ANALYSIS ON THE EFFECT OF DIFFERENT BRACING TYPES AND LAYOUTS ON LATERAL DRIFT OF 30-STOREY STEEL FRAMED BUILDING SUBJECTED TO LATERAL FORCES USING ANSYS

DUSHENDRAN A/L BALA KRISNAI

Thesis submitted in fulfillment of the requirements for the award of the Bachelor of Engineering (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITY MALAYSIA PAHANG

JUNE 2015
ABSTRACT

High-rise steel construction is increasing at an expanding scale and in modern construction stiffness of the structure has become paramount criteria as the building increases in height. However, the aerial threat of wind forces had become a crucial factor to affect the building stiffness. Designers see great danger of this situation and it has led to introduction of bracing system that was often used to provide sufficient lateral stiffness to the structure. The main objective of this study is to determine the effect of different types and orientations of bracing on the frame structure in terms of lateral drift. Finite Element Analysis (FEA) of ANSYS 12.0 software has been used to model 30-storey of 90 m height steel frame building subjected to substantial basic wind speed, or 3-second gust, of 24 meter per second, and wind load of 0.969 kPa. Four types of bracing: X-bracing, Inverted V-bracing, K-bracing and single-diagonal bracing were explored and 84 models of different configurations were run. Prior to limiting the lateral drift, the 84 models were again used to study the effect of changing from using pin connections to a combined pin-moment connections. All the beam and column used is made up of I-beam of structural steel grade S275 and of 3D Spar Link 8 element type. The X-bracing and Inverted V-bracing were relatively known as good in limiting lateral drift with regard to both types and configurations of bracing compared to K-bracing and single diagonal bracing. Meanwhile, changing from using pin connection to a combined pin-moment connections had reduced the lateral drift to about 26% to 48% depending on the type of bracing used.
ABSTRAK

Bangunan tinggi struktur keluli meningkat secara mendadak dan pesat pada masa kini dan semestinya kekukuhan struktur adalah mustahak sama sekali dalam sebarang pembinaan moden terutamanya apabila bangunan itu melangkah tinggi. Walau bagaimanapun, kekuatan sesuatu bangunan akan menjadi lumpuh di bawah pengaruh daya angin. Isu yang kritikal ini dilihat sendiri oleh pereka bangunan dan oleh yang demikian sistem struktur perambatan telah diperkenalkan untuk mengukuhkan sesuatu bangunan. Pada dasarnya, objektif utama kajian ini adalah untuk mengetahui kesan penggunaan perambat dan orientasinya yang berbeza terhadap struktur kerangka sesuatu bangunan dalam perspektif kepesongan sisi struktur tersebut. Finite Element Analysis (FEA) daripada perisian ANSYS 12.0 telah digunakan untuk menghasilkan model struktur kerangka keluli 30 tingkat, bersamaan dengan tinggi 90m, di mana ia dikenakan kelajuan angin asas dengan kadar tiupan 3 minit atau 24 meter sesaat dan beban angin sebanyak 0.969 kPa. Empat jenis perambat iaitu: Perambat X, Perambat V-Terbalik, Perambat K, dan perambat pepenjuru tungal telah dikenalpasti untuk dikaji dan 84 model yang berbeza susun aturnya dalam struktur kerangka keluli telah dikaji dalam perisian tersebut. Selanjutnya, 84 model ini digunakan untuk tujuan mengkaji kesan perubahan daripada penggunaan sambungan pin dalam struktur kerangka kepada sambungan pin moment bagi tujuan mengurangkan kadar kepesongan sisi bangunan. Kesemua rasuk dan tiang yang digunakan dalam kajian ini adalah rasuk-I yang merupakan grad keluli S275 dan daripada elemen jenis 3D Spar Link 8. Kesimpulannya, Perambat X dan Perambat V-Terbalik dapat menstabilkan struktur kerangka pada kadar yang lebih baik berbanding dengan Perambat K dan perambat pepenjuru tungal dalam kedua-dua aspek jenis dan orientasi perambat. Malahan, perubahan daripada penggunaan sambungan pin kepada sambungan pin moment telahpun mengurangkan kepesongan sisi sebanyak 26% hingga 48% bergantung kepada jenis perambat yang digunapakai.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPERVISOR’S DECLARATION</td>
<td>ii</td>
</tr>
<tr>
<td>STUDENT’S DECLARATION</td>
<td>iii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>vi</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>vii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xiv</td>
</tr>
</tbody>
</table>

## CHAPTER 1  INTRODUCTION

1.1 General                                              1  
1.2 Problem Statement                                   2  
1.3 Objective of Study                                  3  
1.4 Scope of Study                                      3  

## CHAPTER 2  LITERATURE REVIEW

2.1 Introduction                                         10 
2.2 High Rise Building                                  10 
2.3 Steel Frame                                          11 
2.4 Bracing                                              12 
2.5 Lateral Drift                                        13 
2.6 Drift Limits and Damageability                       14 
2.7 ANSYS Modeling                                      16 
2.8 Wind Load, $W_K$                                    17 
2.9 Effect of Different Bracing Type on the Lateral Drift of High-Rise Steel Frame 18 
2.10 Effect of Varying the Position of Bracing Prior to Minimization of 


Lateral Drift of 30-Stories Steel Frame

2.11 Effect of Changing the All Pin to Combination of Pin-Moment Connections on the Lateral Drift of 30-Stories Steel Frame

CHAPTER 3 METHODOLOGY

3.1 General 21
3.2 Flowchart 23
3.3 Preprocessing 24
  3.3.1 ANSYS Codes and Units 24
  3.3.2 ANSYS Material Properties and Element Type 24
  3.3.3 Cross Section Properties of Steel Frame 26
  3.3.4 Member Properties and Real Constants of Steel Frame 28
  3.3.5 ANSYS Model Generation via Nodes and Elements 29
3.4 Solution 34
  3.4.1 Displacement Constraints for Pin Connection Models 34
  3.4.2 Displacement Constraints for Combined Pin-Moment Connections Model 34
  3.4.3 Lateral Loads Application into Steel Frame 36
3.5 Postprocessing 38

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 General 40
4.2 Analysis on the Effect of Different Bracing Type on Lateral Drift of Steel Frame 40
4.3 Analysis on the Effect of Different Bracing Layouts/Configurations on Lateral Drift of Steel Frame 60
  4.3.1 Bracing the Center Bays vs. Bracing Multiple Bays 69
  4.3.2 Bracing schemes spread over the frame width 69
  3.4.3 Bracing the Center Bay vs. Bracing the Exterior Bays 70
4.4 Analysis on the Effect of Using Simple Pin Connection vs. Combined Pin and Moment Connection 70
CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 General 77
5.2 Conclusions 77
5.3 Recommendations 79

REFERENCES 80

APPENDICES 82
A Wind Load Calculations Procedure 82
B ANSYS Figures 83
C1 Comparison of 4 different types of bracing: Braced along the center bay only 89
C2 Comparison of 4 different types of bracing: Braced along the center bay and at the top floor 90
C3 Comparison of 4 different types of bracing: Braced along the center bay and at the 2nd top floor 91
C4 Comparison of 4 different types of bracing: Braced along the center bay and at the 15th floor 92
C5 Comparison of 4 different types of bracing: Braced along the center bay and at the 1st floor 93
C6 Comparison of 4 different types of bracing: Braced along the center bay and at the 15th and 30th floors 94
C7 Comparison of 4 different types of bracing: Braced along the center bay and at the 14th and 30th floors 95
C8 Comparison of 4 different types of bracing: Braced along the center bay and at the 16th and 30th floors 96
C9 Comparison of 4 different types of bracing: Braced along the center bay and at the 16 & 17th and 30th floors 97
C10 Comparison of 4 different types of bracing: Braced along the center bay and at the 15 & 16th and 30th floors 98
C11 Comparison of 4 different types of bracing: Braced along the center bay and at the 14 & 15th and 30th floors 99
C12 Comparison of 4 different types of bracing: Braced along the center bay and at the 14 & 16th and 30th floors 100
bay and at the 29th and 30th floors

C13 Comparison of 4 different types of bracing: Braced along the center bay and at the 15th and 16th floors

C14 Comparison of 4 different types of bracing: Braced along the center bay and at the 1st and 2nd floors

C15 Comparison of 4 different types of bracing schemes spread over buildings width (zigzag)

C16 Comparison of 4 different types of bracing schemes spread over buildings width (diagonal)

C17 Comparison of 4 different types of bracing schemes spread over the first and third bays

C18 Comparison of 4 different types of bracing: Braced completely the outer bays and the 30th floor

C19 Comparison of 4 different types of bracing: Braced completely the outer bays and the 15th floor

C20 Comparison of 4 different types of bracing: Braced completely the outer bays and the 15 & 30th floors

C21 Comparison of 4 different types of bracing schemes spread over the buildings width

C22 Comparison of 4 different types in terms of maximum lateral drift, interstory drift index, and total drift index

D1 Lateral Drift Pattern of Various Orientations of Inverted V-Bracing

D2 Lateral Drift Pattern of Various Orientations of K-Bracing

D3 Lateral Drift Pattern of Various Orientations of Single Diagonal Bracing

E1 Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 30th floor

E2 Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 2nd top floor

E3 Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 15th floor

E4 Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 1st floor
E5  Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 15th and 30th floors

E6  Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 14th and 30th floors

E7  Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 16th and 30th floors

E8  Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 16 & 17th and 30th floors

E9  Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 15 & 16th and 30th floors

E10 Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 14 & 15th and 30th floors

E11 Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 29th and 30th floors

E12 Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 15th and 16th floors

E13 Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 1st and 2nd floors

E14 Pin Connection vs. Pin-Moment Connection: Bracing schemes spread over buildings width (zigzag)

E15 Pin Connection vs. Pin-Moment Connection: Bracing schemes spread over buildings width (diagonal)

E16 Pin Connection vs. Pin-Moment Connection: Bracing schemes spread over the first and third bays

E17 Pin Connection vs. Pin-Moment Connection: Braced completely the outer bays and the 30th floor

E18 Pin Connection vs. Pin-Moment Connection: Braced completely the outer bays and the 15th floor

E19 Pin Connection vs. Pin-Moment Connection: Braced completely the outer bays and the 15 & 30th floors

E20 Pin Connection vs. Pin-Moment Connection: Bracing schemes spread over the buildings width
<table>
<thead>
<tr>
<th>Table No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>General Properties of Steel Frame</td>
<td>5</td>
</tr>
<tr>
<td>3.1</td>
<td>Cross Section Properties of Steel Frame</td>
<td>27</td>
</tr>
<tr>
<td>4.1</td>
<td>Drift Indices and Drift Damage Indices</td>
<td>44</td>
</tr>
<tr>
<td>4.2</td>
<td>Comparison of 4 different types of bracing in terms of maximum lateral drift</td>
<td>45</td>
</tr>
<tr>
<td>4.3</td>
<td>Comparison of 4 different types of bracing in terms of interstory drift index</td>
<td>46</td>
</tr>
<tr>
<td>4.4</td>
<td>Comparison of 4 different types of bracing in terms of total drift index</td>
<td>47</td>
</tr>
<tr>
<td>4.5</td>
<td>Comparison of different bracing layouts on lateral drift of X-bracing and Inverted V-bracing</td>
<td>65</td>
</tr>
<tr>
<td>4.6</td>
<td>Comparison of different bracing layouts on lateral drift of K-bracing and single diagonal bracing</td>
<td>66</td>
</tr>
<tr>
<td>4.7</td>
<td>Drift reduction between pin connection and combined pin-moment connection of X-bracing and Inverted V-bracing</td>
<td>72</td>
</tr>
<tr>
<td>4.8</td>
<td>Drift reduction between pin connections and combined pin-moment connections of K-bracing and diagonal-bracing</td>
<td>73</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Four different types of bracing</td>
<td>5</td>
</tr>
<tr>
<td>1.2</td>
<td>Models of X-bracing</td>
<td>6</td>
</tr>
<tr>
<td>1.3</td>
<td>Models of Inverted V-bracing</td>
<td>7</td>
</tr>
<tr>
<td>1.4</td>
<td>Models of K-bracing</td>
<td>8</td>
</tr>
<tr>
<td>1.5</td>
<td>Models of Single Diagonal-bracing</td>
<td>9</td>
</tr>
<tr>
<td>2.1</td>
<td>Drift Measurements</td>
<td>15</td>
</tr>
<tr>
<td>2.2</td>
<td>Drift Damageable Zone (DDF)</td>
<td>16</td>
</tr>
<tr>
<td>3.1</td>
<td>Methodology Flowchart</td>
<td>23</td>
</tr>
<tr>
<td>3.2</td>
<td>Define the Materials</td>
<td>25</td>
</tr>
<tr>
<td>3.3</td>
<td>Defining the Element Types</td>
<td>25</td>
</tr>
<tr>
<td>3.4</td>
<td>Beam Cross Section Properties</td>
<td>26</td>
</tr>
<tr>
<td>3.5</td>
<td>Example of column cross-section properties (for 1st-5th floor)</td>
<td>27</td>
</tr>
<tr>
<td>3.6</td>
<td>Bracing Cross-Section Properties</td>
<td>27</td>
</tr>
<tr>
<td>3.7</td>
<td>Defining the Member Properties</td>
<td>28</td>
</tr>
<tr>
<td>3.8</td>
<td>Defining the Beam/Column/Bracing Properties</td>
<td>28</td>
</tr>
<tr>
<td>3.9</td>
<td>Set Node at (0, 0) First</td>
<td>29</td>
</tr>
<tr>
<td>3.10</td>
<td>Second Node Start at (6, 0)</td>
<td>30</td>
</tr>
<tr>
<td>3.11</td>
<td>The Complete Establishment of Nodes for Steel Frame</td>
<td>30</td>
</tr>
<tr>
<td>3.12</td>
<td>Element Attributes for Beam</td>
<td>31</td>
</tr>
<tr>
<td>3.13</td>
<td>Defining the Elements to Connect the Nodes Horizontally to Form Beam Members</td>
<td>31</td>
</tr>
<tr>
<td>3.14</td>
<td>Element Attributes for Columns</td>
<td>32</td>
</tr>
<tr>
<td>3.15</td>
<td>Defining the Elements to Connect the Nodes Vertically to Form Column Members</td>
<td>32</td>
</tr>
<tr>
<td>3.16</td>
<td>Element Attributes for Bracing Member</td>
<td>33</td>
</tr>
<tr>
<td>3.17</td>
<td>Defining bracing elements between the nodes to form bracing members</td>
<td>33</td>
</tr>
<tr>
<td>3.18</td>
<td>Model Constrained in All DOF</td>
<td>34</td>
</tr>
<tr>
<td>3.19</td>
<td>Constraining y-axis and z-axis at each bracing node to form pin</td>
<td>35</td>
</tr>
</tbody>
</table>
3.20 Constrained pin-moment connection model

3.21 Picking the nodes to be applied with lateral loading in windward direction

3.22 Picking the nodes to be applied with lateral loading in leeward direction

3.23 Total applied load of 17442 N loads to the frame

3.24 Plotting the drift result of the model in the x-direction

3.25 Listing out the x-direction drift result of the model

4.1 Comparison of 4 different types of bracing: Braced along the center bay only for model B1, B2, B3, and B4

4.2 Comparison of 4 different types of bracing: Braced along the center bay and at the top floor for model B1-1, B2-1, B3-1, and B4-1

4.3 Comparison of 4 different types of bracing: Braced along the center bay and at the 2nd top floor for model B1-2, B2-2, B3-2, and B4-2

4.4 Comparison of 4 different types of bracing: Braced along the center bay and at the 15th floor for model B1-3, B2-3, B3-3, and B4-3

4.5 Comparison of 4 different types of bracing: Braced along the center bay and at the 1st floor for model B1-4, B2-4, B3-4, and B4-4

4.6 Comparison of 4 different types of bracing: Braced along the center bay and at the 15th and 30th floors for model B1-5, B2-5, B3-5, and B4-5

4.7 Comparison of 4 different types of bracing: Braced along the center bay and at the 14th and 30th floors for model B1-6, B2-6, B3-6, and B4-6

4.8 Comparison of 4 different types of bracing: Braced along the center bay and at the 16th and 30th floors for model B1-7, B2-7, B3-7, and B4-7

4.9 Comparison of 4 different types of bracing: Braced along the center bay and at the 16 & 17th and 30th floors for model B1-8, B2-8, B3-8, and B4-8

4.10 Comparison of 4 different types of bracing: Braced along the center bay and at the 15 & 16th and 30th floors for model B1-9, B2-9, B3-
4.11 Comparison of 4 different types of bracing: Braced along the center bay and at the 14 & 15th and 30th floors for model B1-10, B2-10, B3-10, and B4-10

4.12 Comparison of 4 different types of bracing: Braced along the center bay and at the 29th and 30th floors for model B1-11, B2-11, B3-11, and B4-11

4.13 Comparison of 4 different types of bracing: Braced along the center bay and at the 15th and 16th floors for model B1-12, B2-12, B3-12, and B4-12

4.14 Comparison of 4 different types of bracing: Braced along the center bay and at the 1st and 2nd floors for model B1-13, B2-13, B3-13, and B4-13

4.15 Comparison of 4 different types of bracing schemes spread over buildings width (zigzag) for model B1-14, B2-14, B3-14, and B4-14

4.16 Comparison of 4 different types of bracing schemes spread over buildings width (diagonal) for model B1-15, B2-15, B3-15, and B4-15

4.17 Comparison of 4 different types of bracing schemes spread over the first and third bay for model B1-16, B2-16, B3-16, and B4-16

4.18 Comparison of 4 different types of bracing: Braced completely the outer bays and the 30th floor for model B1-17, B2-17, B3-17, and B4-17

4.19 Comparison of 4 different types of bracing: Braced completely the outer bays and the 15th floor for model B1-18, B2-18, B3-18, and B4-18

4.20 Comparison of 4 different types of bracing: Braced completely the outer bays and the 15 & 30th floors for model B1-19, B2-19, B3-19, and B4-19

4.21 Comparison of 4 different types of bracing schemes spread across the buildings width for model B1-20, B2-20, B3-20, and B4-20

4.22 Lateral drift pattern of X-bracing configurations of model no.1 to
no.7

4.23 Lateral drift pattern of X-bracing configurations of model no.8 to no.13 67

4.24 Lateral drift pattern of X-bracing configurations of model no.14 to no.16 & no.20 67

4.25 Lateral drift pattern of X-bracing configurations of model no.17 to no.19 68

4.26 Pin Connection vs. Pin-Moment Connection of Model B1 74

4.27 Pin Connection vs. Pin-Moment Connection of Model B2 74

4.28 Pin Connection vs. Pin-Moment Connection of Model B3 75

4.29 Pin Connection vs. Pin-Moment Connection of Model B4 75
CHAPTER 1

INTRODUCTION

1.1 GENERAL

High-rise buildings have always been a key construction development over the years in keeping pace with the increasing demand of human population. This in turn had shifted the attention of engineers and designers in looking into various possible way of building or constructing the safe sound structure. Typical high-rise building can be categorized as reinforced concrete frame or steel frame.

Rapid advancement in the field of construction had given a platform for steel construction to develop at enlarging scale. Steel frame, for instance is a structure in which the weight is carried by steel skeleton or framework, as it is opposite to wall support system. It was true enough that steel frame has many advantages compared to ordinary reinforced concrete frame in terms of faster time of erection, better quality control, design flexibility, sustainability, and lesser weight than RC structures which in turn requires lighter foundation, and occupies less space which can be designed for larger span/column free spaces. Basically, the mechanism of loads distribution for both steel frame and reinforced concrete frame are similar, in which load from the beam was transferred to column, and finally to the foundation. Steel frame particularly function well under high lateral (wind) loading, because of its ductility, and that’s make it preferable in high-rise structure. More than that, steel frame has capability to bend without breaking and absorb the energy acting on it. Steel frames were able to carry the weight of more floors, so walls became simply cladding for the purpose of insulating and adorning the building.
On the other hand, the construction of braced steel frame structure has become equally important in construction industry as it will resist the lateral forces that might act on the structure. Braced steel frame is well known in Malaysia in the context of high-rise structure. Generally, this frame exists under the provision of bracing elements that was aimed to provide stability and resist wind loads. Bracing is an element used to support and strengthen various part of a building and it will usually provide lateral stability for columns and beams. Steel braced frame with lateral bracing is very common in high-rise construction and has advantages in terms of simplicity and economical construction.

Typically, there are four types of bracing that are used in practice, which includes X-bracing, Inverted V-bracing, K-bracing and diagonal bracing. Each of these bracing provides has different strength on the structural integrity of steel frame. Similarly, each of these bracing types can be used either on one bay or multiple bays. Therefore, there are plenty of ways in which to brace a building. For this study, multitude of these combinations were modeled and analyzed to determine the appropriate bracing type and layout for 30-stories steel frame building subjected to wind load.

1.2 PROBLEM STATEMENT

A very significant parameter that influences the limits of today’s high rise construction is the wind loading, and yet one of the biggest concerns is to deal with the lateral drift. Over the years, numerous studies have been conducted on the issue of lateral drift on the structure that was deemed the biggest threat to high-rise construction due to wind loading and any serviceability issues that may arise from this lateral movement. Engineers and designers faced a hardest task when designing high-rise structure subjected to substantial wind forces which has lead them to address the issue in the early stage of design development. Building is about to face severe damages if too much of drift takes place on the building under lateral loading. According to Ho and Schierle (1990), excessive lateral drift on building can cause significant damage on secondary systems, such as partitions, curtain walls and structure’s interior walls, which in turn will generate secondary column stress due to P-delta moments that can also
induce problem on column stability. Basically, there are three paramount perspectives in regards to drift and lateral stability, which are structural stability, architectural integrity and potential damage to various non-structural components and lastly human comfort during and after the building experiences the motions. Thus, in buildings over approximately 30-stories, the bracing technique becomes a vital part of the design. Providing bracing to the steel frame could reduce the lateral drift of the structure and thus lead to safer building to the users. However, choosing the correct bracing type and its’ appropriate orientations in frame structure is of utmost importance in order to generate fruitful results of resisting the lateral forces.

1.3 OBJECTIVES OF STUDY

The objectives of this study are:

i. To study the effect of different bracing type on the lateral drift of 30-stories steel frame building.

ii. To analyze the effect of varying the position of bracing prior to minimization of lateral drift of 30-stories steel frame building.

iii. To compare the effect of pin connection only to a combination of pin-moment connection in reducing the lateral drift of 30-stories steel frame building.

1.4 SCOPE OF STUDY

The scope of this study was related to the design of steel frame structures with different bracing technique and its’ orientations on frame structure using Eurocode 3 of ANSYS. The general information regarding the steel frame was shown in Table 1. The structural integrity of 30-stories steel frame building to take on drift control with different bracing types and layouts was discussed in detail. Illustrated in Figure 1.1, four types of bracing were used throughout this course of study, which includes X-bracing, Inverted-V-bracing, K-bracing and single diagonal bracing. Moreover, each of the bracing system was tested using 21 different models, at which each model will have different bracing location prior to lateral drift minimization, as shown in Figure 1.2 (for
X-bracing), Figure 1.3 (for Inverted-V-bracing), Figure 1.4 (K-bracing) and Figure 1.5 (for single diagonal bracing). Each of these different types of bracing has capability to show different resistance to drift control. In that sense, this study offers a platform to determine the effective bracing type and layout that could best fit the 30-stories steel frame. In all cases the bracing that was used is of size L 90 x 90 x 7.

Generally, X-bracing (also known as cross bracing) was arguably the most common bracing method and yet utilizes its two full length members to connect to four beam-column joints in a bay. The members were considered to be only stressed in tension and only one member was stressed at a time, resulting in the possibility to use smallest member sizes. Meanwhile, Inverted V-bracing is another form of bracing used commonly to effectively brace a structure against lateral drift. Usually, two members at the bottom were connected to the beam-column joints and the top member was connected to center of beam. The advantage of this bracing was more towards architectural insight than the structural perspective. The bracing allows for the placement of doorways and corridors. From structural angle, tying the Inverted V-bracing into the middle of the span of the floor above allows for the beam to be analyzed as a two span continuous beam, which in turn allowing for that particular member to be reduced in size. Unlike X-bracing, both members of this bracing are considered to be working at all times in both compression and tension.

As for K-bracing, two members were connected to two beam-column joints in one direction, while the opposite direction was connected into the mid-section of each column at each story. Normally, K-bracing was used when full height openings are required. However it was believed that K-bracing is not as efficient as X-bracing due to the fact of potential of collapse of column as the compression brace buckles in K-bracing. Apart from that, diagonal bracing was a form of bracing used to achieve lateral stability for the structural frame. This technique is not nearly as common in high-rise buildings. Since the members have to bear tension and compression load, the member sizes to accommodate the load would have to be quite large.
Table 1.1: General Properties of Steel Frame

<table>
<thead>
<tr>
<th>Item</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total frame height</td>
<td>90m (3m/story)</td>
</tr>
<tr>
<td>Total bay distance</td>
<td>9m (3m/bay)</td>
</tr>
<tr>
<td>Steel Grade</td>
<td>S275</td>
</tr>
<tr>
<td>Beam Size</td>
<td>UB 457 x 191 x 89</td>
</tr>
<tr>
<td>Column Size</td>
<td>UC 356 x 406 x 634 (1st - 5th Floor)</td>
</tr>
<tr>
<td></td>
<td>UC 356 x 406 x 467 (6th - 10th Floor)</td>
</tr>
<tr>
<td></td>
<td>UC 356 x 406 x 393 (11th - 15th Floor)</td>
</tr>
<tr>
<td></td>
<td>UC 356 x 406 x 287 (16th - 20th Floor)</td>
</tr>
<tr>
<td></td>
<td>UC 356 x 406 x 235 (21st - 25th Floor)</td>
</tr>
<tr>
<td></td>
<td>UC 305 x 305 x 198 (26th - 30th Floor)</td>
</tr>
<tr>
<td>Bracing Size</td>
<td>L 90 x 90 x 7</td>
</tr>
<tr>
<td>Bracing Lengths</td>
<td></td>
</tr>
<tr>
<td>- X-bracing</td>
<td>6.8 m</td>
</tr>
<tr>
<td>- Inverted-V-bracing</td>
<td>4.3 m</td>
</tr>
<tr>
<td>- K-bracing</td>
<td>6.3 m</td>
</tr>
<tr>
<td>- Diagonal bracing</td>
<td>6.8 m</td>
</tr>
</tbody>
</table>

Figure 1.1: Four different types of bracing
Figure 1.2: Models of X-bracing
Figure 1.3: Models of Inverted V-bracing
Figure 1.4: Models of K-bracing
Figure 1.5: Models of single diagonal-bracing
CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Over the years, numerous research literatures and studies have been conducted regarding the design of multi-story steel frame. One of the largest, yet hardest tasks of the designer in high-rise building was to limiting the lateral drift that was associated with wind forces. Generally, the design of steel frame must not fail under ultimate limit states (strength, yielding, buckling) or serviceability limit states (deflection) either. In this study, a method known as Direct Design Method which has the capability to analyze drift criteria of steel frame was used to model the structures. The method does not stand alone as computer simulation program called ANSYS 12.0 software was used throughout this study to test the steel frame with lateral bracing against the frame’s lateral drift under substantial lateral forces.

2.2 HIGH RISE BUILDING

Nowadays, the construction of high rise buildings has become vital especially for developing country like Malaysia. There is no absolute definition of what constitutes a high-rise building. The definition for high-rise building is still not clear and not precise, since various bodies quoted different meanings for that. To illustrate, Emporis Standard (2010), define high-rise buildings as multi-story structures with height ranges from 35-100 meters tall, or the building which has 12-39 floors for unknown height.
But, most building engineers and architects insist high rise as building with minimum height of 23 meter or approximately 6 stories high (IBC, 2009). Nevertheless, high-rise building is known as any structure at which the height can have a serious impact on evacuation, according to The International Conference on Fire Safety in High-Rise Buildings, 1971.

Apart from that, ‘The Council of Tall Buildings and Urban Habitat’ (2014) defines tall buildings as the one that exhibits some elements of tallness in or more of the following categories. First, this is about height relative to context. High rise building is not just about height, but it is also about the context in which it exists. For instance, in high-rise city such as Hong Kong and Chicago, 14-story building may not be considered a tall building compared to provincial European city or a suburb which may consider it tall. Next, it is about proportion, which define that a tall building is not just about height but also about proportion. There are numerous buildings which are slender enough to give the appearance of a tall building, but then there are not particularly high. In contrast to that, there are numerous big or large footprint buildings which are apparently tall but their size or floor area rules them out as being classified as a tall building.

Then, the last one is about tall building technologies. Building can be classed as a high-rise structure provided the building contains technologies which may be attributed them as being a product of ‘tall’ (structural wind bracing as a product of height). Thus, in general ‘The Council of Tall Buildings and Urban Habitat’ (2014) define high-rise building as a building of perhaps 14 or more stories or over 50 meters (165 feet) in height.

2.3 STEEL FRAME

There have been significant developments in the structural design of steel-framed buildings in developing countries, like Malaysia. Steel structure becomes an ideal solution for multi-story residential buildings requiring open plan space. Basically, most of the multi-story frames are three dimensional structures with orthogonal horizontal grids, that is the primary and secondary beams are in two directions at 90° (ESE Strategies, 2010). High-rise steel buildings have become prominent since the