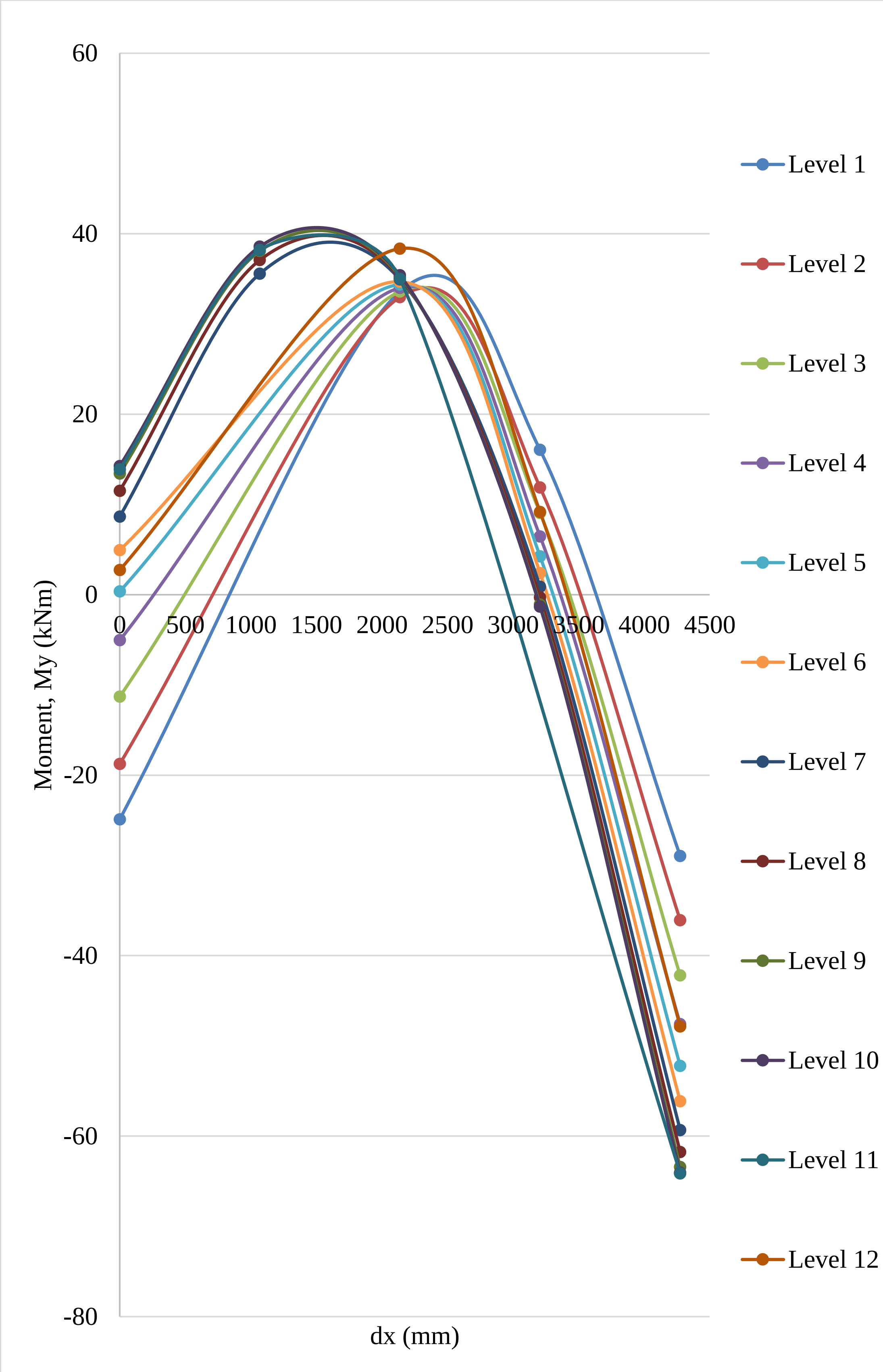

Figure 4.29: Beam Bending Moment Diagram under ULS at Different Floor Level by Scia Engineer

Other than Ultimate Limit State, the shear force and bending moment diagram under seismic resistance both major in x direction (1.0 G_k + 0.3 Q_k + 1.0 E_{dx} + 0.3 E_{dy}) and y direction (1.0 G_k + 0.3 Q_k + 0.3 E_{dx} + 1.0 E_{dy}) are generated by both Midas Gen and Scia Engineer. For simplification and clearer visualisation, only level 3, 6, 9 and 12 will be illustrated.

Shear force diagram of beam due to x direction seismicity in Sabah generated by Midas Gen and Scia Engineer are shown in Figure 4.30 and Figure 4.31 respectively. Midas Gen shows a fluctuated line, Scia Engineer shows a smooth straight line, and the values by both software have significant differences. Shear force diagram of beam due to y direction seismicity for Midas Gen and Scia Engineer are almost similar with that is in x direction and are shown in Appendix.

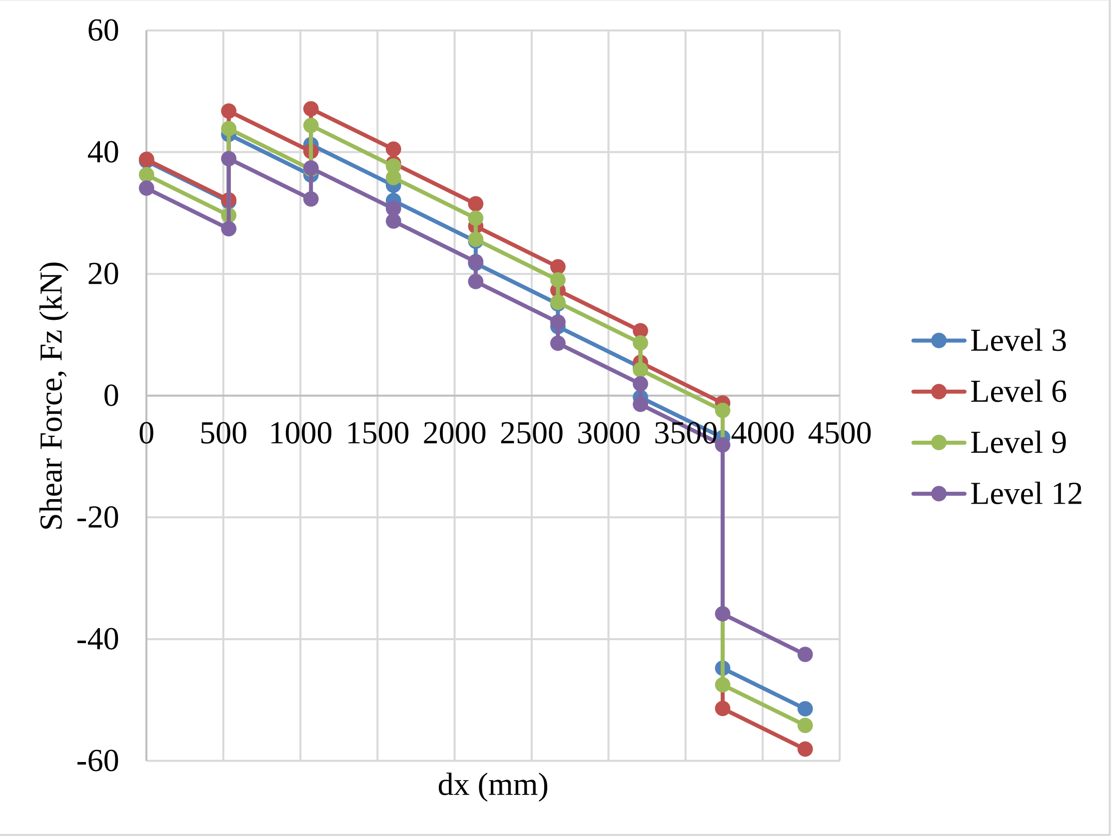

Figure 4.30: Shear Force Diagram of Beam due to X-direction Seismicity at Sabah (PGA = 0.16 g) by Midas Gen

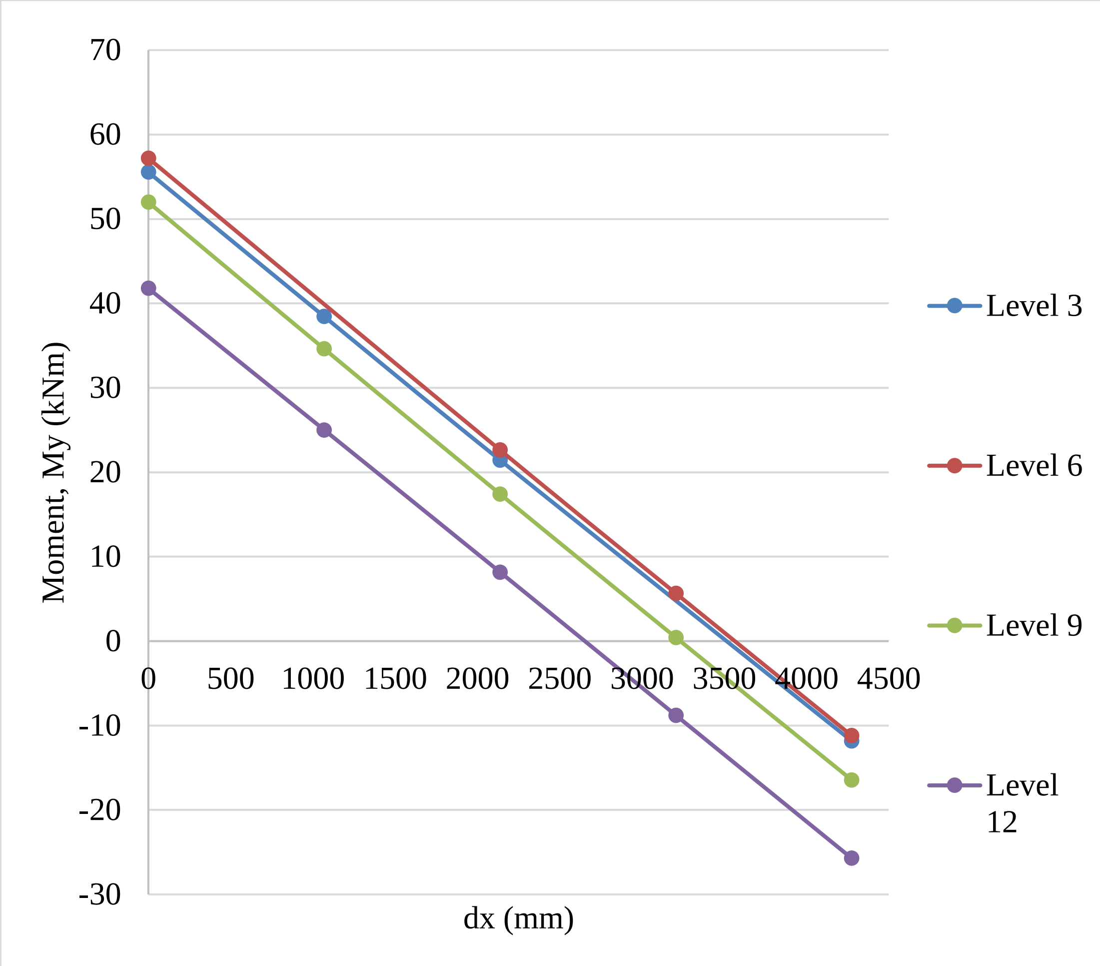

Figure 4.31: Shear Force Diagram of Beam due to X-direction Seismicity at Sabah (PGA = 0.16 g) by Scia Engineer

Bending moment diagram of beam due to x direction seismicity in Sabah generated by Midas Gen and Scia Engineer are shown in Figure 4.32 and Figure 4.33 respectively. Midas Gen shows a hogging curve, Scia Engineer shows a sagging curve, and the values by both software have significant differences. Bending moment diagram of beam due to y direction seismicity for Midas Gen and Scia Engineer are almost similar with that is in x direction and are shown in Appendix.

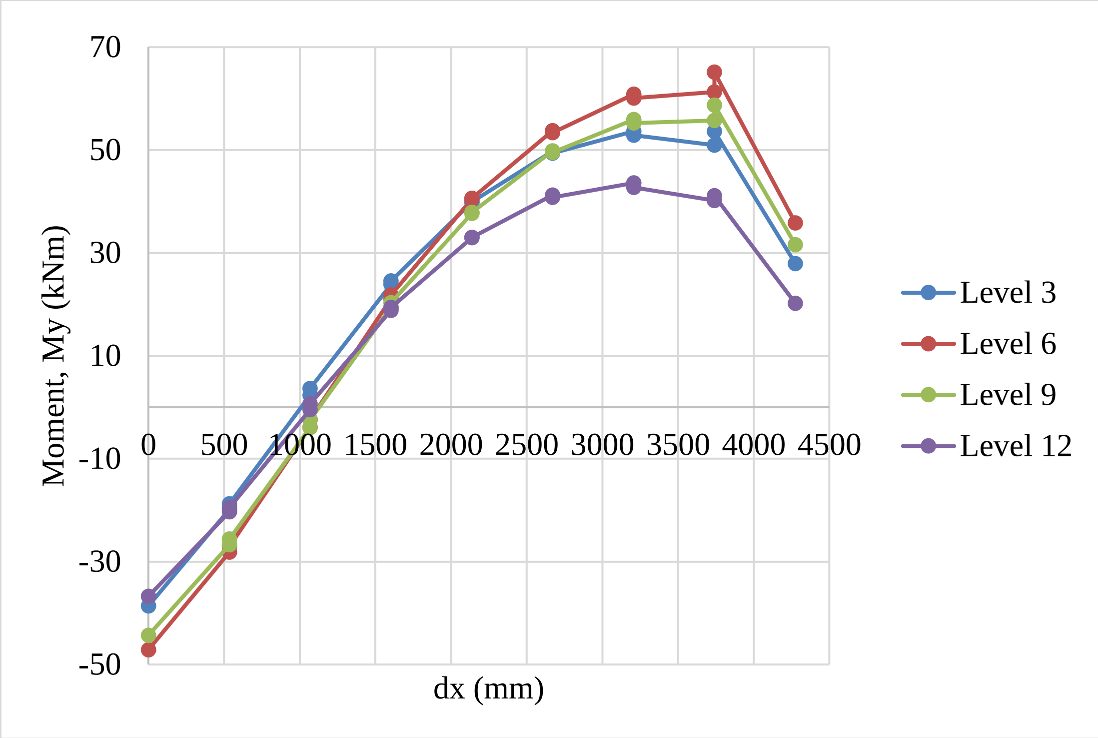

Figure 4.32: Bending Moment Diagram of Beam due to X-direction Seismicity at Sabah (PGA = 0.16 g) by Midas Gen

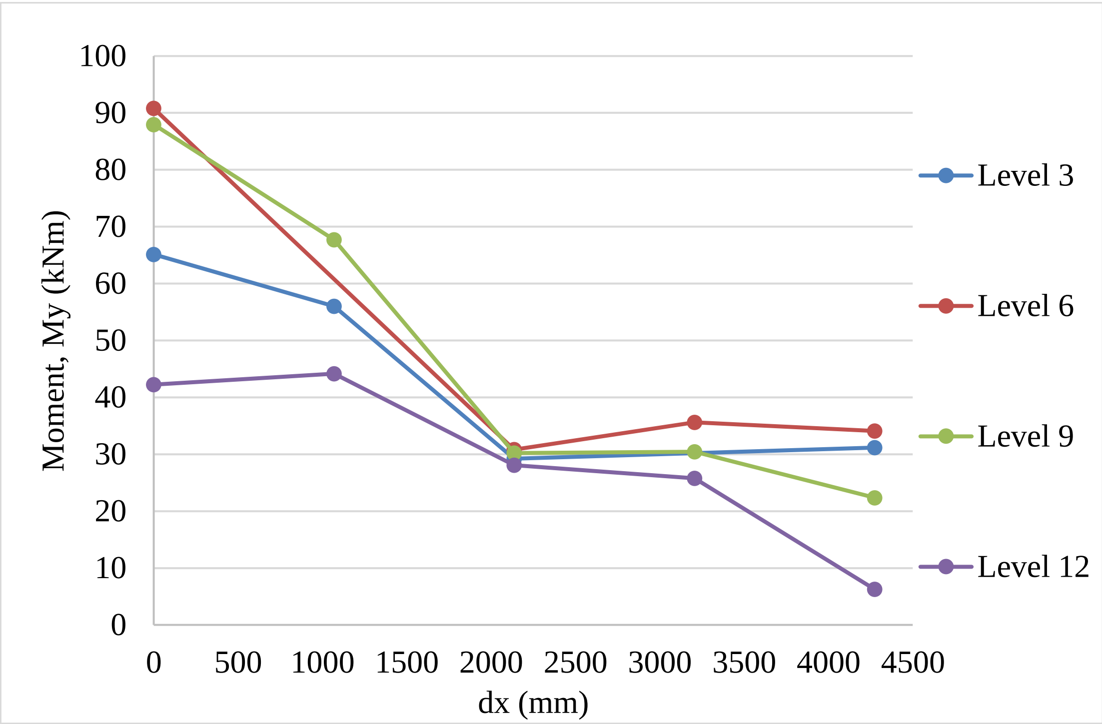

Figure 4.33: Bending Moment Diagram of Beam due to X-direction Seismicity at Sabah (PGA = 0.16 g) by Scia Engineer

The shear force and bending moment diagram of a specific beam in level 7 are selected for comparison between different load cases namely Ultimate Limit State, Peninsular Malaysia (PGA = 0.08 g), Sarawak (PGA = 0.09 g) and Sabah (PGA = 0.16 g). Beam in level 7 is selected because the interstorey drift showing level 7 possesses the highest storey displacement and the bending moment curve of the particular beam also showing the highest maximum point in level 7.

Shear force diagram of level 7 beam due to x direction in different region generated by Midas Gen and Scia Engineer are shown in Figure 4.34 and Figure 4.35 respectively. The curves are having a significant differences where Midas Gen shows a staircase like curve and Scia Engineer shows a straight line curve. Shear force diagrams due to y direction seismicity by Midas Gen and Scia Engineer are almost identical with that of x direction and are shown in Appendix.

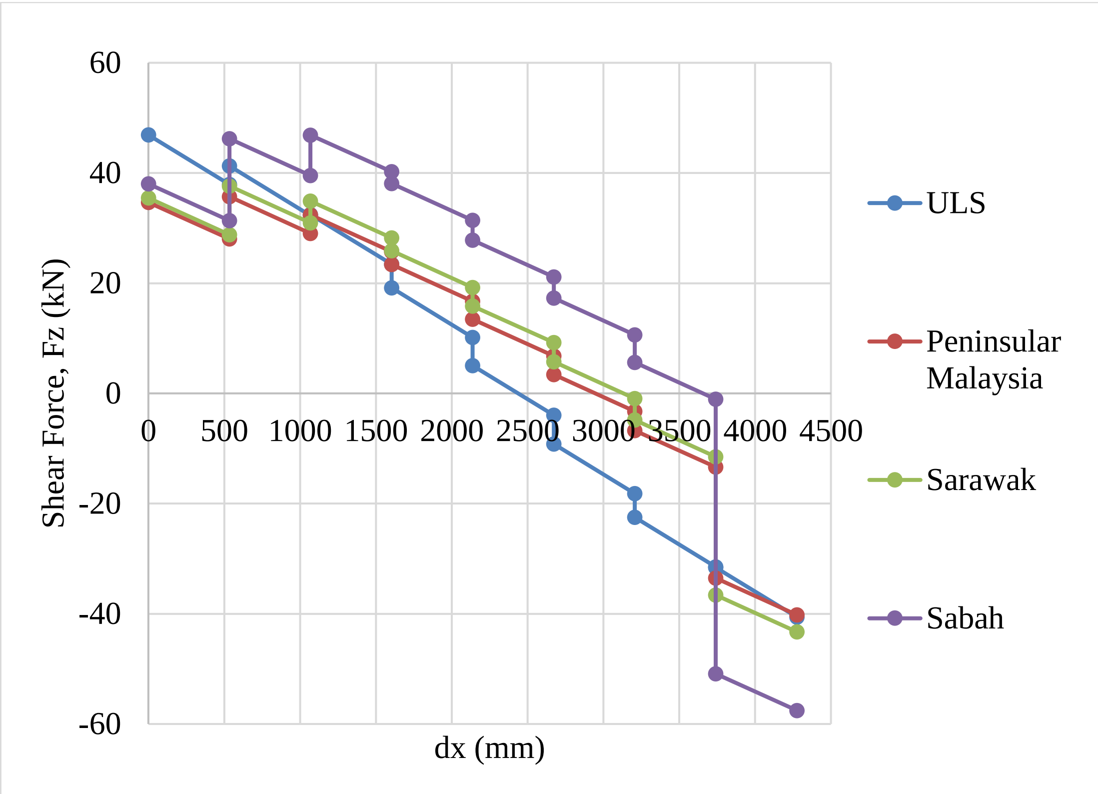

Figure 4.34: Shear Force Diagram of Level 7 Beam due to X-direction Seismicity in Different Region by Midas Gen

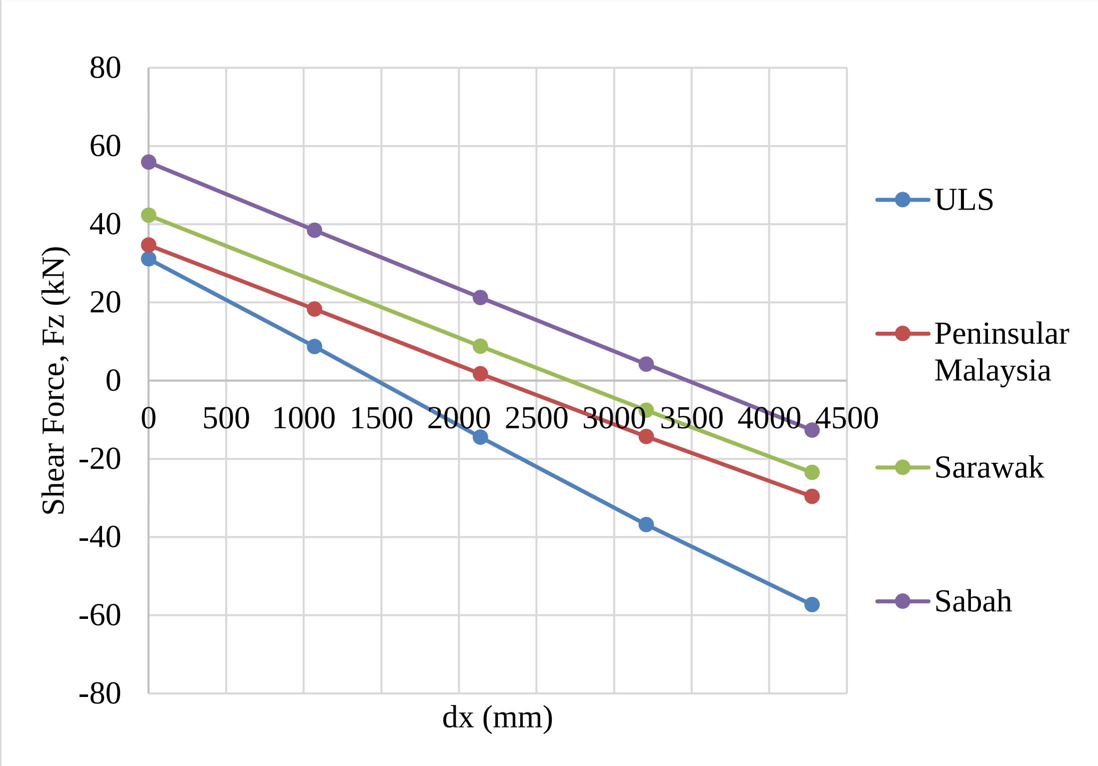

Figure 4.35: Shear Force Diagram of Level 7 Beam due to X-direction Seismicity in Different Region by Scia Engineer

Bending moment diagram of level 7 beam due to x direction in different region generated by Midas Gen and Scia Engineer are shown in Figure 4.36 and Figure 4.37 respectively. Midas Gen shows that the maximum moment for the particular beam under ULS is lied between dx = 2000 mm to dx = 2500 mm, when it comes to seismic action namely Peninsular Malaysia (PGA = 0.08 g), Sarawak (PGA = 0.09 g) and Sabah (PGA = 0.16 g), the maximum moment position has been shifted slightly to the right side. In Midas Gen, Sabah is having the highest maximum moment, followed by ULS, Sarawak and Peninsular Malaysia. Whereas in Scia Engineer, ULS and the seismic action load cases are having different curve such that ULS has a hogging curve, Peninsular Malaysia has a less obvious hogging curve, Sarawak has a straight line and Sabah has a sagging curve. Bending moment diagrams due to y direction seismicity by Midas Gen and Scia Engineer are almost identical with that of x direction and are shown in Appendix.

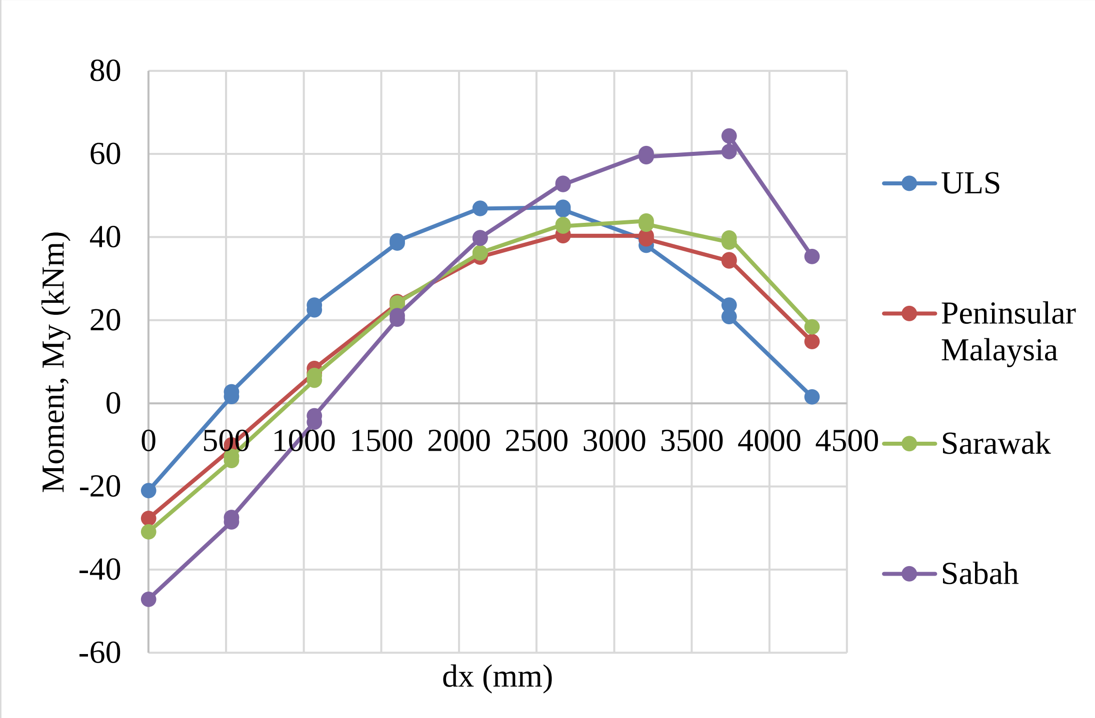

Figure 4.36: Bending Moment Diagram of Level 7 Beam due to X-direction Seismicity in Different Region by Midas Gen

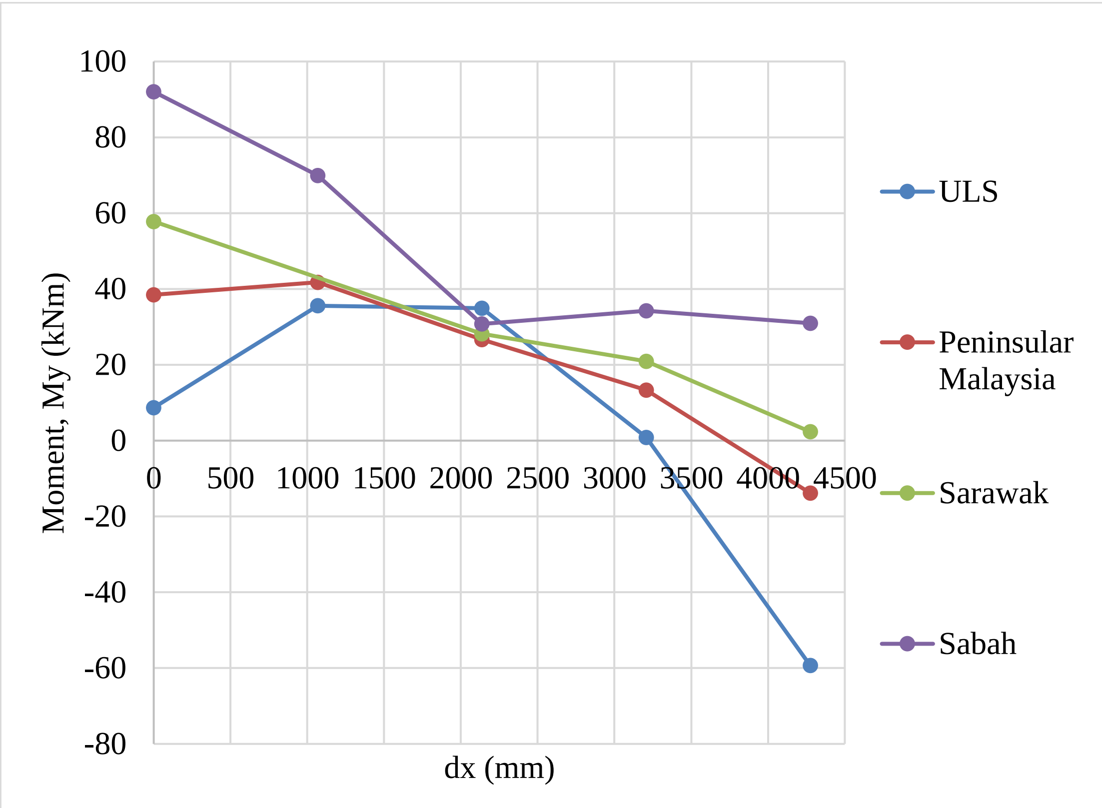

Figure 4.37: Bending Moment Diagram of Level 7 Beam due to X-direction Seismicity in Different Region by Scia Engineer

4.6.2 Column

The selected column is shown in Figure 4.25 which has circled red in colour. The parameters that are used to be analysed are axial force, shear force and bending moment. X and Y direction are analysed in three regions in Malaysia and Ultimate Limit State is studied as well by Midas Gen and Scia Engineer.

Axial force of column due to x direction seismicity by Midas Gen and Scia Engineer are shown in Figure 4.38 and Figure 4.39 respectively. Both software show a similar trend such that the axial force of column is highest in ultimate limit state followed by Peninsular Malaysia, Sarawak and Sabah. However, there are some minor differences in the value which the average percentage difference of the axial force between Midas Gen and Scia Engineer in different load cases will be tabulated in Table 4.4. Midas Gen and Scia Engineer generated an almost identical axial force in column under ultimate limit state, however Midas Gen generated a higher axial force in column than Scia Engineer in other seismic action load cases. The axial force of column in y direction by Midas Gen and Scia Engineer under different load cases are almost identical with that of in x direction and are shown in Appendix.

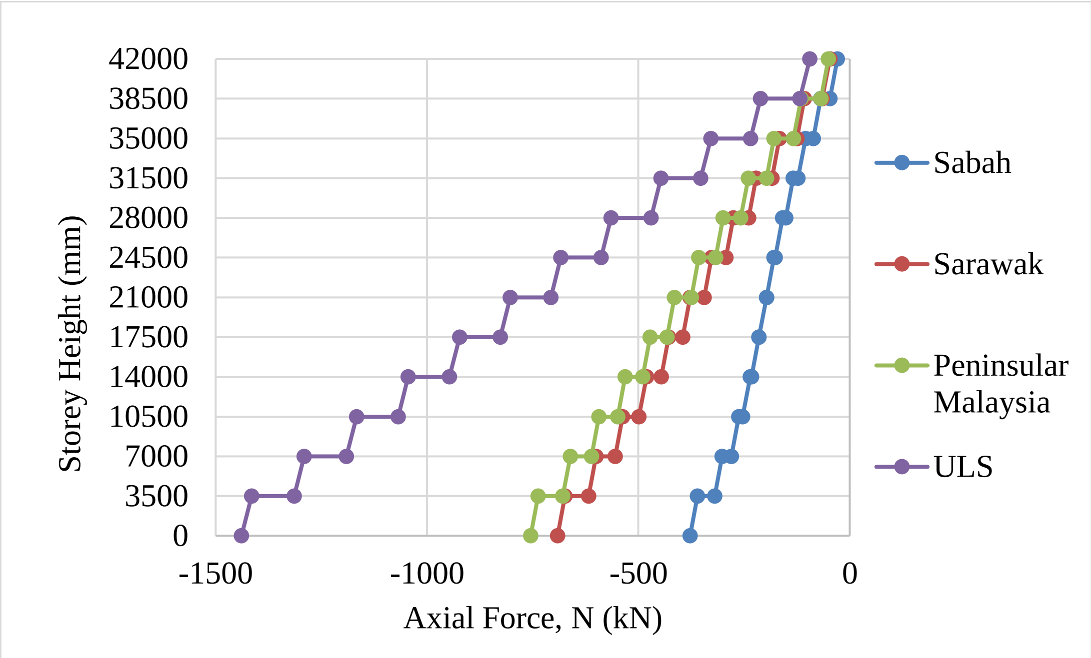

Figure 4.38: Column Axial Force due to X-direction Seismicity in Different Region by Midas Gen

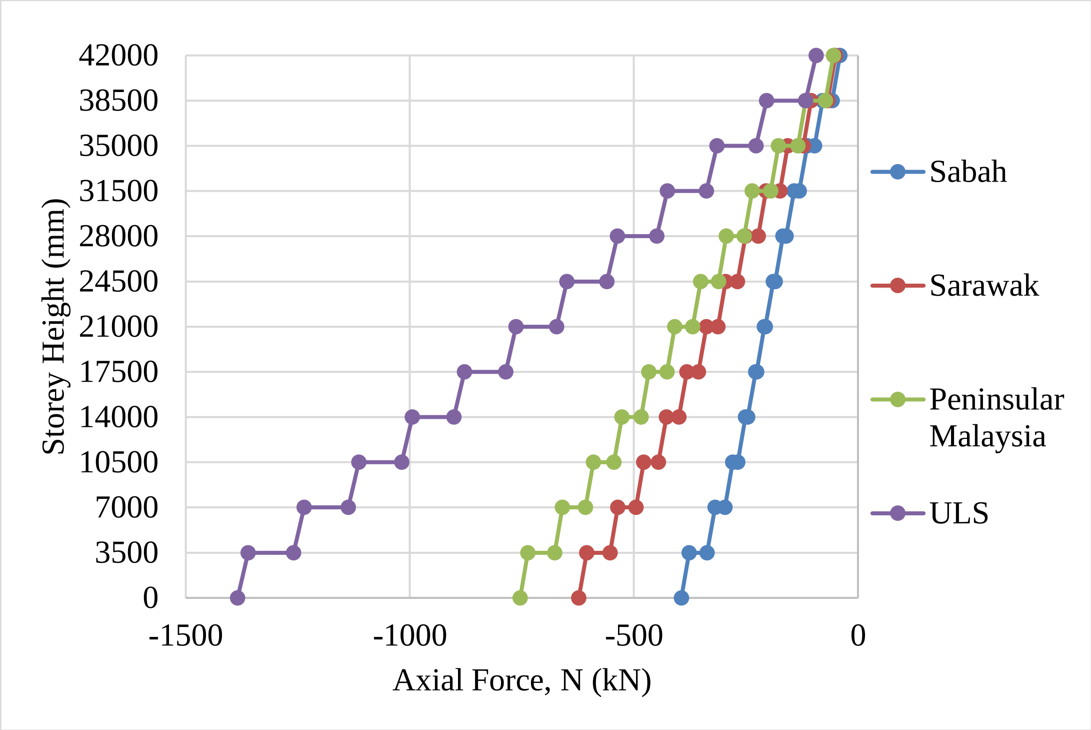

Figure 4.39: Column Axial Force due to X-direction Seismicity in Different Region by Scia Engineer

Table 4.4: Average Percentage Difference of Axial Force in Column in Different Region in Malaysia between Midas Gen and Scia Engineer

Average Percentage Difference between Midas Gen and Scia Engineer	
ULS	4.4172 %
Peninsular Malaysia	0.6970 %
Sarawak	9.4924 %
Sabah	6.3100 %

The shear force diagram of column in x direction by Midas Gen and Scia Engineer under different load cases are shown in Figure 4.40 and Figure 4.41 respectively. The shear force diagram of column by both software are having a similar trend with different value in each storey, the average percentage difference is shown in Table 4.5. The shear force diagram of column in y direction by Midas Gen and Scia Engineer under different load cases are almost identical with that of in x direction and are shown in Appendix.

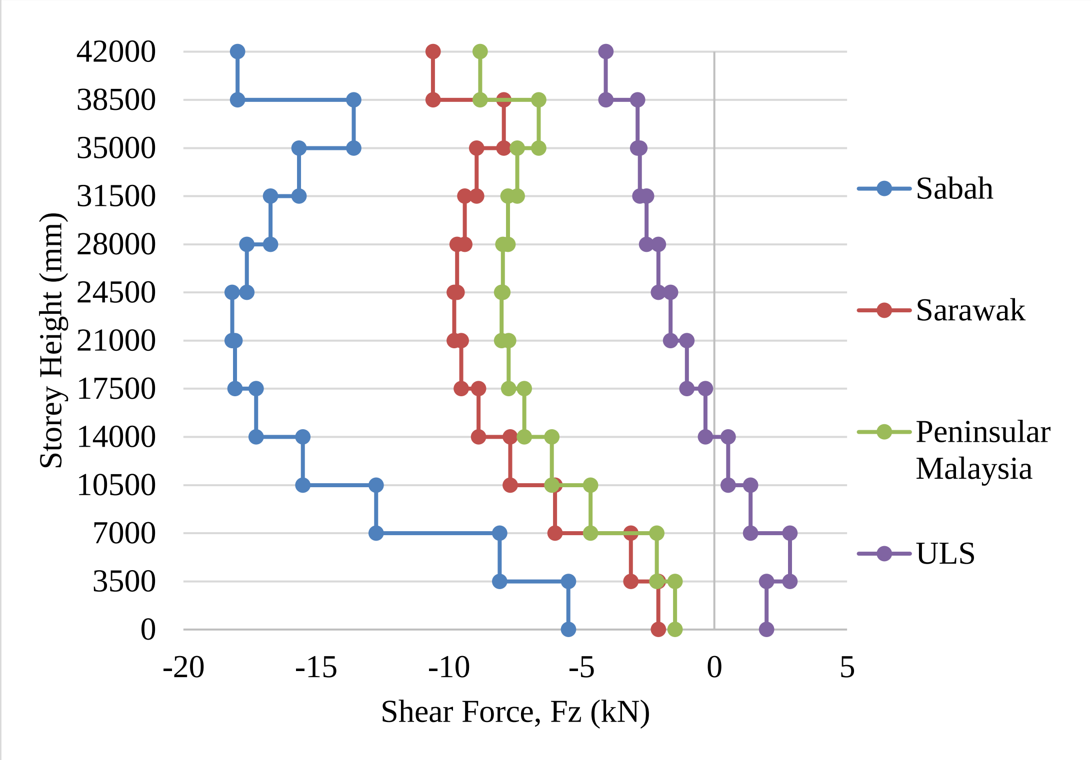

Figure 4.40: Column Shear Force due to X-direction Seismicity in Different Region by Midas Gen

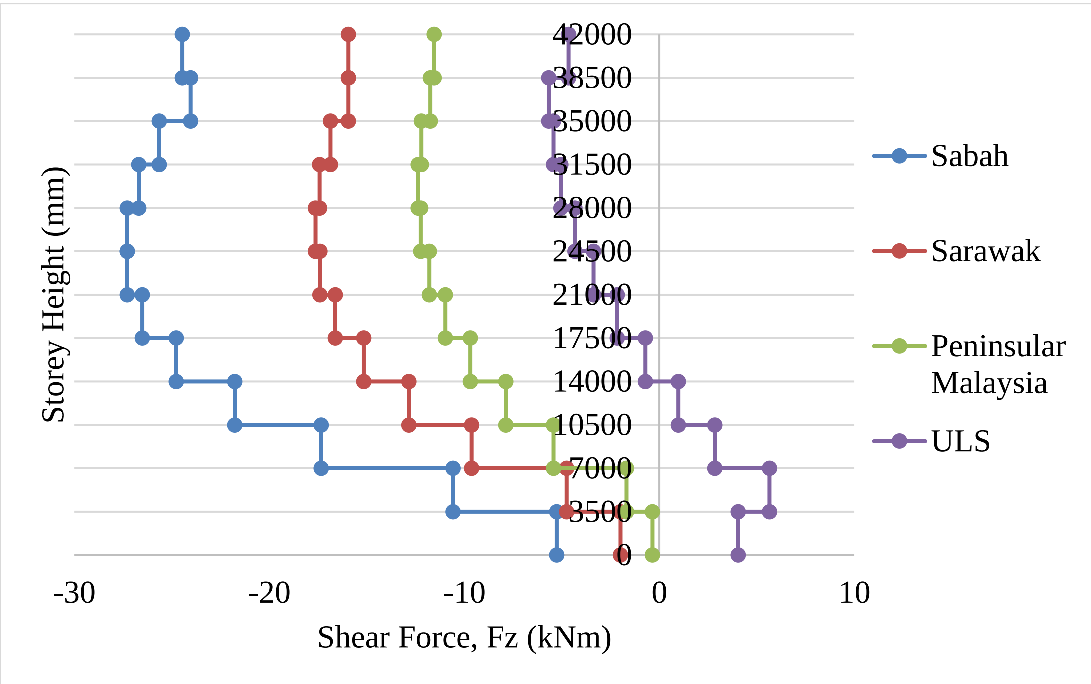

Figure 4.41: Column Shear Force due to X-direction Seismicity in Different Region by Scia Engineer

Table 4.5: Average Percentage Difference of Shear Force in Column in Different Region in Malaysia between Midas Gen and Scia Engineer

Average Percentage Difference between Midas Gen and Scia Engineer	
ULS	65.7990 %
Peninsular Malaysia	42.0540 %
Sarawak	73.0500 %
Sabah	47.9610 %

The bending moment diagram of column in x direction by Midas Gen and Scia Engineer under different load cases are shown in Figure 4.42 and Figure 4.43 respectively. The percentage difference is not calculated as the trends provided by both software are not relevance. The bending moment diagram of column in y direction by Midas Gen and Scia Engineer under different load cases are almost identical with that of in x direction and are shown in Appendix.

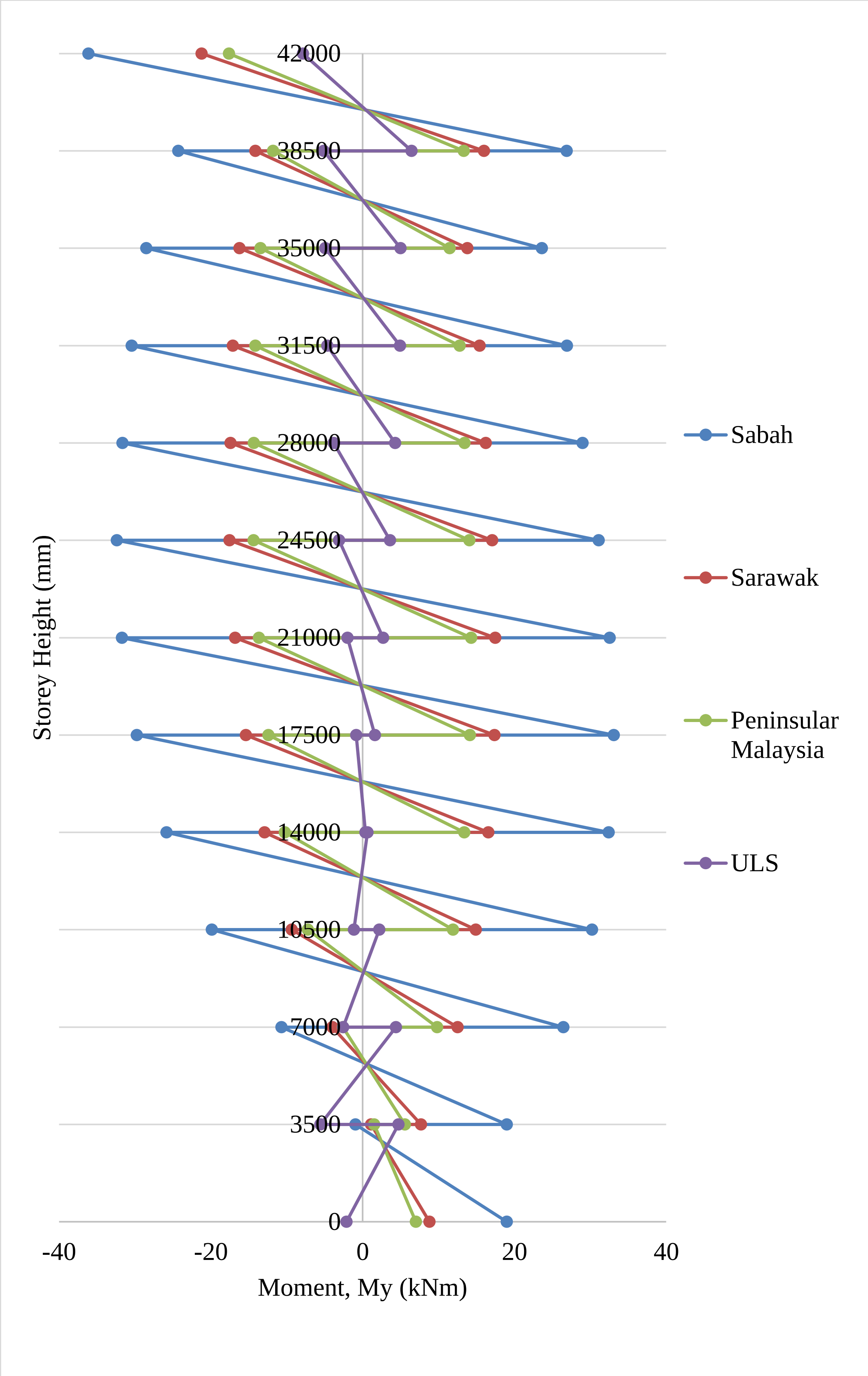

Figure 4.42: Column Bending Moment due to X-direction Seismicity in Different Region by Midas Gen

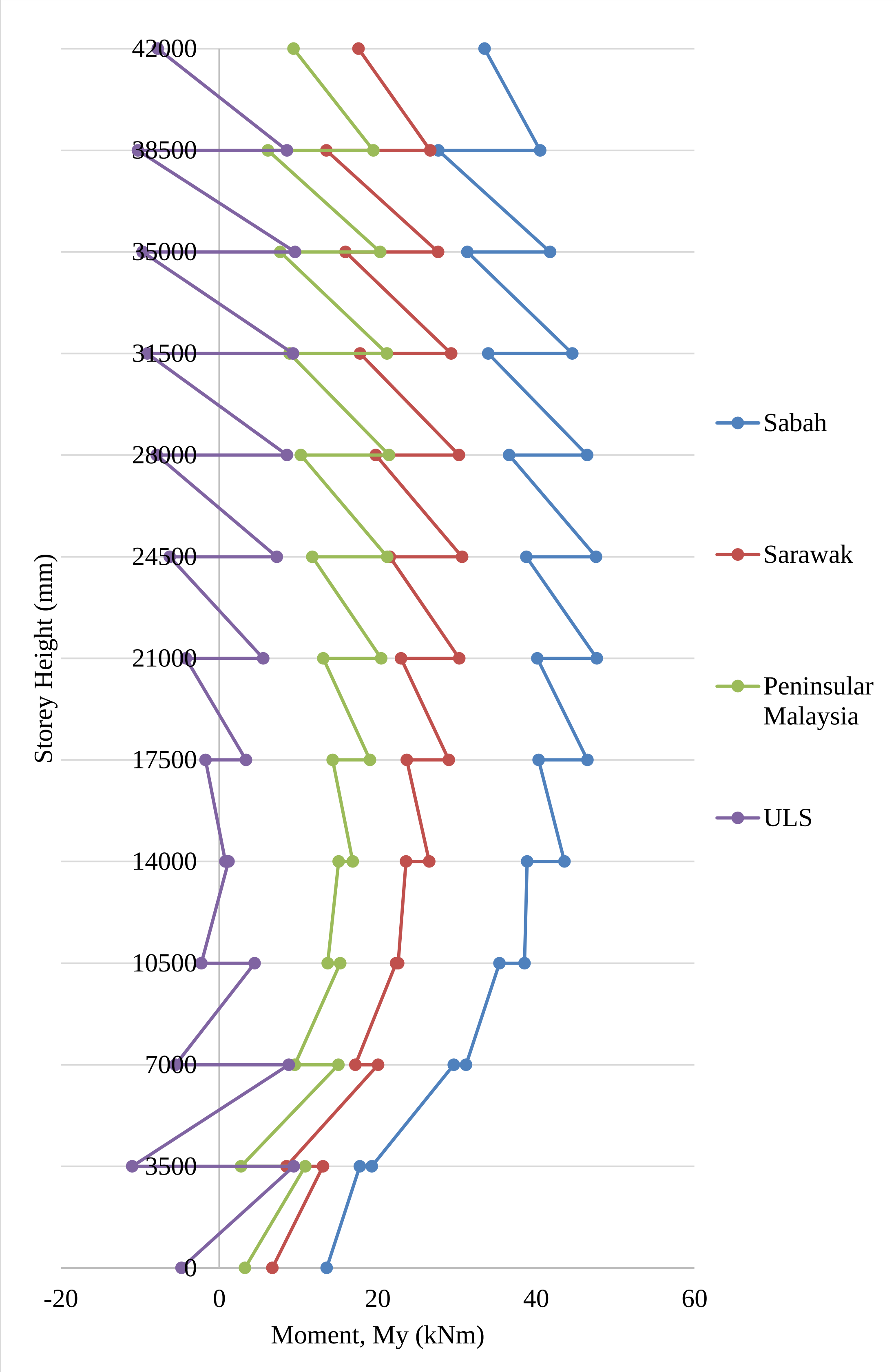

Figure 4.43: Column Bending Moment due to X-direction Seismicity in Different Region by Scia Engineer

4.6.2.1 Column Behaviour

In this study, the high-rise building consists only one column and it is located at a corner. In this case, the column may not react normally as the common portal frame effect. However, the column reacts with large affection by the shear walls of the high-rise building, an assumption can be made that the column with relatively low stiffness is highly dependent to the shear walls with relatively high stiffness as shown in Figure 4.44. An illustration of 2-D models have been made to show the behaviour of column with section properties and important information show in Table 4.6 and Table 4.7.

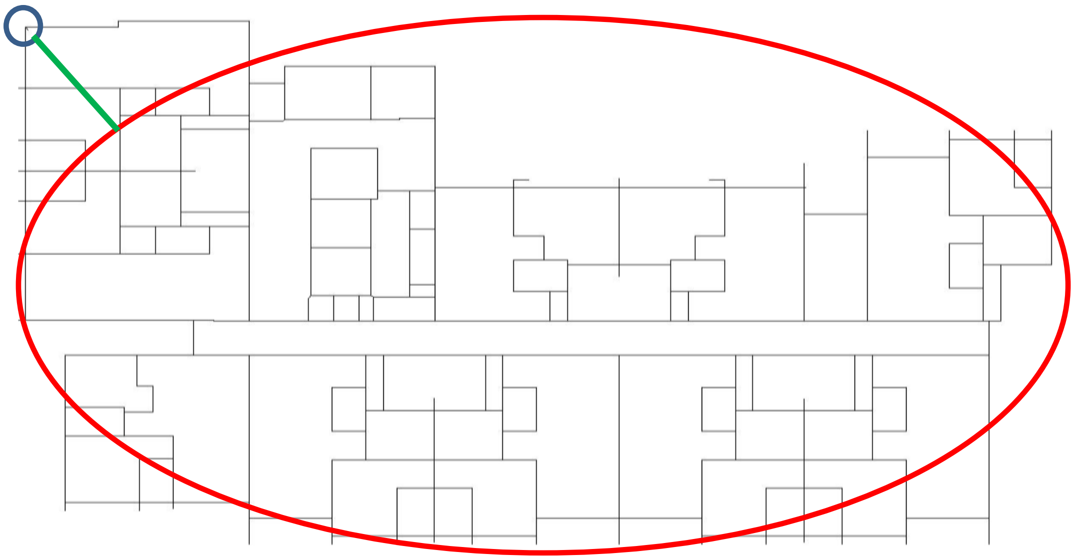

Figure 4.44: Illustration of High Stiffness Shear Walls Structure and Low Stiffness Column with Single Restraining Beam

Table 4.6: Important Information and Section Properties of the 2-D Frame for Column Behaviour Illustration (Larger Left Column)

No. of Floor	5
Floor Height	3500 mm
Left Column Size (high stiffness)	2000 x 2000 mm^2
Right Column Size (low stiffness)	400 x 400 mm^2
Beam Size	200 x 750 mm^2
Loads on Beam	2 kN/m
Horizontal Loads	5 kN on fifth floor
	4 kN on fourth floor
	3 kN on third floor
	2 kN on second floor
	1 kN on first floor

Table 4.7: Important Information and Section Properties of the 2-D Frame for Column Behaviour Illustration (Same Column on Both Sides)

No. of Floor	5
Floor Height	3500 mm
Column Size (high stiffness)	400 x 400 mm^2
Beam Size	200 x 750 mm^2
Loads on Beam	2 kN/m
Horizontal Loads	5 kN on fifth floor
	4 kN on fourth floor
	3 kN on third floor
	2 kN on second floor
	1 kN on first floor

With the above information and section properties for two cases, the simple 2-D frame models are modelled in both Midas Gen and Scia Engineer. Adequate comparison are made and it can be noticed that Midas Gen and Scia Engineer analysed a similar results with minor differences, therefore, the results generated by Scia Engineer will be shown in the Appendix. There are 3 load combinations being studied namely Selfweight + Vertical Loads + Horizontal Loads (SW+V+H), Selfweight + Vertical Loads (SW+V) and lastly Horizontal Loads alone (H).

The bending moment diagram of left and right column under load case of SW+V+H are displayed in Figure 4.45 and Figure 4.46 respectively. It is noticeable that when both column size are the same, the moments being taken on both columns are relatively close to each other as the horizontal loads and vertical loads are transferred evenly to two columns, however, when the left column is so much stiffer than that of the right column, the stiffer column will take up most of the moment and it reacts as a cantilever condition whereas the lower stiffness column becomes less dominant and it may react with dependent to the stiffer column.

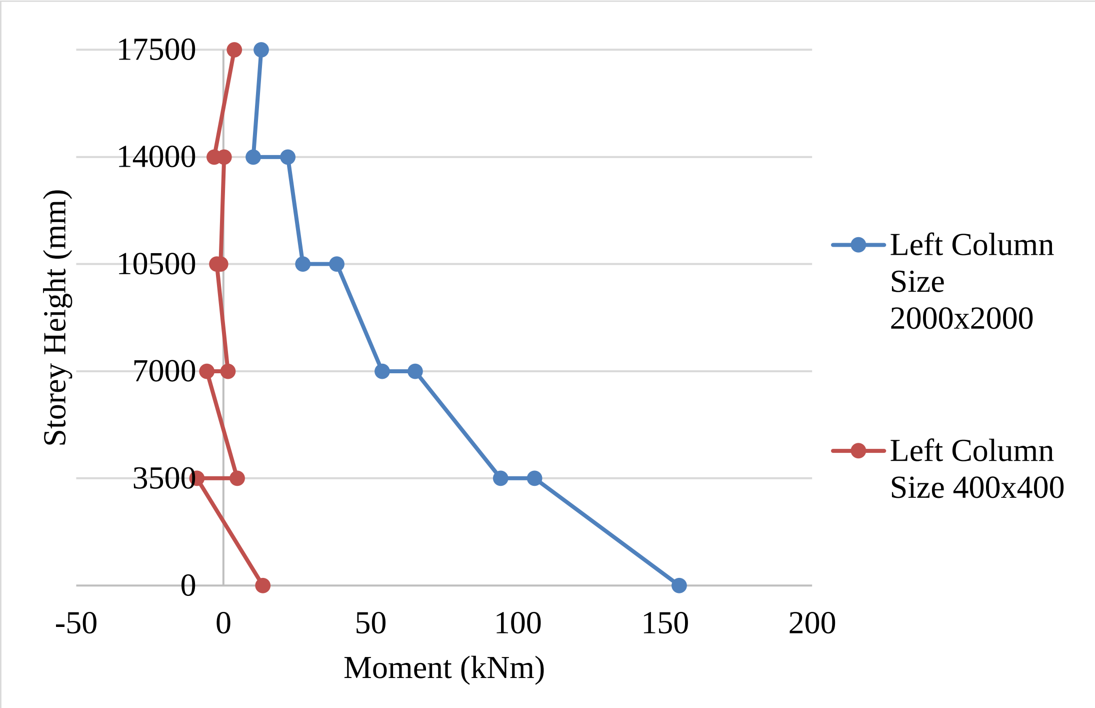

Figure 4.45: Bending Moment Diagram of Left Column for Simple 2-D Frame Illustration under Load Case SW+V+H by Midas Gen

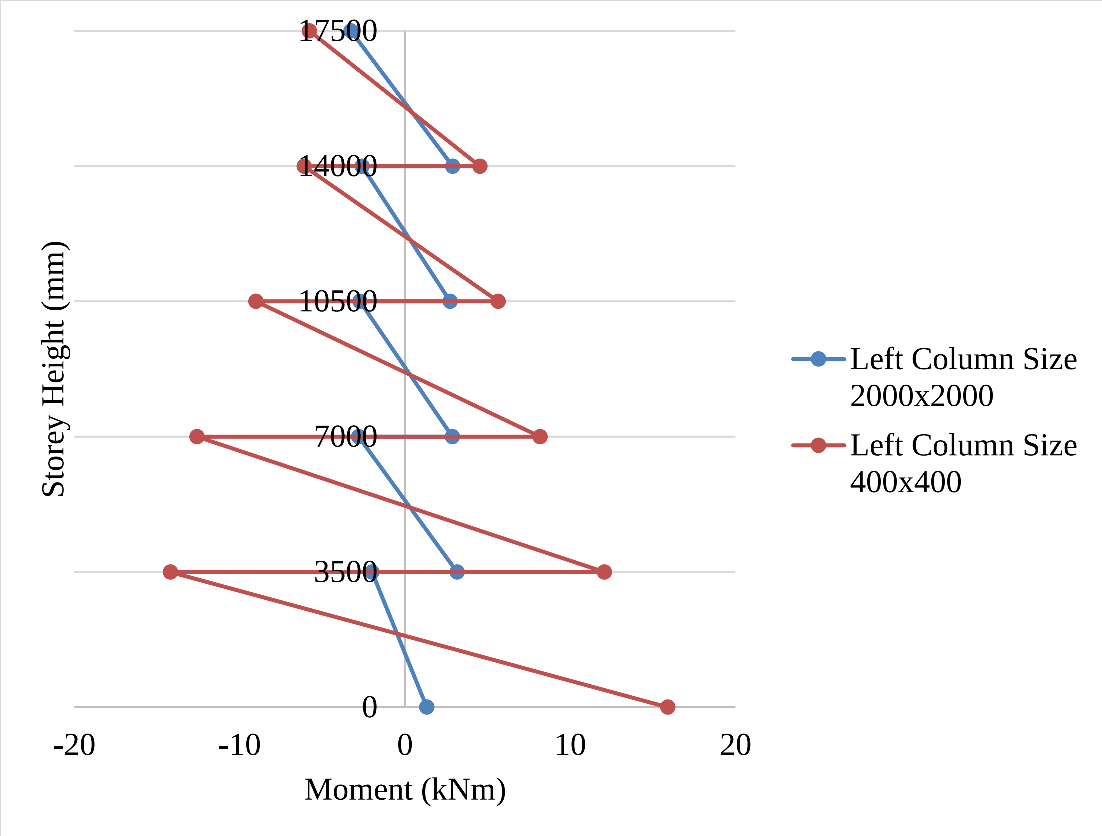

Figure 4.46: Bending Moment Diagram of Right Column for Simple 2-D Frame Illustration under Load Case SW+V+H by Midas Gen

The superimposed loads in load case SW+V+H are being separated according to horizontal and vertical components. The bending moment of load case SW+V for left and right column by Midas Gen are shown in Figure 4.47 and Figure 4.48 respectively. This load case consists of only vertical loads components and it shows the trend that is similar to the previous discussed load case.

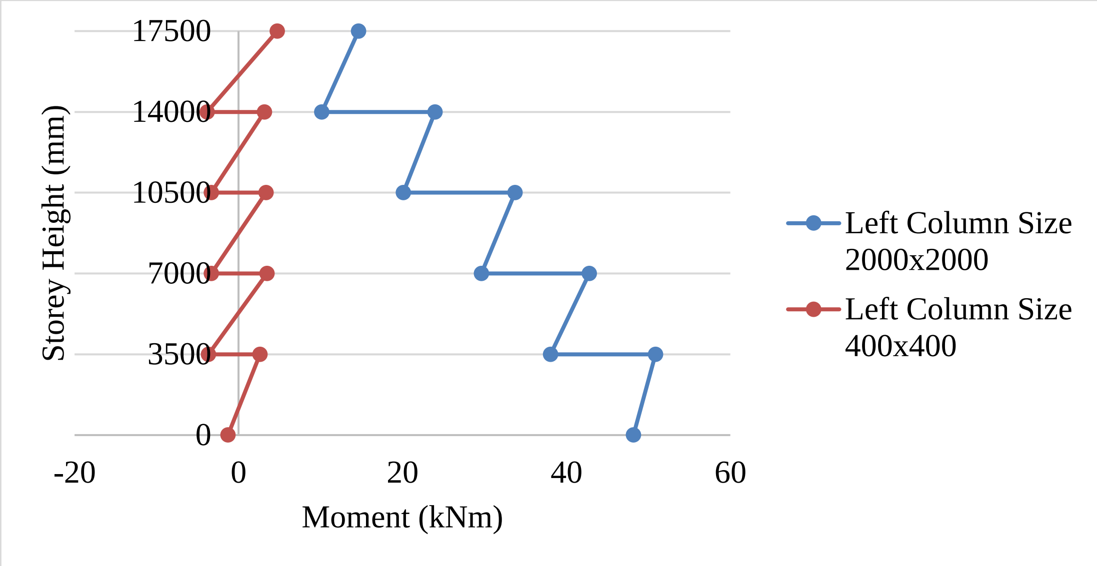

Figure 4.47: Bending Moment Diagram of Left Column for Simple 2-D Frame Illustration under Load Case SW+V by Midas Gen

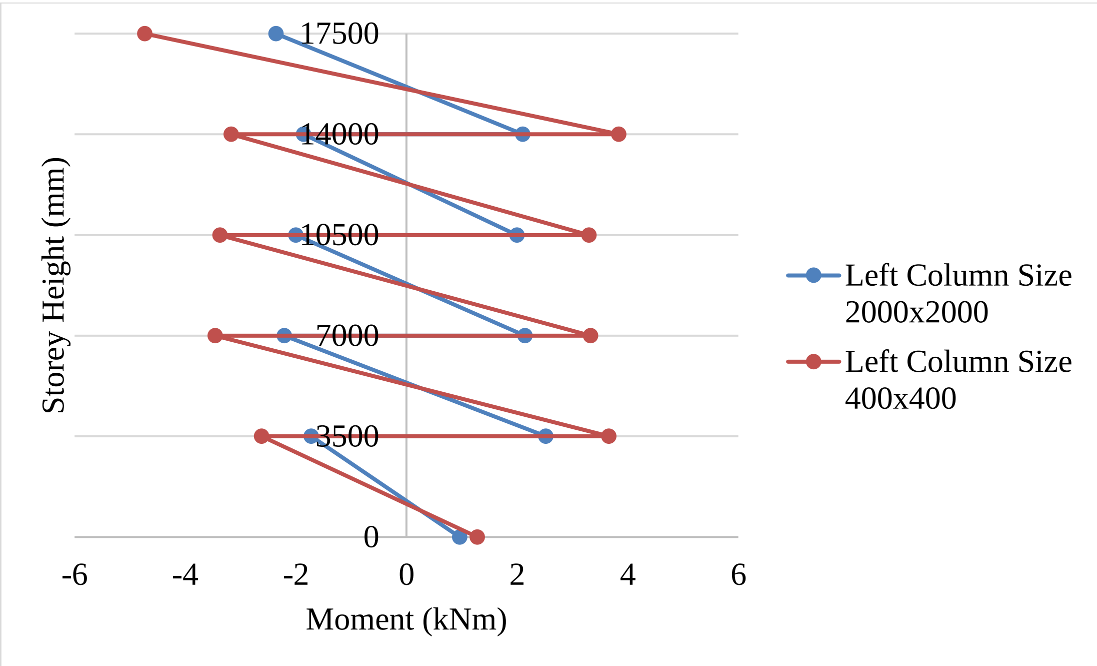

Figure 4.48: Bending Moment Diagram of Right Column for Simple 2-D Frame Illustration under Load Case SW+V by Midas Gen

The bending moment diagram of load case H for left and right column are shown in Figure 4.49 and Figure 4.50 respectively. This load case consists of only horizontal loads component, the loads tend to transfer to the stiffer column as described previously.

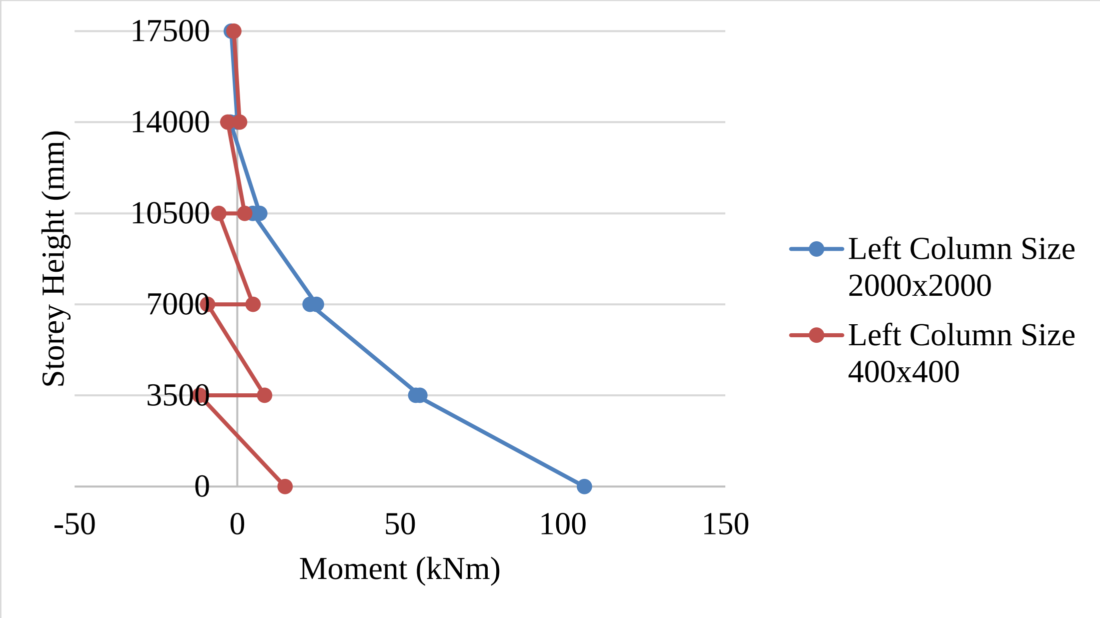

Figure 4.49: Bending Moment Diagram of Left Column for Simple 2-D Frame Illustration under Load Case H by Midas Gen

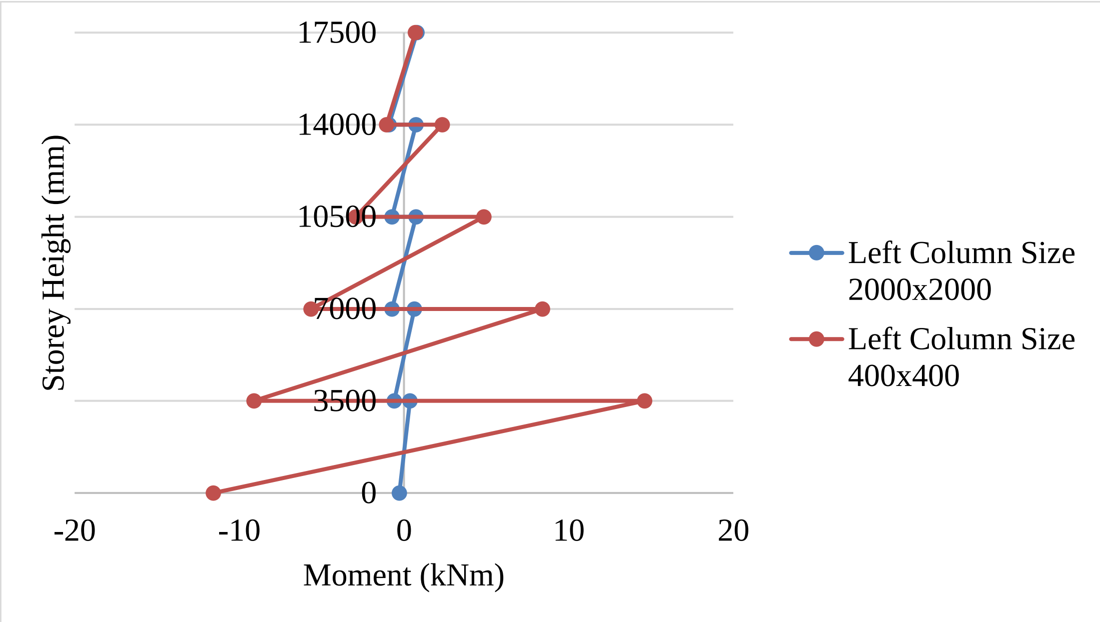

Figure 4.50: Bending Moment Diagram of Right Column for Simple 2-D Frame Illustration under Load Case H by Midas Gen

4.6.2.2 Load Case Comparison

The internal forces of the column analysed in section 4.6.2 such as shear force and bending moment are having significant differences, therefore, the superimposed loads are being separated to analyse individually. The shear force and bending moment diagram under different load cases namely Selfweight + Dead Load (SW+DL), Live Load (LL) and Seismic Action in X-direction of specifically Sabah Region (Ex) are generated by Midas Gen and Scia Engineer.

The shear force diagram of column under load case SW+DL by Midas Gen and Scia Engineer is shown in Figure 4.51. The two curve generated by Midas Gen and Scia Engineer are showing a similar trend with minor different in maximum and minimum value.

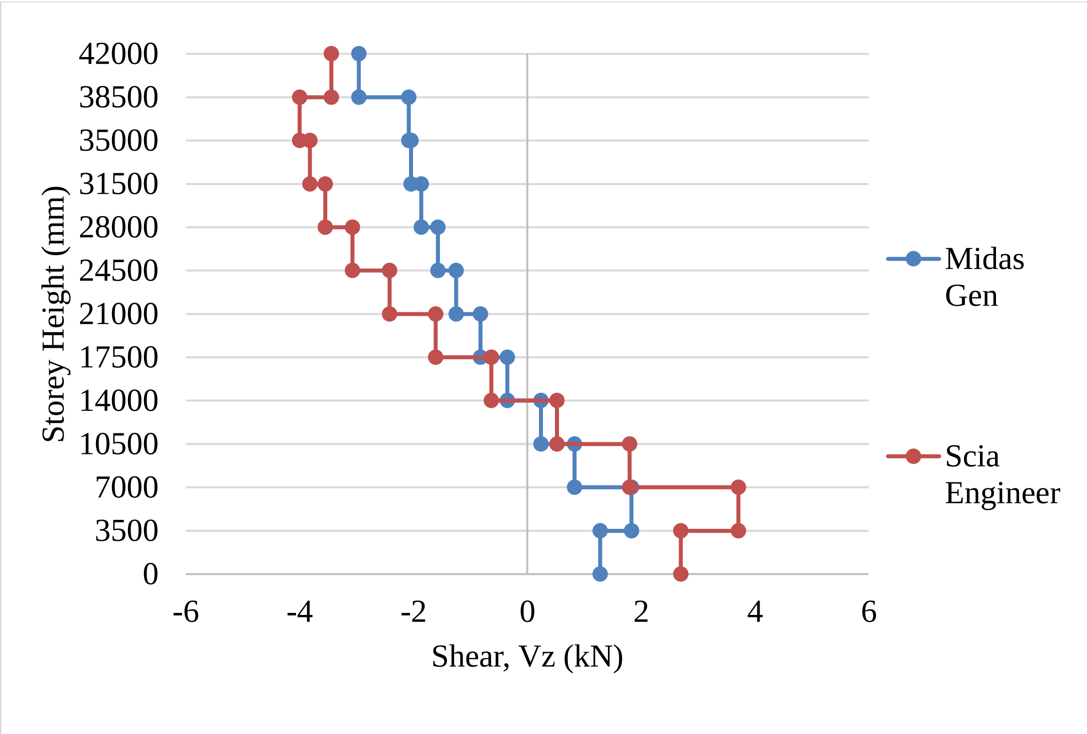

Figure 4.51: Column Shear Force Diagram under Load Case SW+DL by Midas Gen and Scia Engineer

The bending moment diagram of column under load case SW+DL by Midas Gen and Scia Engineer is shown in Figure 4.52. The two curve generated by both software are having similar trend, Midas Gen has a higher upper level bending moment whereas Scia Engineer has a higher lower level bending moment.

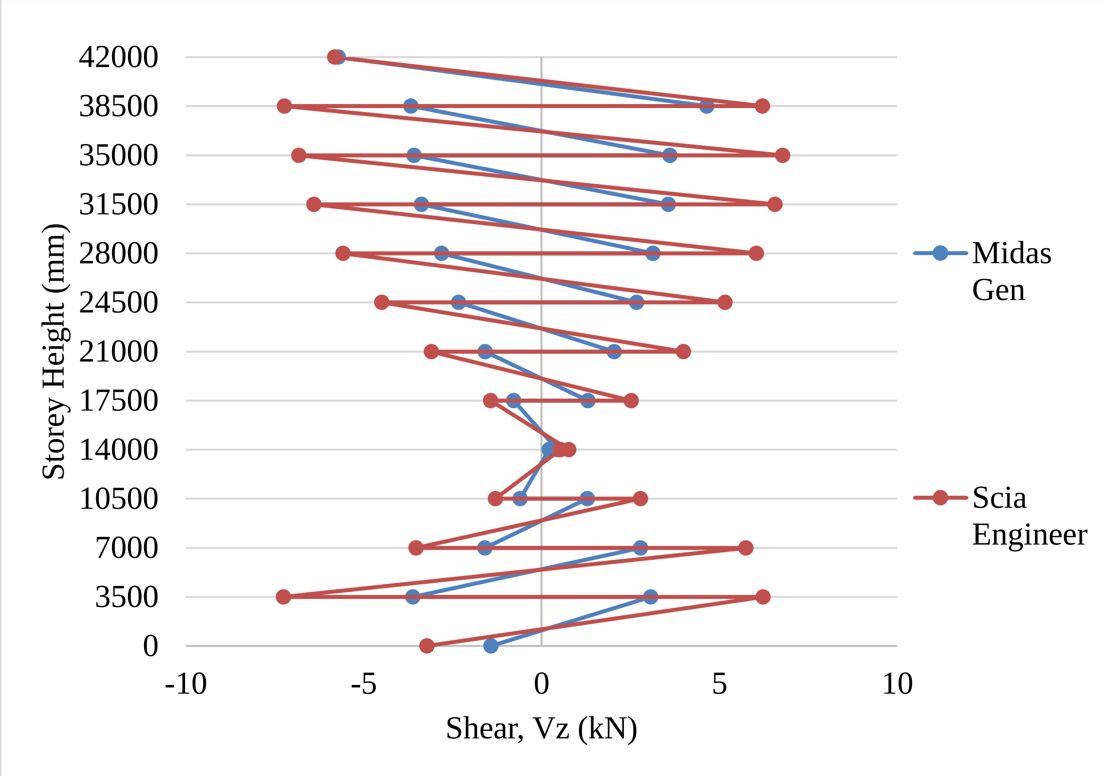

Figure 4.52: Column Bending Moment Diagram under Load Case SW+DL by Midas Gen and Scia Engineer

In load case LL, the shear force and bending moment diagram of column are shown in Figure 4.53 and Figure 4.54 respectively. The trend of both shear force and bending moment diagram are similar, however the values of between both software are different.

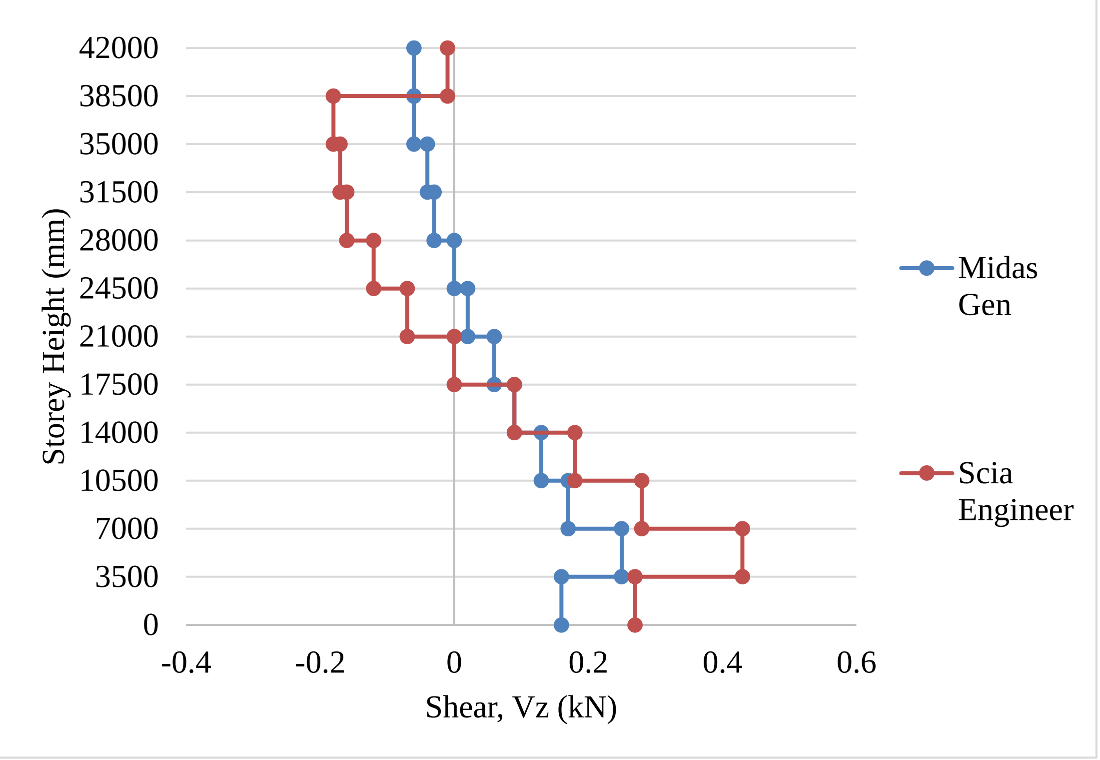

Figure 4.53: Column Shear Force Diagram under Load Case LL in Sabah Region by Midas Gen and Scia Engineer

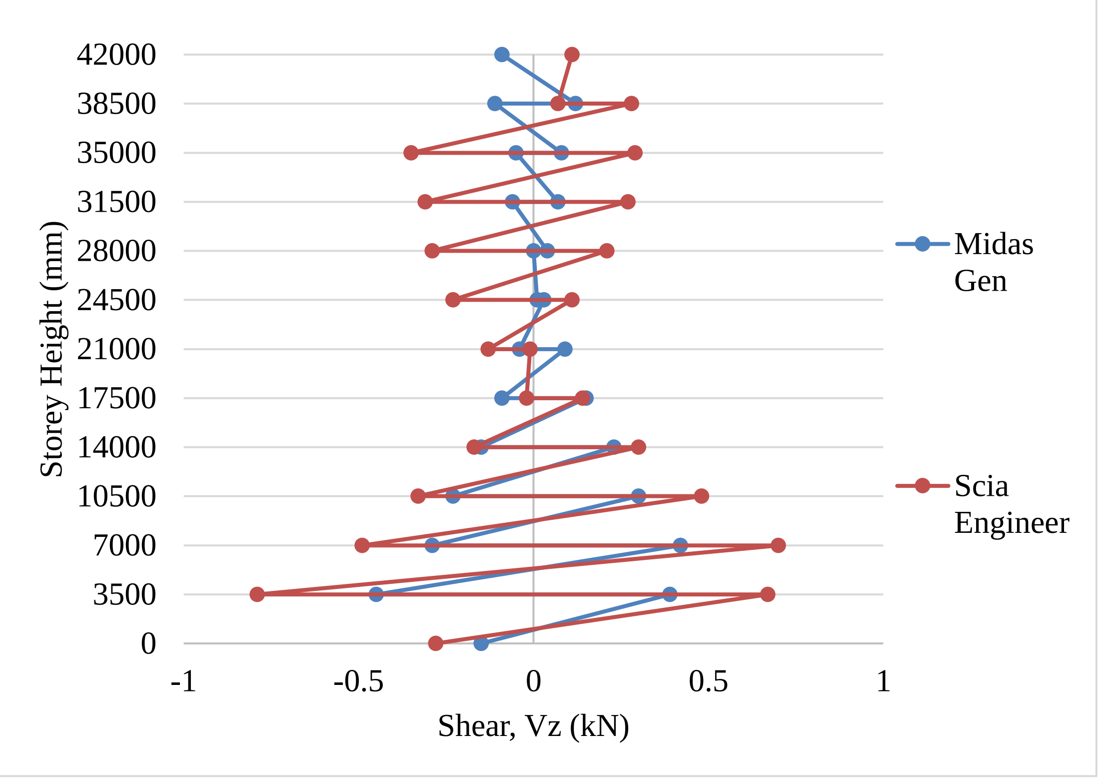

Figure 4.54: Column Bending Moment Diagram under Load Case LL in Sabah Region by Midas Gen and Scia Engineer

Under load case Ex in Sabah region, the shear force and bending moment diagram are shown in Figure 4.55 and Figure 4.56 respectively. In shear force diagram, Scia Engineer provides a very large shear force than that of Midas Gen. In bending moment diagram, Scia Engineer has a curve slanted to the positive side with a very high moment, however in Midas Gen, the bending moment curve exists in both positive and negative side with a smaller maximum value.

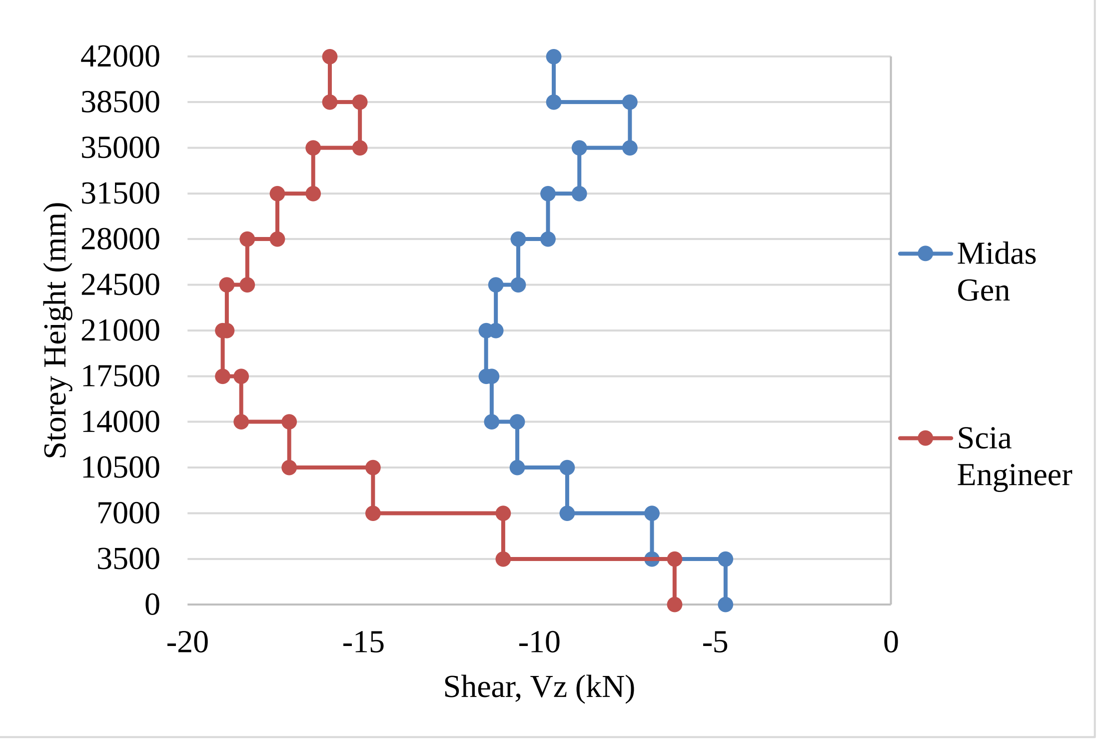

Figure 4.55: Column Shear Force Diagram under Load Case Ex in Sabah Region by Midas Gen and Scia Engineer

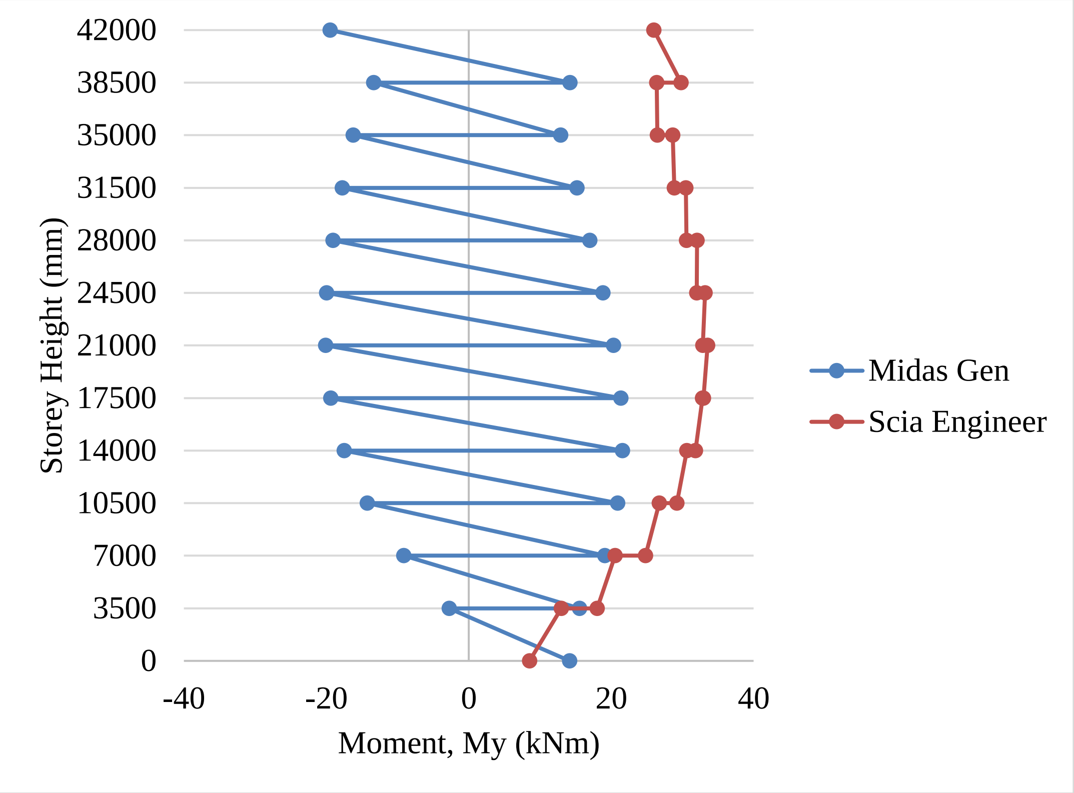

Figure 4.56: Column Bending Moment Diagram under Load Case Ex in Sabah Region by Midas Gen and Scia Engineer

4.7 Summary

In chapter 4, there are a lot of important parameters that are used in seismic resistance structures are being analysed by Midas Gen and Scia Engineer software such as fundamental period and deformed shape, base and storey shear, storey displacement and interstorey drift, and internal forces of beam and column. Other than internal forces of elements, the basic parameters are in small yield of differences between both software. However in internal forces, both software are giving a largely difference results especially in bending moment of elements. Due to the differences in the internal forces, the column behaviour such that an assumption of the column to be reacted as cantilever has been made, superimposed load case are being separated to study the load cases one by one.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Based on the results and discussion, a number of conclusions can be drawn.

The first objective of modelling 12 storey high-rise building under seismic action in different region in Malaysia according to NA to EC8 by using Midas Gen and Scia Engineer are completed. The seismic loadings are being adopted from NA to EC8 that the maximum PGA value in respective region of Malaysia are selected where Peninsular Malaysia has PGA value of 0.08 g, Sarawak has PGA value of 0.09 g and Sabah has PGA value of 0.16 g. The response spectrum curves for ground type B were selected for every region in both software. Models in both software are modelled in an identical way to ensure the comparison of parameters in both software are justice.

The second objective of analysing the high-rise building under seismic loading in different region in Malaysia using Midas Gen and Scia Engineer is achieved. There are some important seismic resistance building indicator had been analysed namely fundamental period, base and storey shear, storey displacement and interstorey displacement.

i. The fundamental period of 12 storey high-rise building is 0.7719 seconds and 0.5175 seconds in x-direction and y-direction for mode 1 and mode 3 respectively in Midas Gen. The fundamental period of 12 storey building is 0.8002 seconds and 0.5448 seconds in x-direction and y-direction for mode 1 and mode 3 respectively in Scia Engineer. The number of modes required for the sum of participating mass to achieve 90 % in Midas Gen and Scia Engineer is 25 modes and 13 modes respectively.
ii. The base and storey shear of 12 storey high-rise building decrease over storey height. The base and storey shear of 12 storey high-rise building increase as the PGA value increases. The average percentage of discrepancy of base and storey shear in Sabah region between Midas Gen and Scia Engineer are 14.05 % and 2.41 % for x-direction and y-direction respectively.
iii. The storey displacement of 12 storey high-rise building increase over storey height. The storey displacement of 12 storey high-rise building increase as the

PGA value increases. The percentage of discrepancy of base and storey shear in Sabah region between Midas Gen and Scia Engineer are 4.38 % and 8.25 % for x-direction and y-direction respectively.

iv. The interstorey drift of 12 storey high-rise building increase as the PGA value increases. The interstorey displacement of 12 storey high-rise building is the highest at Sabah which is 0.00026 and 0.00019 for x-direction and y-direction respectively. The maximum interstorey drift is far to exceed the limit by EC8.

The third objective of comparing the effect of seismic loading on high-rise building in different region in Malaysia using Midas Gen and Scia Engineer is achieved. Internal forces of beam and column are studied in term of axial force, shear force and bending moment.

i. In general, the shear force and bending moment of beam increase as the PGA value increases. Shear force diagram generated by Midas Gen possesses staircase-like step while bending moment diagram generated by Scia Engineer does not possess typical curve (hogging at support and sagging at midspan).
ii. Internal forces of column namely axial force, shear force and bending moment generally increase as the PGA value increases.
iii. In column's axial force, the average percentage difference between Midas Gen and Scia Engineer are 4.4172 %, 0.6970 %, 9.4924 % and 6.3100 % for Ultimate Limit State, Peninsular Malaysia, Sarawak and Sabah respectively.
iv. In column's shear force, the average percentage difference between Midas gen and Scia Engineer are 65.7990 %, 42.0540 %, 73.0500 % and 47.9610 % for Ultimate Limit State, Peninsular Malaysia, Sarawak and Sabah respectively.
v. In column's bending moment, the results by both software are totally irrelevant. Therefore, a further investigation of cantilever behaviour of column is carried out. Superimposed load was separated to identify the source of discrepancy.

5.2 Recommendations for future work

In this research, the internal forces of beam and column were studied. It is suggested to study the internal forces of shear wall and substructures of high-rise building upon the seismic action.

Besides, it is recommended to carry out the analysis of high-rise building subjected to seismic action by different software such as STAAD Pro, SAP 2000 and ETABS so that the results may be compared.

It will be more appropriate to obtain site investigation data of the targeted location to take into account the site effects on the building during seismic activity. In this study, the ground type was assumed to be ground type B, however in fact, the ground type must be identified as it is crucial for the ground motion to transfer to building through ground.

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APPENDICES

APPENDIX A: Internal Forces of Beam due to Seismic Action in y-direction

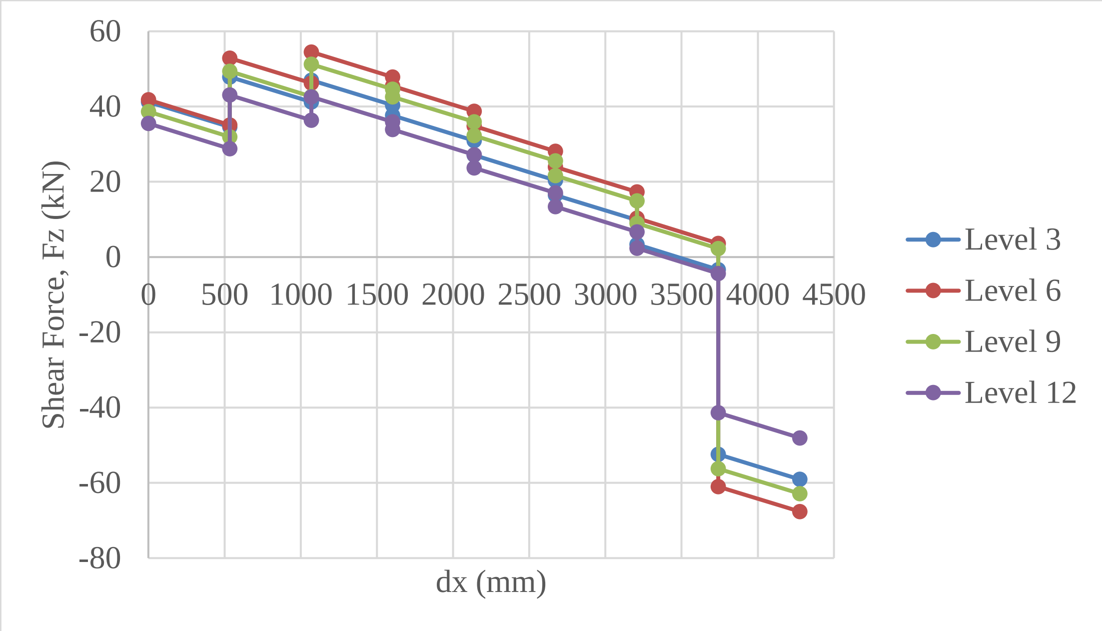

Figure A-1: Shear Force Diagram of Beam due to Y-direction Seismicity at Sabah (PGA = 0.16 g) by Midas Gen

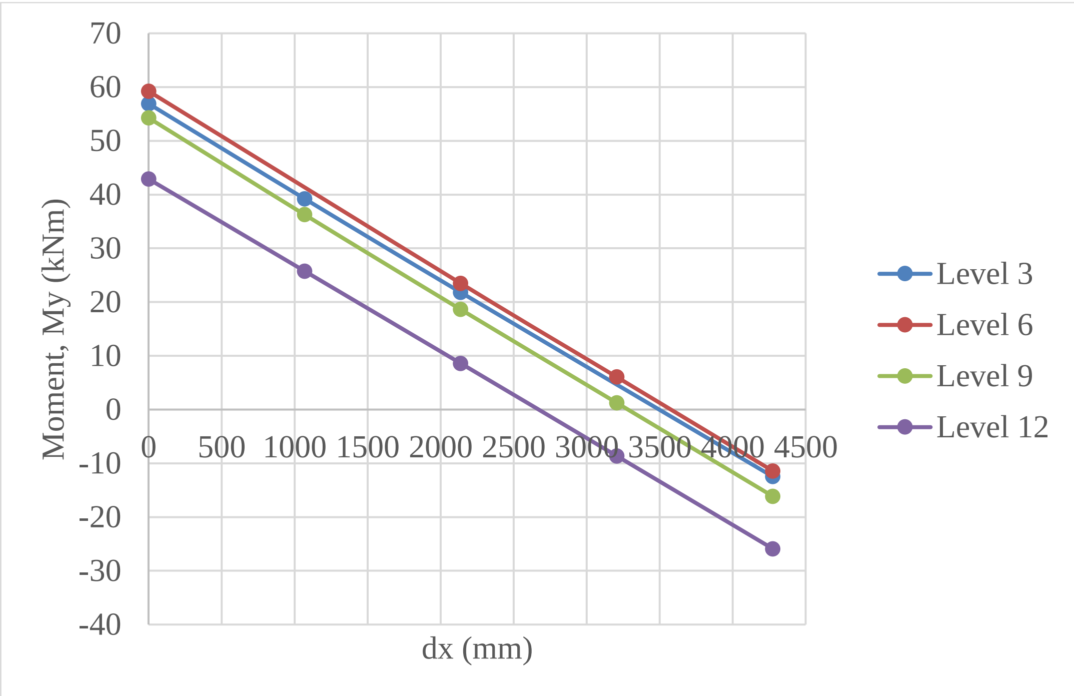

Figure A-2: Shear Force Diagram of Beam due to Y-direction Seismicity at Sabah (PGA = 0.16 g) by Scia Engineer

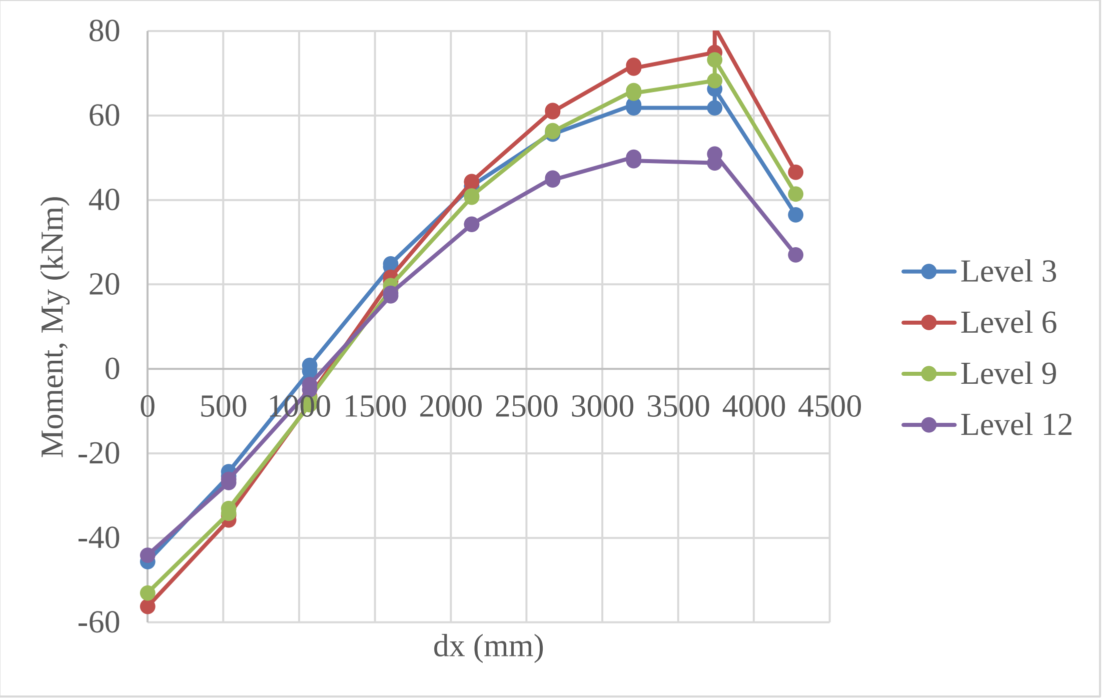

Figure A-3: Bending Moment Diagram of Beam due to Y-direction Seismicity at Sabah (PGA = 0.16 g) by Midas Gen

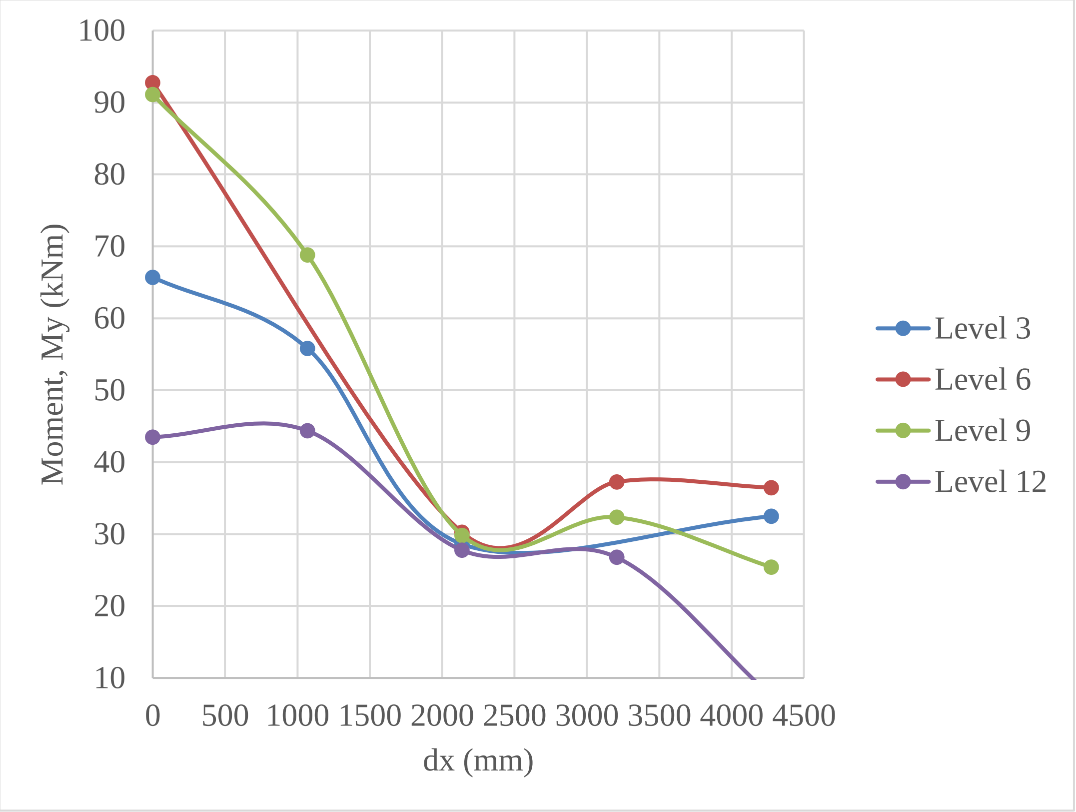

Figure A-4: Bending Moment Diagram of Beam due to Y-direction Seismicity at Sabah (PGA = 0.16 g) by Scia Engineer

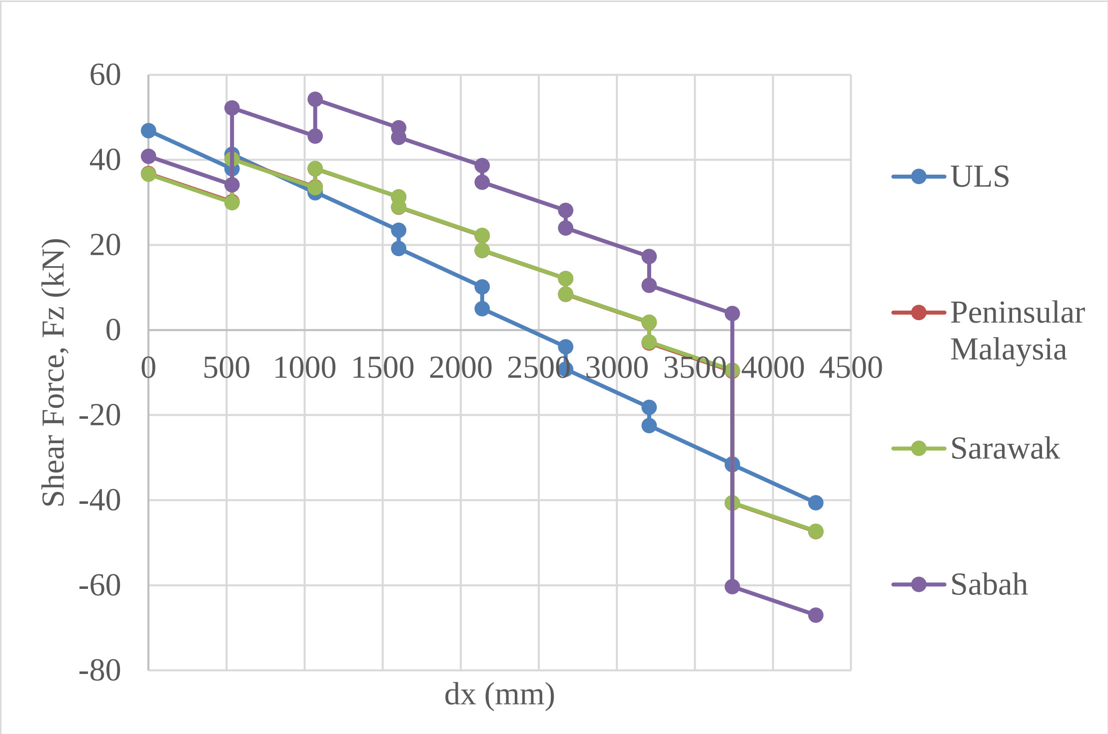

Figure A-5: Shear Force Diagram of Level 7 Beam due to Y-direction Seismicity in Different Region by Midas Gen

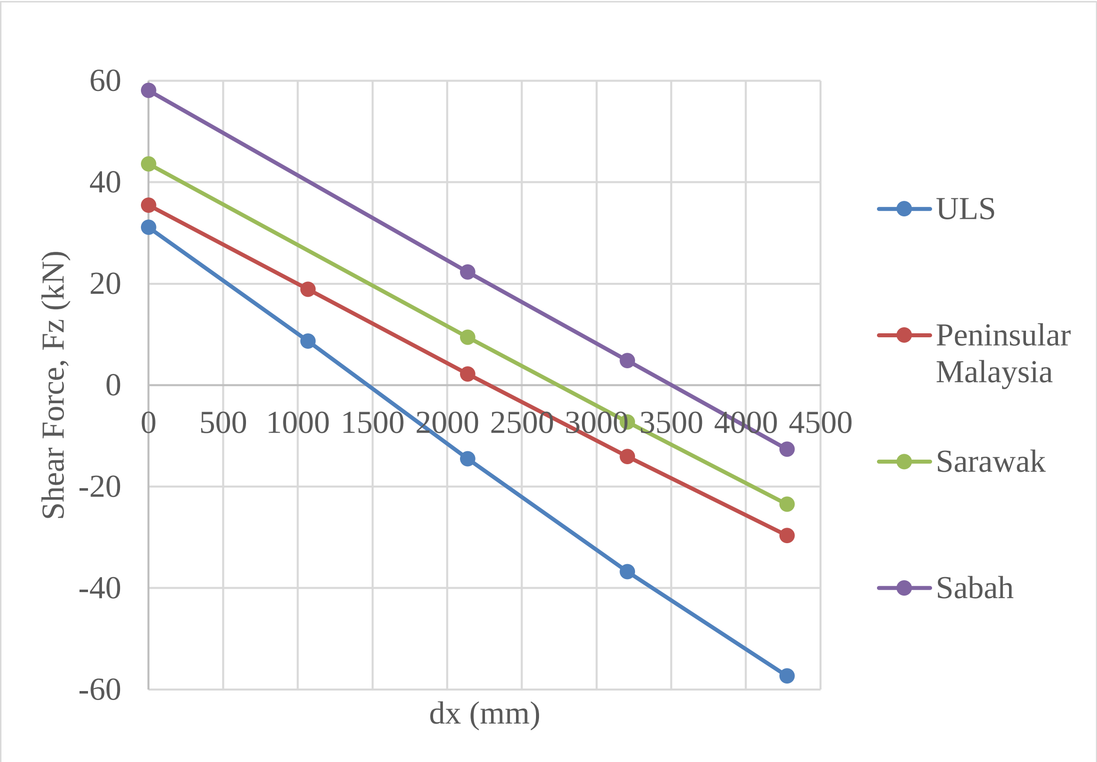

Figure A-6: Shear Force Diagram of Level 7 Beam due to Y-direction Seismicity in Different Region by Scia Engineer

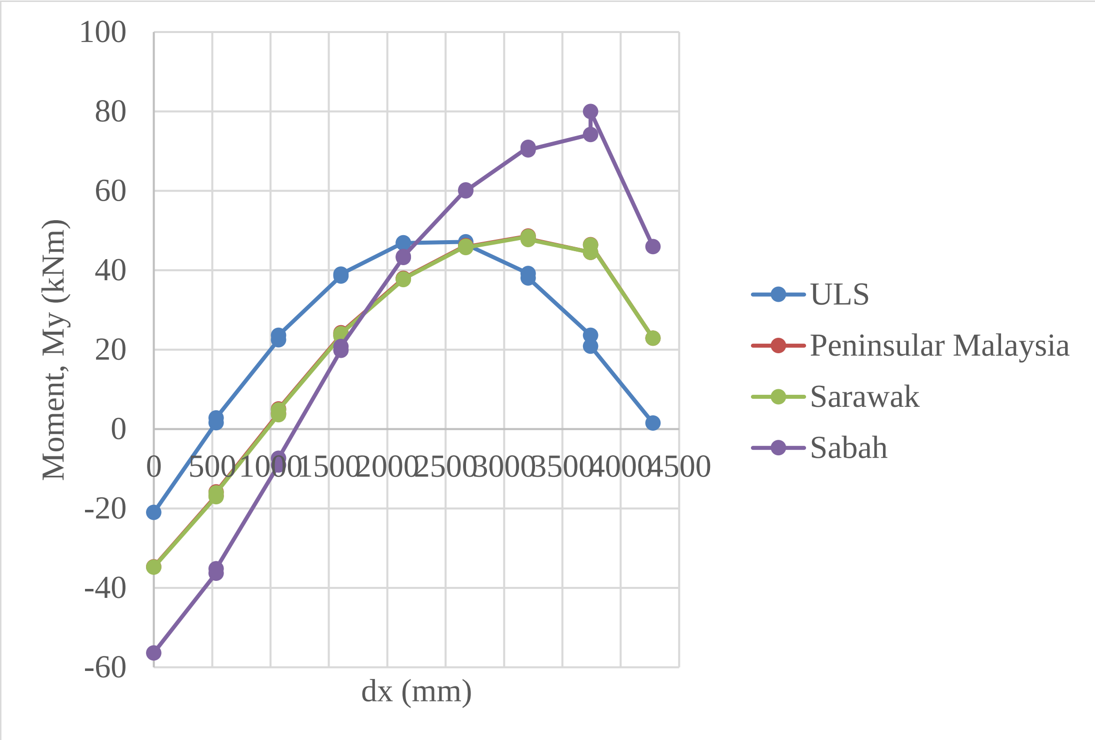

Figure A-7: Bending Moment Diagram of Level 7 Beam due to Y-direction Seismicity in Different Region by Midas Gen

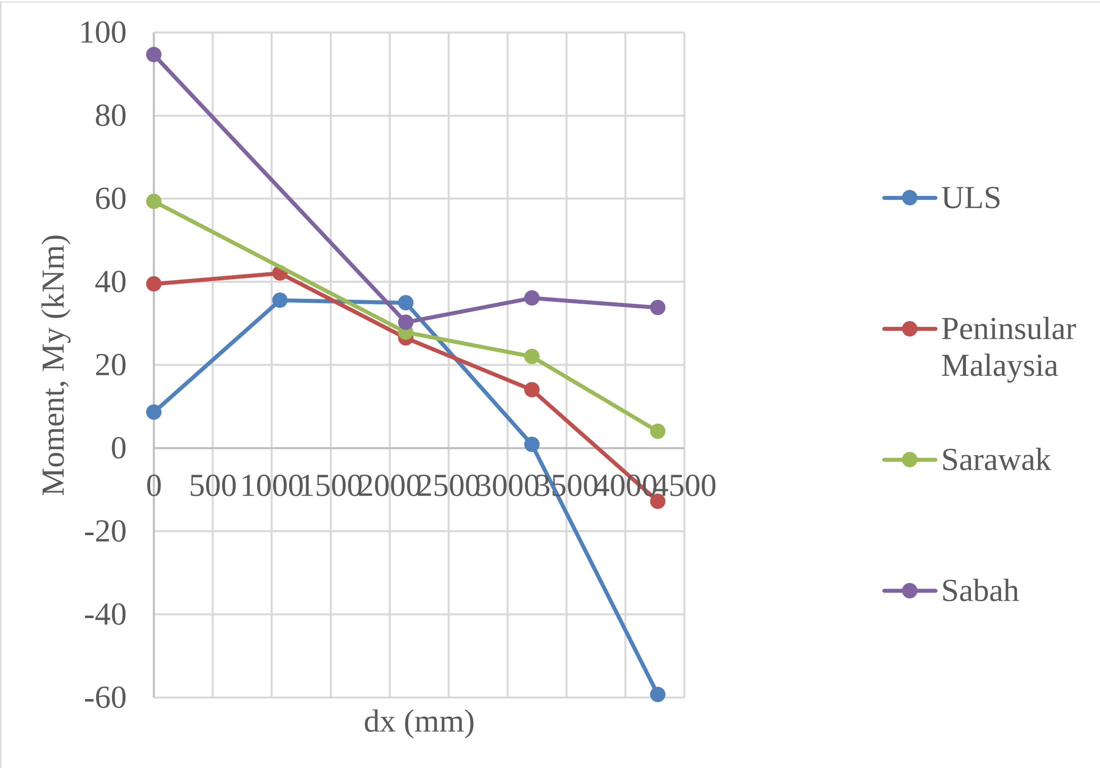

Figure A-8: Bending Moment Diagram of Level 7 Beam due to Y-direction Seismicity in Different Region by Scia Engineer

APPENDIX B: Internal Forces of Column due to Seismic Action in y-direction

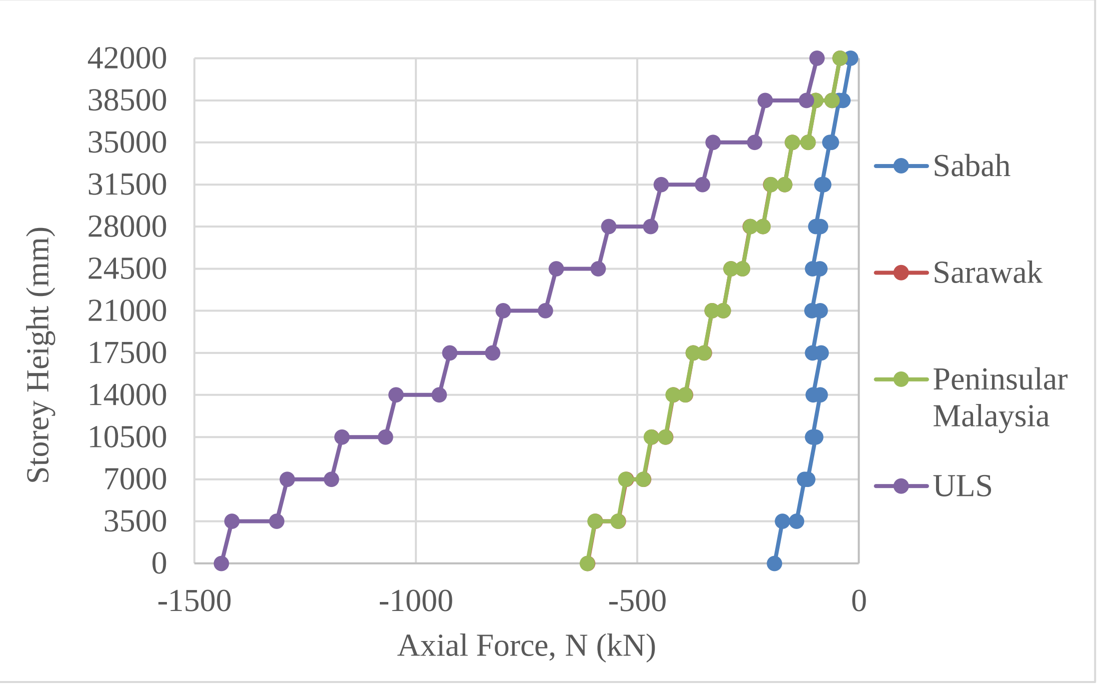

Figure B-1: Column Axial Force due to Y-direction Seismicity in Different Region by Midas Gen

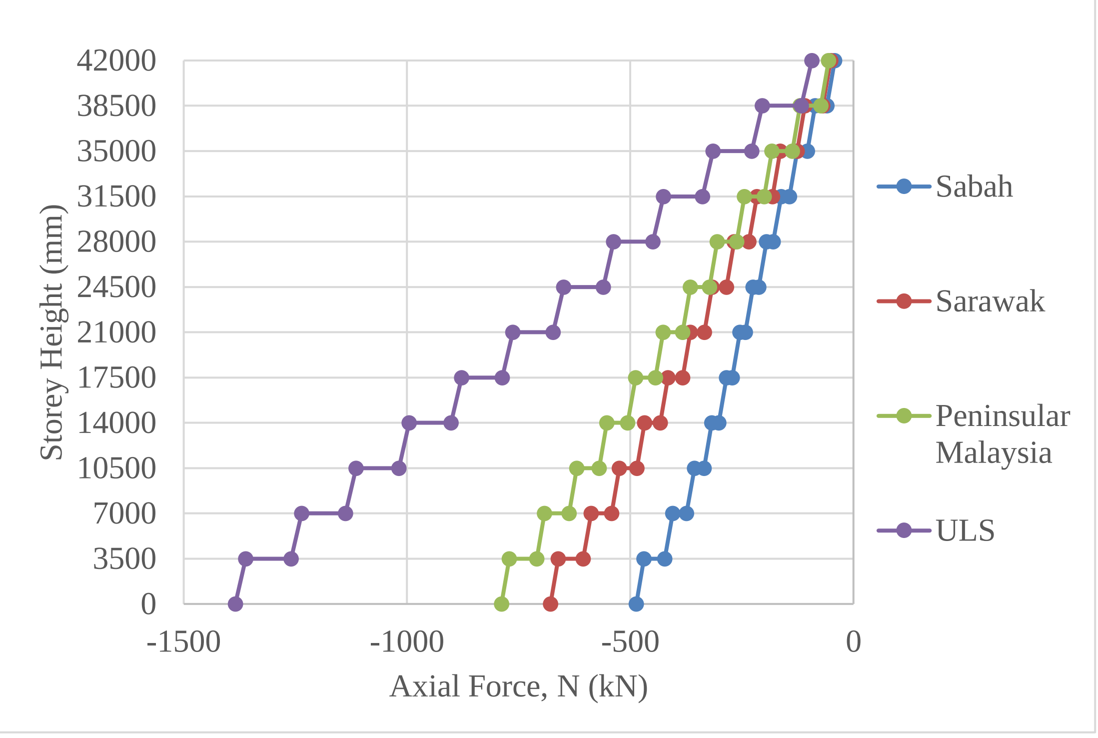

Figure B-2: Column Axial Force due to Y-direction Seismicity in Different Region by Scia Engineer

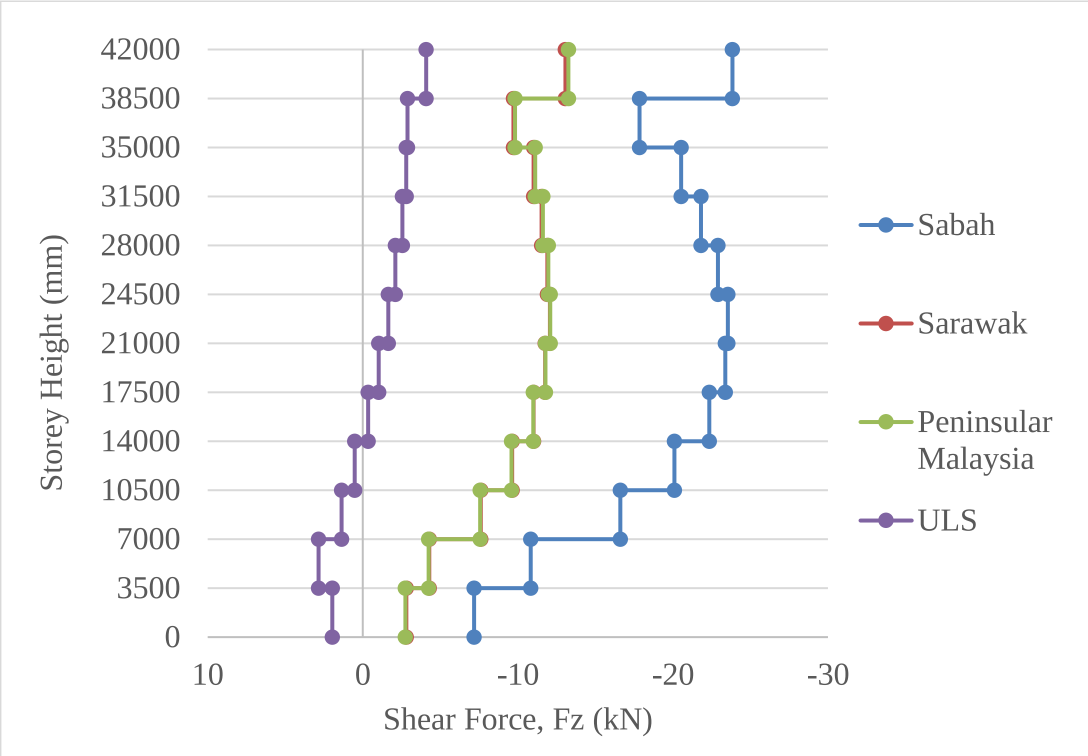

Figure B-3: Column Shear Force due to Y-direction Seismicity in Different Region by Midas Gen

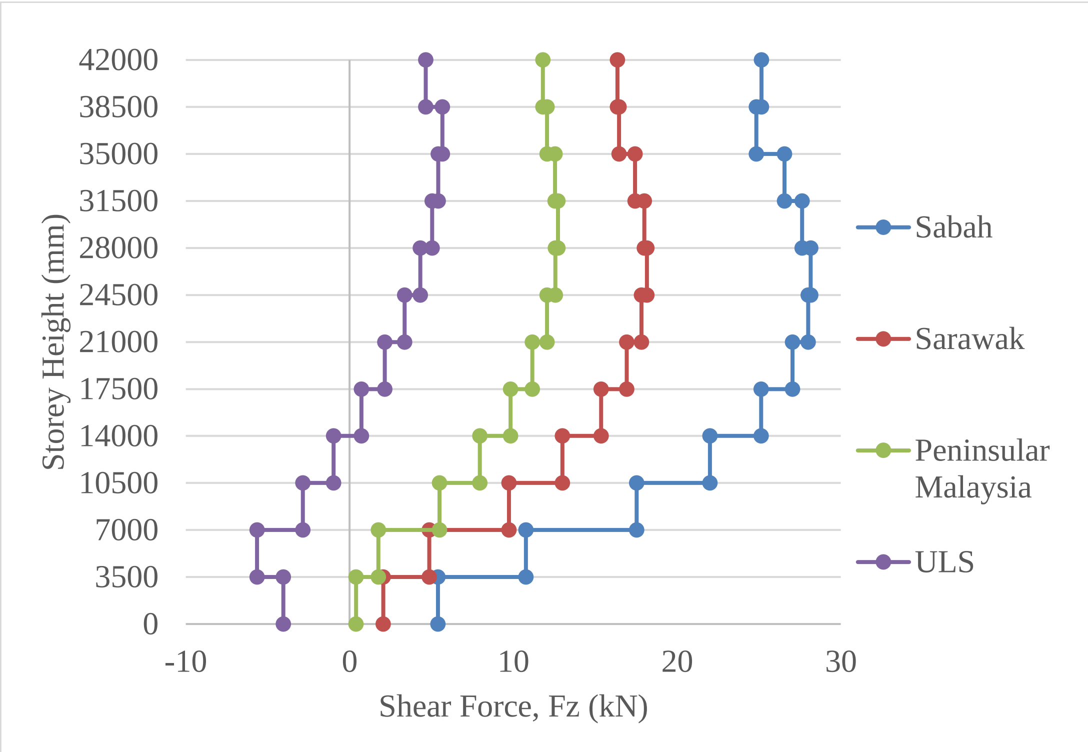

Figure B-4: Column Shear Force due to Y-direction Seismicity in Different Region by Scia Engineer

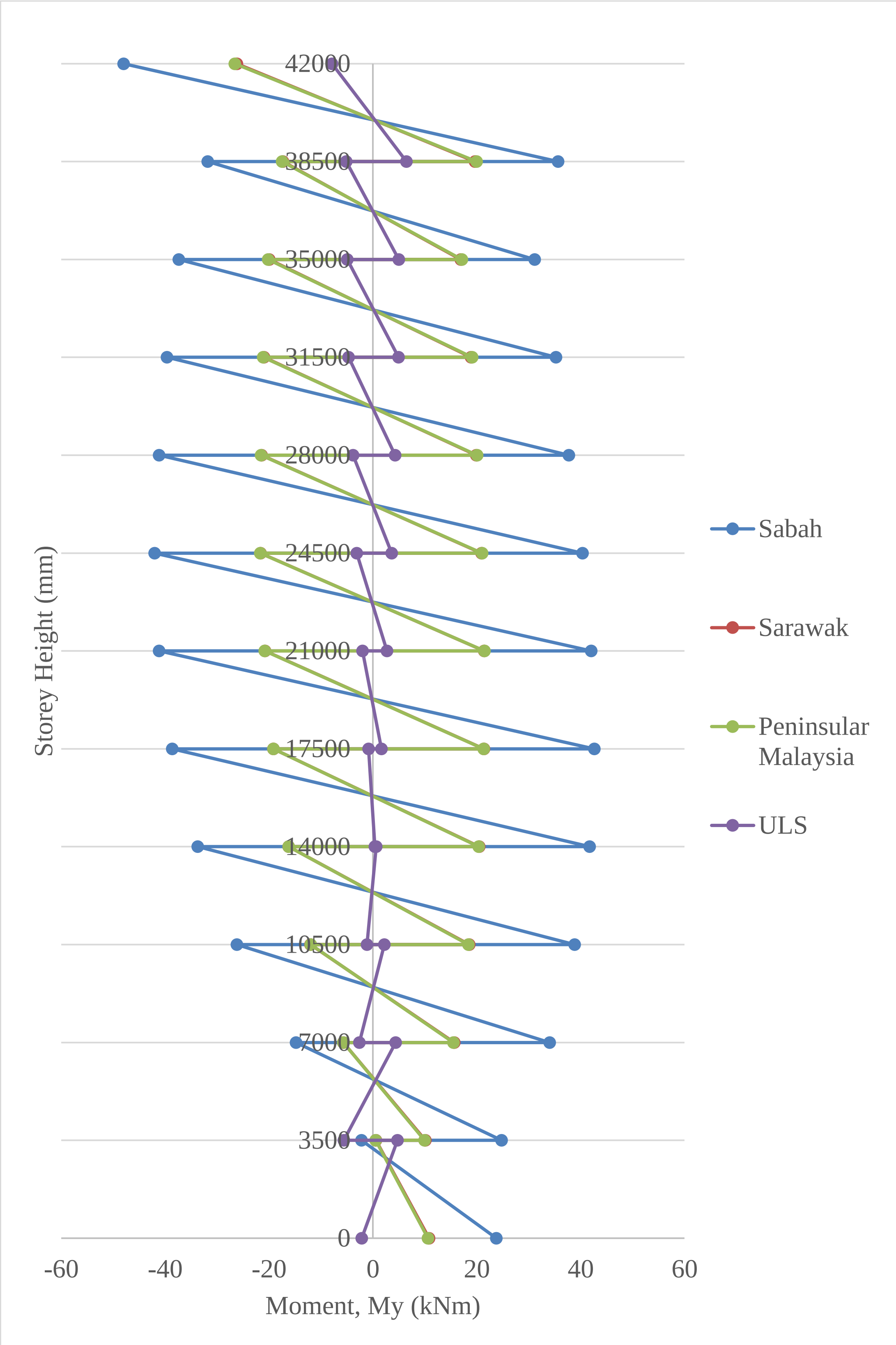

Figure B-5: Column Bending Moment due to Y-direction Seismicity in Different Region by Midas Gen

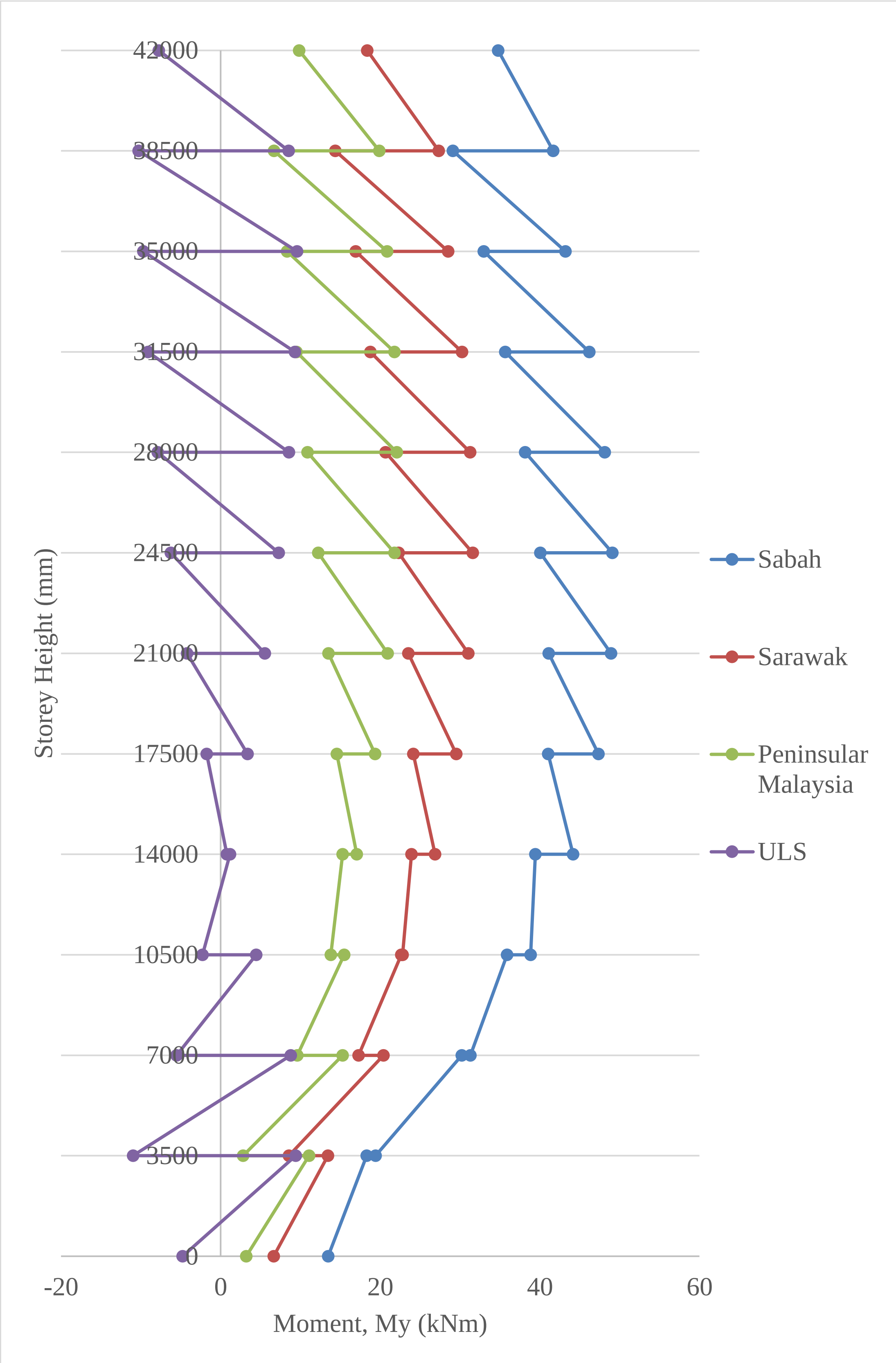

Figure B-6: Column Bending Moment due to Y-direction Seismicity in Different Region by Scia Engineer

APPENDIX C: Column Behaviour Study by Scia Engineer Software

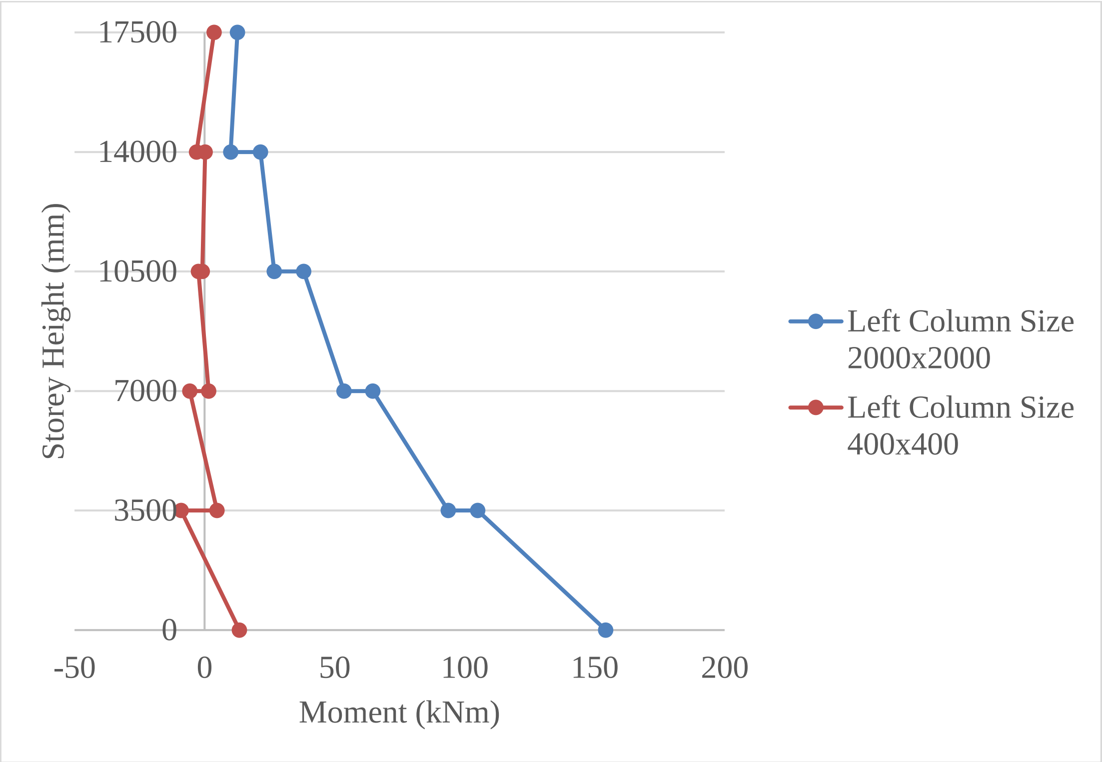

Figure C-1: Bending Moment Diagram of Left Column for Simple 2-D Frame Illustration under Load Case SW+V+H by Scia Engineer

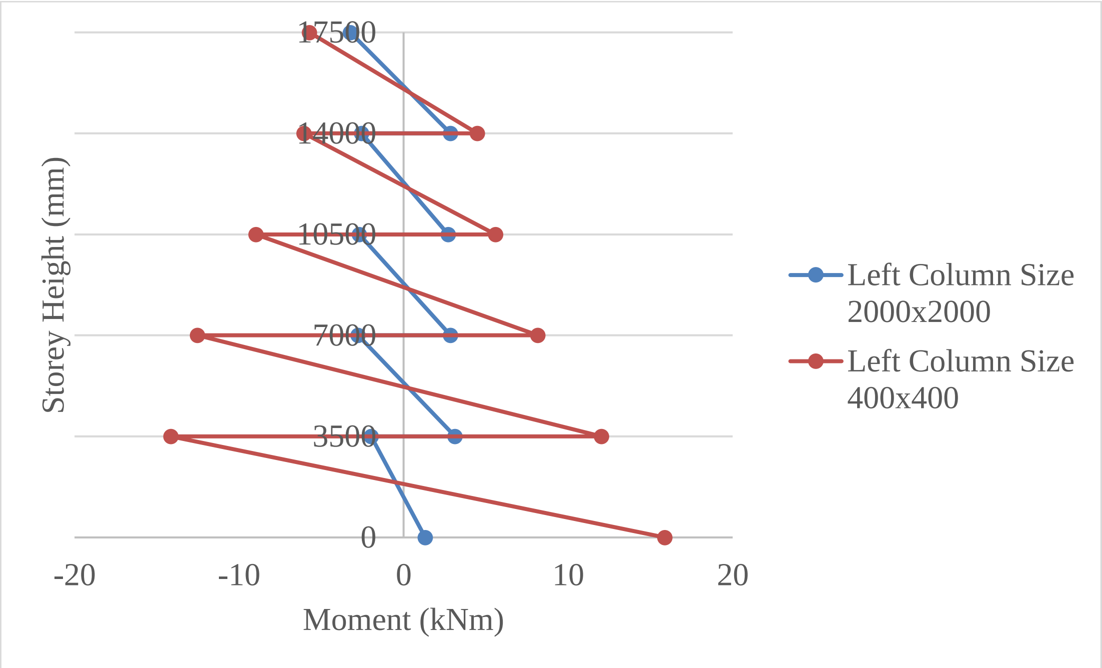

Figure C-2: Bending Moment Diagram of Right Column for Simple 2-D Frame Illustration under Load Case SW+V+H by Scia Engineer

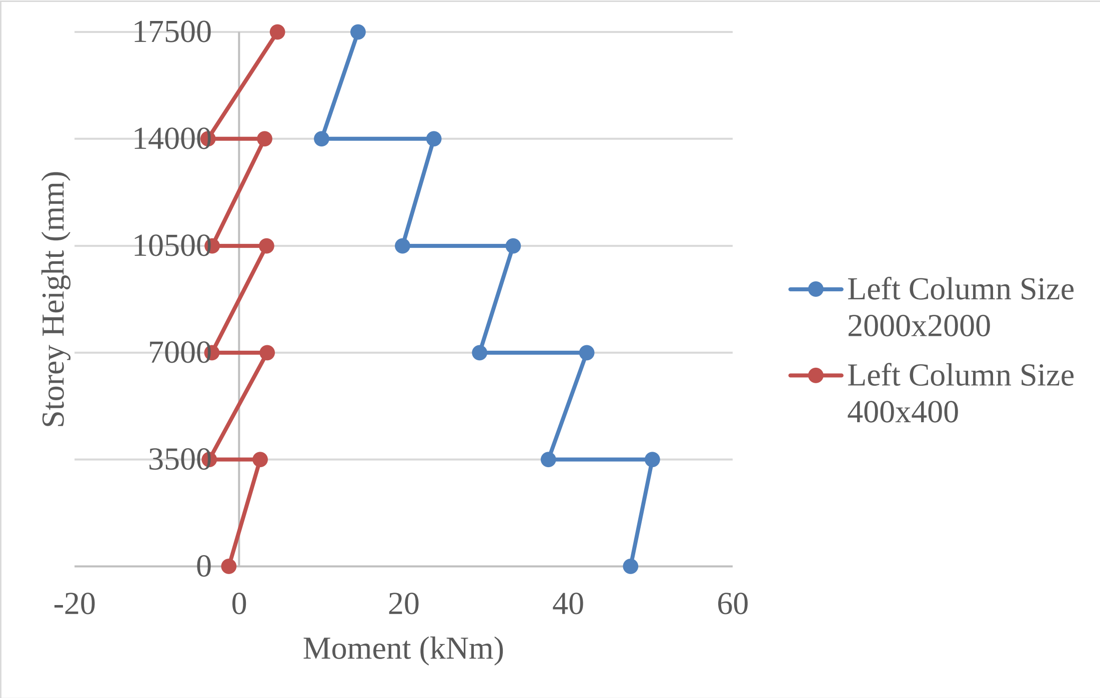

Figure C-3: Bending Moment Diagram of Left Column for Simple 2-D Frame Illustration under Load Case SW+V by Scia Engineer

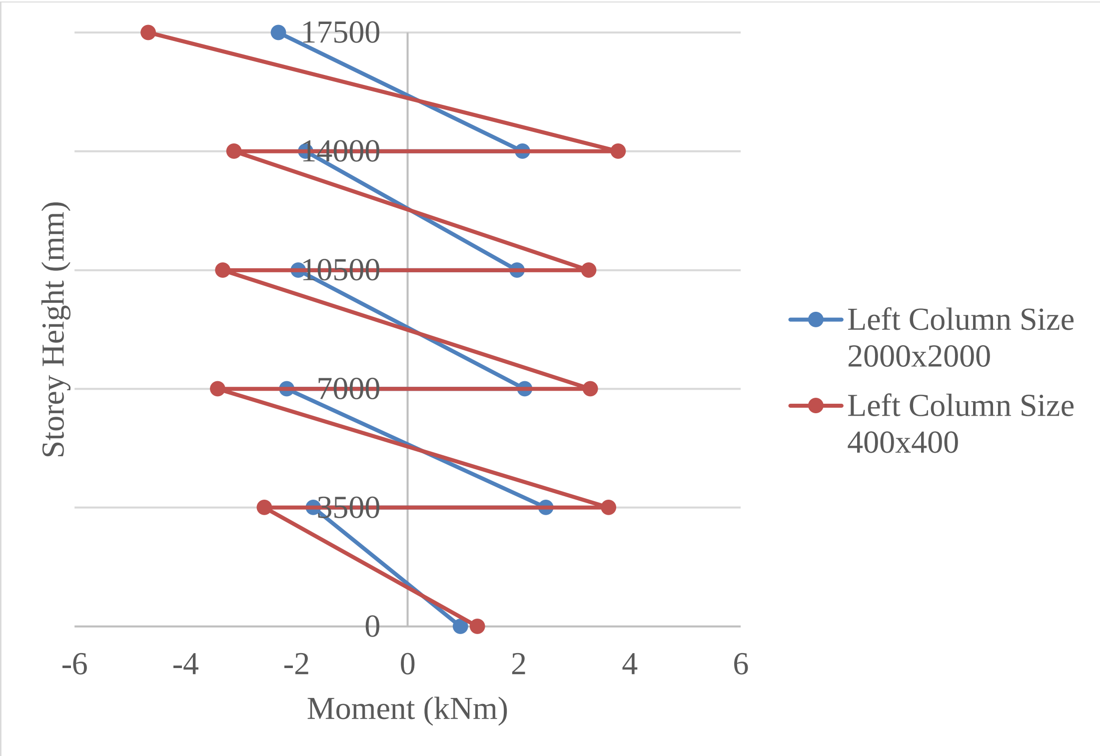

Figure C-4: Bending Moment Diagram of Right Column for Simple 2-D Frame Illustration under Load Case SW+V by Scia Engineer

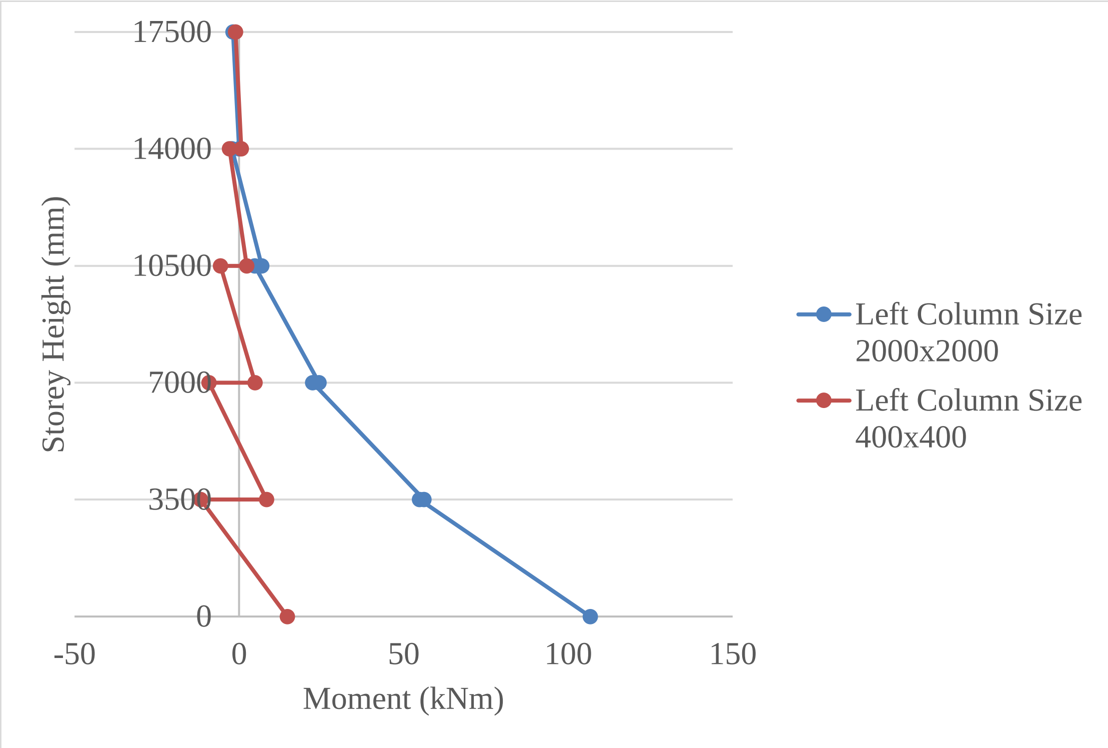

Figure C-5: Bending Moment Diagram of Left Column for Simple 2-D Frame Illustration under Load Case H by Scia Engineer

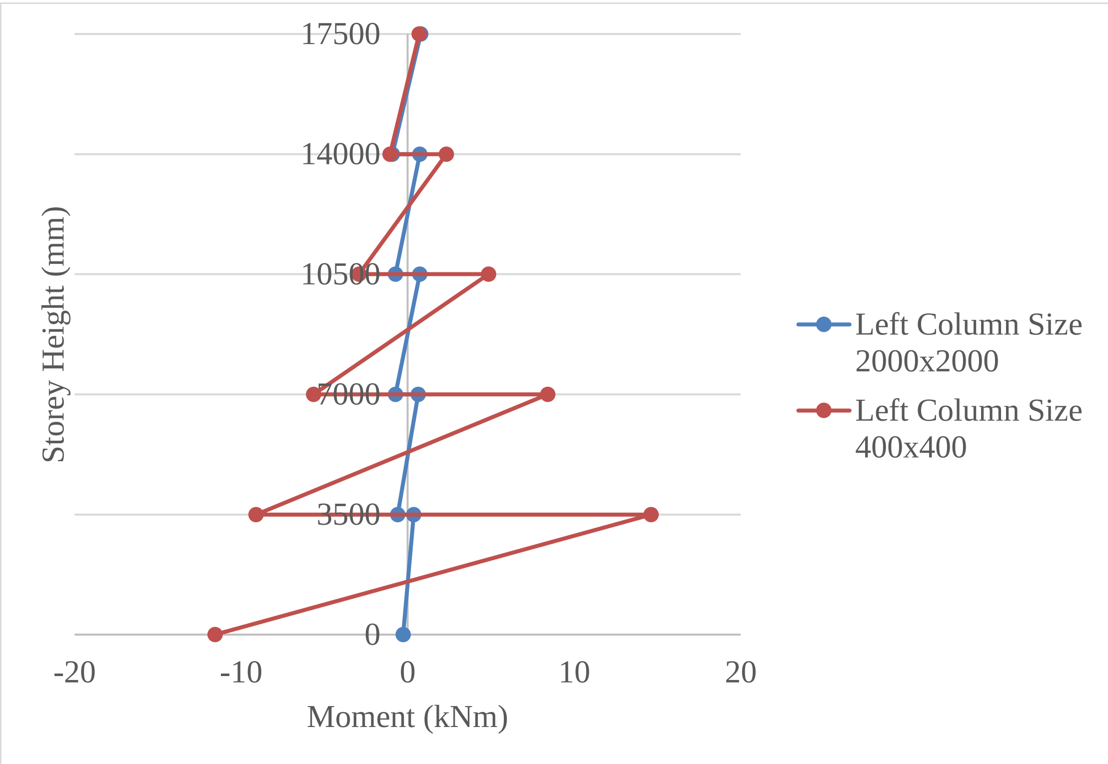

Figure C-6: Bending Moment Diagram of Right Column for Simple 2-D Frame Illustration under Load Case H by Scia Engineer