ANALYSIS ON THE EFFECT OF DIFFERENT X-BRACING ARRANGEMENTS AND LOCATIONS ON LATERAL DRIFT OF DIFFERENT STOREY STEEL FRAME BUILDINGS SUBJECTED TO LATERAL FORCES USING ANSYS

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
B. Eng (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JUNE 2017

ACKNOWLEDGEMENTS

First and foremost, I would like to take this chance to say thank you to the Faculty of Civil Engineering and Earth Resources for providing me the opportunity to carry out this research. Next, I would like to appreciate to my supervisor, Mr Mohd Arif Bin Sulaiman for his creative ideas and continuous guidance for making this research complete on time and successfully. I am very grateful for his supervision on this research and tolerance on my mistakes.

Besides that, I would like to express appreciation to my friends and group members for helping each other by sharing the required information in this study. All the useful information provided by them was very useful and essential as this information was able to enrich the content of this research.

Next, I would like to express special thanks to my parents for their encouragement as to provide me the strength and believe to finish this research. Moreover, the funds provided by them were really appreciated by me because without this money, I was not able to carry out this research successfully. Last but not least, I also thank to those people who have directly or indirectly given me helps to this study.

ABSTRAK

Angin telah menyebabkan kegagalan struktur dalam 150 tahun yang lalu dan sebahagian besar kegagalan bangunan yang disebabkan oleh angin berlaku semasa pembinaan bingkai keluli. Untuk bangunan tinggi yang membawa beban melintang daripada angin, kerangka dirembat telah digunakan untuk menahan beban angin kerana ia mampu mengurangkan pergerakan melintang bangunan tinggi dengan berkesan. Matlamat kajian ini adalah untuk mengetahui kesan kedudukan x-perembatan yang berbeza, sambungan pin serta sambungan tetap kepada indeks hanyut, dan kesan keluli tingkat yang berbeza kepada drift melintang. Terdapat 35 model rangka keluli bertingkat 28 yang terdiri daripada x perembatan dengan susunan yang berbeza terlibat dalam kajian ini dengan menggunakan ANSYS. Selepas itu, lokasi perembatan yang optimum dipilih untuk digunapakai dalam bangunan 24, 20 dan 16 tingkat untuk memerhatikan drift melintang. Ia diikuti dengan menukar sambungan pin daripada model optimum untuk bangunan tinggi 28 tingkat ke sambungan tetap bagi memerhatikan jenis sambungan yang boleh menyediakan kestabilan terbaik untuk rangka keluli. Akhir sekali, ia didapati bahawa teluk luaran perembatan bersama dengan perembatan tingkat berdekatan antara satu sama lain serta penempatan perembat di tengah bingkai keluli menyediakan kestabilan terbaik untuk rangka keluli.

ABSTRACT

Wind had caused to structural failures in the past 150 years and most of the building failures caused by wind happened while the erection of steel frame. For a high rise building that carry lateral loads from wind, braced frame was used to resist the wind loads as it was able to reduce the lateral drift of high rise building effectively. This study was aim to determine the effect of varying the position of x-bracing, joint connection which was pin and fixed connection to the drift index, and different storey steel frame building to the lateral drift. There were total of 35 models of 28-storey steel frame in term of different arrangements of the bracing involved in this study by using ANSYS. After that, the optimum arrangement and location of bracing was chosen then apply to 24, 20 and 16-storey building to observe the lateral drift. It was followed by changing the pin connection from optimum location and arrangement of bracing for 28-storey to fixed connection in order to observe which type of connection provides the best stability to the steel frame. Finally, it was known that the exterior bay bracing along with the floors bracing near to each other and located at the middle of the steel frame provided the best stability to the steel frame.

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LIST OF SYMBOLS

Δ	Lateral Displacement at Top of Building
A	Area of Section
C_{dyn}	Dynamic Response Factor
$C_{fig,\ leeward}$	Aerodynamic Shape Factor in Leeward Wall
$C_{fig,\ windward}$	Aerodynamic Shape Factor in Windward Wall
F_x	Axial Force
F_y	Shear Force
h	Total Height of Building or Depth of Section
H	Horizontal Force
I	Importance Fator
M_d	Wind Directional Multiplier
M_h	Hill Shape Multiplier
M_s	Shielding Multiplier
M_z	Bending Moment
$M_{z,cat}$	Terrain / Height Multiplier
$P_{leeward}$	Pressure in Leeward Wall
P_{total}	Total Pressure Acting to the Wall
$P_{windward}$	Pressure in Windward Wall
t_f	Thickness of Flange
t_w	Thickness of Web
u	Displacement in x Direction or Horizontal Displacement
V_{sit}	Wind Speed for a Site
V_{des}	Building Design Wind Speed
y	Displacement in y Direction or Vertical Deformation
z	Rotation in z Direction

LIST OF ABBREVIATIONS

2d Elast	Two Dimensional Elastic
ASCE	American Society of Civil Engineers
Civil FEM	Civil Finite Element Method
SI	International System
Vs	Versus

CHAPTER 1

INTRODUCTION

1.1 General

High rise building is commonly known as 'tall building" which mean it has multi-story that need the used of elevator to reach at the particular level of the building. In Malaysia, the rapid economic growth that results in the increasing demand for business and residential areas has limited land to accommodate the huge number of citizens. Therefore, this has creating a new challenge for the engineers to search for numerous ways to produce a safe 'tall building'.

Application of steel frame in the construction of high rise building is an effective way to achieve structural stability. Steel frame is a construction technique from the combination of steel columns and I-beams. The combinations of the two elements form a rectangular grid which gives support to the floors, roof and walls of the high rise building. Normally, the type of steel used is mild steel that is very strong and thus make the steel frame has a lot benefits to the high rise building. Steel frame has high flexibility such that it is able to bend without crack. Thus, it is good in resist dynamic force. Besides, steel exhibits characteristics which are plasticity and ductility or other means it will not crack suddenly when huge force is applied on it. In addition, steel frame has faster time of erection as it can be built fast during construction. Therefore, the time and cost for a particular construction project can be reduced.

The movement of air in the atmosphere is more commonly known as wind. The motion of air for wind is in horizontal and it gives weights or loads upon the high rise building. Air flows from high to low pressure, thus wind speed is increasing with the height of a building. Therefore, it is more dangerous to resist high wind speed for tall, long span and slender structures.

For a high rise building that carry lateral loads from wind, braced frame is used to resist the wind loads. It is very often to apply brace frame in high rise construction as it is simple and economical in construction. It is found that brace frame is able to reduce horizontal displacement or other mean to reduce the lateral drift of high rise building effectively as it resists torsion act on a building. There are various types of bracing such as X-bracing, K-bracing, V-bracing, diagonal bracing and so on. However, X-bracing was used throughout the research. X-bracing or well-known as cross-bracing applies two diagonal steel which crossing each other. X-bracing not only can be applied in one bay but multiple bays. Thus, there are various arrangements and positions can be applied to locate the bracing at high rise building in order to achieve high lateral stiffness, this increasing the stability of building.

1.2 Problem Statement

Wind has caused to structural failures in the past 150 years and most of the building failures caused by wind happened while the erection of steel frame (McCormac & Csernak, 2012). One of the great examples can be considered is the Union Carbide Building in Toronto, Canada (1958). The structure mentioned collapsed because of the steel frame of the building swayed due to wind speed that reached 90km/h at about 6.20pm (Bradburn, 2011). It was found out that the bracing provided was no longer enough to give support against the high speed of the winds (Bradburn, 2011). From all those information, it is important to realise that wind loading and bracing are important factors to consider when designing a high rise building. There are a lot of studies have been carried out over the years regarding to the issues of lateral drift on high rise structure. Design of high rise structure that subjected to wind loading is a difficult task that face by engineers today as the wind speed varies from time to time. In addition, the layouts of bracing need to be studied well so that optimal bracing layout can be applied to the high rise building. Building is about to face severe damages such as broken glass and local component failures if too much lateral drift imposes by wind load (Zhang et al., 2014). Thus, it is very important to choose and locate the bracing type correctly in a steel frame structure for different storeys of high rise building to resist wind load successfully. However, time consume is long if the analysis is carried out by experimented method. In order to shorten the time of experiment, ANSYS software is used as the analysis tool which can also give accurate results.

1.3 Objectives

The objectives of this research are stated as follow:

i. To determine the effect of varying the position of x-bracing to the drift index.

ii. To determine the effect of different storey steel frame building to the lateral drift.

iii. To determine the effect of joint connection which is pin connection only, and the combination of pin and fixed connection to the drift index.

1.4 Scope of Study

The scope of study for this research was to run the analysis for high rise steel frame with different x-bracing locations and arrangements for 28-storey by utilization of Eurocode 3, ANSYS 12.0. There were a few arrangements involved in this study which were centre bay bracing with single, double and triple floor bracing, pattern bracing and exterior bracing. After that, the optimum layout of bracing was chosen then applied to 24, 20 and 16-storey building to observe and study the lateral drift through simulation. It was followed by changing pin connection from optimum location and arrangement of bracing for 28-storey to the pin-moment connection in order to observe which type of connection provides the best stability to the high rise building. The plan of the building was shown in Figure 1.1, the information need for the modelling of steel frame was shown in Figure 1.2, and the layouts of x-bracing for 28-storey high rise building was illustrated in Figure 1.3, 1.4, 1.5 and 1.6.

X-bracing was the most common bracing used in steel frame construction due to it was good in compression and tension. In order to obtain comparable results of lateral drift, the size of column for each storey for every type of high rise building was decided such that bottom half of total storey for the structure used the same size of column (UC 356x406x634mm), then top half of total storey for the storey was divided by two again so that divided bottom part used the same size of column (UC 356x406x467mm) and top part used column size which was UC 356x406x393mm. Besides, the layouts for the bracing was also decided such that centre bay bracing with single floor bracing at top, bottom, middle, 1/3 of total storey from top, 1/3 of total storey from bottom, centre bay bracing with double and triple floor bracing with the combination of each single floor bracing mentioned earlier, exterior bracing and some types of special bracing arrangements.

The calculation of wind load was based on 'MS1553: Code of Practice on Wind Loading for Building Structures, 2002' as shown in Appendix A. In Malaysia, most of the high rise building was built in Kuala Lumpur. According to the standard, Kuala Lumpur is located at Zone 1 that brings wind speed with 33.5m/s for 3 second gust. Thus, the basic wind speed was 24m/s. The wind speed was changed to wind pressure which was equal to 1432N/m^2, then applied to the steel frame in horizontal direction. Lastly, the drift index limit was set not to exceed 0.01 as to verify the validation of the results (ASCE 7-05, 2006).

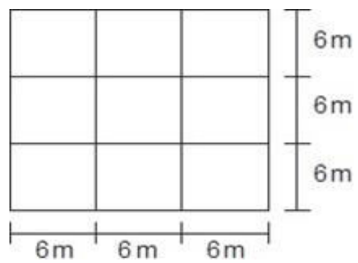

Figure 1.1 Plan View of Steel Frame

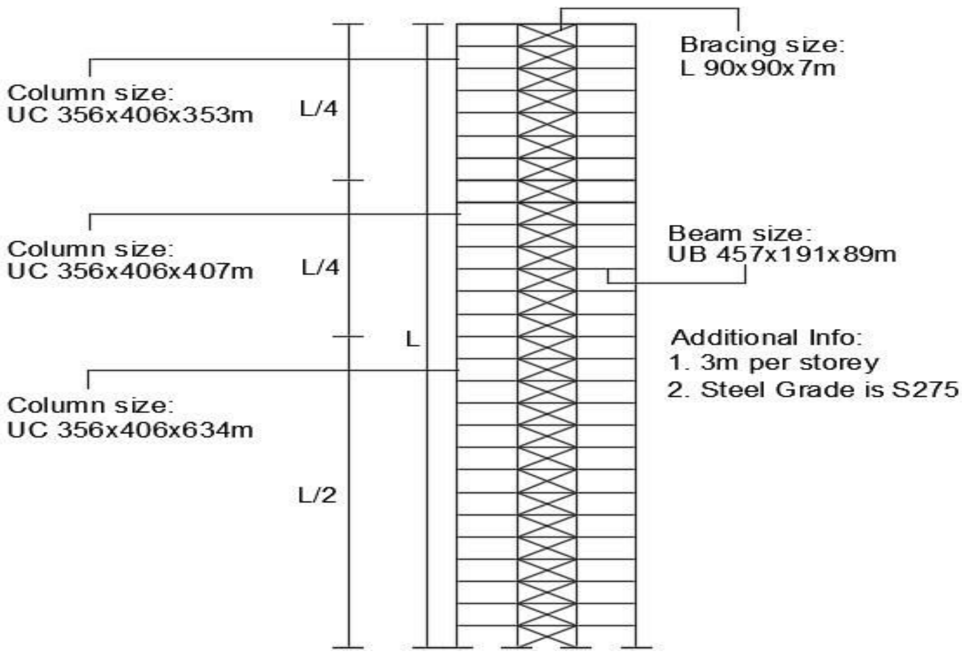

Figure 1.2 General Properties of Steel Frame

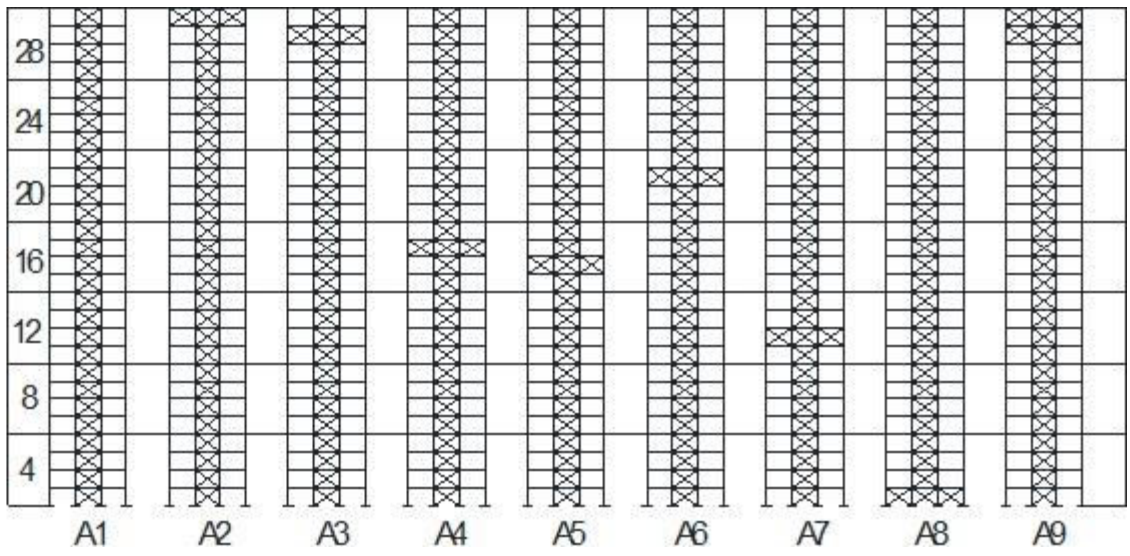

Figure 1.3 Models (A1-A9) of X-bracing for 28-storeys High Rise Building

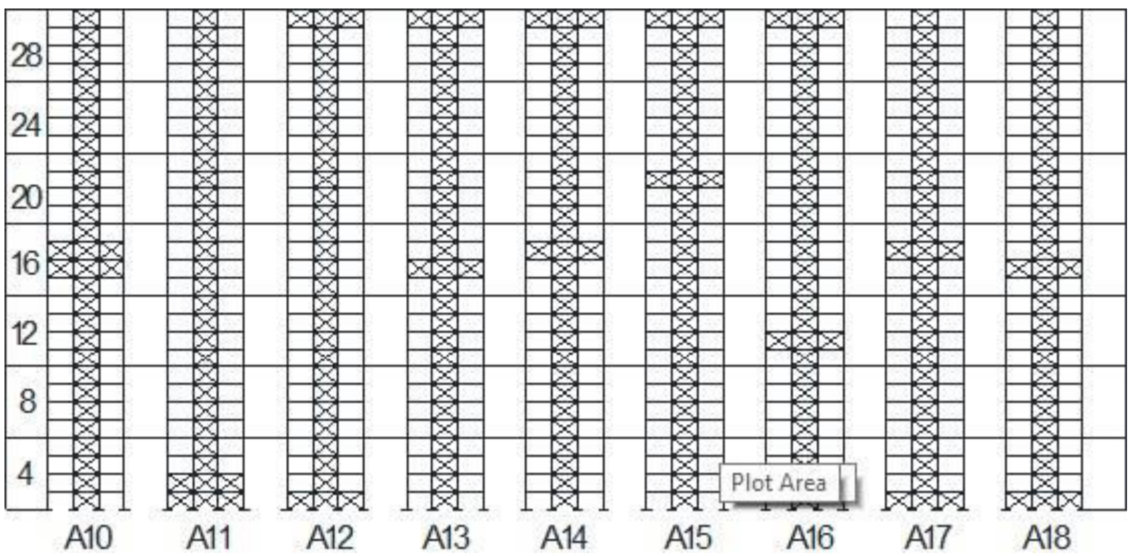

Figure 1.4 Models (A10-A18) of X-bracing for 28-storeys High Rise Building

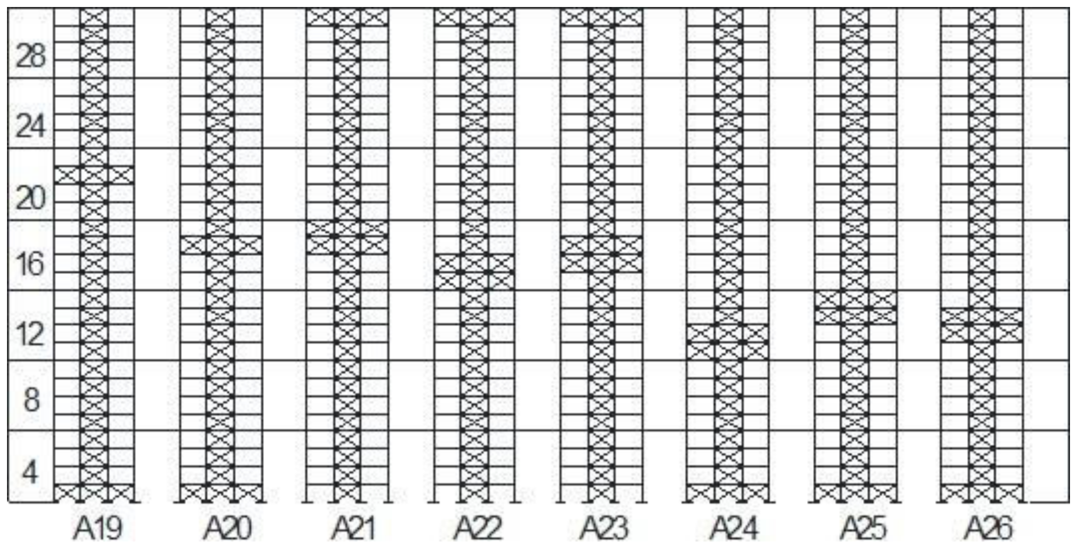

Figure 1.5 Models (A19-A26) of X-bracing for 28-storeys High Rise Building

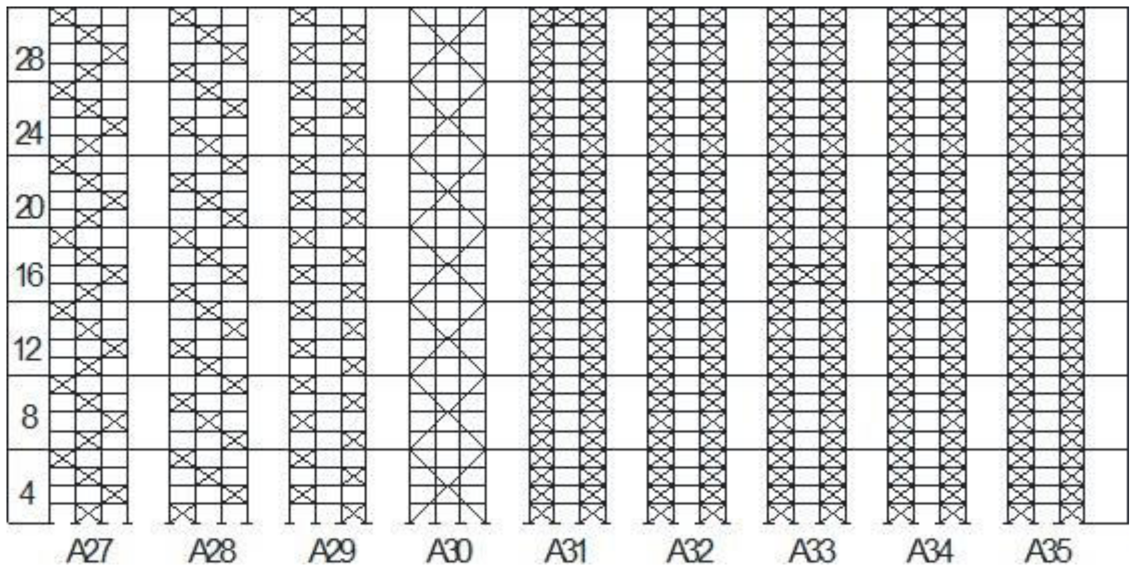

Figure 1.6 Models (A27-A35) of X-bracing for 28-storeys High Rise Building

CHAPTER 2

LITERATURE REVIEW

2.1 General

There were a lot of researches and studies had been done related to the analysis of high rise building. The lateral load resistance system applied to the high rise building might be shear wall or bracing. It was realized as well, the task in designing a high rise building was not easy as the wind forces were included throughout the design process as to produce a safe and stable building in accepted lateral drift. The main focus of this research was steel braced frame building that subjected to wind forces. In addition, the ANSYS 12.0 simulation program was used as it was a handy tool in helping the researchers to analyse a complex structure based on the finite element analysis in order to gain an approximate solutions for the desired results.

2.2 Application of High Rise Building in Malaysia

The epic growth of economy and population in urban areas of Malaysia had increased the construction activities for tall building. High rise building did not have specific definition as there were a lot of standards or parties own their definitions. However, it was found out that most of the engineers defined tall building as building with height exceeded 23m, which measured from the building access at the lowest floor level of the building (California Building Code, 2013). High rise building can be quoted as a building that the lateral forces such as wind loads and earthquakes need to be considered during the design process as those forces affected the stability of the building (Kavilkar & Patil, 2014). Basically, the two kinds of bracing systems which commonly applied in Malaysia were shear wall system and steel bracing system. Both systems were explained in details in the following section.

2.3 Application of Shear Wall in High Rise Building

The lateral forces that act on parallel to the surface of the high rise concrete building definitely required shear wall to resist the loads effectively. In other meaning, the horizontal forces were resisted by the vertical elements which were shear walls. The effectiveness was seen through the capability of shear wall in providing the reasonable strength and stiffness to minimize the horizontal displacement. In addition, it gave advantage in reducing the construction cost. On the other hand, it was found out that the location of shear wall if located along exterior perimeter of the high rise building was the most effective way in resisting horizontal forces (Kalikavu, 2015). The shear wall was illustrated in Figure 2.1 and the effective shear wall arrangement was shown in Figure 2.2.

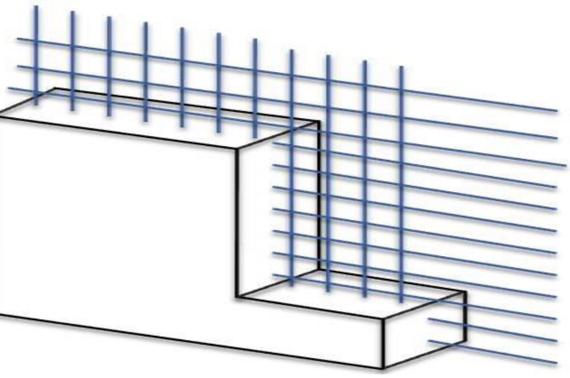

Figure 2.1 Reinforced Concrete Shear Wall

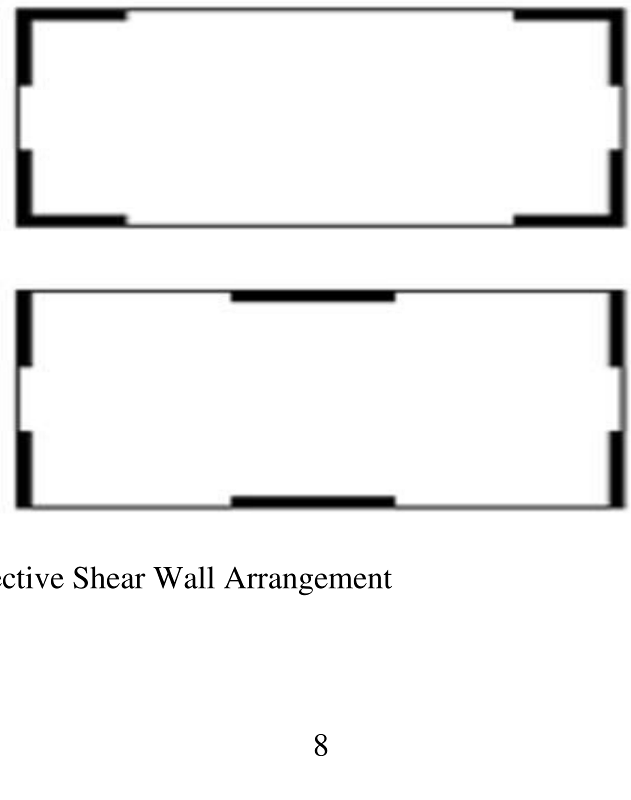

Figure 2.2 Effective Shear Wall Arrangement

2.4 Application of Steel Frame in High Rise Steel Frame Building

Nowadays, steel structure was crucial in the construction industry. The design of high rise steel structure was affected by horizontal forces such as wind loads and earthquakes due to the height to width ratio of a structural system increased. Therefore, horizontal forces should be resisted efficiently by having enough rigidity and stability through proper design (Hasançebi, 2016). There were two types of steel frame which were braced and unbraced frame. Unbraced frame was not efficient as the bending of columns and girders produce shear racking component to deflect and further lead the building to drift (Jason, 2006). However, the efficiency of steel frame was improved through utilization of braced frame as shown in Figure 2.3 because it balanced up the shear racking and bending (Jason, 2006).

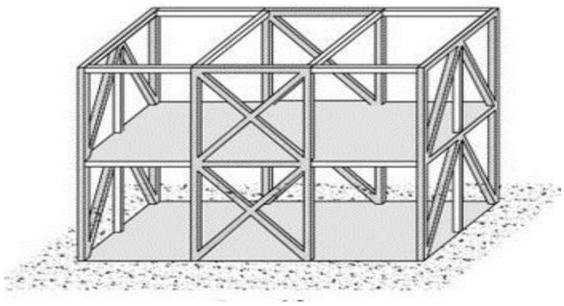

Figure 2.3 Braced Frame

2.5 Application of Bracing in High Rise Steel Frame Building

There were various type of bracing systems such as X-bracing, V-bracing, K-bracing and single diagonal bracing as shown in Figure 2.4. Bracing systems were found out to efficiently resist the lateral forces as the systems greatly reduced the bending of column and beam, thus increased the stiffness of the steel frame (Jagadish & Doshi, 2013). In this research, X-bracing was chosen as bracing system for the steel frame. It was because the cross bracing systems were widely used by the designers in the worldwide to achieve structure stability (Richardson et al., 2013). X-bracing was connected to the four edges of beam and column connections in a bay by the intersections of two full length steel members. It gave advantage to use the bracing at smaller size as it only be stressed in tension, thus make it more economical (Mcewen, 2011). X-bracing was the most efficient bracing system in reducing lateral drift in high rise building (Zasiah Tafheem, 2013).

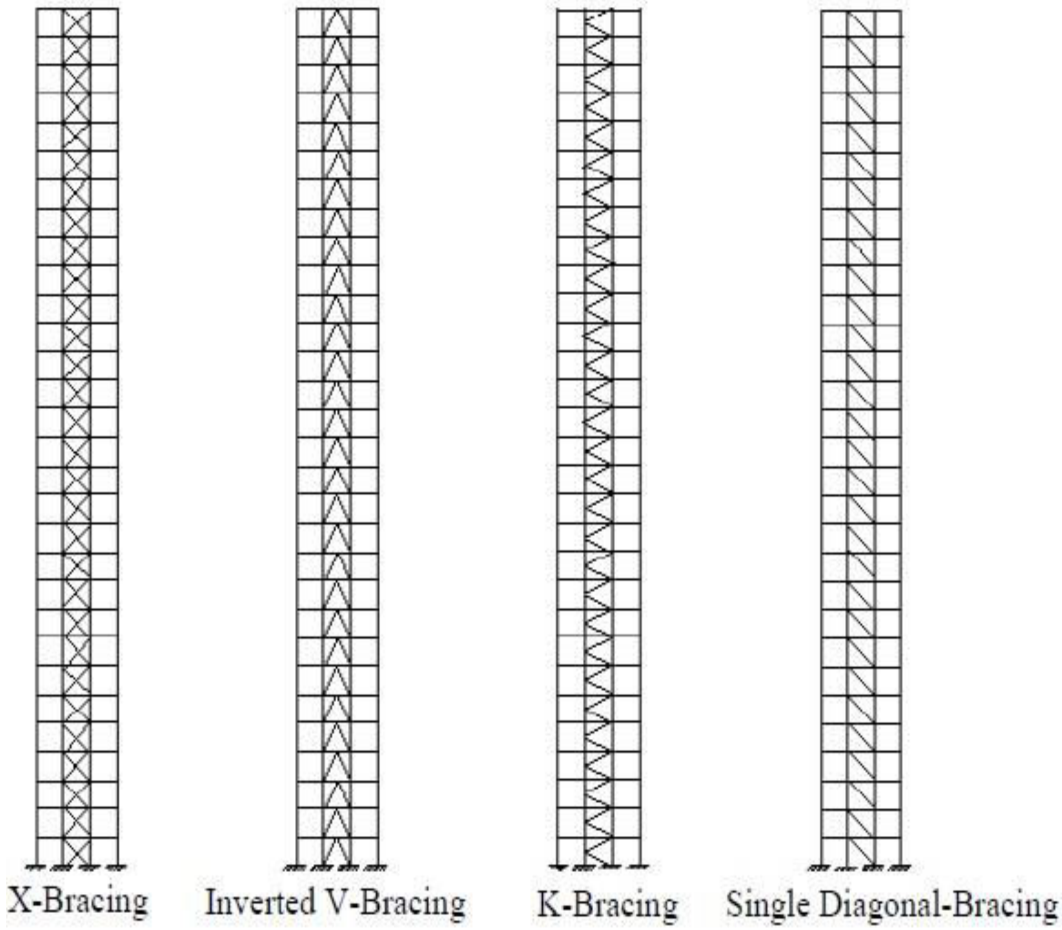

Figure 2.4 Various Types of Bracing

2.6 Lateral Drift in High Rise Building

Lateral drift was illustrated as the swayed of a structure when subjected to lateral forces. Drift must be considered in designing high rise building. In a lot of cases, size of beams and columns need to be increased as to reduce the maximum drift to an accepted limit (Kamruzzaman et al., 2002). However, this is not economical because it will increase the cost of a construction project. In addition, too much lateral drift in high rise structure will cause damage to partition or curtain walls (Ho & Schierle, 1990). Basically, there were three structural characteristics decided the lateral drift on a structure which were stiffness, strength and deformation capacity (Ghobarah, 2004). Thus, application of bracing can easily achieved the structural characteristics mentioned earlier as bracings were supplied to increase the stiffness and stability of a steel frame which subjected to lateral forces and it was able to minimize the lateral drift (Sonawane et al., 2016).

2.7 Drift Limit and Drift Index in High Rise Building

An adequate drift limit can ensure a building acquire excellent building stiffness. There were two reasons to apply drift limit in designing a tall building. The drift limit was used to prevent damaged to architectural components of a building or commonly known as acceptable serviceability limit state and the other important reason was to provide a feeling of safety to the occupants in a high rise building (McCormac & Csernak, 2012).

In the past researches, there was actually no specific drift limit was explicitly stated in design codes of current practice for the engineers to take into consideration of any definite limit on the allowable value of drift limit to be suitable applied to the high rise building. However, drift was normally measured by drift index. The usual practice drift index in designing tall building was kept in between 0.0015 to 0.0030 radians for the worst storms that occurred in a period of ten years (90mph) as to provide enough lateral stiffness to the building (McCormac & Csernak, 2012). Besides, there was another code specify the drift index for a tall building should stayed between 1/600 to 1/400 of the building height or not to exceeded about 0.01m as to sufficiently resist damaged to cladding and architectural walls and partitions (ASCE 7-05, 2006).

Drift index can be explained as the ratio between lateral displacement on top of building, Δ and total height of building, h as illustrated in equation 2.1 and Figure 2.5 that indicates on how the measurement on drift can be obtained correctly when the steel frame was loaded with horizontal force, H (McCormac & Csernak, 2012).

$$Drift\ Index = \frac{Drift, \Delta}{Building\ Height, h} \qquad 2.1$$

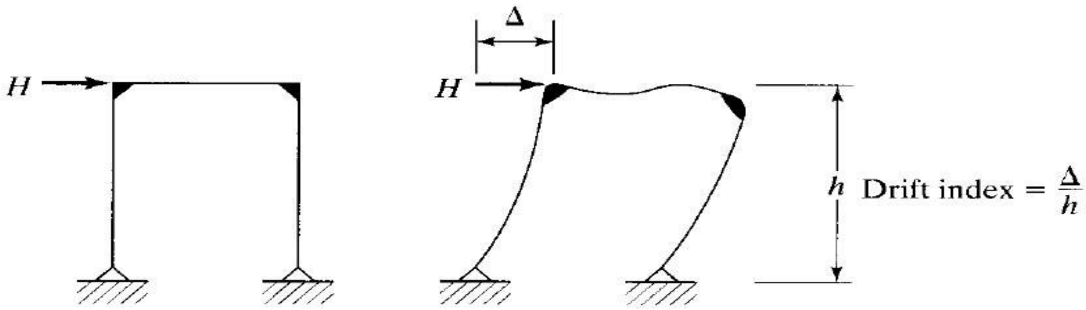

Figure 2.5 Drift Measurement

2.8 Wind Loading Calculations for High Rise Building

The calculation of wind loads as shown in Appendix A throughout this research was referred to MS 1553 2002, Code of Practice in Wind Loading for Building Structure. Firstly, the air moving from high pressure to low pressure area was called wind speed (Nyuwus, 2015). Basic wind speed was defined as in 50 years at a height of 10m, the prediction of 3 second gust speed to be over the average at only once (MS 1553 Code of Practice in Wind Loading for Building Structure, 2002). Most of the high rise structures were located in Kuala Lumpur. Thus, the basic wind speed for Zone 1 (Kuala Lumpur) was 33.5m/s. After considering all the basic parameter required, the calculated wind pressure was 1432N/m^2. The pressure was then converted to windward pressure which was 881N/m^2 and leeward pressure that carries a value of 551N/m^2. The calculated wind pressures were applied to the models in this research.

2.9 Application of Pinned Connection and Fixed Connection in Steel Frame

The application of connection must be considered and chosen correctly in order to transfer the loads acted to the structure effectively. The joint connections in steel frame can be either bolting or welding. To be more specified, the joint connections can be divided into two types which were pinned connection as shown in Figure 2.6 or fixed connection as shown in Figure 2.7. Connection of beam and column form the steel frame in rectangular grid and this formation gives effects to the performance and behaviour of the structure that subjected to different loading. In the practice of common engineering, it was normally to assume a joint connection was either rigid or pinned. The flange of the beam needed to be connected to the column if a joint connection was designed to transfer moment (Kyriakos, 2012). Moment connection or commonly known as fixed connection or rigid connection transferred shear force as well. The tension and compression from beam transferred the moment produced in the structure. On the other hand, pin connection was designed as flexible connection which was free to rotate (Dave & Savaliya, 2010). Pin connection or commonly known as semi-rigid or shear connection transferred vertical shear forces only. Therefore, it was important to recognize whether the connections were to be assumed as rigid or semi rigid. In order to compare these two types of joint connection, combination of pin and fixed connection had lesser drift index in compare with pin connection only at joint (Mcewen, 2011).

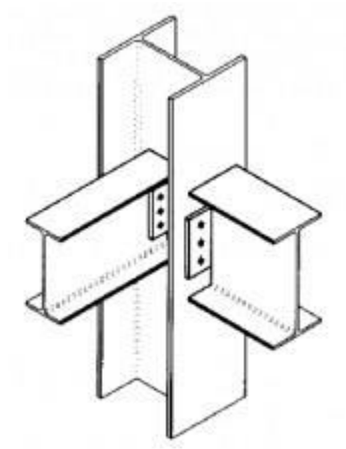

Figure 2.6 Pinned Connections

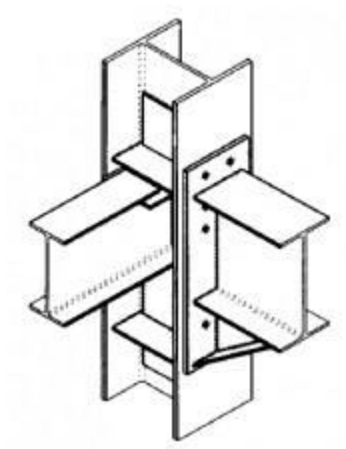

Figure 2.7 Moment Connections

2.10 Application of Finite Element Method in Civil Engineering

The Finite Element Method was a numerical approach that commonly used to solve partial differential equation in order to obtain approximate results of a model (Jerry, 2006). The application of this method was widely used in a lot of engineering fields such as structural, mechanical and aerospace in order to analyse the dynamic motions, thermal analysis and several mechanics behaviour of a body (Weck & Kim, 2004). The need in solving complex structural analysis problems in Civil Engineering was encouraged to apply this method. Finite Element Method was used as to visualize and indicate the distribution of stresses and strains for a model of a structure. In addition, the displacement in various directions of a node was determined as well. The Finite Element Analysis was commonly worked in three main steps which were Pre-processing, Solution and Post-processing as shown in Figure 2.8.

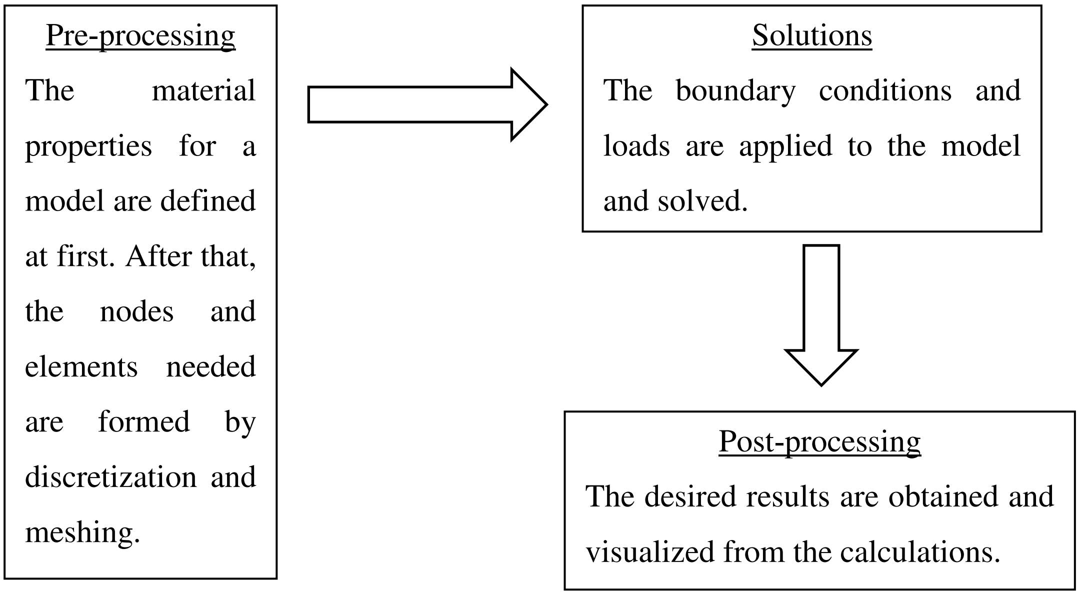

Figure 2.8 Steps in Finite Element Analysis

2.11 Elements, Nodes and Degree of Freedom in Finite Element Method

The larger size of an object was divided into a few smaller pieces by adding the nodes to the object then forming the elements by joining the nodes (Weck & Kim, 2004). The elements formed contained material properties and geometrical properties which were constant. After that, the object were modelled by the used of suitable element such as frame element, plate element, shell element and so on. In this research, the element used to analyse the frame was frame element. There was infinite number of displacements in a structure. This infinite number of displacements were well-known as number of degrees of freedom. Thus, the degree of freedoms in a structure was limited and set clearly as to obtain a reasonable solution (Barkanov, 2001). For example, there were three degree of freedoms in a node of 2-dimensional frame element as shown in Figure 2.9 which were displacement at x and y directions, (u,v), and rotation at z direction, (Θ_z).

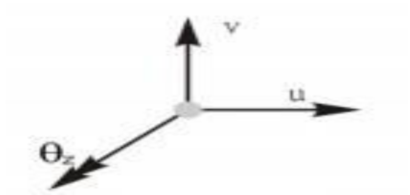

Figure 2.9 Degree of Freedom in a Node of 2-Dimensional Frame Element

2.12 Application of Plane Frame to Two Dimensional Frame

Plane Frame was commonly known as 2-dimensional frame. It was formed through the combination of 2-dimensional beam and plane truss. The members were jointed in the same plane and were connected by pin or rigid connections. Thus, the formation of plane frame had internal stresses consisted of axial force (F_x), bending moment(M_z) and shear force(F_y) (Logan, 2007) as shown in Figure 2.10. As a result, the plane frame consisted of axial deformation (u), vertical deformation (v) and rotation (Θ_z) as degree of freedoms in a node as shown in Figure 2.9 in previous section.

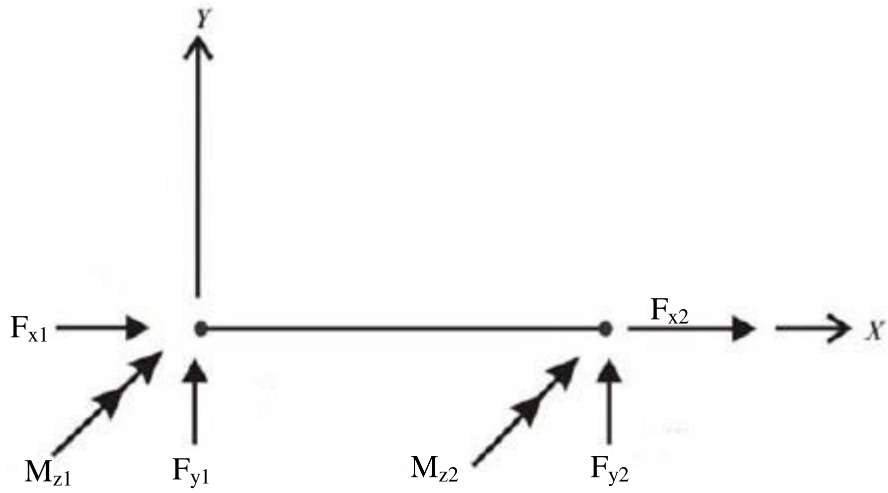

Figure 2.10 Forces in the Nodes of Plane Frame

2.13 Modelling of Two Dimensional Steel Frame by Using ANSYS

The computer software used for this study was ANSYS 12.0. This software was selected for a few reasons. The largest reason contribute the used of this software was most probably because of its simplicity and availability in the computer laboratory. On the other hand, this software was selected as it was difficult to assemble the actual size of the desired steel frame in laboratory. ANSYS 12.0 was computer software that worked based on the Finite Element Method to analyse a model and it can be considered as one of the most powerful software in calculation and analysis ability (Rui & Jianmin, 2008). The element of steel frame was modelled by the use of 2D Elast Beam 3. This two-dimensional elastic beam element was actually same as frame element in Finite Element Analysis.

CHAPTER 3

METHODOLOGY

3.1 General

The ANSYS 12.0 program was powerful software that used to perform a lot of finite element analysis. There were a few important steps involved throughout the simulation process. Thus, this chapter was further explained in detail for the steps involved in the simulation process by using ANSYS 12.0 software. There were three main phases involved in this research which are pre-processor, solution and post-processor. Each phase was very important to carry out in a careful way as to minimize the mistakes, thus increasing the accuracy of the approximated results near to the exact solutions.

3.2 Methodology Flow Chart for Analysis Process of High Rise Steel Frame Modelling

The methodology flow chart as shown in Figure 3.1 had clearly shown the modelling process involved in this research. Basically, the three main steps were pre-processor phase, solution phase and post-processor phase. Each of the phases was further divided into a few steps as to complete each phase successfully.

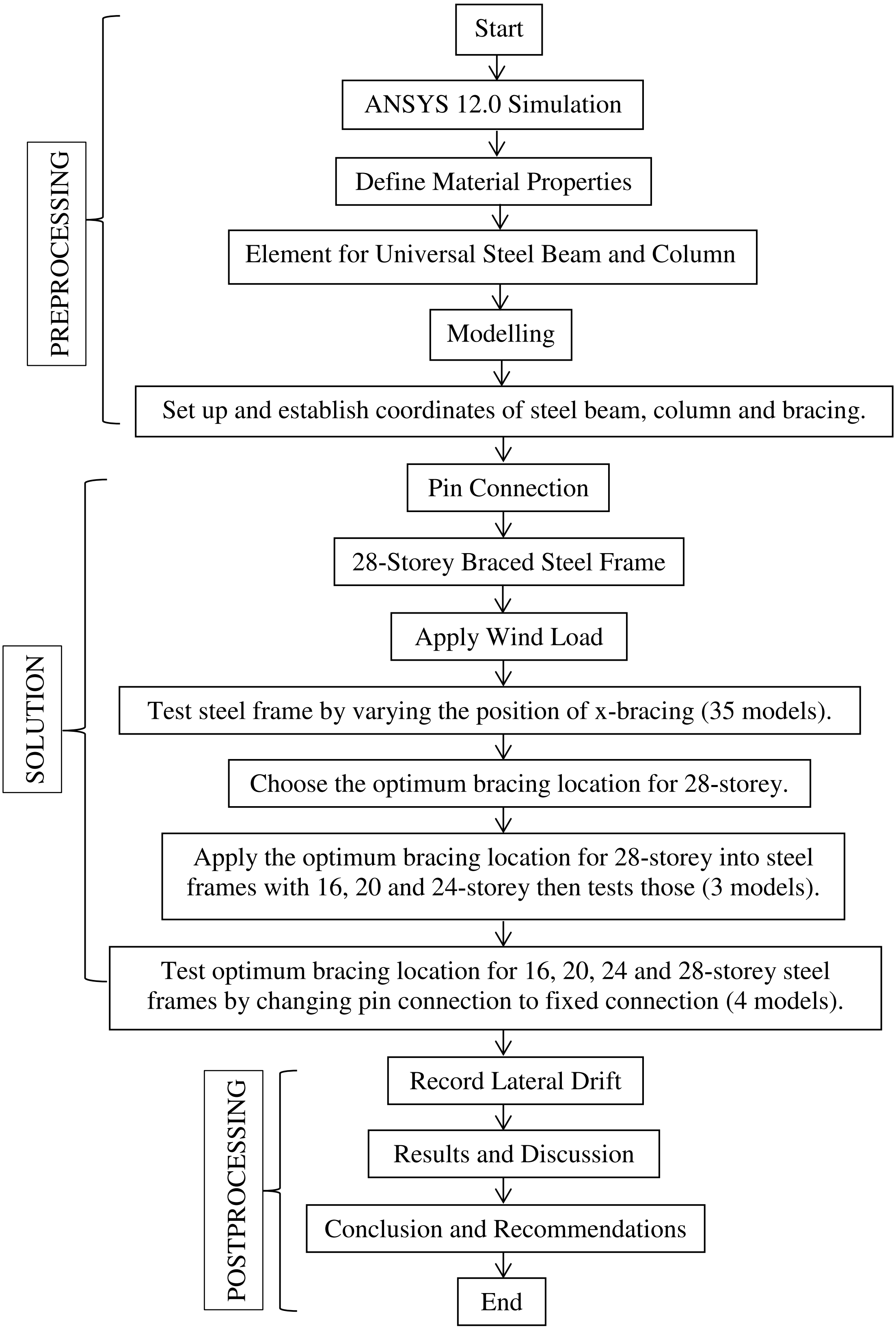

Figure 3.1 Methodology Flow Chart

3.3 Pre-processor Phase

Pre-processor was a modelling process that normally a desired frame was created in this phase. This phase was used to set the units, code, material properties, element type, element real constant, section and geometry of the frame. At first, the CivilFem in the ANSYS software was activated as to allow the user to use this special program created for the simulation of civil engineering structure. The existence of CivilFEM program in ANSYS 12.0 had made the simulation process easier as there were a lot of inputs can be chosen and automatically set in the ANSYS 12.0 software in the modelling process. At first, the analysis of the frame was started by entering or creating the new title. It was important to define a job's name for a model so that no files were overwritten in the simulation process. Thus, if the title of a job does not specify at the beginning of the analysis, the system will receive the same name for every model, therefore make the simulation process become complicated when a file need to be search upon needed.

3.3.1 Defining Codes and Units

The ANSYS program does not assume any code or units throughout the analysis of the frame. Thus, it is required to set the codes and units that one preferred in the CivilFEM. In this research, there were only steels involved in the analysis. Thus, the code was set to be Eurocode 3. After that, the units used throughout this research are SI units which the length was in meters, force was in Newton and pressure was in Pascal.

3.3.2 Defining Material Properties and Element Type

The steel grade used for the frame was S275. Therefore, the structural steel material used in the modelling was chosen as Fe E275 in CivilFEM as shown in Figure 3.2. After that, the material properties of the steel such as Poisson's ratio and Young's modulus were automatically defined in the system.

Next, the analysis of two dimensional frames by using finite element method was called frame equation. The frame equation in finite element method was actually line element. Thus, the element type was chosen as 2D Elast Beam 3 in the CivilFEM as shown in Figure 3.3 which carried the same meaning of frame equation in finite element analysis.

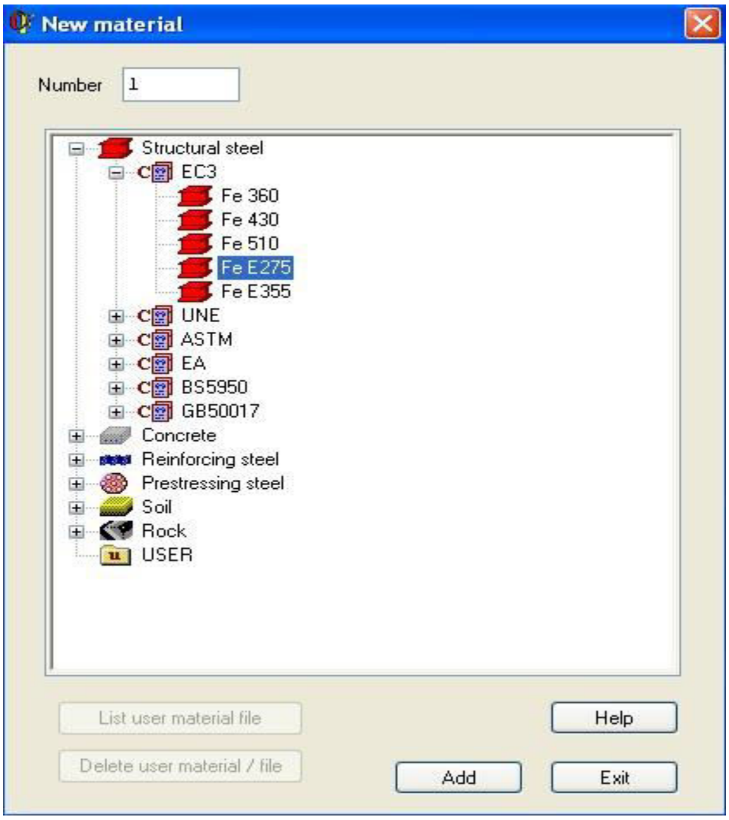

Figure 3.2 Defining Material

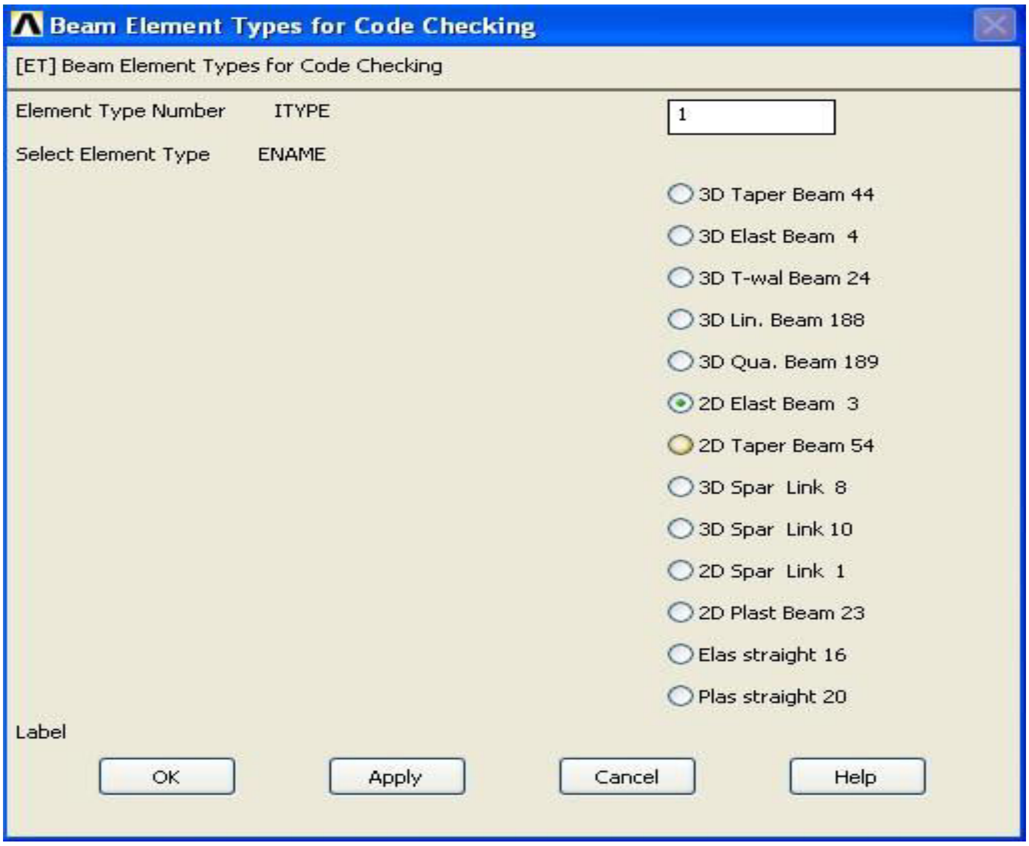

Figure 3.3 Defining Element Type

3.3.3 Defining Element Real Constants

Upon choosing the element type, the element real constant definitely depend on it. The element real constant was defining the cross section of the material chosen. Thus, the cross section of beam, columns and bracing were chosen in the hot rolled shapes library which located in CivilFEM. After the chosen of cross section in the library, the cross section properties such as depth of section, h, thickness of web, t_w, and flange, t_f, area of section, A, second moment of inertia about x, y and z axis, and so on of the properties were automatically defined in the system. For example, the cross section properties of beam section, column section and bracing section were chosen based on Figure 1.2 as shown in Figure 3.4, 3.5 and 3.6 accordingly.

Next, the member properties for each of the cross section had been set as illustrated in Figure 3.7 as to give the specific length of the various cross sections chosen earlier. After that, the material, cross section and member properties were combined as shown in Figure 3.8 to specify the real constant of each component of frame.

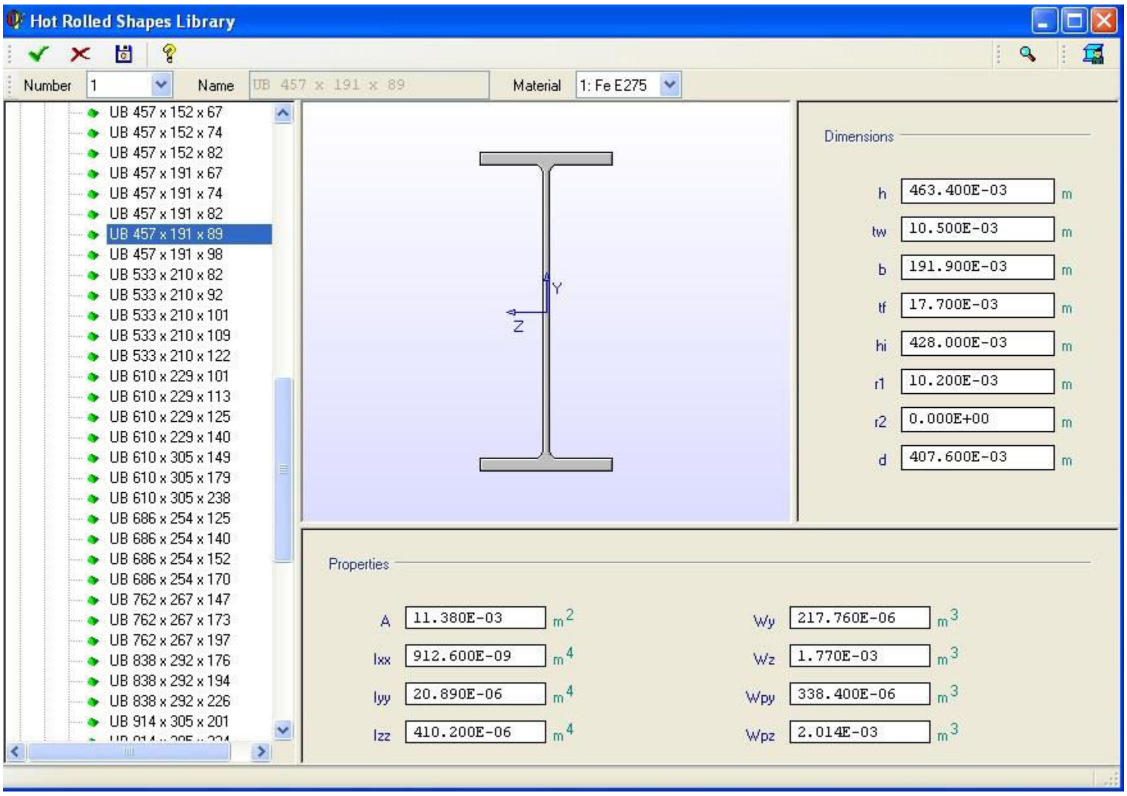

Figure 3.4 Cross Section Properties of Beam

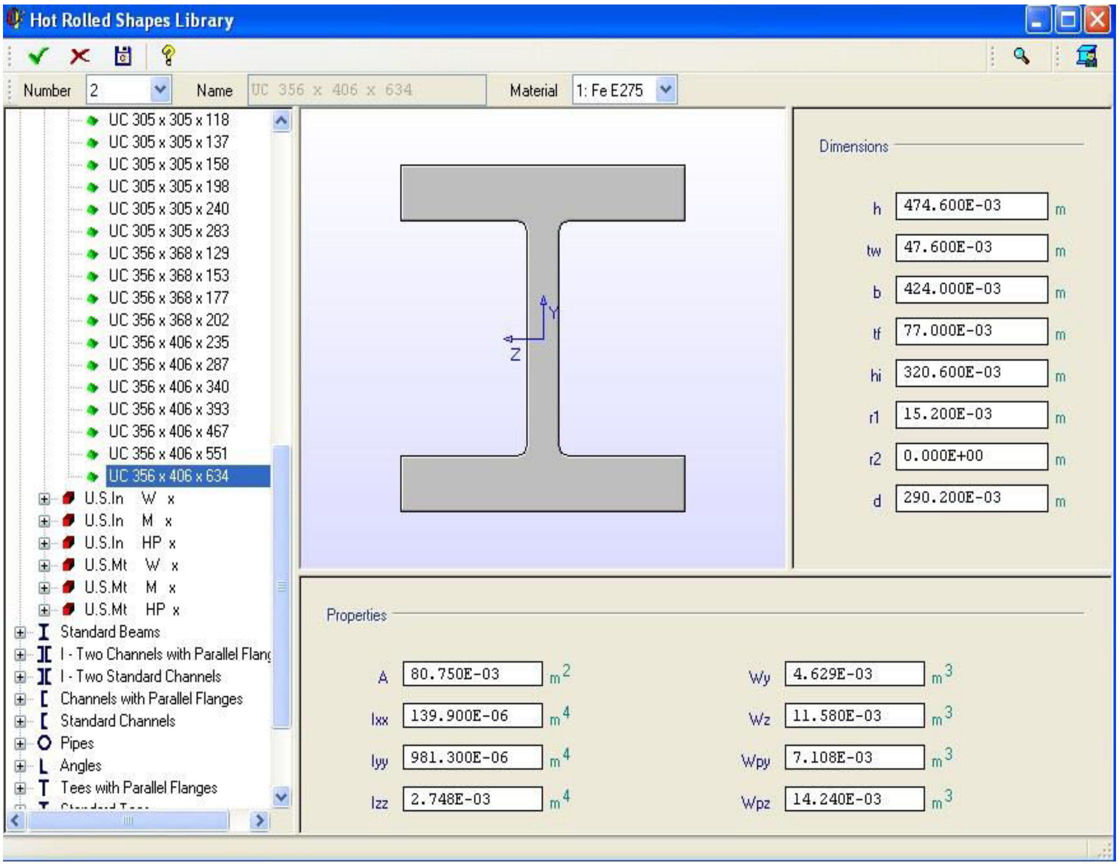

Figure 3.5 Cross Section Properties of Column (Half of the Total Storey of Frame)

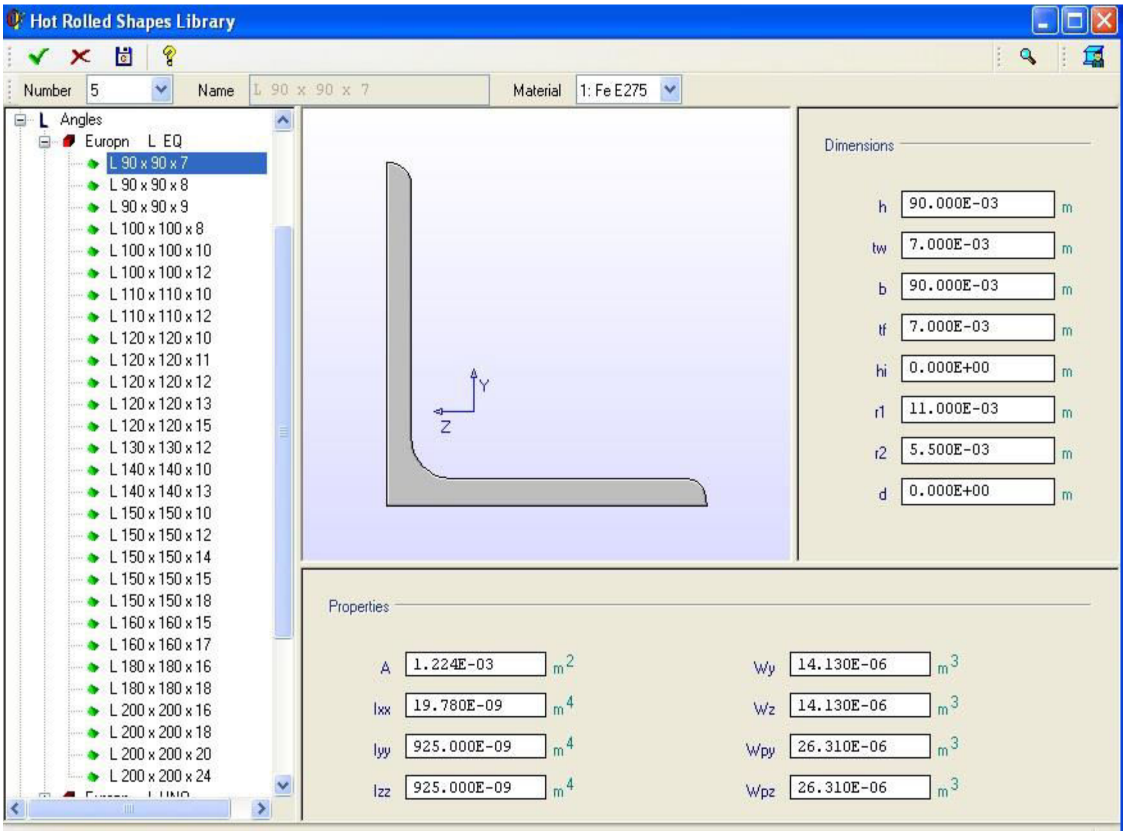

Figure 3.6 Cross Section Properties of Bracing

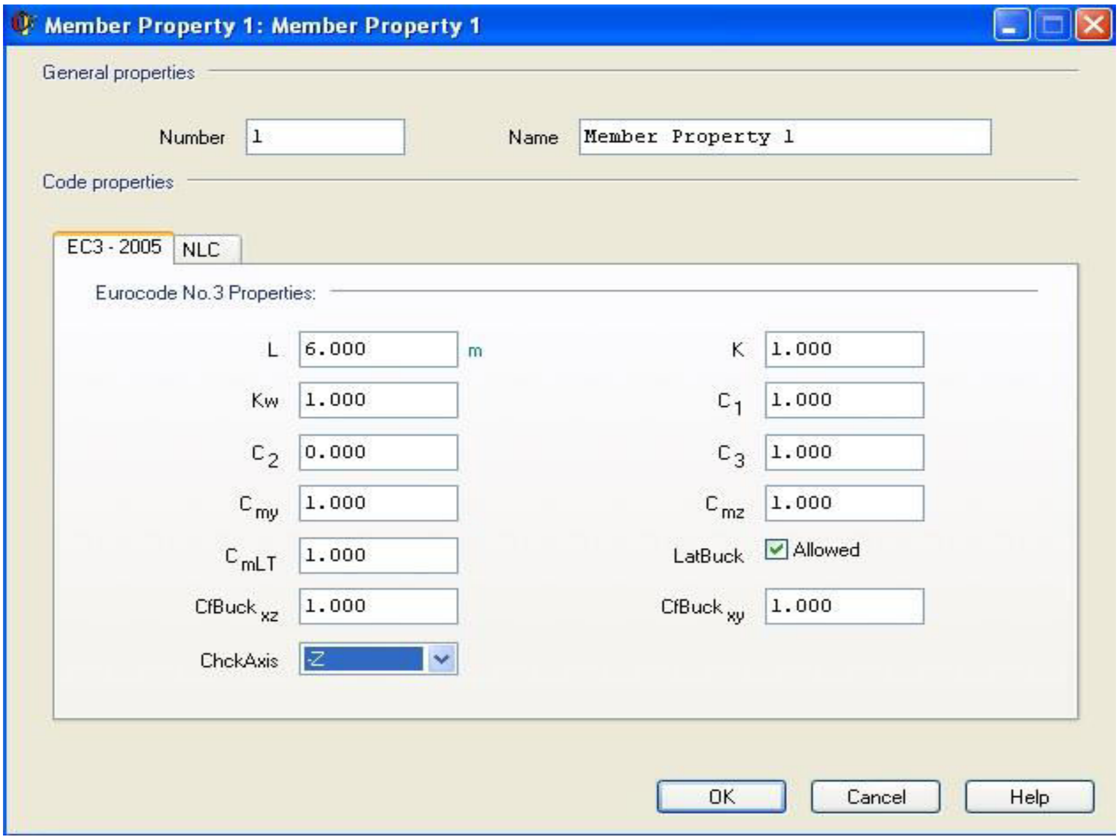

Figure 3.7 Member Properties of Beam

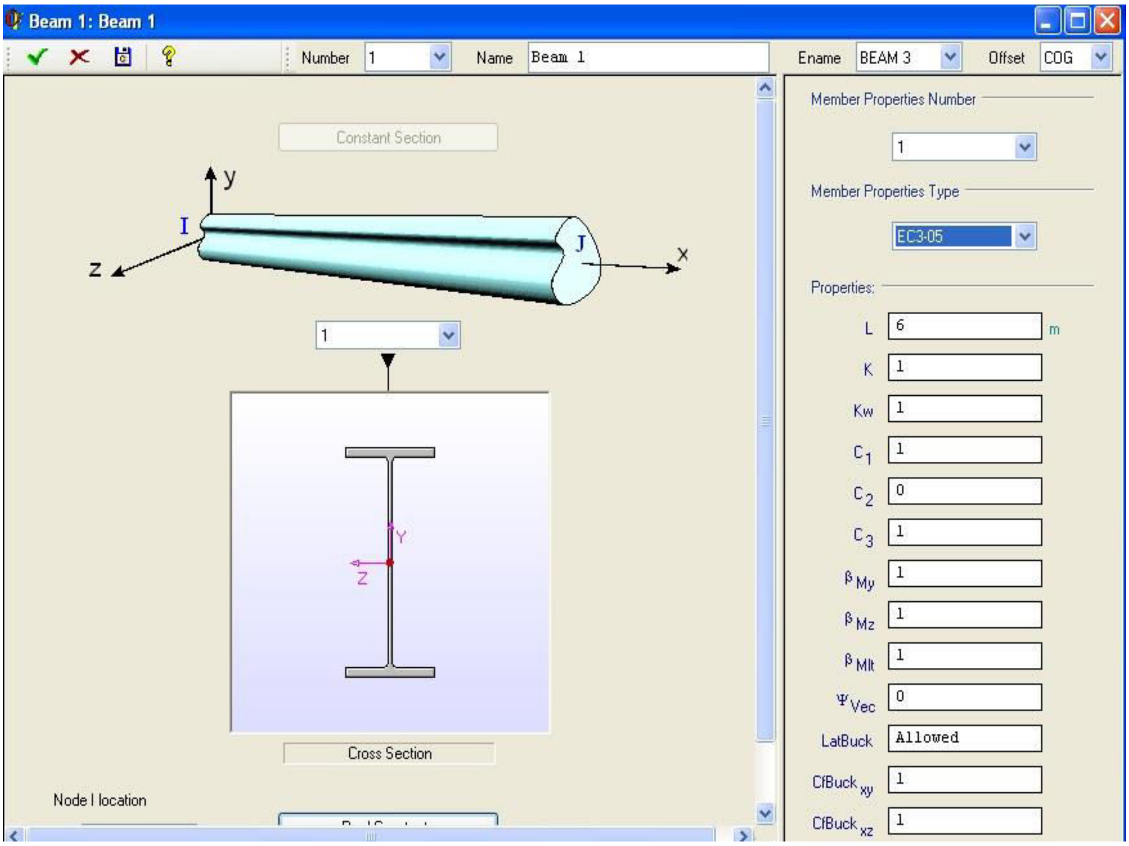

Figure 3.8 Real Constant of Beam

3.3.4 Inserting the Nodes and Elements of the Frame

At first, the first two nodes need for the modelling of frame was created in the system as shown in Figure 3.9 and 3.10. After that, the following nodes were continuously created as to meet the desired shape of the frame. The horizontal distance between two nodes in order to form a bay for the frame is 3m and the vertical distance between two nodes in order to form a storey for the frame is 6m.

Upon completing the establishment of nodes as shown in Figure 3.11, all the elements were defined in Element Attributes in such a way that real constant number 1 was specified for beam section as shown in Figure 3.12, real constant number 2 to 4 were specified for column section as shown in Figure 3.13 and real constant number 5 was specified for bracing section as shown in Figure 3.14. After choosing the real constant number in Element Attributes, the complete beam, column and bracing members were jointed as illustrated in Figure 3.15, 3.16 and 3.17 respectively.

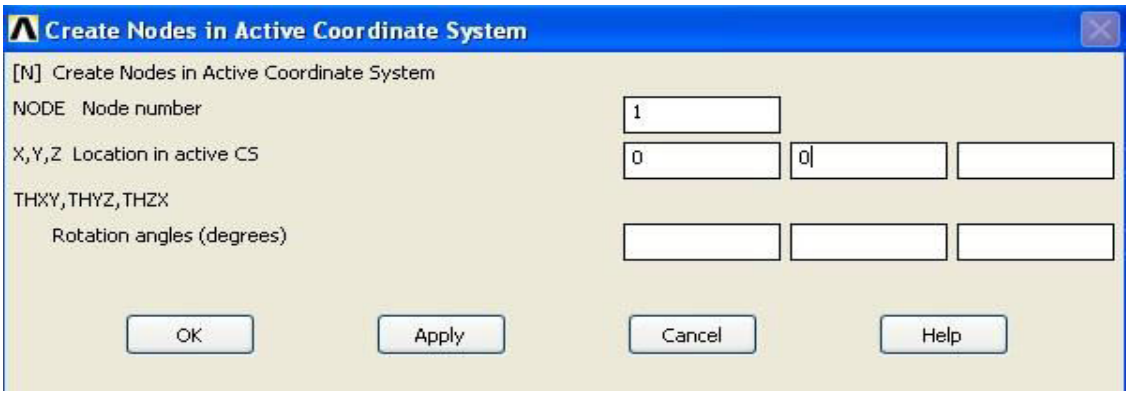

Figure 3.9 Setting the First Node of the Frame

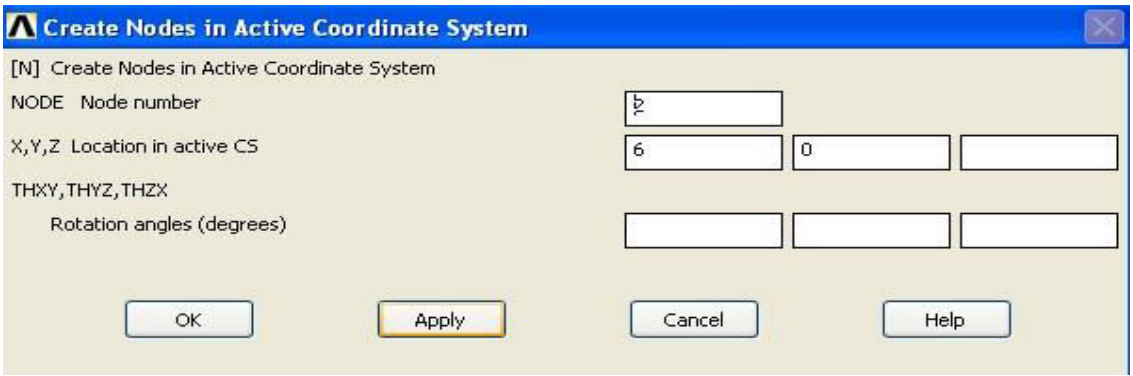

Figure 3.10 Setting the Second Nodes of the Frame

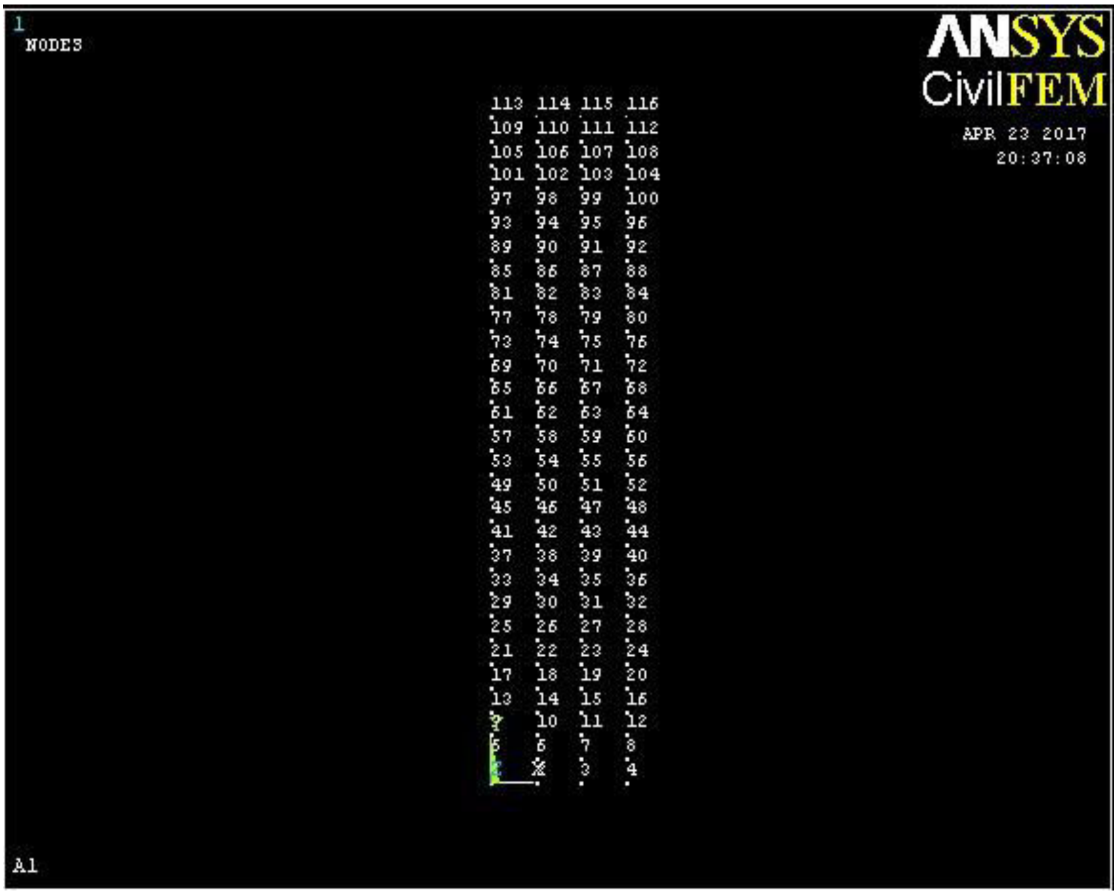

Figure 3.11 Complete Formation of Nodes Required for Frame

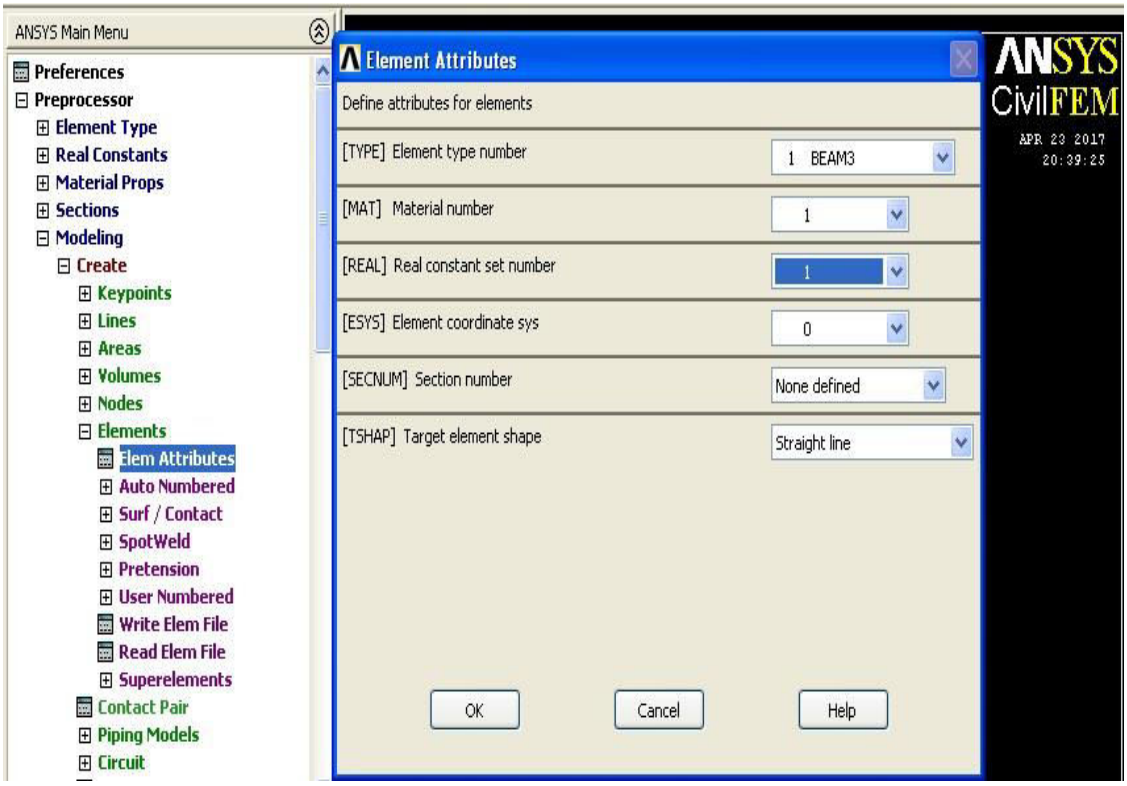

Figure 3.12 Choosing Real Constant Number 1 as Beam Element for Frame

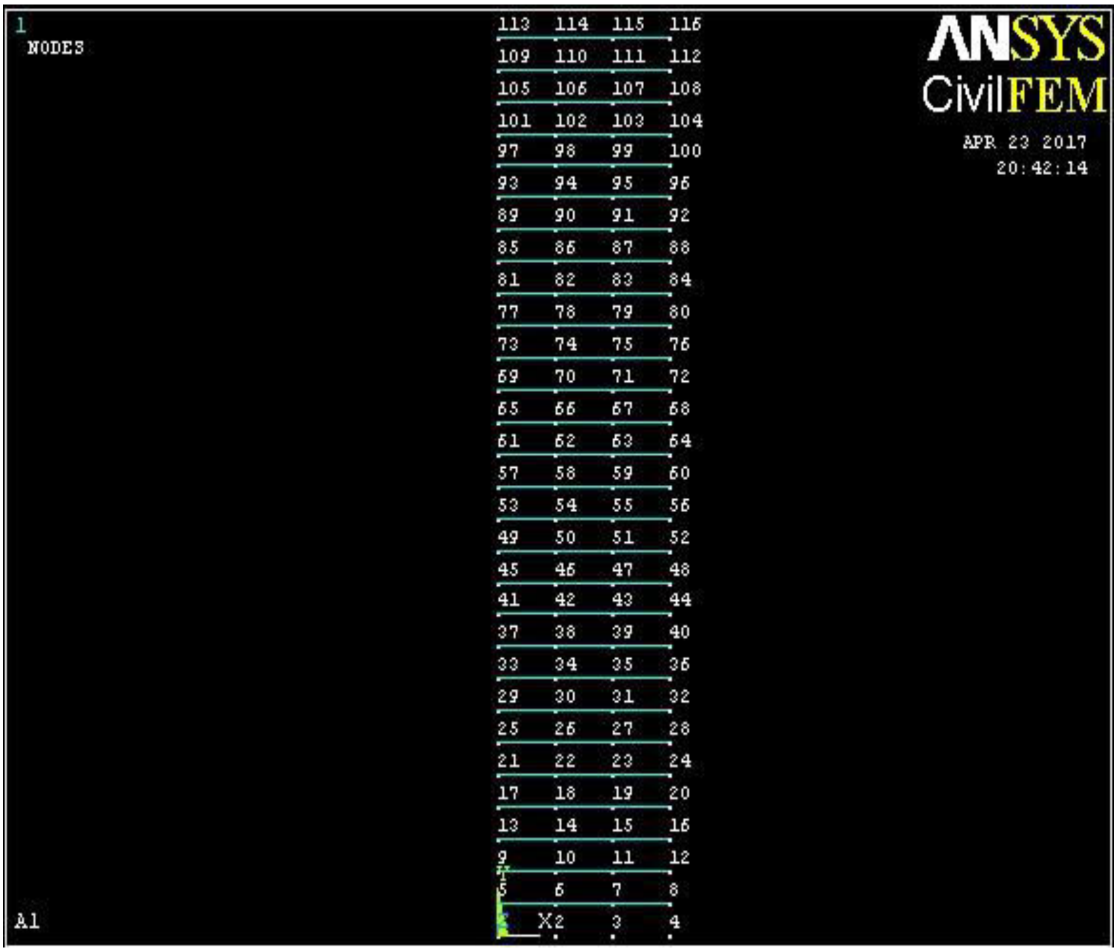

Figure 3.13 Complete Formation of Beam Elements for Frame

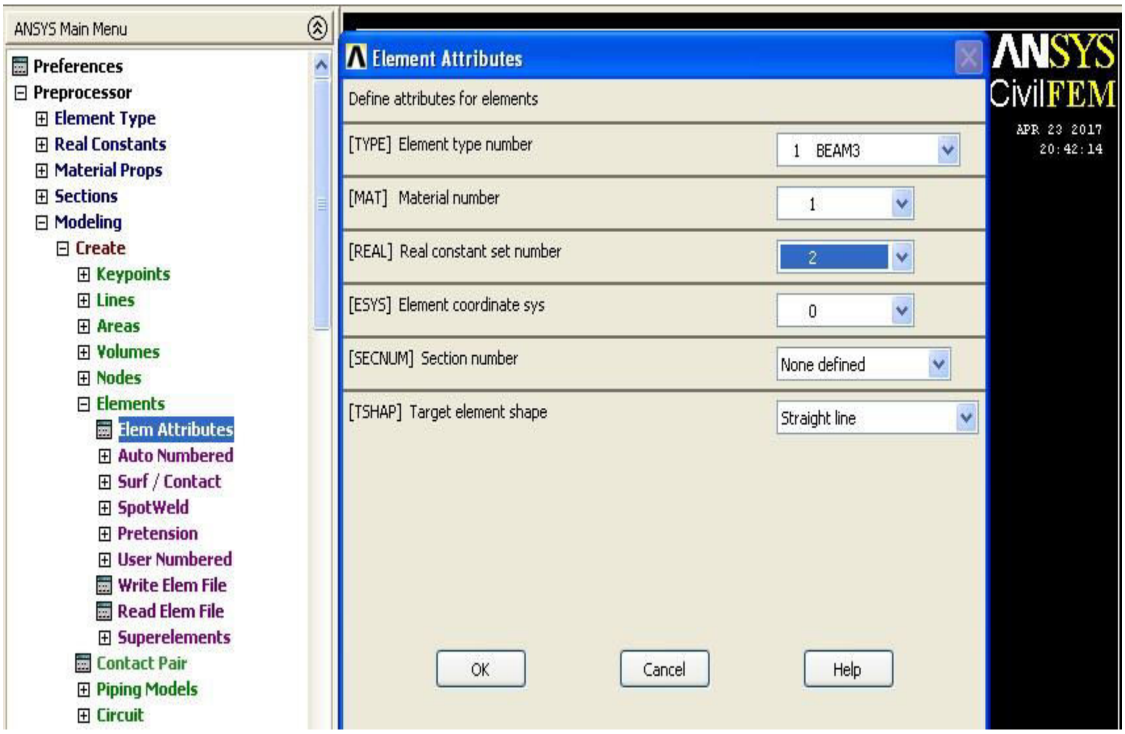

Figure 3.14 Choosing Real Constant Number 2 as Column Element for Frame

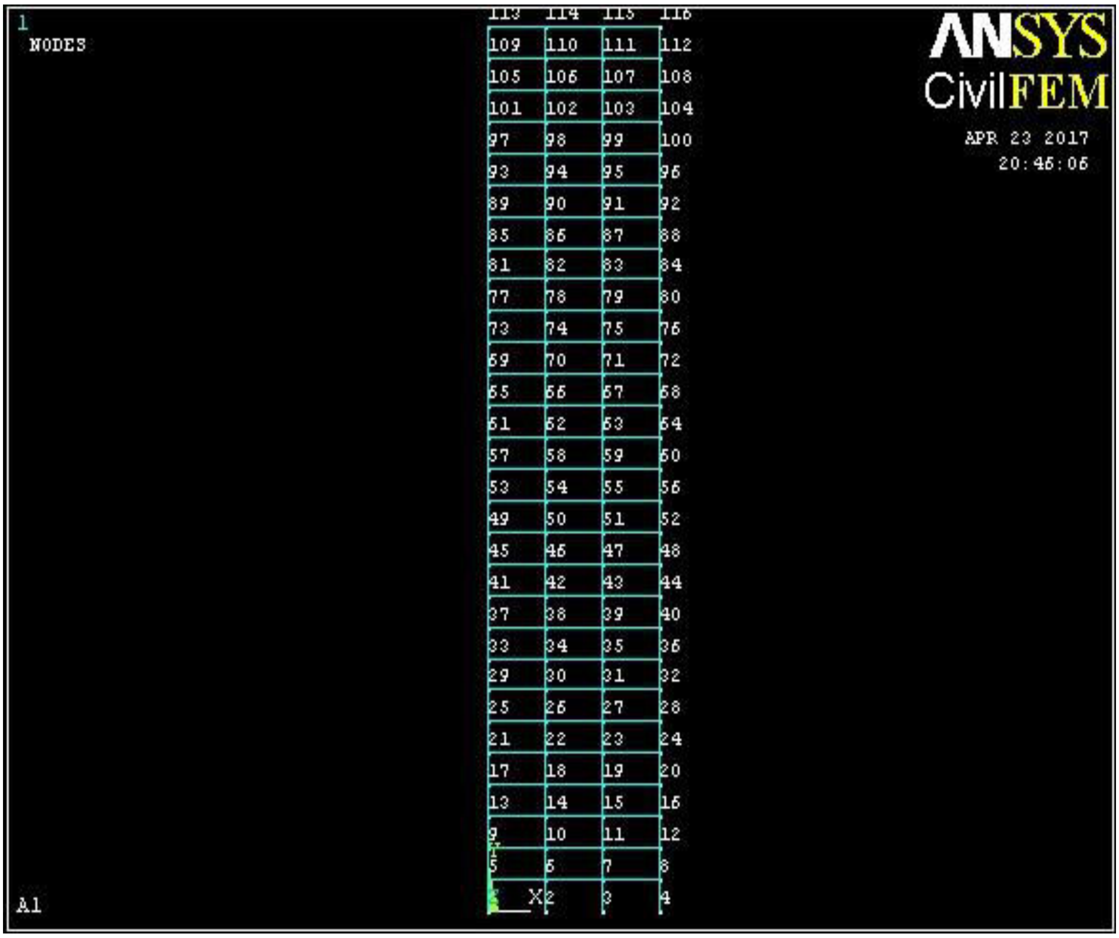

Figure 3.15 Complete Formation of Column Elements for Frame

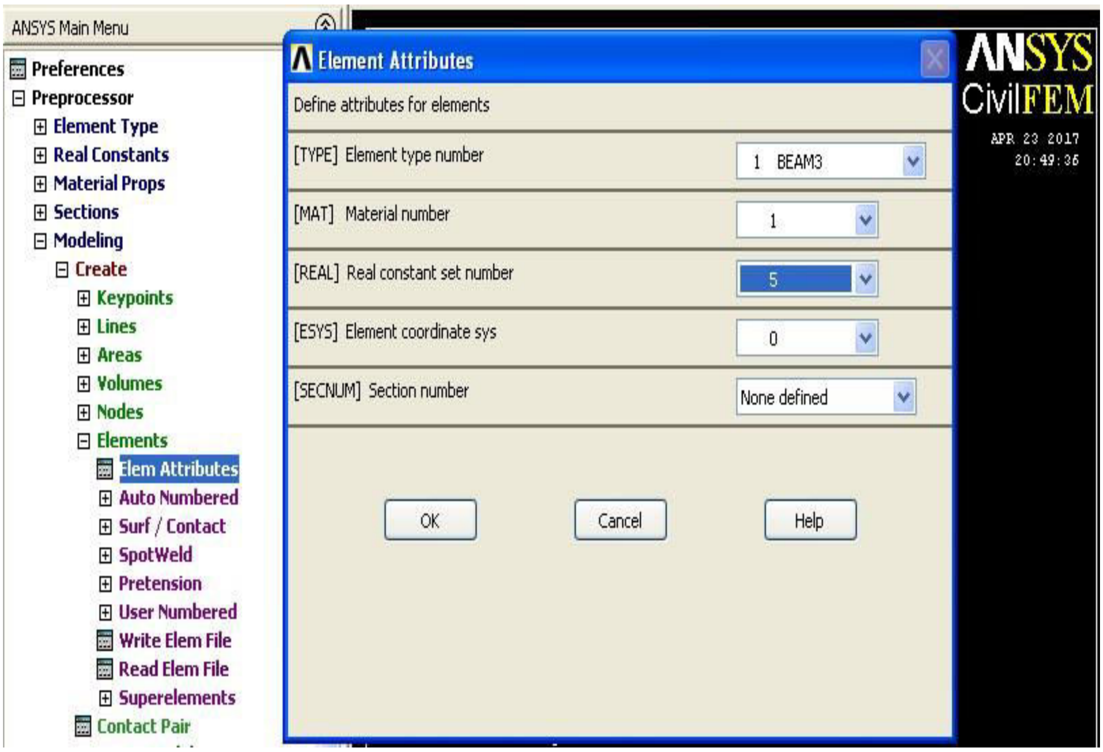

Figure 3.16 Choosing Real Constant Number 5 as Bracing Element for Frame

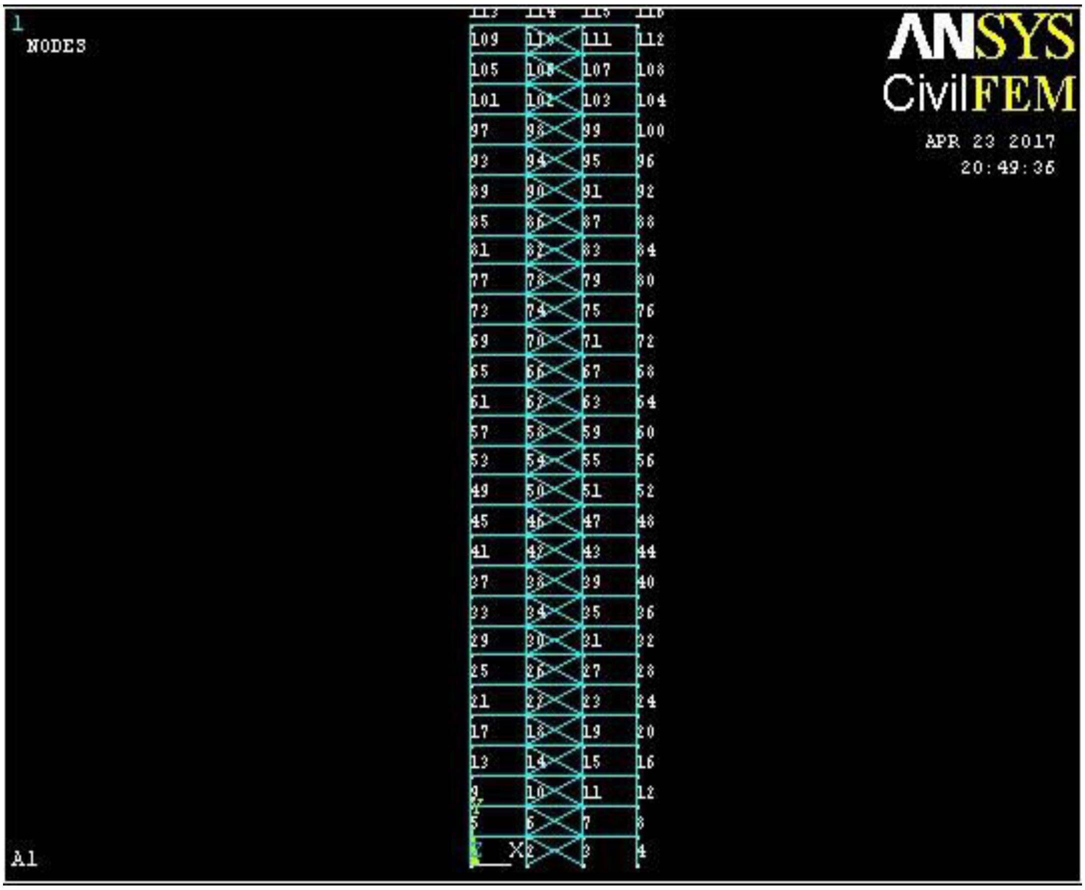

Figure 3.17 Complete Formation of Bracing Elements for Frame

3.4 Solution Phase

This phase was essential as to apply the boundary conditions and loads to the frame so that the analysis of the frame was continued. After applying the desired boundary conditions and loads, then only the software solved the calculations needed so that the desired results were obtained by using Finite Element Method. As a reminder, the results that obtained from the analysis were approximated solutions which were not the exact solutions.

3.4.1 Constraining the Displacement of Pinned Connection Frame and Combined Pin-Moment Connection Frame

For the pinned connection frame, the bottom part of it is prevented from any movement. Thus, all degree of freedom of nodes at the bottom part were constrained as shown in Figure 3.18. On the other hand, for the pin-moment connection frame, whenever the nodes were applied with bracing, the degree of freedom for rotation in z directions was restricted.

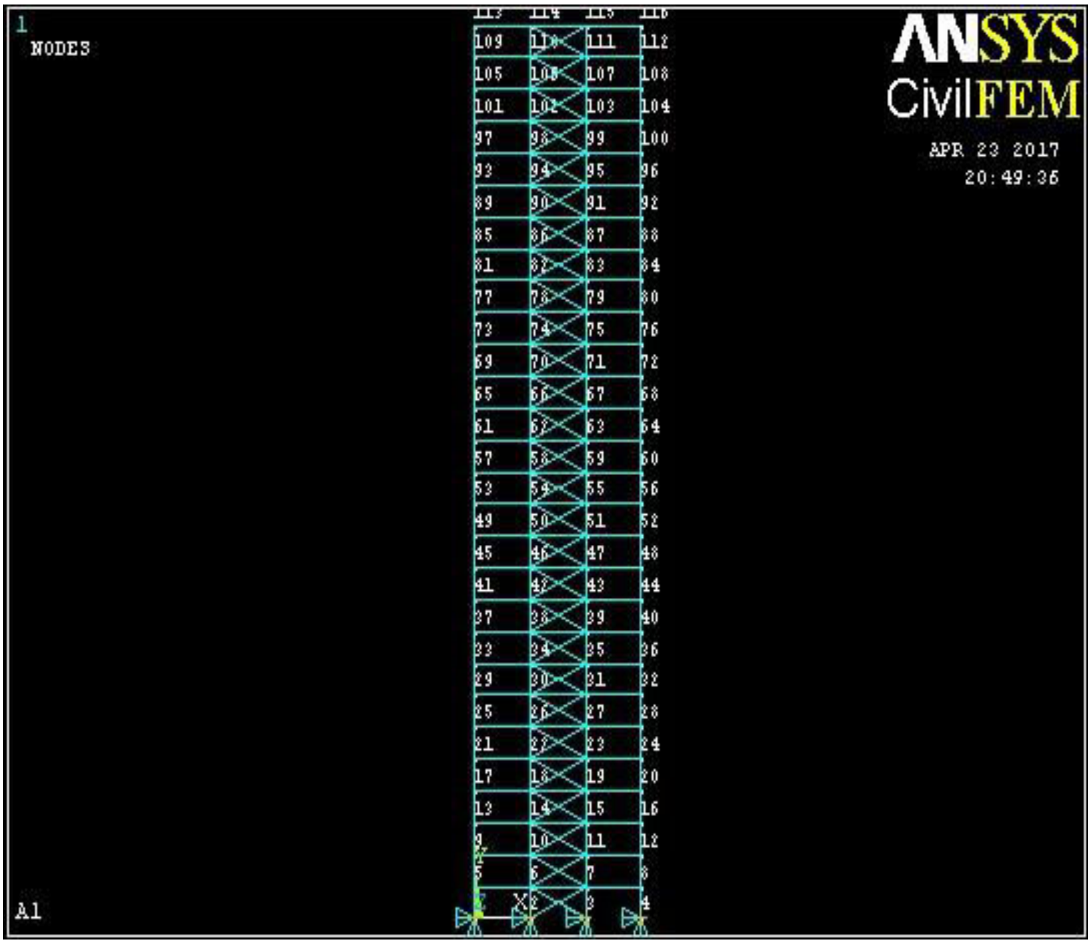

Figure 3.18 Constraining All the Degree of Freedom for Bottom Nodes

3.4.2 Application of Lateral Pressures from Wind to the Steel Frame

The final step of the modelling was to key in the lateral pressure acted onto the frame. The wind loading calculations were performed by manual calculations. After obtained the lateral pressure in manual calculations, the lateral pressures from wind was applied in windward direction and leeward direction as shown in Figure 3.20. The wind pressures acted in windward direction was 881N/m^2 and wind pressures acted in leeward direction was 551N/m^2 which gave a total lateral pressure of 1432N/m^2. After that, the model was solved as to obtain the lateral drift for the analysis.

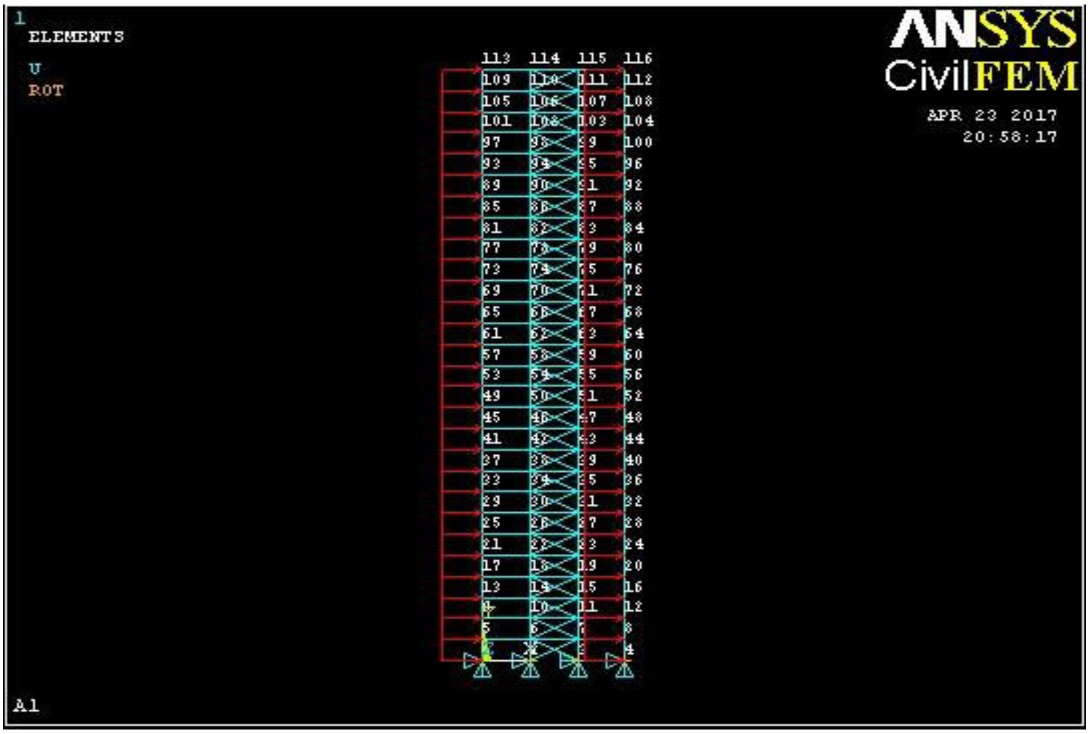

Figure 3.19 Total Lateral Pressures of 1432N/m^2 acting to the Frame

3.5 Post-processor Phase

This phase was important as to obtain the desired result for the analysis. It was the part used to review the results either in table or graphical form. The lateral drift of frame was specified as x-component of displacement or other meant the horizontal displacement can be obtained through the nodal solutions as shown in Figure 3.20.

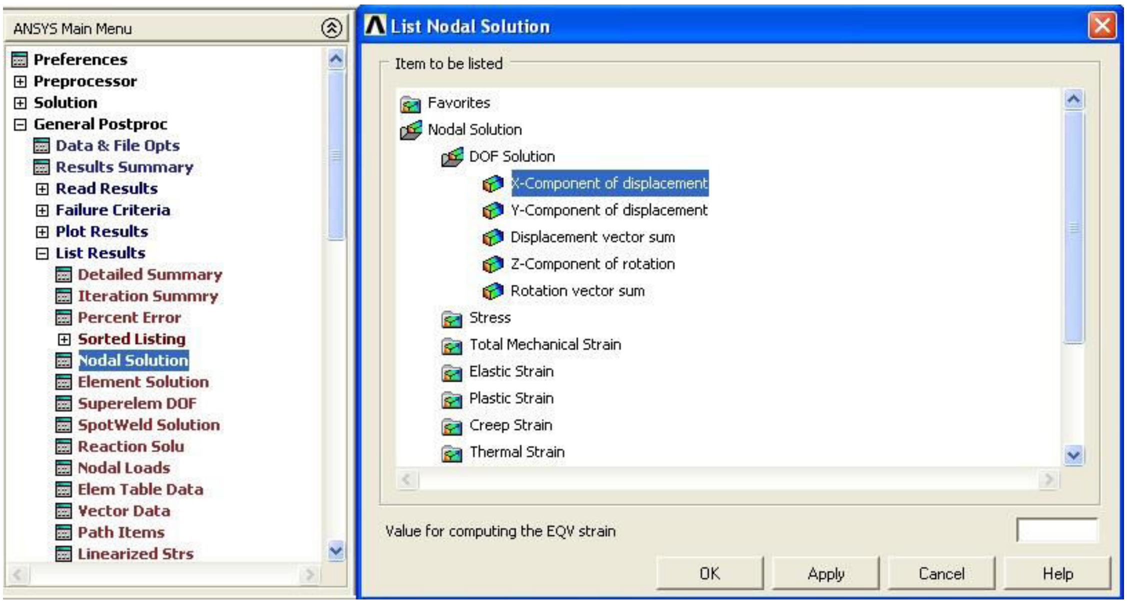

Figure 3.20 Reviewing the Lateral Drift of the Frame

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

It was impossible to test every single possible arrangement available as it will consume a lot of time for this study. In addition, different building will definitely requires different type of arrangement to achieve structure stability. In order to solve this problem, a few studies were taken as references as to determine the possible stable arrangement that fitted the steel frame in this research. After obtained the desired results, the results were tabulated and the graphs were plotted as to ease the process of comparison.

4.2 Analysis on the Effect of Centre Bay Bracing with Single Bracing on the Drift Index of 28-Storey Steel Frame

The first type of arrangement which was selected to analyse was centre bay bracing with single bay bracing with models labelled A1 to A8. For model A1, the lateral drift obtained was 0.019006m which gave a drift index of 0.0006788 whereas the lateral drift obtained for model A2 was 0.018823m and gave a drift index value of 0.0006723. Next, model A3 had moved 0.018746m laterally thus had a drift index of 0.0006695. On the other hands, model A4 had yield a horizontal displacement of 0.018213m and further resulted a value of 0.0006505 as drift index. Not only that, model A5 had a lateral drift of 0.018194m and drift index of 0.0006498. After that, model A6 and A7 were analysed, thus obtained lateral drift of 0.018370m and 0.018100, and drift index of 0.0006561 and 0.0006464 respectively. Lastly, the lateral drift and drift index obtained for model A8 were 0.018837m and 0.0006728. The summarized results of lateral drift and drift index can be viewed through Table 4.1.

Table 4.1 Drift Index of Centre Bay Bracing with Single Bracing for 28-Storey Steel Frame

Model	Maximum Lateral Drift, x (m)	Drift Index, Δ
A1	0.019006	0.0006788
A2	0.018823	0.0006723
A3	0.018746	0.0006695
A4	0.018213	0.0006505
A5	0.018194	0.0006498
A6	0.018370	0.0006561
A7	0.018100	0.0006464
A8	0.018837	0.0006728

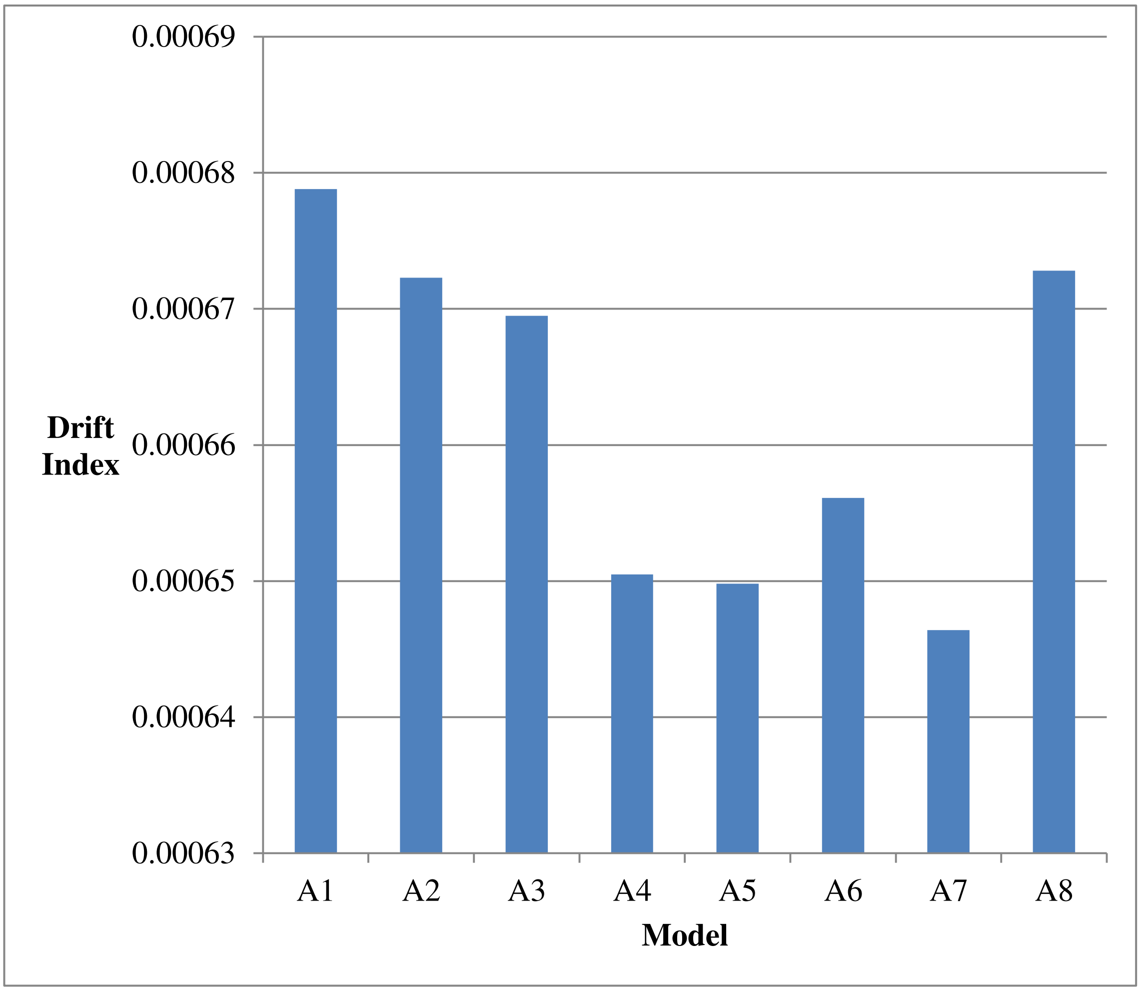

Figure 4.1 Graph of Centre Bay Bracing with Single Bracing for 28-Storey Steel Frame

The drift index for each of the model was used to compare as shown in Figure 4.1 in order to obtain the most ideal model in term of arrangement at the single bay bracing among the model of centre bay bracing only. As shown in Table 4.1 for the maximum lateral drift, the maximum drift of the floor for every model was in the range of 0.018100m to 0.019006m, whereas the drift index for the models were in the range of 0.0006728 to 0.0006788. The drift index for model A2 and A3 had reduced by 0.07% and 0.49% respectively when compared to model A8. Next, the drift index for model A5 had reduced by 0.11% as compared to model A4. The drift index for model A7 had reduced by 1.47% when compared to model A6. From Figure 4.1, it can be clearly seen that model A1 had the largest lateral drift as it had the biggest drift index value as compared with other seven models. Oppositely, it can be seen that model A7 had the lowest drift index among the models which indicated it had the minimal drift. As a result, the drift index of A7 had reduced by 4.77% as compared to model A1. Thus, the most ideal model in this comparison was model A7.

4.3 Analysis on the Effect of Centre Bay Bracing with Double Bracing on the Drift Index of 28-Storey Steel Frame

The second type of arrangement which was selected to analyse was centre bay bracing with double bay bracing with models labelled A9 to A20. For model A9, the lateral drift obtained was 0.018641m which gave a drift index of 0.0006658 whereas the lateral drift obtained for model A10 was 0.017655m and gave a drift index value of 0.0006305. Next, model A11 and A12 had moved 0.018746m and 0.018654m laterally thus had a drift index of 0.0006544 and 0.0006662 respectively. On the other hand, model A13 and A14 had yield horizontal displacement of 0.018032m and 0.018053m, thus further resulted 0.0006440 and 0.0006448 as drift index respectively. Not only that, model A15 and A16 had a lateral drift of 0.018217m and 0.017933m, thus gave drift index of 0.0006506 and 0.0006405 respectively. After that, model A17 and A18 were analysed, thus obtained lateral drift of 0.018046m and 0.018026, and drift index of 0.0006445 and 0.0006438 respectively. Lastly, the lateral drift obtained for model A19 and A20 were 0.018202m and 0.017933m, thus resulted values of 0.0006501 and 0.0006405 as drift index. The summarized results of lateral drift and drift index were illustrated in Table 4.2.

Table 4.2 Drift Index of Centre Bay Bracing with Double Bracing for 28-Storey Steel Frame

Model	Maximum Lateral Drift, x (m)	Drift Index, Δ
A9	0.018641	0.0006658
A10	0.017655	0.0006305
A11	0.018322	0.0006544
A12	0.018654	0.0006662
A13	0.018032	0.0006440
A14	0.018053	0.0006448
A15	0.018217	0.0006506
A16	0.017933	0.0006405
A17	0.018046	0.0006445
A18	0.018026	0.0006438
A19	0.018202	0.0006501
A20	0.017933	0.0006405

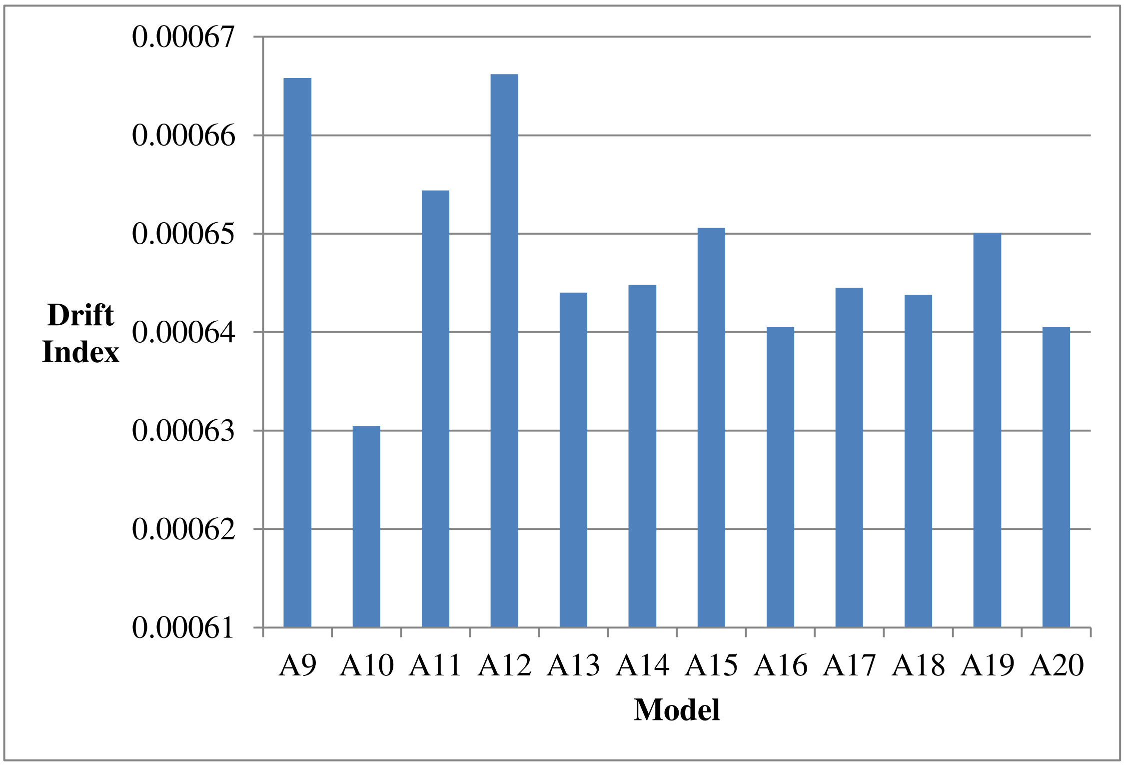

Figure 4.2 Graph of Centre Bay Bracing with Double Bracing for 28-Storey Steel Frame

The drift index for each of the model was used to compare as to obtain the most ideal model in term of arrangement at the double bay bracing among the model of centre bay bracing only. As shown in Table 4.2 for the maximum lateral drift, the maximum drift of the floor for every model was in the range of 0.017655m to 0.018654m, whereas the drift index for the models were located in the range of 0.0006305 to 0.0006662. On the other hands, the drift index for model A10 and A11 had reduced by 5.30% and 1.71% respectively when compared to model A9. Next, the drift index for model A13 had reduced by 0.12% as compared to model A14. Not only that, the drift index for model A16 had reduced by 1.55% when compared to model A15. Furthermore, model A18 had obtained a reduction of 0.11% for drift index in comparison with model A17, whereas model A20 had obtained a reduction of 1.47% for drift index in comparison with model A19. From Figure 4.2, it can be clearly seen that model A12 had the largest lateral drift as it had the biggest drift index value or it had moved with the largest lateral displacement as compared with other eleven models. Oppositely, it can be seen that model A10 had the lowest drift index among the models which indicated it had the minimal drift or other meant it had the least horizontal movement. As a result, the drift index of A10 had reduced by 5.36% as compared to model A12. Thus, the most ideal model in this comparison was model A10 and it was shown in Figure 4.2.

4.4 Analysis on the Effect of Centre Bay Bracing with Triple Bracing on the Drift Index of 28-Storey Steel Frame

The third type of arrangement which was selected to analyse was centre bay bracing with triple floor bracing with models labelled A21 to A26. For model A21, the lateral drift obtained was 0.017562m which gave a drift index value of 0.0006272 whereas the lateral drift obtained for model A22 was 0.017465m and gave a drift index value of 0.0006238. Next, model A23 had moved 0.017509m laterally thus had a drift index value of 0.0006253. On the other hand, model A24 had yield a horizontal displacement of 0.017300m and further resulted a value of 0.0006179 as drift index. Not only that, model A25 had a lateral drift of 0.017353m and drift index value of 0.0006198. Lastly, the lateral drift and drift index obtained for model A26 were 0.017323m and 0.0006187. The summarized results of lateral drift and drift index can be viewed through Table 4.3 and Figure 4.3.

Table 4.3 Drift Index of Centre Bay Bracing with Triple Bracing for 28-Storey Steel Frame

Model	Maximum Lateral Drift, x (m)	Drift Index, Δ
A21	0.017562	0.0006272
A22	0.017465	0.0006238
A23	0.017509	0.0006253
A24	0.017300	0.0006179
A25	0.017353	0.0006198
A26	0.017323	0.0006187

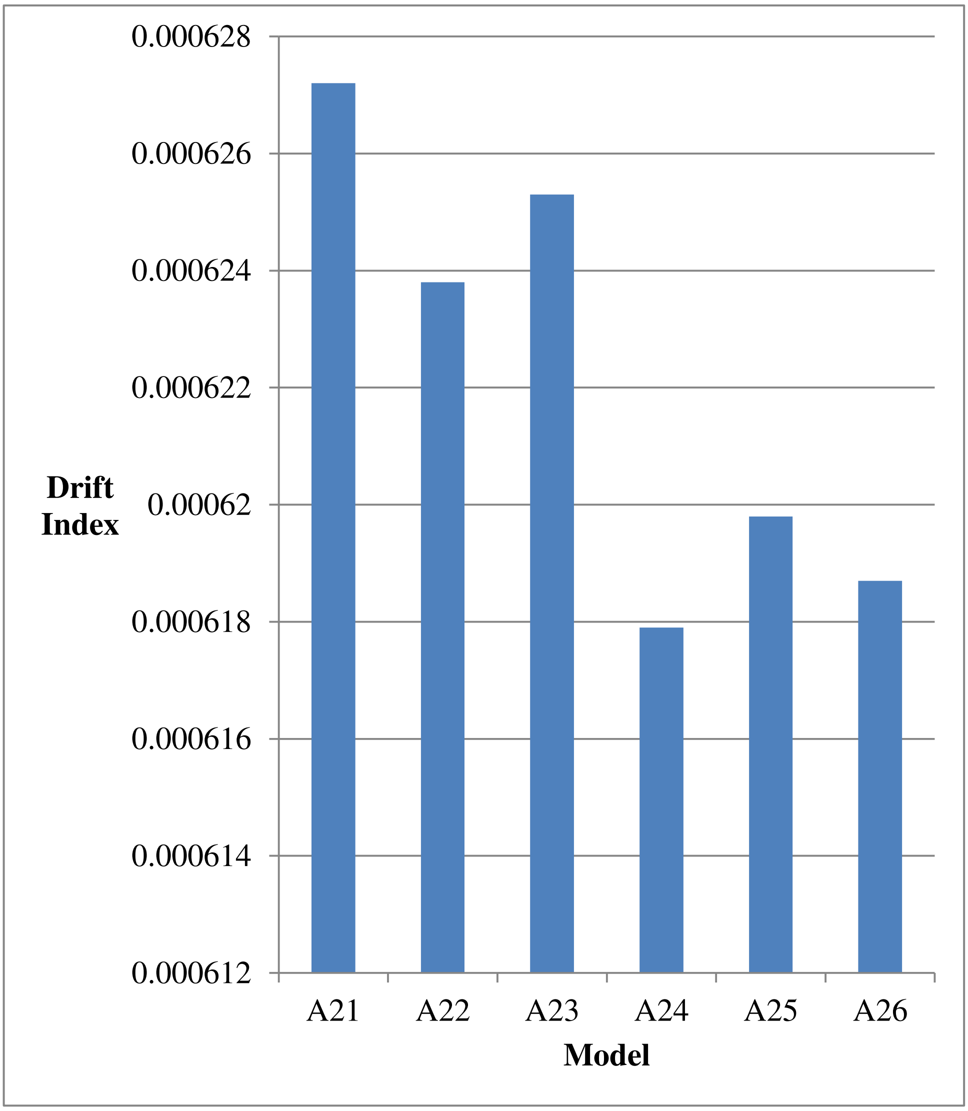

Figure 4.3 Graph of Centre Bay Bracing with Triple Bracing for 28-Storey Steel Frame

The drift index for each of the model was used to compare as to obtain the most ideal model in term of arrangement at the tripe bay bracing among the model of centre bay bracing only. As shown in Table 4.3 for the maximum lateral drift, the maximum drift of the floor for every model was in the range of 0.017300m to 0.017562m, whereas the drift index for the models were located in the range of 0.0006179 to 0.0006272. The drift index for model A22 and A23 had reduced by 0.54% and 0.30% respectively when compared to model A21. Furthermore, model A24 had obtained a reduction of 0.31% for drift index in comparison with model A25, whereas model A26 had obtained a reduction of 0.18% for drift index in comparison with model A25. From Figure 4.3, it can be clearly seen that model A21 had the largest lateral drift as it had the biggest drift index value as it had move laterally at larger displacement when compared with other five models. It can be seen that model A21 had the lowest drift index among the models which indicated it had the minimal drift or other mean it had the lowest horizontal displacement in the comparison. The drift index of A21 reduced by 1.48% compared to model A24. Thus, the most ideal model in this comparison was model A21.

4.5 Analysis on the Effect of Pattern Bracing on the Drift Index of 28-Storey Steel Frame

The fourth type of arrangement which was selected to analyse was pattern bracing with models labelled A27 to A30. For model A27, the lateral drift obtained was 0.017086m which gave a drift index of 0.0006102 whereas the lateral drift obtained for model A28 was 0.017259m and gave a drift index of 0.0006164. Next, model A29 had moved 0.019219m laterally in x direction, thus had a drift index of 0.0006864. Lastly, model A30 had yield a horizontal displacement of 0.016562m and further resulted a value of 0.0005915 as drift index. The summarized results of lateral drift and drift index were illustrated in Table 4.4 and Figure 4.4.

Table 4.4 Drift Index of Pattern Bracing for 28-Storey Steel Frame

Model	Maximum Lateral Drift, x (m)	Drift Index, Δ
A27	0.017086	0.0006102
A28	0.017259	0.0006164
A29	0.019219	0.0006864
A30	0.016562	0.0005915

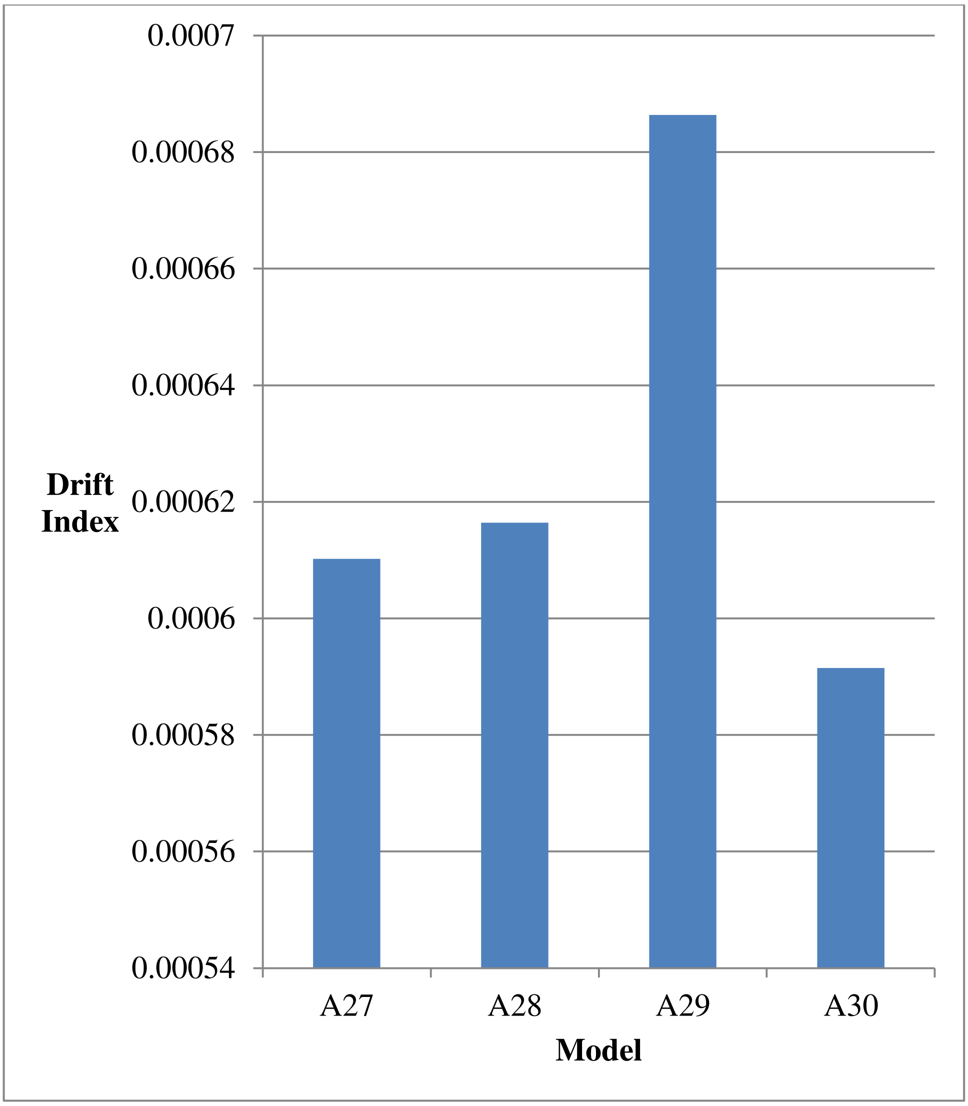

Figure 4.4 Graph of Pattern Bracing for 28-Storey Steel Frame

The drift index for each of the model was used to compare as to obtain the most ideal model in term of arrangement in pattern bracing. As shown in Table 4.4 for the maximum lateral drift, the maximum drift of the floor for every model was in the range of 0.016562m to 0.019219m, whereas the drift index for the models were located in the range of 0.0005915 to 0.0006864. Model A27 had obtained a reduction of 11.10% for drift index in comparison with model A29, whereas model A28 had obtained a reduction of 10.20% for drift index in comparison with model A29. From Figure 4.4, it can be clearly seen that model A29 had the largest lateral drift as it had the biggest drift index value as compared with other three models. Oppositely, it can be seen that model A30 had the lowest drift index among the models which indicated it had the minimal drift. As a result, the drift index of A30 had reduced by 13.83% as compared to model A29. Thus, the most ideal model in this comparison was model A30.

4.6 Analysis on the Effect of Exterior Bracing on the Drift Index of 28-Storey Steel Frame

The last type of arrangement which was selected to analyse was exterior bay bracing with models labelled A31 to A35. For model A31, the lateral drift obtained was 0.014960m which gave a drift index of 0.0005343 whereas the lateral drift obtained for model A32 was 0.014710m and gave a drift index value of 0.0005254. Next, model A33 had moved 0.014716m laterally thus had a drift index of 0.0005256. On the other hand, model A34 had yield a horizontal displacement of 0.014497m and further resulted a value of 0.0005178 as drift index. Finally, model A35 had a lateral drift of 0.014495m and drift index of 0.0005177. The summarized results of lateral drift and drift index can be viewed through Table 4.5 and Figure 4.5.

Table 4.5 Drift Index of Exterior Bracing for 28-Storey Steel Frame

Model	Maximum Lateral Drift, x (m)	Drift Index, Δ
A31	0.014960	0.0005343
A32	0.014710	0.0005254
A33	0.014716	0.0005256
A34	0.014497	0.0005178
A35	0.014495	0.0005177

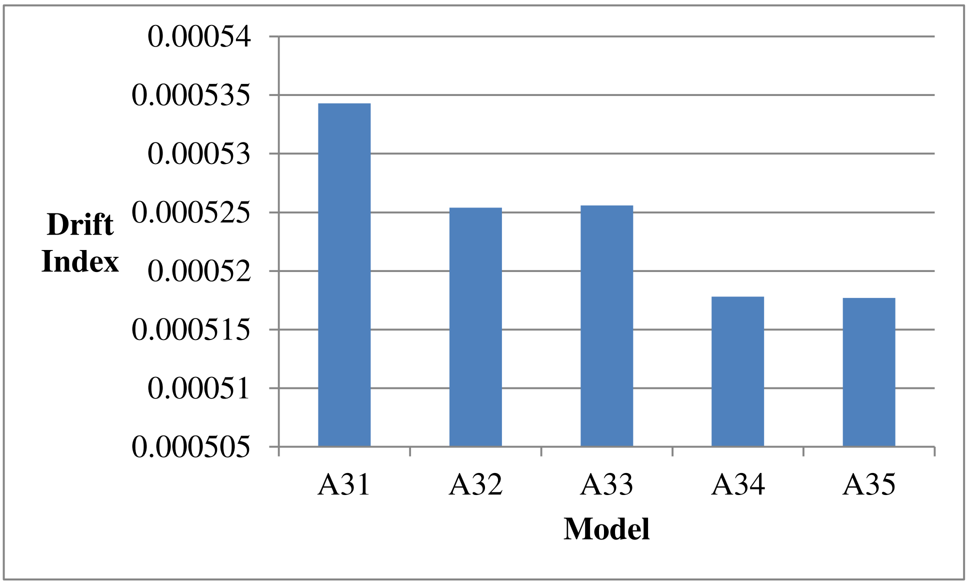

Figure 4.5 Graph of Exterior Bracing for 28-Storey Steel Frame

The drift index for each of the model was used to compare as to obtain the most ideal model in term of arrangement at exterior bracing. As shown in Table 4.5 for the maximum lateral drift, the maximum drift of the floor for every model was in the range of 0.014495m to 0.014960m, whereas the drift index for the models were located in the range of 0.0005177 to 0.0005343. Model A32 had obtained a reduction of 0.04% for drift index in comparison with model A33, whereas model A35 had obtained a reduction of 0.02% for drift index in comparison with model A34. From Figure 4.5, it can be clearly seen that model A31 had the largest lateral drift as it had the biggest drift index value as compared with other four models. Oppositely, it can be seen that model A35 had the lowest drift index among the models which indicated it had the minimal drift. As a result, the drift index of A35 had reduced by 3.1% as compared to model A31. Thus, the most ideal model in this comparison was model A35.

4.7 Comparison of Drift Index of Best Models for Each of the Case for 28-Storey Steel Frame

The drift index for each of the best model in each of the case for 28-storey steel frame was used for comparison as to get the most ideal model in term of arrangement. As shown in Table 4.6 for the maximum lateral drift, the maximum drift of the floor for every model is in the range of 0.014495m to 0.018100m, whereas the drift index for the models were located in the range of 0.0005177 to 0.0006464. The comparison for the best model in each case was illustrated in Figure 4.6.

Table 4.6 Drift Index of Best Models for Each Case of 28-Storey Steel Frame

Model	Maximum Lateral Drift, x (m)	Drift Index, Δ
A7	0.018100	0.0006464
A10	0.017655	0.0006305
A24	0.017300	0.0006179
A30	0.016562	0.0005915
A35	0.014495	0.0005177

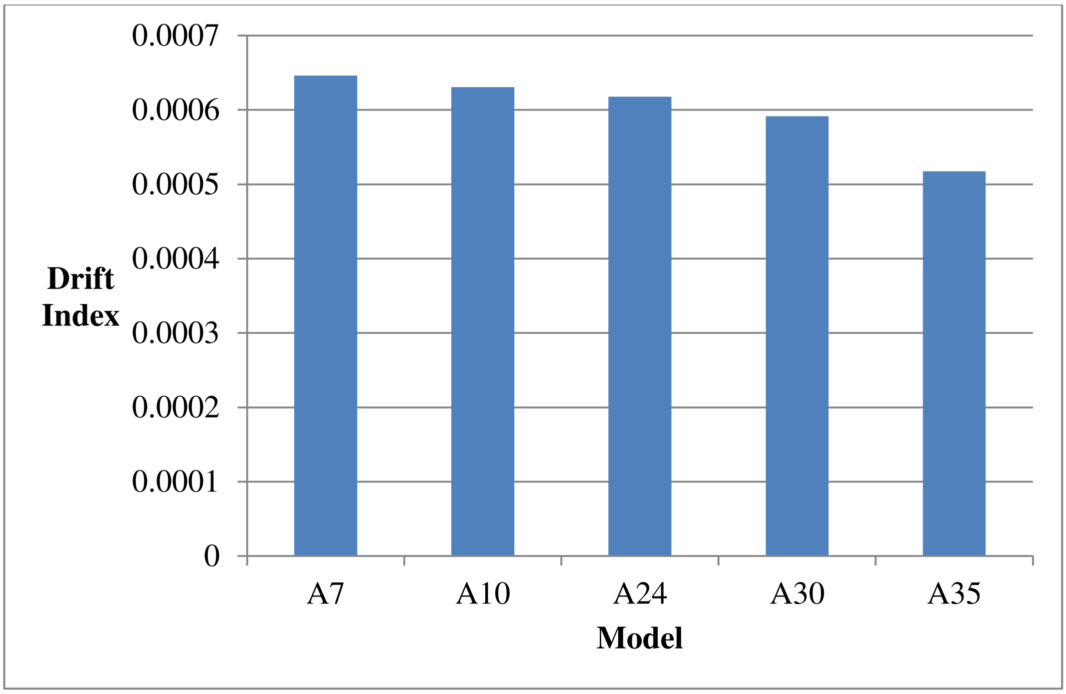

Figure 4.6 Graph of Best Models for Each of the Case for 28-Storey Steel Frame

Model A10 had obtained a reduction of 2.46% for drift index in comparison with model A7, whereas model A24 had obtained a reduction of 4.41% for drift index in comparison with model A7. On the other hand, drift index for model A30 had decreased 4.27% when compare to model A24. After that, the further comparison had shown that there was a reduction of 12.48% in model A35 as compared to model A30. From Figure 4.6, it can be clearly seen that model A7 had the largest lateral drift as it had the biggest drift index value as compared with other four models. Oppositely, it can be seen that model A35 had the lowest drift index among the models which indicated it had the minimal drift. As a result, the drift index of A35 had reduced by 19.91% as compared to model A7. Thus, the most ideal model in this comparison was model A35.

4.7.1 Single Bay Bracing Vs Double Bay Bracing Vs Triple Bay Bracing

These three types of bracing methods were commonly known as bracing through multiple floors. Application of this bracing method was simple as the number and weight of steel involved throughout the construction was less, thus the joints to construct became lesser which increased the possibility of opening bay in each bay of the frame. It was realized that all the comparisons were in pinned connection. After the analysis was run, the increment of number of floor in braced resulted in less drift index as the stiffness of the model was increased as well (Heidari et al., 2010).

Another result can be observed from the single bay bracing; double bay bracing and triple bay bracing were the most effective arrangement was located at the middle of the total storey of the frame. This similarity happened because locating the braced in the middle bay decreased the lateral drift as the bracing at the middle of the total storey of the building acted as a support to transfer the wind load in a more equal way to the foundation (Heidari et al., 2010). Thus, it was notified that this type of arrangement increased the lateral stiffness of the frame as well.

Besides, in the condition of double bracing and triple bay bracing, it can be found out as well when the braced bays were closer to each other, the lateral drift resulted in the model decreased as well. It was because the increased of the distance between two braced bays consequently increased the ultimate distances of the frame which further decreased the lateral stiffness of the frame (Heidari et al., 2010). Therefore, in order to obtain a satisfy model in the design of frame, with the combination of all those findings, the braced bays should be closer and located at the middle of the total storey of the frame.

4.7.2 Centre Bay Bracing Vs Pattern Bracing

The pattern bracing applied to the frame in this simulation was actually bracing method that spread across the full width of the frame. It was clearly seen as the bracing applied to the frame had fully spread throughout the width of the frame and significantly reduced the lateral drift as compared the bracing at centre bay only. It was mainly due to the lateral stiffness of the frame increased as the bracing elements were spanning at least one bay along the frame width (Mcewen, 2011). Thus, it was very interesting that this bracing method was very useful and effective in reduction of lateral drift for the frame.

4.7.3 Centre Bay Bracing Vs Exterior Bay Bracing

In order to increase the stiffness of the frame, application of exterior bay bracing can effectively resulted into less lateral drift (Mcewen, 2011). However, application of exterior bay bracing definitely increased the cost of the construction project as the number and weight of steel, and more joints were needed throughout the construction process. Therefore, after the analysis, it was found out that fully bracing the exterior bays induce lesser drift to the frame but the only concern was the cost versus benefit.

4.8 Analysis on the Effect of Different Storey Steel Frame to the Drift Index

There were four types of number of storey were selected to analyse and compare which were 28, 24, 20 and 16 storey steel frame. The parameter used as comparison for this analysis was maximum lateral drift. For 28-storey steel frame, the lateral drift obtained was 0.014495m whereas the lateral drift obtained for 24-storey steel frame was 0.009683m. Next, 20-storey steel frame had moved 0.006083m laterally. Lastly, 16-storey steel frame had yield a horizontal displacement of 0.003497m. The summarized results of maximum lateral drift were shown in Table 4.7 and Figure 4.7.

Table 4.7 Drift Index of Different Storey Steel Frame

Number of Storey	Maximum Lateral Drift, x (m)
28	0.014495
24	0.009683
20	0.006083
16	0.003497

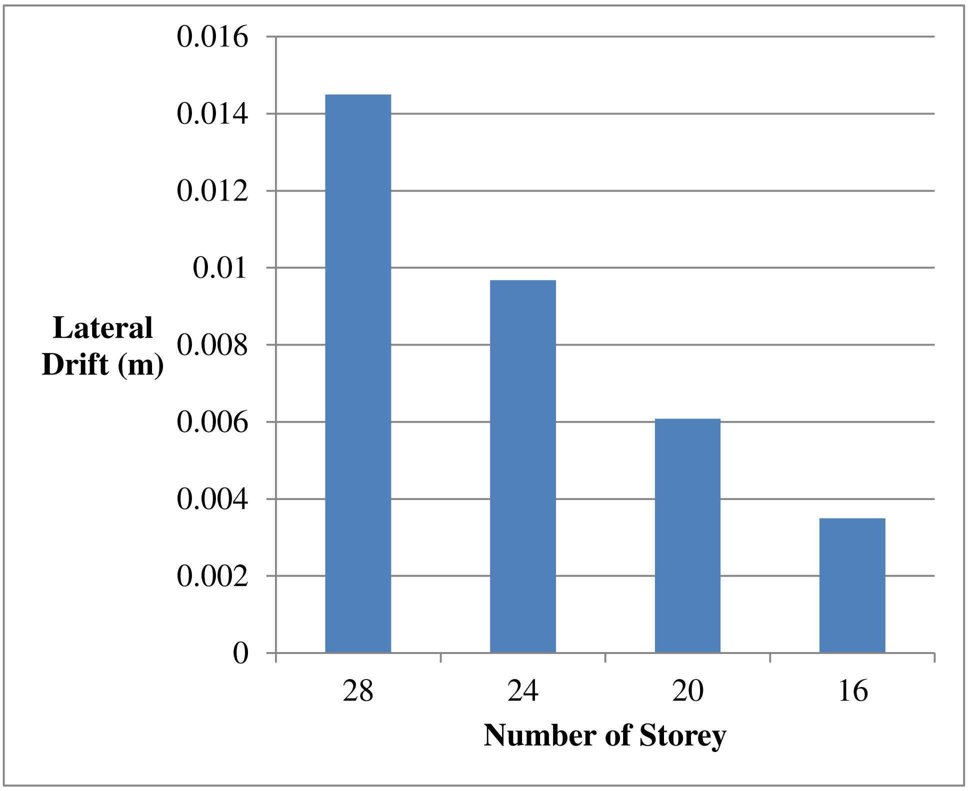

Figure 4.7 Graph of Lateral Drift for Different Storey Steel Frame

The lateral drift for each of the model was used as comparison as to determine the effect of different storey steel frame to the drift index. As shown in Figure 4.7 for the maximum lateral drift, the maximum drift of the floor for every model was decreasing as the number of storey for the steel frame is decreasing as well. As shown in Table 4.7 for the maximum lateral drift, the maximum drift of the floor for every model was in the range of 0.003497m to 0.014495m. 24-storey steel frame had obtained a reduction of 33.20% for lateral drift in comparison with 28-storey steel frame, whereas 20-storey steel frame had obtained a reduction of 37.18% for lateral drift index in comparison with 24-storey steel frame. On the other hand, there was a reduction of lateral drift in 42.51% for 16-storey steel frame when compared with 20-storey steel frame. Therefore, it was realized that the percentage of reduction was increasing as the number of storey for the frame became lesser. From Figure 4.7, it can be clearly seen that 28-storey steel frame had the largest lateral drift as compared with other three type models. Oppositely, it can be seen that 16-storey steel frame had the lowest lateral drift among the models which indicated it had the minimal drift. As a result, the lateral drift of 16-storey steel frame had reduced by 75.87% as compared to 28 storey steel frame. Thus, there was existence of a situation in such a way that the lateral drift occurred in the frame decreased continuously as the number of storey for the steel frame decreased.

The reason behind was related to two parameters which were lateral stiffness and wind loading. Firstly, according to the Hook's Law, the lateral drift of a structure was inversely proportional to the lateral stiffness of the structure. Stiffness can be defined as the rigidity of an object or the ability of structure to resist applied load towards deformation (Rokhgar, 2014). Therefore, in other words, whenever the frame was higher, the lower the stiffness of the frame which further resulted in higher lateral drift that occurred in the structure.

Next, the wind speed causes by the movement of air which induced higher pressure to lower pressure on the surface of frame created loading which was continuously varying from top to the bottom of the structure (Nyuwus, 2015). Thus, it can be said that the wind speed was continuously decreased by the surface friction. In other words, when the height of structure increased, the wind speed became larger. As a result, this had caused the frame to experience larger drift when the height of the frame was larger.

4.9 Analysis on the Effect of Using Pinned Connection versus Fixed Connection on the Best Model of 28-Storey Steel Frame

The final analysis selected for comparison was between pinned connection and fixed connection. For pinned connection, the lateral drift obtained was 0.014495m which gave a drift index of 0.0005177 whereas the lateral drift obtained for fixed connection was 0.001727m and gave a drift index value of 0.0000617. The summarized results of lateral drift and drift index can be viewed through Table 4.8 and Figure 4.8.

Table 4.8: Drift Index of Pinned and Fixed Connection

Type of Connection	Maximum Lateral Drift, x (m)	Drift Index, Δ
Pinned	0.014495	0.0005177
Fixed	0.001727	0.0000617

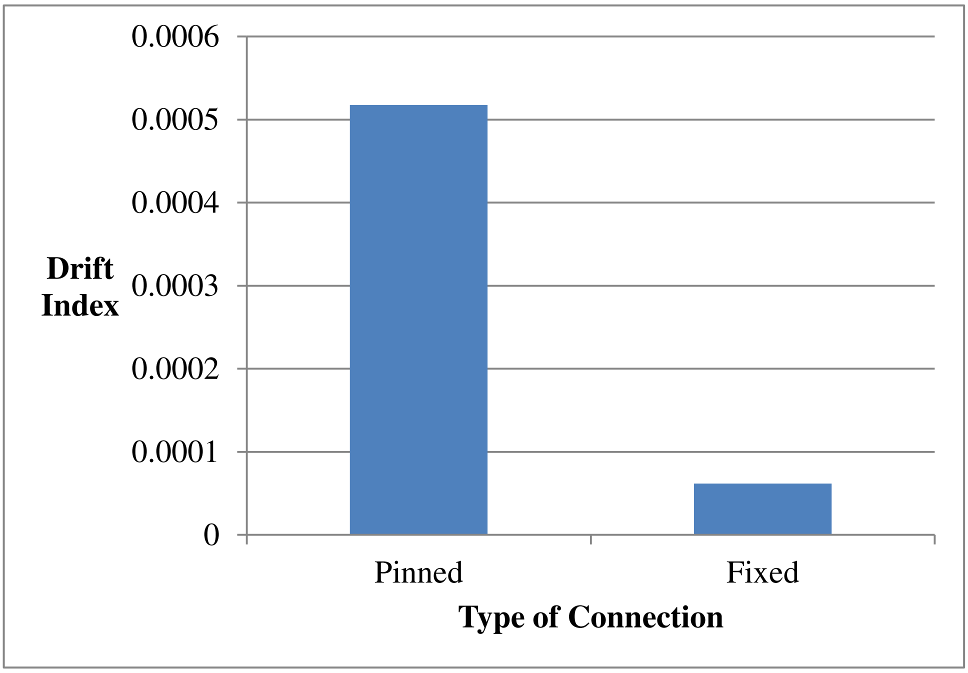

Figure 4.8 Graph of Pinned Connection versus Fixed Connection

The drift index for each of the model was used to compare as to determine the effect of pinned connection and fixed connection to the steel frame. As shown in Table 4.8 for the maximum lateral drift, the maximum drift of the floor for pinned connection is 0.014495m, whereas the drift index for the fixed connection is 0.001727m. The fixed connection applied to the frame had obtained a reduction of 88.08% of drift index in compare to pinned connection. Therefore, it can be clearly seen from Figure 4.8 that the model with pinned connection had the largest drift as it had the biggest drift index value as compared to the model with fixed connection. On the other hand, it can be seen that the model with fixed connection had the lowest drift index compared to the model with pinned connection which indicates it had the minimal drift. Thus, the most ideal connection for the model in this comparison was the model with fixed connection.

There were some benefits and bad sides in order to use pinned connection or fixed connection throughout the construction process of a steel frame. The construction procedures became easier as the frame was designed in pinned connection as it reduced the requirement of skilled labour and led to faster erection of the frame and further reduced the time and cost consumed for the construction process. On the other hand, the very great advantage in implementing the fixed connection into the frame was it able to show great reduction in lateral drift of the high rise building (Mcewen, 2011).

The reason behind was because the fixed connection was able to transmit moment and shear force, such that the tension and compression forces in the top and bottom flange of the beam transmitted the moment and the shear force which was transferred by the web of the beam which was connected to the column (Kyriakos, 2012). However, the time consuming and cost was higher as compared to pinned connection as it required the skilled worker to erect the complex connection.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

The main focus of this chapter was to emphasize on the conclusion and recommendation of this research. The importance to draw conclusions for this study provides a summary results which can be understand in an easier way. The conclusions were made based on the analysis of this research as to determine whether all those results found satisfied the objectives made early of this study. On the other hand, recommendations were drawn as well. It was important because the development of this study can be improved in the future and further providing the idea for the next person who has the interest to processes a study related to this field. To be more specified, the conclusions were drawn based on the effect of arrangement of the bracing among the models to the drift index, effect of number of storey of the buildings to the lateral drift and the effect of the condition of joint connections to the drift index.

5.2 Conclusions

After conducting this study, it can be concluded that:

i. The drift index of the steel frame was decreased as the number of floor to be braced was increased provided that the lateral stiffness of the structure had increased. It was clearly seen that the drift for triple floor bracing had reduced by 4.41% in comparison with the single floor bracing. In addition, when the braced bays were closed to each other for the conditions of double and triple bay bracing, the drift index reduced as well. In the cases of single, double and triple bay bracing, the drift index was reduced by at least 1.48% in comparing with the worst models in each case. Moreover, pattern bracing provided a decreased of 4.27% when compared to all the models with centre bay bracing. It was happened mainly because the bracing applied to the frame was fully spread throughout the width of the frame. Not only that, application of exterior bay bracing obviously was able to reduce the drift index in a great amount. The used of exterior bay bracing further reduced the drift index by 19.91% as compared to centre bay bracing only. Thus, it was concluded that the best arrangement of bracing could be applied to the steel frame was exterior bay bracing with the combinations of various conditions such as increased the number of floor to be braced which the braced bay could be near to each other.

ii. The increased on number of storey resulted in the increase of lateral drift in the steel frame. It was happened as the lateral stiffness was decreased but the wind loading became larger. Wind speed caused the movement of air which induced higher pressure to lower pressure on the surface of steel frame. The results of the study significantly shown that the lateral drift for 16-storey steel frame was decreased by 75.87% as compared to 28-storey steel frame. Thus, the conclusion was drawn as the lateral drift occurred in the frame reduced continuously as the number of storey for the steel frame was decreased as well.

iii. Finally, the application of fixed connection was significantly reduced the drift index of the steel frame building in comparison with pinned connection. This result can be clearly seen as the fixed connection was able to reduce the drift index by 88.08% in compared to pinned connection. The reason behind was because the fixed connection was able to transmit moment and shear force effectively, such that the tension and compression forces in the top and bottom flange of the beam transmitted the moment and the shear force which was transferred by the web of the beam that connected to the column.

iv. In a nutshell, the conclusions drawn earlier met the objectives of this research as the best arrangement of bracing and connection were determined.

5.3 Recommendations

A few suggestions were made for the future researchers to carry out the study related to this field. The suggestions were as followed.

i. It was suggested that the wind loads applied to the steel frame can be in varying distributed loads rather than uniform wind load or point load as the nature of wind loading is in triangular form.

ii. It was suggested as well the type of connection such as welding, belt cap, gusset plate or bolting can be analysed as to observe whether there is any significant change in drift index.

iii. The parameters which can be studied in the future are lateral stiffness and shear distortion at the base of the building. This model of research can be changed to reinforced concrete structure instead of steel frame as to determine the similarity and difference in term of trend of the results.

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APPENDIX A
WIND LOADING CALCULATIONS

V_{sit} = M_d x $M_{z,cat}$ x M_s x M_h

Where V_{sit} is wind speed for a site

M_d is wind directional multiplier

$M_{z,cat}$ is terrain / height multiplier

M_s is shielding multiplier

M_h is hill shape multiplier

V_{sit} = 33.5 x 1 x 1.01 x 1 x 1

= $33.84ms^{-1}$

V_{des} = V_{sit} x I

Where V_{des} is building design wind speed

I is importance factor

V_{des} = 33.84 x 1.15 = $38.92ms^{-1}$

$C_{fig, windward}$ = 0.80

Where $C_{fig, windward}$ is aerodynamic shape factor in windward wall

$C_{fig, windward}$ = -0.50

Where $C_{fig, windward}$ is aerodynamic shape factor in leeward wall

C_{dyn} = 0.988

Where C_{dyn} is dynamic response factor

$P_{windward}$ = 1.2 x 0.613 x V^2_{des} x $C_{fig, windward}$ x C_{dyn}

Where $P_{windward}$ is pressure in windward wall

$P_{windward}$ = 1.2 x 0.613 x 38.92^2 x 0.80 x 0.988

= 881Pa

$P_{leeward}$ = 1.2 x 0.613 x V^2_{des} x $C_{fig, leeward}$ x C_{dyn}

Where $P_{windward}$ is pressure in leewardward wall

$P_{leeward}$ = $1.2 \times 0.613 \times 38.92^2 \times -0.50 \times 0.988$

= -551Pa

P_{total} = $P_{windward} - P_{leeward}$

Where P_{total} is total pressure acting to the wall

P_{total} = 881 + 551

= 1432Pa