EFFECTIVE BRACING SYSTEM FOR TELECOMMUNICATION TOWERS

FATIN ATIQAH BT RASDIN

B. ENG (HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

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ID Number : AA15055

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ABSTRAK

Pada masa kini, menara rangkaian komunikasi digunakan secara meluas di seluruh dunia dengan tujuan komunikasi tanpa wayar dan penyiaran. Masalah utama yang menjadi kebimbangan adalah kegagalan struktur tersebut dalam bencana alam kerana rangkaian komunikasi tanpa wayar menara jenis ini memainkan peranan penting. Oleh itu, mengkaji semua kebarangkalian bencana alam yang melampau sebelum mereka bentuk menara tersebut adalah sangat penting. Kajian ini dijalankan untuk menentukan kesan ketinggian menara yang berbeza pada ketinggian 30 m, 40 m, 50 m, dan 60 m serta pelbagai jenis sistem bentuk seperti K dan Y digunakan dengan beban angin yang bertindak di atas menara . Kelajuan angin yang digunakan dalam kajian ini adalah 33.5 m-1 dan 44.0 ms-1. Analisis angin dan simulasi menara dilakukan menggunakan perisian, STAAD. ProV8i. Keputusannya dibandingkan dari segi anjakan dan tekanan pada element menara. Berdasarkan keputusan yang diperolehi, anjakan menara dengan sistem bentuk Y didapati lebih rendah daripada sistem bentuk K kira-kira 36% sementara tekanan pada element menara dengan sistem bentuk K didapati lebih besar daripada sistem bentuk Y pada 56% pada kelajuan angin 44.0 ms-1.

ABSTRACT

Nowadays, towers with four-legged self-supporting system are widely used worldwide for wireless and broadcast communication purpose. However the major concern is the failure of such structure in a disaster since in wireless communication network these kinds of towers play a significant role. Thus, all these tendencies of extreme conditions are considered for designing such towers are of the utmost importance. This study was carried out to determine the effects of different heights of towers at 30 m, 40 m, 50 m, and 60 m as well as different types of bracing systems such as K and Y with respect to the wind load acting on the towers. The wind speeds considered in this study were 33.5 m^{-1} and 44.0 ms^{-1}. The wind modelling and simulation of the tower was conducted using commercial available software STAAD. ProV8i. The results were compared in terms of displacement and member stress. Based on the result obtained, the displacement of towers with Y bracing system was found lesser than K bracing system approximately 36% while the member stress of the tower with K bracing system was found more than Y bracing system about 56% at wind speed 44.0 ms^{-1}.

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LIST OF SYMBOLS

V_{des}	Design wind speed
V_s	Wind speed
M_d	Wind directional multiplier
$M_{z, cat}$	Terrain/ height multiplier
M_s	Shielding multiplier
M_h	Hill shape multiplier
C_{fig}	Aerodynamic shape factor
C_{dyn}	Dynamic response factor
l_h	Turbulence intensity
g_v	Peak factor
B_S	Background factor
S	Size reduction factor
E_t	Spectrum of turbulence
ζ	Ratio of structural damping to critical damping
g_r	Peak factor for resonant response

LIST OF ABBREVIATIONS

STAAD	Structural Analysis and Design

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the telecommunication industry plays an important role in the present societies. Thus, more attention is now being paid to telecommunication tower compared to the past and development of Malaysia's socio-economic also due to telecommunication industry contribution. The communication tower is the space structures in steel that carry communication antenna and this tower is mostly square in plan, made of standards steel angles and connected together by bolts and nuts. Then, the communication tower which is vulnerable to wind-induced oscillation and displacement, are required to study for effect in the event of wind load. Actually, communication tower can be classified into three categories which are guyed masts, monopole, and self-supporting tower. Usually, at Malaysia, self-supporting towers are generally preferred and the bracing members of communication towers are arranged in many forms with the aim to carry only tension or alternatively tension and compression. Study on the types of bracing system is important to determine the most effective and economical bracing system. Generally, the common use of the bracing system is double diagonal (X-X) bracing, V, K, W, Y, and X bracing. Also, study on the effective height of the communication tower to withstand the wind load effect.

1.2 Problem Statement

Due to the fastest growing in the telecommunication market, the number of telecommunication tower demand has been increased rapidly. Hence, the major concern of the structure is its failure in a disaster. Thus, in designing and constructing a telecommunication tower should be considering all possible extreme condition. Most of the researches have considered the effect of wind only on the towers. Since the telecommunication tower is very sensitive or prone to the presence of wind load. The higher the structure, the more it is exposed to lateral loads and the tendency to sway also increase. Furthermore, the strength of bracing in terms of arrangement has an important role to avoid the tower from failure as well. The bracing members are arranged in many forms, which to carry solely tension, or alternatively tension and compression. If the bracing is weak and wrong in arrangement the compression member would easily to buckle. Hence, the implementation of the latest technology to modeling and simulate the tower can help the engineer to analyze the effect of wind load to the tower and identify the most efficient and economical bracing system for telecommunication tower.

1.3 Objectives of the Research

The main objectives of the research include:

i. To identify the displacement effect to the communication towers in the event of wind load.
ii. To identify the most effective height of the communication tower in the event of wind load.
iii. To determine the most effective and economical bracing system for communication towers in the event of wind load.

1.4 Scope of the Research

Structural analysis and design which also known as STAAD Pro software were adopted in this research. The various bracing steel sections such as pipe section, angular section, and wind analysis had been run in STAAD Pro software to identify the most effective bracing system in the event of different wind zones. Four-legged telecommunication towers of height 30 m, 40 m, 50 m, and 60 m were designed. Both pipe and angular cross-sections considering two types of bracing patterns which were K and Y bracing at different basic wind speeds (33.5 ms^{-1} and 44 ms^{-1}) had been modeled to analyze the strength or performance of the different bracing system in different wind zones. Then, the base and top width of the tower were decided to be 5m and 2m respectively.

1.5 Significance of Research

Wind disaster is the natural disaster that destroys local resources, risks safety community and be the main factor failure of telecommunication tower as well. Thus, designing and constructing the telecommunication tower without considering the maximum wind speed that will occur at a certain zone or region area may increase the tendency failure of telecommunication tower. As structure engineer, accuracy in choosing the form of bracing system is important to increase the strength of bracing section and the compression member will not easily to buckle when the tower suddenly faces the maximum wind load. Therefore, this research was conducted to identify the most efficient and economical bracing system with modeling and simulate the telecommunication tower with various tower height at different wind speed.

1.6 Overview of the Research

Chapter one explains the background of the telecommunication tower which focusing on the different type bracing system, height of the tower and different wind speeds. In this chapter also revealing the challenges or problems that are facing by engineers to design and construct telecommunication tower. There are also other subtopics in this chapter including research objective, the scope of the research and significance of the research.

Chapter two is the literature review which needs to study and listing all the finding of researchers. The main point can be taken from the journal and articles that had studied by other authors. In this chapter also, the effect of different type of bracing systems and various heights on the displacement of communication tower is discussed. Then, the different parameters and most efficient bracing system proposed by other authors are listed and further discuss the suitability for the research. Lastly, the result and verification with experiment results are also explained and discussed in the chapter.

Chapter three is explain the research methodology that implemented in the whole process of simulation research. From obtaining material properties, modeling of the tower, analyzing the tower models, abstracting result data and validating and justifying the results of the research is clearly stated in the chapter.

Chapter four is discussed on the data and results obtained from STAAD Pro. The models of different heights of the tower with a different type of bracing system are compared. These towers are compared to find the most effective bracing system in the form of deflection. Height-displacement curve will be plotted.

Chapter five is the conclusion and recommendation. The conclusion is concluded the most effective and economical bracing system for communication towers in the event of wind load while recommendation to improve the research after analyzing the data and results.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Telecommunication Tower

In the area of analysis and design of steel tower, there are many analytical works have been conducted and published worldwide. There are many experimental and theoretical study has been performed on the lattice self-supporting telecommunication towers to investigate the effects of lateral load (wind load and seismic load), the suitability of the bracing system for a communication tower at various wind zones and different height of the tower as well. Phanindranath (2017) carried out the study to reduce the displacements to the telecommunication towers in the event of natural calamities by introducing the lateral resisting system. By evaluation of the response of the structure with various bracing systems subjected to wind loads and to identify the suitable bracing system for resisting wind loads which give way in the reduction of property loss sometimes even human loss in the event of drastic winds. The study revealed that both X and Y bracing systems performed well at various wind zones while coming to sections angular section performed well in all aspects. Also, Raju (2017) designed for legged telecommunication towers of height 24m with both pipe and angular cross-sections considering four types of bracing patterns at different basic wind speeds (33m/s, 39m/s, 44m/s, 47m/s, 50m/s and 55m/s), had been models to evaluate the performance of different bracing system in different wind zones. It can be concluded that for a 24m height four-legged telecommunication tower, an angular cross-section with K bracing pattern is found to be most effective and economical at all considered basic wind speeds.

2.2 The Behavior of Telecommunication Tower

The telecommunication tower act as vertical trusses and wind load is resisting by cantilever action. Generally, telecommunication tower is effective in term of high load carrying load system and produce lesser horizontal displacement than another tower. However, there is an issue problem toward the structural behavior based on the different parameters such as the high intensity of wind load, the different height of the tower, type of bracing system, dead load, seismic load and design strength of structural steel member on superstructure including connection and foundation. Naidu (2017) found that telecommunication tower with a height less than or equal to 40 meters is not preferred but with height beyond 50 meter and above are more suitable. This is because increasing in height of the tower has increased the stiffness and easiness of modification in case of a member failure.

2.2.1 Effect of Wind Load

The important aspect in the design of tall buildings is wind effect because the dominant load case is wind loading. In addition, the acceleration and excessively swayed of a tall building in the strong building are leading by the dynamic response.

The structures like towers and masts are sensitive to dynamic wind load. The need to design a lattice tower considering the resonant dynamic response to wind loads arises when their natural frequencies are low enough to be excited by the turbulence structures like towers and masts are sensitive to dynamic wind load in the natural wind (Phanindranath, 2017).

The adequacy or inadequacy of a building can be fully comprehended if the designers have an accurate estimate of the wind speeds to which the construction was subjected. In the development, wind speed data is the tools to further understanding and preparedness for a natural disaster. The better understanding of the nature of hurricane force wind and impact on the structure can reduce the failure of towers.

Figure 2.1 shows the wind speed at various meteorological stations in Malaysia. On the hourly period, the data was collected at the varied height of the anemometer from station to station. The highest wind speed area was recorded in Mersing followed by other East coast areas such as Kuala Terengganu and Kota Bharu. In general, the

West Coast areas experienced lower wind speed, mostly below 2m/s (Shafii and Othman, 2017).

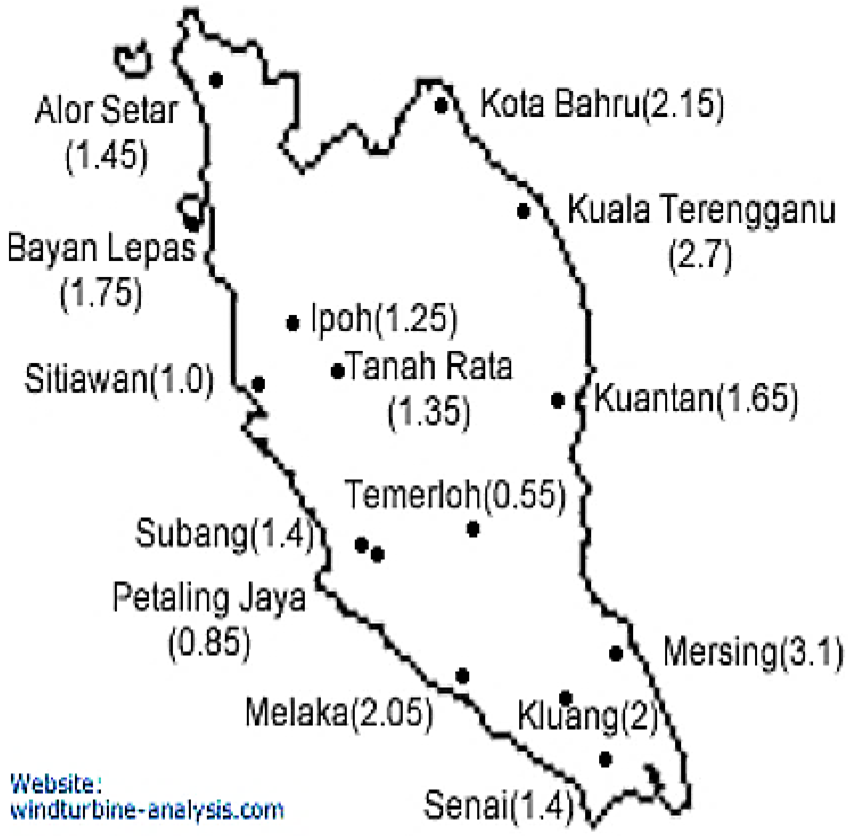


Figure 2.1: Annual wind speed at 18 Meteorological stations in Peninsular Malaysia
Source: (Shafii and Othman, 2017)

Besides, in MS 1553: 2002 there are three procedures are specified for calculation of wind pressures on building which are the simplified procedure is limited in application to buildings of rectangular in plan and not greater than 15.0 m high while analytical procedure is limited to regular buildings that are not more than 200 m high and structure with roof spans less than 100 m and the wind tunnel procedure is used for complex building. Basic wind speed for Peninsular Malaysia is shown in Figure 2.2.

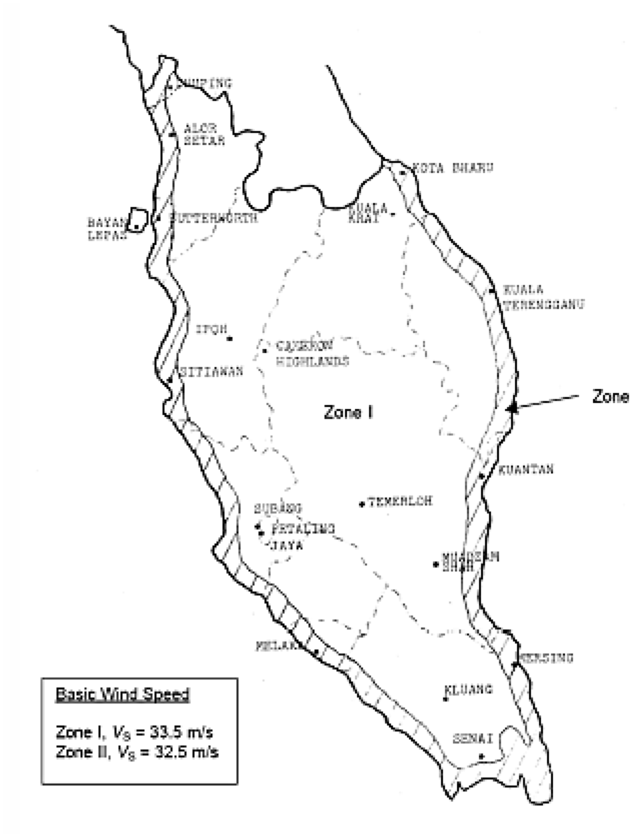


Figure 2.2: Basic wind speed for Peninsular Malaysia

Source: (MS 1553:2002)

Rajasekharan and Vijaya (2014) research on the effect of wind load on tower structures for different wind zones using gust factor and also to study the seismic effect on the tower structures by carrying out the modal analysis and response spectrum analysis. It was concluded that for an increase in wind speed from 50 to 55 m/s with no change in direction the displacement as well as the member stresses increase by 15% to 17%.

Also, Naidu (2017) carried out the study to compare the performance of Monopole and Self-Support type towers with respect to lateral displacements and the quantity of steel required. Analysis and design of Monopole and Self-Support Towers were performed using STAAD(X) Tower software for different heights with different wind speeds and compared. It was concluded that Self-Support tower has lower lateral displacement compared to Monopole Towers of the same height and the same amount of loading due to the fact that both of tower have higher stiffness.

2.2.2 Effect of Height

Height is the most significant dimension of a tower. Most of the researcher and studies are using different heights of the tower structures for their research in order to help to understand the effect of horizontal load. Pathrikar and Kalurkar (2017) stated that the higher the structure, the more it is exposed to lateral loads such as wind load since it has a higher tendency to sway.

Rajasekharan and Vijaya (2014) designed the lattice tower for three heights of 30m, 40m and 50m with different types of bracings to study the effect of wind load on 4-legged lattice tower for wind zone V and VI using gust factor. It was observed that from 30m to 40m tower height, the increase in displacement is nearly linear but as the heights increase from 40m to 50m, there is a steep increase in the displacement in all the wind zones.

2.2.3 Effect of Bracing System

Steel bracing is a structural system which transfers lateral loads (seismic loads and wind loads) into soil bypassing columns and beams which are designed only for gravity loads (Phanindranath, 2017). Communication towers are needed to be designed to resist wind load and to make the structure at least for life safety in the event of natural calamities since the tower are very sensitive to wind loads.

The bracing members as in Figure 2.2 are arranged in many forms, which carry tension or alternatively tension and compression. If the bracing is weak, the tower will fail because the compression member will be buckled. Besides, the structure that has poor lateral stiffness, the bracing system will allow obtaining a great increase of stiffness with a minimal added weight. Next, the diagonal bracing works in axial stress and the minimum member sizes will provide the stiffness and strength against horizontal shear. Thus, lateral movement and torsional motion of the structures under lateral loading (seismic loads and wind loads) will be reduced by the bracing system.

Borthakur and Chetia (2016) carried out a study on the reduction in responses of a structure under lateral loading due to the incorporation of a bracing system. From the results obtained, it is observed that lateral movement decrease up to 80% due to the incorporation of the bracing system. Also, Phanindranath (2017) proposed different types of steel bracing systems like X, V, K, Y systems were assigned. These bracing systems were model by considering 3 different steel sections like pipe section, angular section and multi-section (pipe section for columns, an angular section for beam and bracings) 24 models with the bracing system have been developed to run for wind analysis.

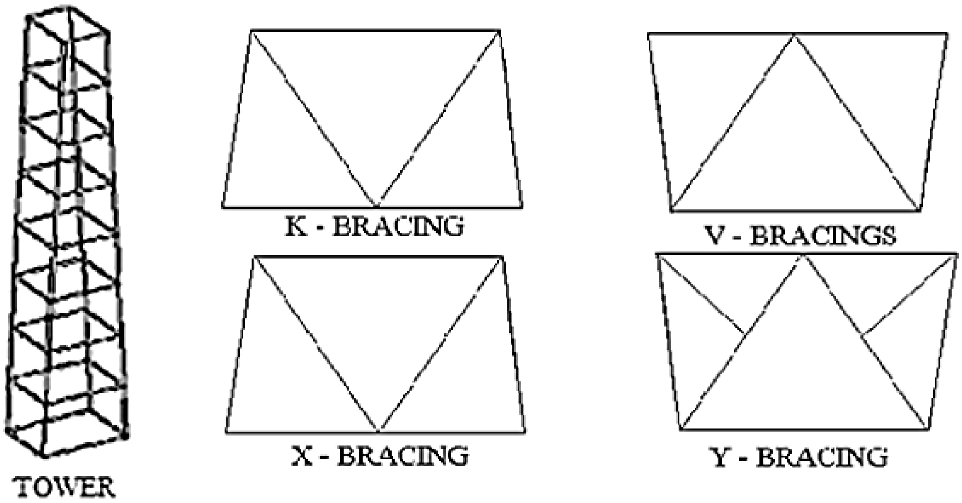


Figure 2.3: Elevations of typical tower and 4 bracing configuration
Sources: (Raju, 2017)

2.3 Material Properties in Modelling of Telecommunication Tower

Modeling, analysis, and design of tower are using software STAAD Pro. This software is created to remove the tedious and long procedure of the manual methods and also structural engineers can automate their tasks. The structural analysis and design of concrete and steel can be produced based on several steps. STAAD Pro features a state-of-the-art user interface, visualization tools, powerful analysis and design engine with advanced finite element and dynamic capabilities (Pathrikar and Kalurkar, 2017). Steel, concrete, and timber design code can be support by this software. The various forms of analysis can be used from the traditional 1^{st} order static analysis, 2^{nd} order p-delta analysis, geometric non-linear analysis or a buckling analysis.

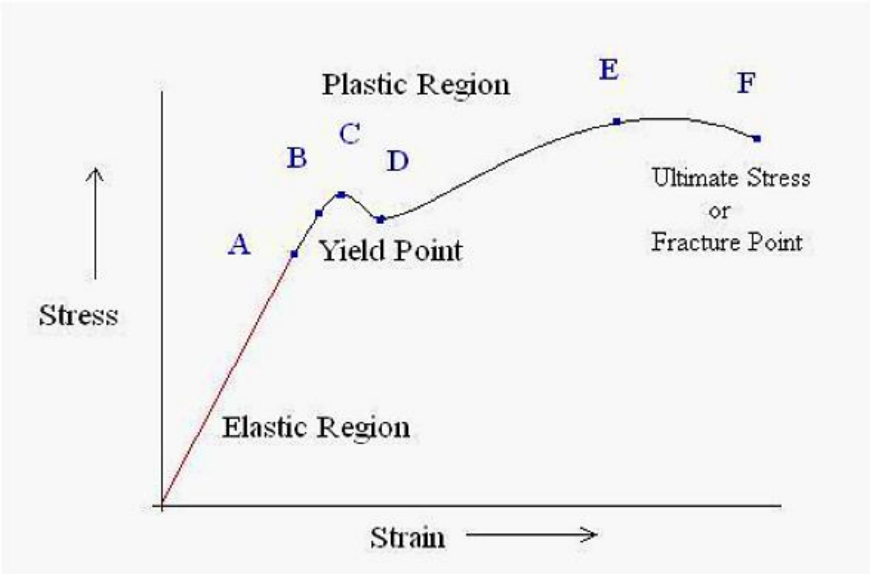
2.3.1 Steel Grade

The different types of steel are based on their properties and all the type of steel is distinguish by steel grade. In modeling of telecommunication tower, the steel grade that selected must be suitable with the design of the tower and enable to withstand the lateral load especially in the high intensity of wind load. Besides, steel grade for bracing and legs of the tower are different. Commonly, steel grade for legs is higher than bracing because the legs of the tower need to transfer more load rather than bracing.

Naidu (2017) proposed a steel grade for bracing and leg for a 4-sided self-support tower are E250 and E410 respectively. Journal *et al.* (2018) suggested to design of self- support angle sectioned and self-support pipe sectioned of towers with steel grade for bracing is E250 and E410 for steel grade of legs. Both of the researchers use the minimum grade of steel because to reduce or decrease the yield stress in the design of the tower.

2.3.2 Yield Stress

Yield stress is the minimum stress at which the material will deform without increasing the load or at the point stress level where the material starts to have permanent deformation. Naidu (2017) carried out the study to compare the performance of monopole and self-support type towers with respect to lateral displacements and the quantity of steel required had proposed the yield stress to material adopted for analysis tower is 410Mpa.



Source: (Curves *et al.*, 2016)

2.4 Displacement Limitation

Wind and seismic sources are the lateral loadings that usually dominate the structural design of tall towers. Strength considerations, stiffness and the effect on deflection are usually the important criteria which determine structural cost and element sizes. In order to justify the performance of these towers, it is essential to understand and know the lateral deflections limits. Smith (2017) stated many modern design codes do not apply limits on a lateral deflection on building and table 2.1 shows the deflection limits in international standards which only several standards provide the guidance at top deflection limit. Gao and Wang (2018) carried out the study about progressive collapse analysis of latticed telecommunication towers under wind loads and find out the limitation value is 1.83 and 7.77 for the tri-pole tower and angle tower respectively which far from the standard limit that stated by (Standard, 2007) which is 1m.

Table 2.1 Deflection limits in international standards

Source: (Smith, 2017)

Standard/ Reference	Effect	Type	Inter-storey Drift Ratio Limit	Top Deflection Limit
Chinese Standard				
JGJ3-2002 Technical specification for concrete structures of tall building	Wind (H>250m)	Concrete/ Steel/ Composite	1/500	No guidance
	Seismic (50yrs) (H>250m)	Concrete/ Steel/Composite	1/500	No guidance
JGJ 99-98 Technical specification for steel structure of tall building	Wind	Steel Structure	1/400	No guidance
	Seismic (50yrs)	Steel Structure	1/250	No guidance
DG/TJ08-015-2004 Code for design of steel – concrete hybrid structures for high – rise buildings (Shanghai)	Wind (H>250m)	Composite	1/500	No guidance
	Seismic (50yrs) (H>250m)	Composite	1/500	No guidance
Hong Kong Code				
Code of practice on Wind Effects in Hong Kong 2004	Wind	RC/Steel	No guidance	No guidance
Code of Practice for Structural use of Concrete 2004	Wind	RC	No guidance	1/500
Code of Practice for Structural Use of Steel 2005	Wind	Steel	1/400	1/500
Eurocode				
Eurocode 3 ENV 1993-1-1:2005:	Wind	Steel	No guidance	No guidance
Eurocode 8 EN 1998-1-2004	Seismic (approx 95 year)	Steel / Concrete (limits depend on finishes)	1/200 – 1/100	No guidance
British Standards				
BS 5950 – structural steel in buildings	Wind	Steel	1/300	No guidance
BS 8110 – structural use of concrete (limit applies unless partition, claddings have been specifically detailed ..)	Wind	Concrete	1/500	No guidance
American Standards				
ASCE 7-05 – Minimum design loads for buildings and other structures	Wind		No guidance	No guidance
	Seismic (2/3 of 2475 event)	Steel / Concrete	1/100 – 1/200	No guidance

2.5 Summary

Table 2.2 summarized the findings of several literatures. Based on the available literatures mentioned, a summary of the research findings for the research gap is made. Most of the researches are conducted the simulation by considered the height of tower in range 30 m to 50 m. Hence, in this study the range of tower height is increases from 50 m to 60 m. In addition, simulation based research is conducted in FEA software by using STAAD Pro V8i. According to the findings from most of the reviews, majority of the researches are considering seismic load in the analysis as well, however in this study only wind load is considered to analyse.

Table 2.2: Findings of Literature Review

Author	Year	Title	Parameter	Result
Jesumi. A	2013	Optimal Bracing System for steel tower.	Wind load Weight	Y bracing has been found to be the most economical bracing system up to 50 m.
S. Vijaya	2014	Analysis of Telecommunication Tower subjected to seismic and wind loading.	Wind load Displacement Frequency	The tower model of 50 m with XB bracing and Y bracing fail in wind load 35 m/s.
S.K. Duggle	2015	Comparative Analysis of steel Telecommunication Tower subjected to seismic and wind loading.	Displacement	The displacement is maximum for W bracing and minimum for V bracing XBX bracing.
Harika T.S.D	2017	Selection of suitable bracing system for a telecommunication tower at various zone.	Displacement Axial load	Both X and Y bracing system performed well at various wind zone.
M. Pavan Kumar	2017	Parametric comparison of communication tower with different bracings.	Wind load Bracing system	For a 24 m height 4-legged communication tower K bracing be the most effective and economical.

CHAPTER 3

METHODOLOGY

3.1 General

The chapter explains the step of modeling and analyzing of telecommunication tower of height 30 m, 40 m, 50 m, and 60 m. Then, the towers were provided with different types of bracing system such as K and Y. For this project, these bracing systems were modeled in STAAD. Pro with different bracing steel sections such as pipe section, angular section, multi-section, and wind analysis had been run to find out better bracing system along with the bracing section in the event of selected wind zones. The results obtained for different parameters of these models were compared. The details of the different towers are shown in Table 3.1.

Table 3.1: The details of different tower

Height of tower (m)	30	40	50	60
Height of Slant Portion(m)	20	28	36	44
Height of Straight Portion at Top of Tower(m)	10	12	14	16
Base width (m)	5	5	5	5
Top width (m)	2	2	2	2
No. of 4m Panel	5	7	9	11
No. of 2m Panel	5	6	7	8

3.2 Structure modeling in STAAD.Pro

Structural analysis and design, STAAD.Pro has been used in this work to simulate the behavior of four different heights of telecommunication tower in the selected wind zones. The tower has its own specification element, terms and also procedures that have to be used properly.

Generally, to create the model of tower in STAAD.Pro there were various or multiple steps which need to be completed in order for the model to run properly and produce a better result. Figure 3.1 shows the command snap node edit option which this command draws the skeleton of the tower as per requirement. The procedure to model the tower was discussed in the rest of this chapter as well. All these procedures included the supports, assigning nodes, assigning property, load and definition, analysis and design and post-processing.

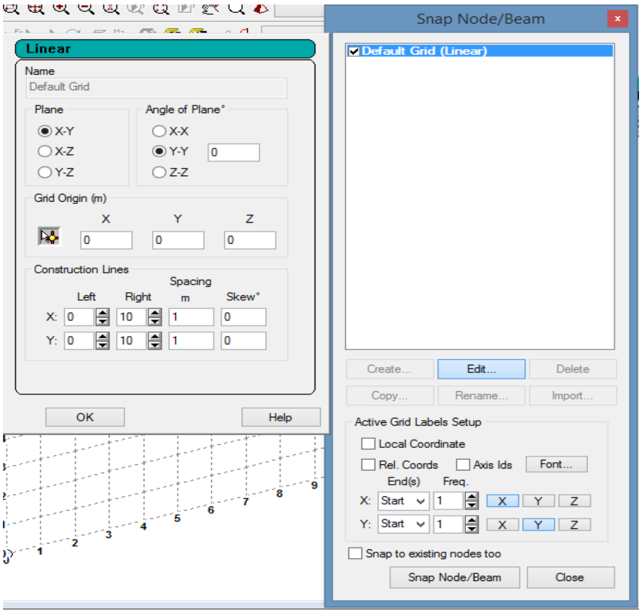


Figure 3.1: Snap Node Edit Option

3.2.1 Model Generation

Table 3.2 lists the details of different tower and the towers were created and modeled as details given. Four different heights of 30 m, 40 m, 50 m, and 60 m towers were modeled using the same procedure or method. Besides, each model had different height of slant portion and a straight portion at top of the tower. However, the base and top width of these towers were the same which decided to be 5m and 2m respectively. Next, supports at the bottom nodes were assigned as fixed support. The towers were created by using nodes according to their coordinate and Figure 3.2 shows the model 30 m of the tower with K-Bracing while Figure 3.3 shows 30 m of the tower with Y-Bracing.

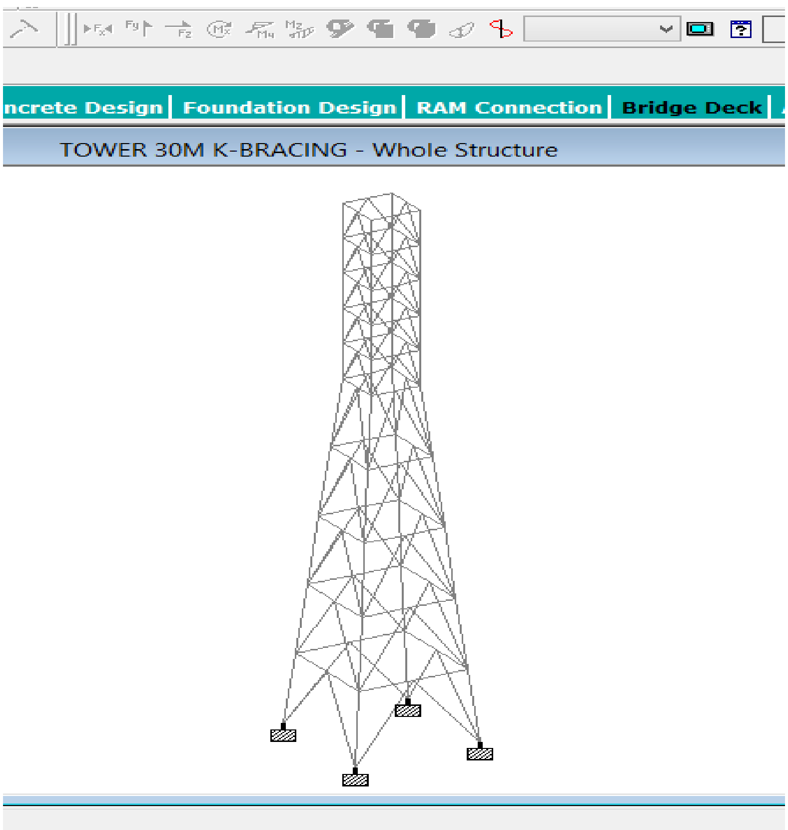


Figure 3.2: Model of the tower with K-Bracing

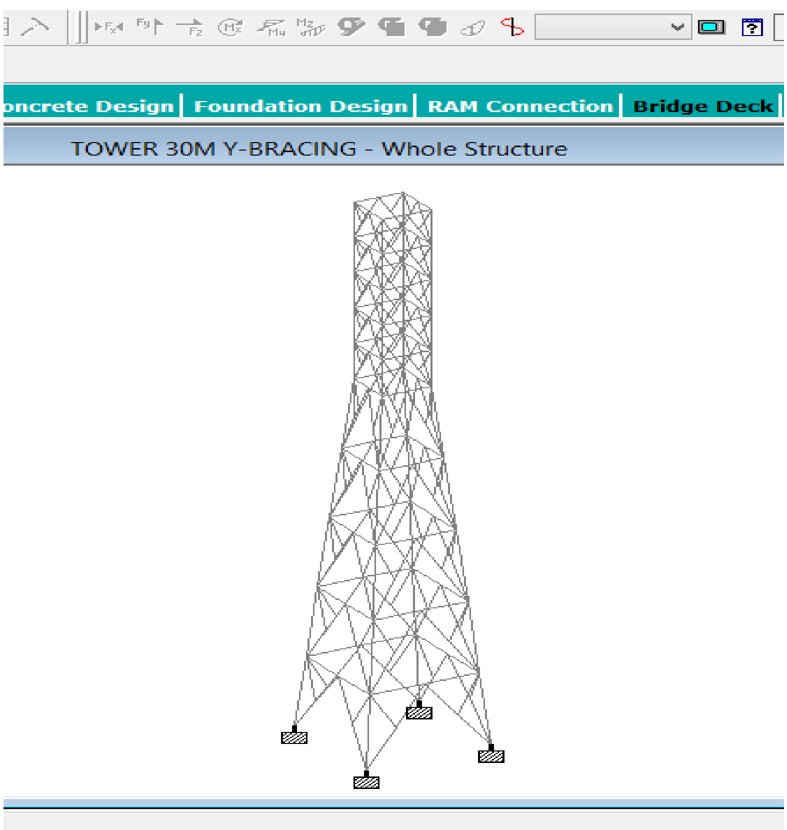


Figure 3.3: Model of the tower with Y-Bracing

3.2.2 Material Properties

Leg members and bracing systems are the main member or element in modeling the telecommunication tower. In order to properly model the tower, the material must be assigned correctly on each of the element. The member details of towers are shown in Table 3.2 while Figure 3.4 shows the command to assign the material properties on the whole structure.

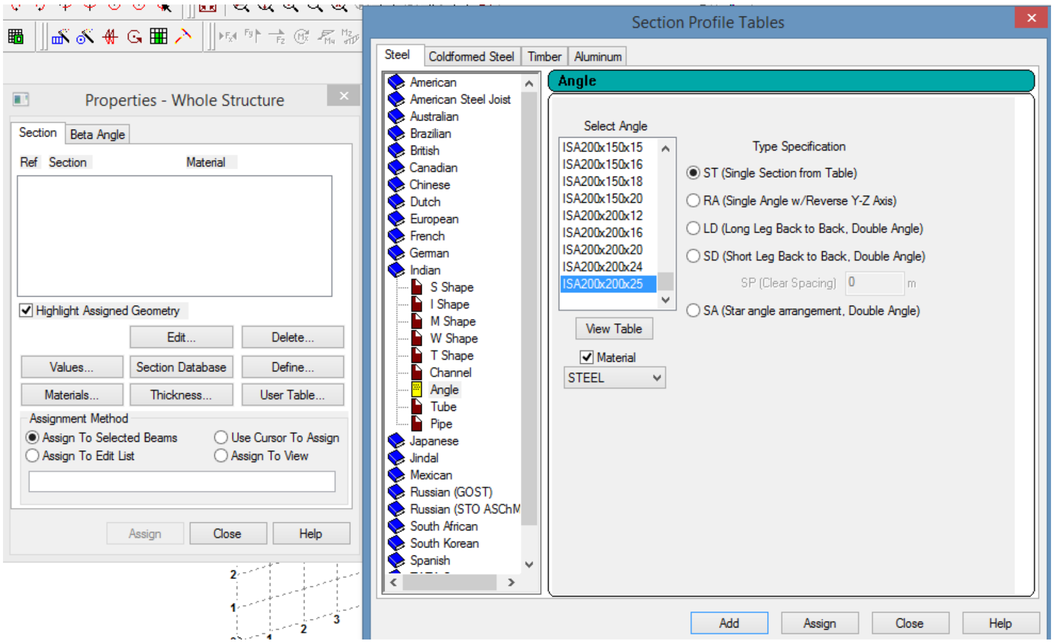


Figure 3.4: Section Profile Tables

Table 3.2: Member Details of Tower

No	Tower Elevation (m)				Member Description	Section
	30 m	40 m	50 m	60 m		
1	0-12	0-16	0-20	0-24	Leg Member	UA 200 X 200 X 24
2					Bracing	UA 150 X 150 X 10
3	12-20	16-28	20-36	24-42	Leg Member	UA 200 X 200 X 16
4					Bracing	UA 120 X 120 X 15
5	21-30	28-40	36-50	42-60	Leg Member	UA 100 X 100 X 15
6					Bracing	UA 90 X 90 X 10

3.3 Loads on Tower

The loads that acting on the structure included the self-weight of the structural elements that based on the type of structural steel used in the tower, a platform load which applied at the top of the tower and wind load. Figure 3.5 shows the command for load and definition which all the load acting on the structure added and assign at the structure.

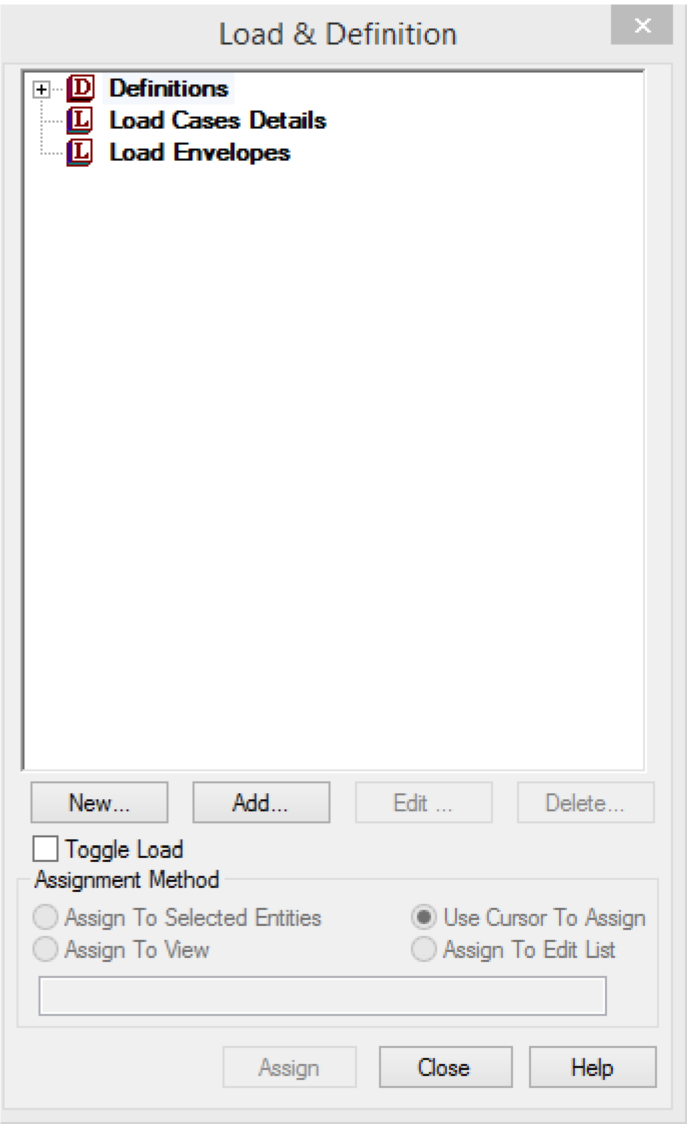


Figure 3.5: Load and Definition

3.3.1 Apply Platform Load

A platform load of 0.82 kN/m^2 was applied at 26 m, 36 m, 46 m, and 56 m respectively for 30 m, 40 m, 50 m, and 60 m towers. Then, 10% of the total weight was assumed to the weight of the ladder and cage assembly. The antenna loads were summed up and evenly distributed to the nodes at the considered height. Table 3.3 shows the details of the antenna provided on the tower.

3.3.2 Apply Wind Load

The prediction of wind loading for structural design in Malaysia is based on MS1553: Code of Practice on Wind Loading for Building Structures, 2002. The code is an adaptation of the Australian and New Zealand Standard, AS/NZS 1170.2: Structural Design- General Requirements and Design Action. For the calculation of the wind load by the gust factor method the parameters considered are as follows:

Design wind pressure:

$$P = 0.613\ [V_{des}]^{2}\ C_{fig}\ C_{dyn}\ \ (Pa) \qquad 3.1$$

Where:

V_{des} = design wind speed

= $V_{sit}\ l$

l = importance factor = 1.0

$$V_{sit} = V_s\ M_d\ M_{z,cat}\ M_s\ M_h \qquad 3.2$$

V_s = wind speed = 33.5 ms^{-1} and 47 ms^{-1}

M_d = wind directional multiplier = 1.00

$M_{z,cat}$ = terrain/ height multiplier. Varies with z. For z= h (Table 4.1)

M_s = shielding multiplier = 1.0

M_h = hill shape multiplier = 1.0

C_{fig} = aerodynamic shape factor

= C_d = drag force coefficient = 3.5

C_{dyn} = dynamic response factor

$$= \frac{1 + 2l_h [g_v^2 B_S + (g_r^2 S E_t / \zeta)]^{0.5}}{(1 + 2 g_v l_h)}$$

l_h = Turbulence intensity at z= h

g_v = peak factor = 3.7

B_S = Background factor

S = Size reduction factor

E_t = spectrum of turbulence

ζ = ratio of structural damping to critical damping = 0.05

g_r = peak factor for resonant response = 3.09

Table 3.3: Antenna Load for the towers

No	Item	Qty	Dia (m) (w x d x h)	Weight/ Antenna (kg)	Location from base (30m tower)	Location from base (40m tower)	Location from base (50m tower)	Location from base (60m tower)
1	CDMA	6	0.26 x 2.5	20	28 m	38 m	48 m	58 m
2	Microwave	1	1.2	77	24 m	34 m	44 m	54 m
3	Microwave	1	0.6	45	24 m	34 m	44 m	54 m
4	Microwave	2	0.3	25	24 m	34 m	44 m	54 m

3.4 Solution Phase

In this phase, the structure was assigned with the wind load, dead load, and platform load. Therefore, this phase is very important to analyze the tower before generating the results at the post-processing phase.

3.4.1 Assigning Wind Load

Assume the wind load in x and z-direction, click on Load and Definition. Then, add load case details with giving title as wind load. Before wind load dialog box popup, go to definitions wind. Finally, give the intensity of wind load at a member of the structure. Figure 3.6 shows the structure that has been assigned with wind load.

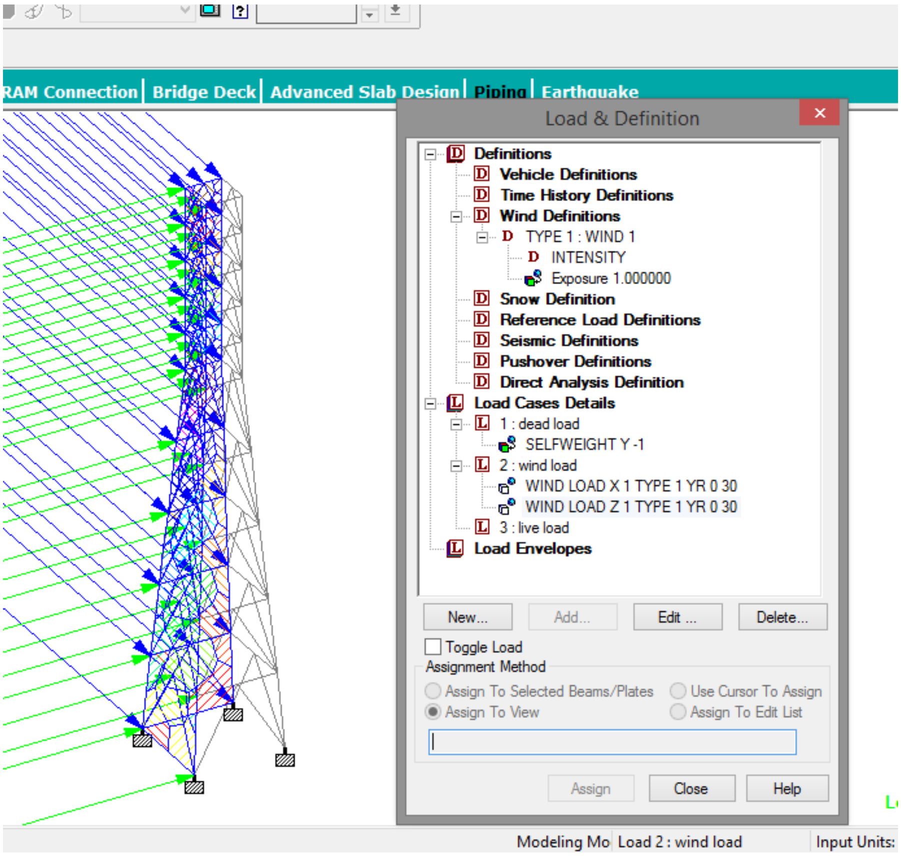


Figure 3.6: Model that has been applied with wind load

3.4.2 Assigning Dead and Platform Loads

For assigning dead and platform load, go to load property and click on load and definitions and give titles as (dead load/ platform load). Then, click on (dead load/

platform load) to assign to view. Then, (dead load/ platform load) are assigned to the entire structure.

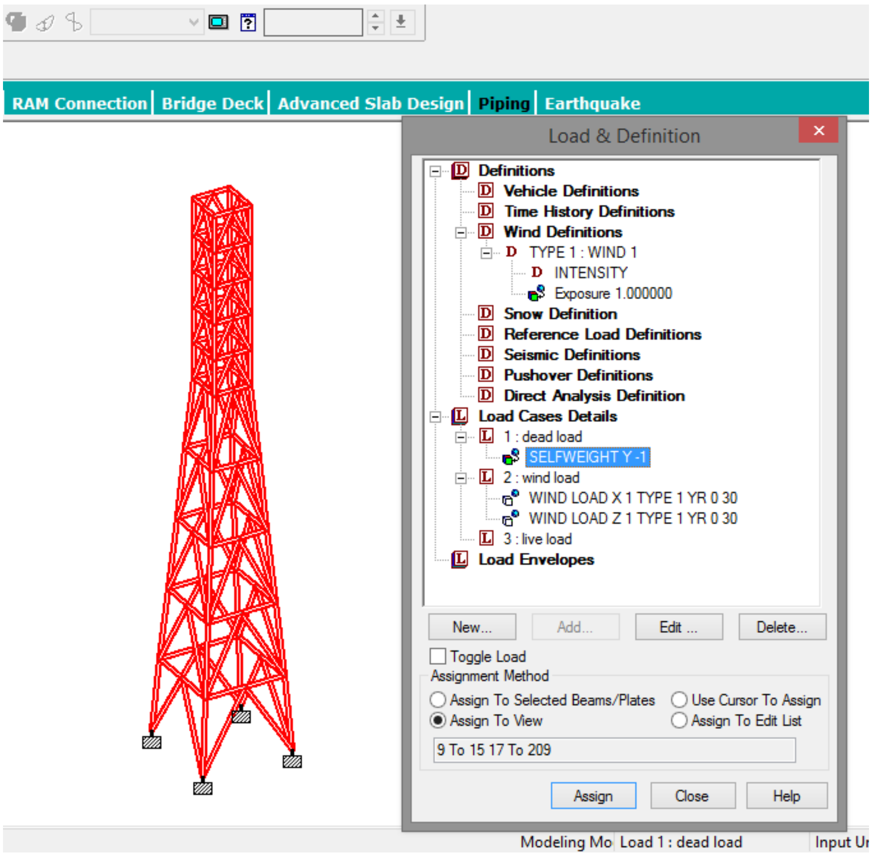


Figure 3.7: Model that has been applied with dead load

3.5 Post Processing

In post-processing, general results for displacement, support reaction, axial forces, and stress can be checked through the value recorded in tabular forms and bars chart as well.

3.5.1 Analysis Process

Analysis of the tower model is to examine the behavior of the tower displacement in the event of wind loads and identify the effective height of the tower. After that displacement and effective height, checking was conducted. The bar chart was produced to compare all the required parameters and the most effective bracing system for a communication tower. Figure 3.5 shows the deflection of the tower.

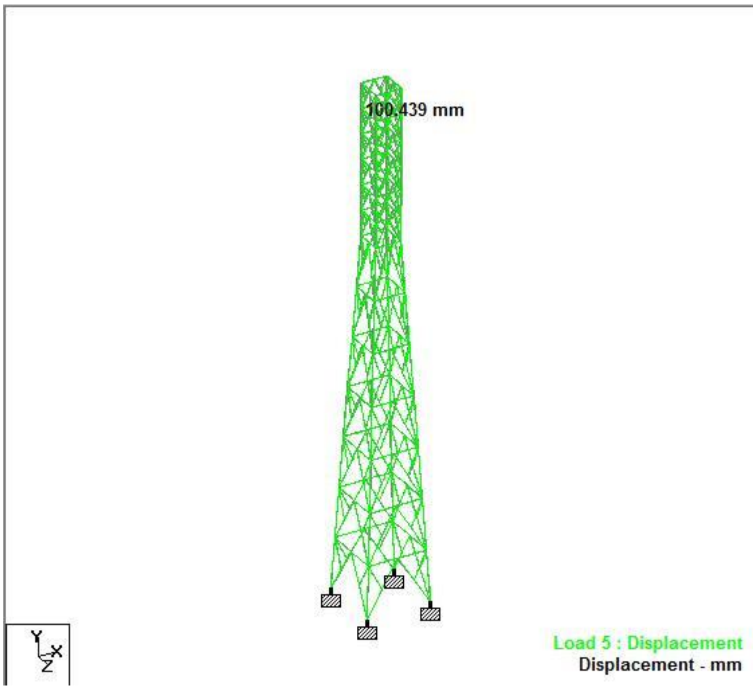


Figure 3.8: Deflection of tower

Source: (Rajasekharan and Vijaya, 2014)

3.6 Methodology Chart

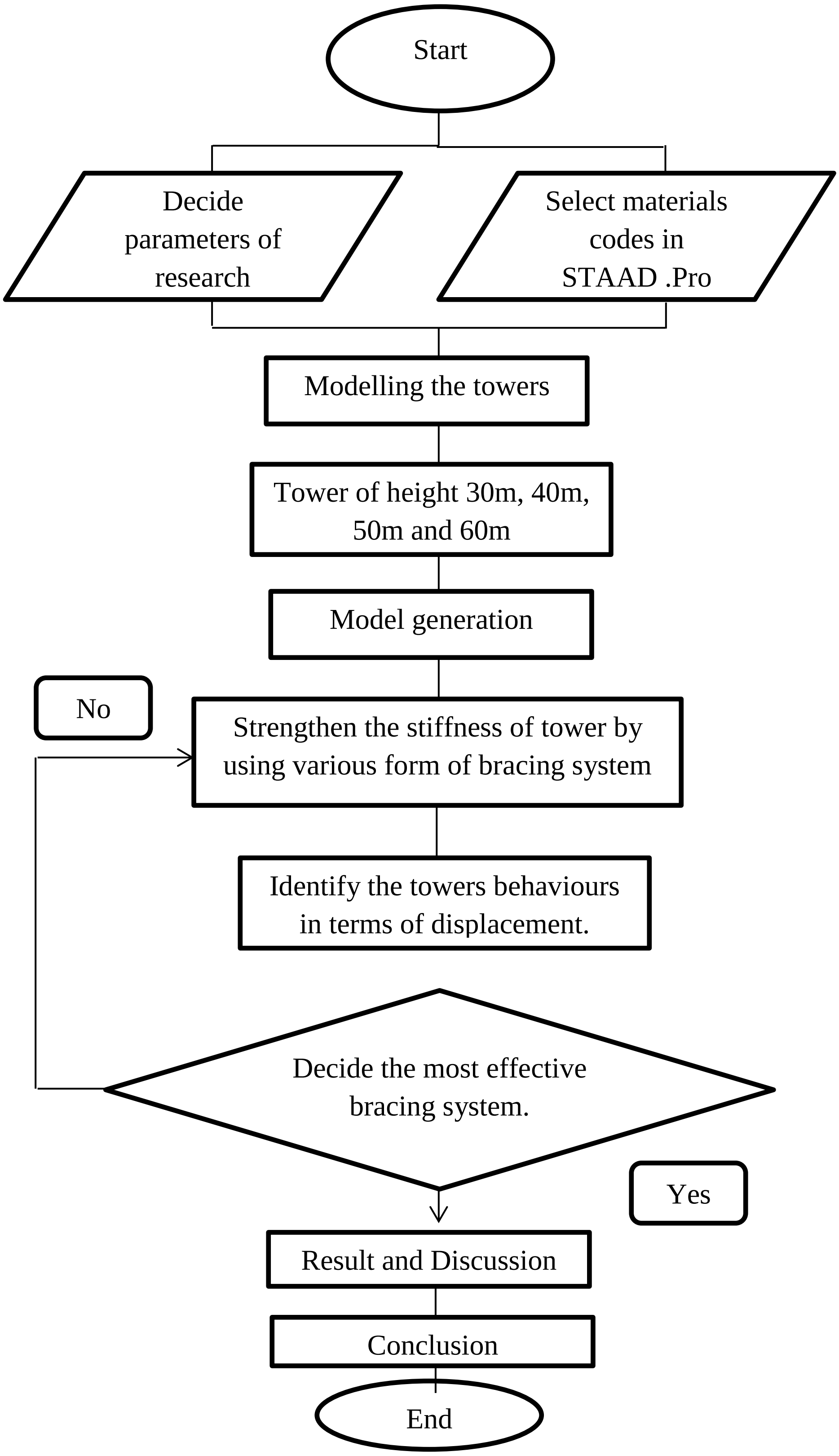


Figure 3.9: Methodology flow chart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

The modeling of the finite element analysis (FEA) of a telecommunication tower together with the dimension was built. The whole length of the model has been run by using this STAAD Pro software. Besides, the design standard of the tower has been adopted from the BS 5950:2000 code. The entire dimension and section designation was taken from the prepared dimension from the table of properties. The behavior of the tower is most important to ensure the service life of the tower under certain services loads. For this study, a comparison has been made between the towers based on the different types of bracing system used. This has been done in order to examine the difference deflection between these towers under a certain loading.

4.2 Finite Element Analysis of Towers

For the analysis of telecommunication tower, the different heights and bracings system are been considered. This steel structure consists of leg members, primary bracings and secondary bracings (inactive). The analysis considers varying heights such as 30m, 40m, 50m, and 60m with the combination of bracing systems like K and Y. The end conditions (supports) are considered as fixed end condition and the properties assigned to the models are kept the same for all the models. STAAD Pro software is used in the analysis. Initially, the wind analysis is carried out on the developed model. The joint displacements at the top of the towers are compared for the different wind zones.

4.3 Wind Analysis Result

Wind analysis is carried out for two wind zones of basic wind speed 33.5 m/s and 44.0 m/s. The combination load that taken for the analysis of the models are dead load, platform load, and wind load. Then, the result of joint displacement and member stress were compared.

4.3.1 Displacement of Tower for Case 1

Figure 4.1 until 4.8 shows the displacement of a tower with different types of height and bracing system. Each tower has the same loading which is self-weight, platform load and wind load. For this section, the wind speed that assigns is 33.5 m/s. From there the tower with least displacement can be determined. Table 4.1 shows the result of displacement at the top of the tower with different types of bracing system. At height 30m of the tower, the steel structure with K-Bracing produced 42.72 mm displacement compared to Y-Bracing. Also, at height 40m and 50m of the tower, the steel structure with K-Bracing shows more displacement compared to Y-Bracing. However, at height 60 m, the displacement produced by a tower with Y-Bracing is greater than K-Bracing which is 287.44mm. This shows that the different displacements between these two bracing about 83.73mm.

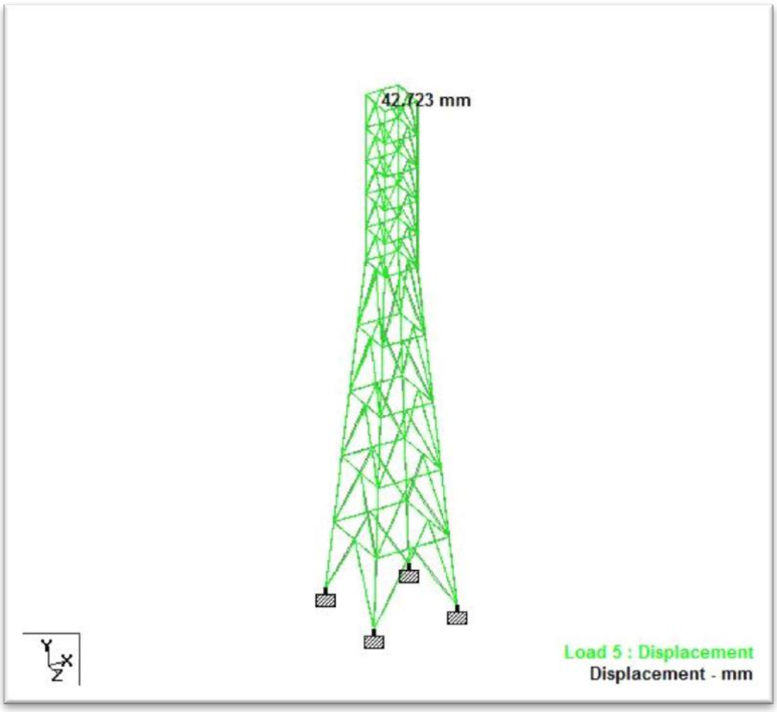


Figure 4.1: Displacement at height 30m of the tower with K bracing

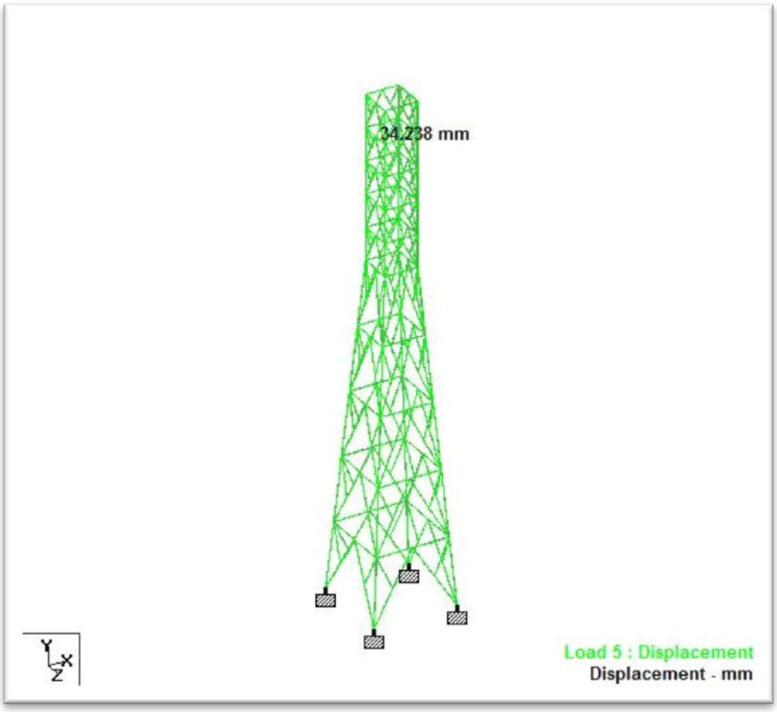


Figure 4.2: Displacement at height 30m of the tower with Y bracing

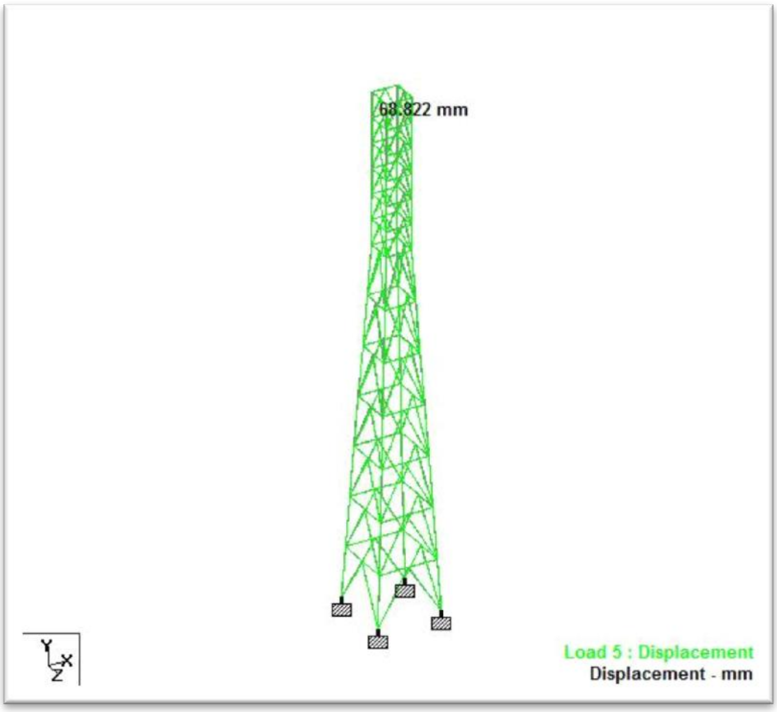


Figure 4.3: Displacement at height 40m of the tower with K bracing

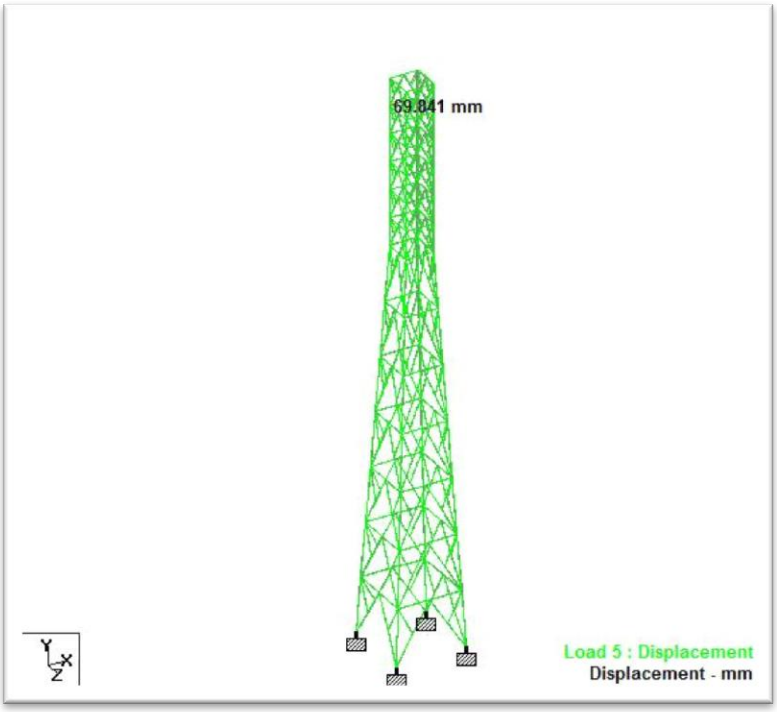


Figure 4.4: Displacement at height 40m of the tower with Y bracing

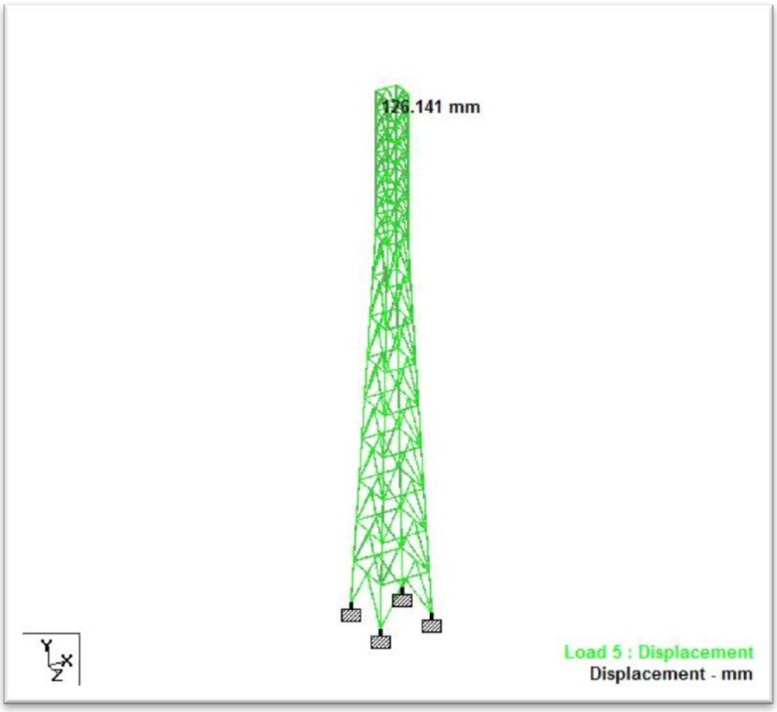


Figure 4.5: Displacement at height 50m of the tower with K bracing

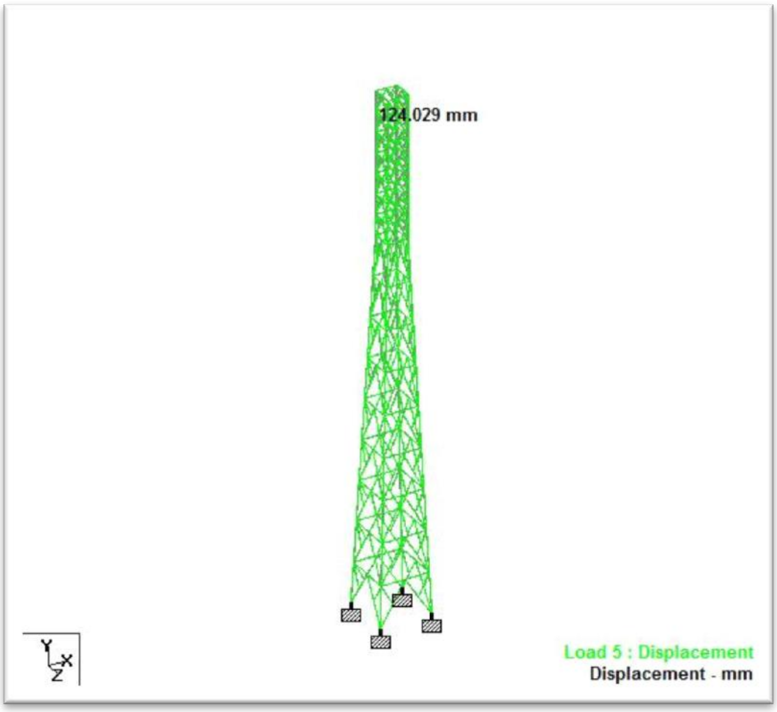


Figure 4.6: Displacement at height 50m of the tower with Y bracing

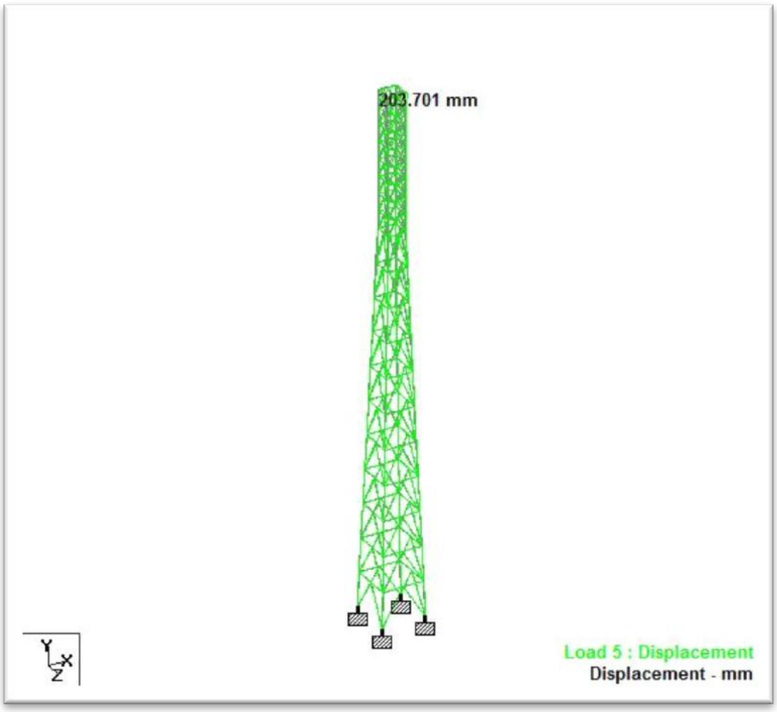


Figure 4.7: Displacement at height 60m of the tower with K bracing

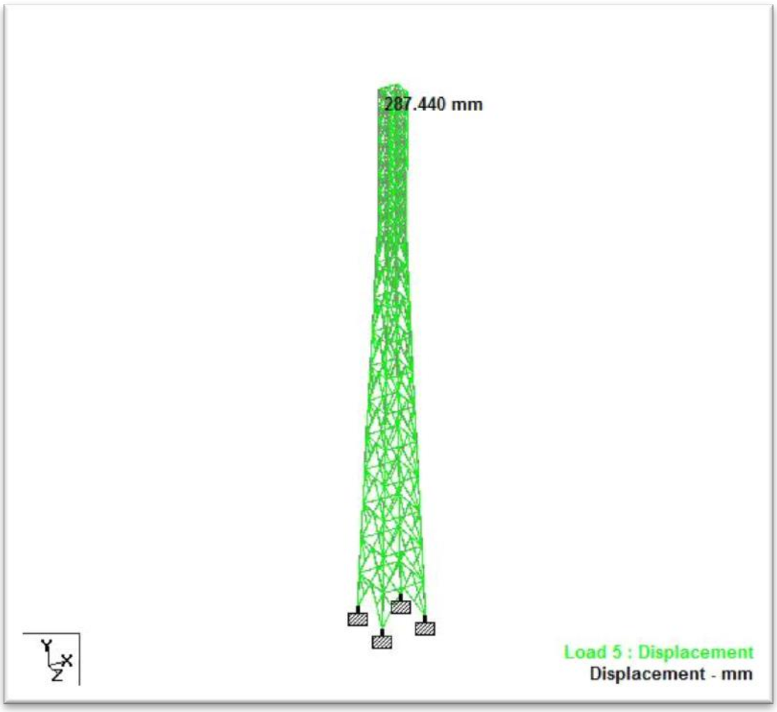


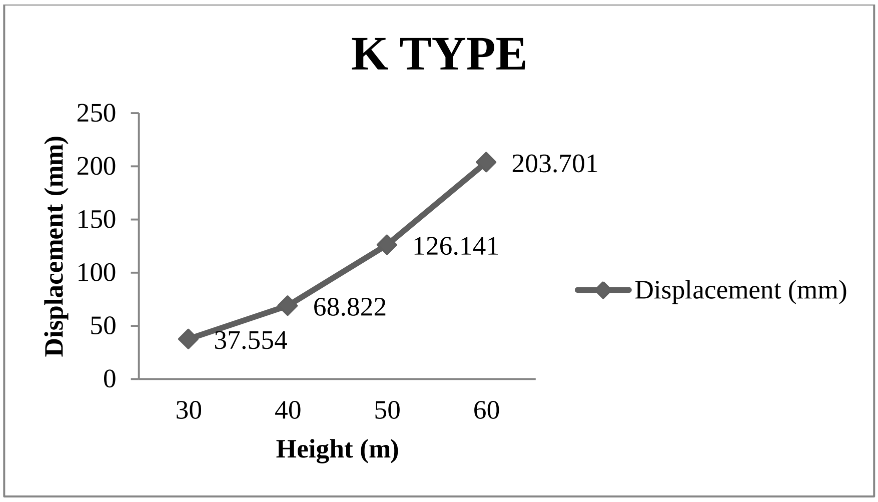
Figure 4.8: Displacement at height 60m of the tower with Y bracing

Table 4.1: Comparison of Displacement

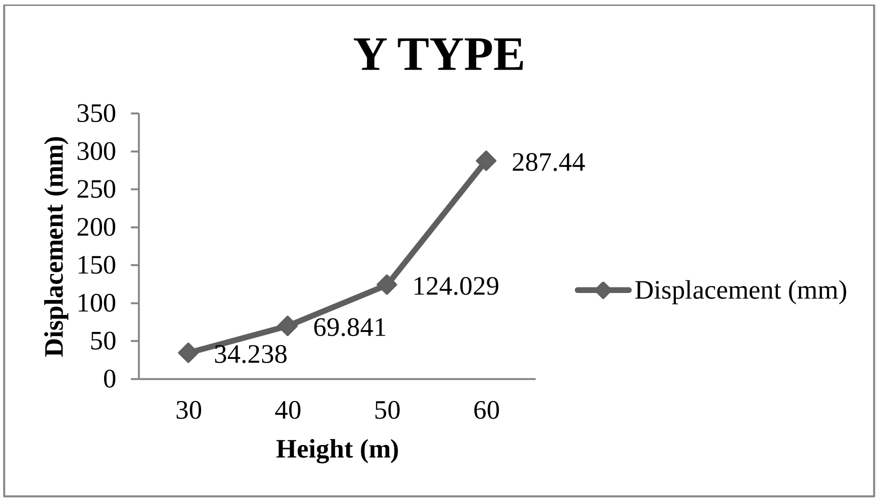
Tower Height (m)	Case 1 (33.5 m/s)	
	Bracing	
	K	Y
30	42.72	34.23
40	68.82	69.84
50	126.14	124.02
60	203.70	287.44

4.3.2 Displacement against Height for Case 1

Figure 4.9(a-b) indicates that the displacement increase as the height of tower increase. Based on the graph that has been obtained, when the height of the tower increases from 30 m to 40 m and 40 m to 50 m the displacement increases by 64%. Besides, at a height from 50 m to 60 m the displacement increases by 66%. The towers with Y bracing perform well that has less joint displacement whereas K bracing has the highest displacement.



(a)



(b)

Figure 4.9(a-b): Variation of Displacement (mm) at Top for Different Tower

4.3.3 Displacement of Tower for Case 2

Figure 4.9 until 4.17 shows the displacement of a tower with different types of height and bracing system. Each tower was added with the same loading which is self-weight, platform load and wind load. For this section, the wind speed that assigns is only 44.0 m/s. From there the tower with less displacement can be determined. Table 4.2 shows the result of displacement at the top of the tower with different types of bracing system. At height 30 m of the tower, the steel structure with K-Bracing produced 48.88 mm displacement while for Y-Bracing only 48.70 mm displacement was produced. Also, at height 40 m and 50 m of the tower, the steel structure with K-Bracing shows more displacement compared to Y-Bracing. Then, at height 60 m, the displacement produced by a tower with K-Bracing is greater than Y-Bracing which is 308.213 mm. This shows that the difference displacements between these two bracing about 10.017 mm.

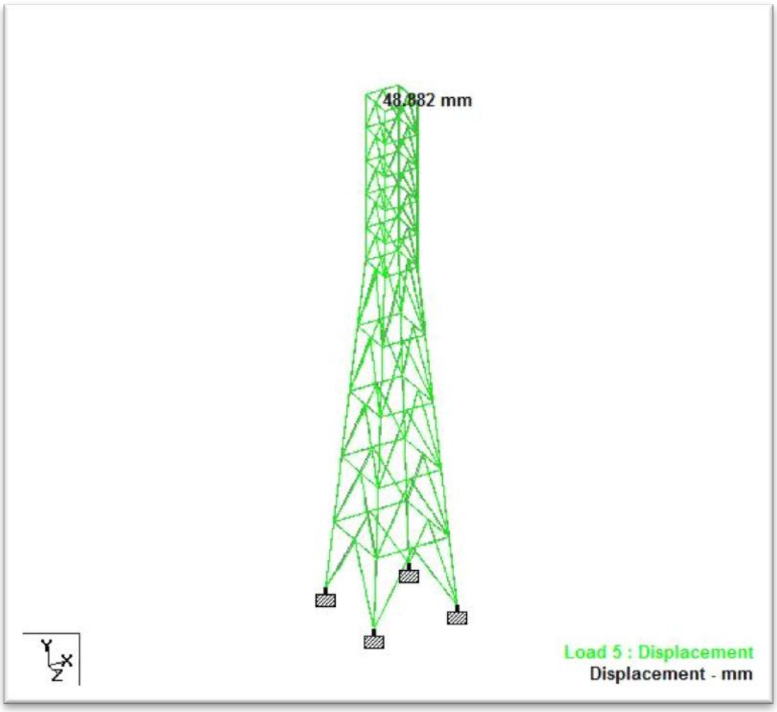


Figure 4.10: Displacement at height 30m of the tower with K bracing

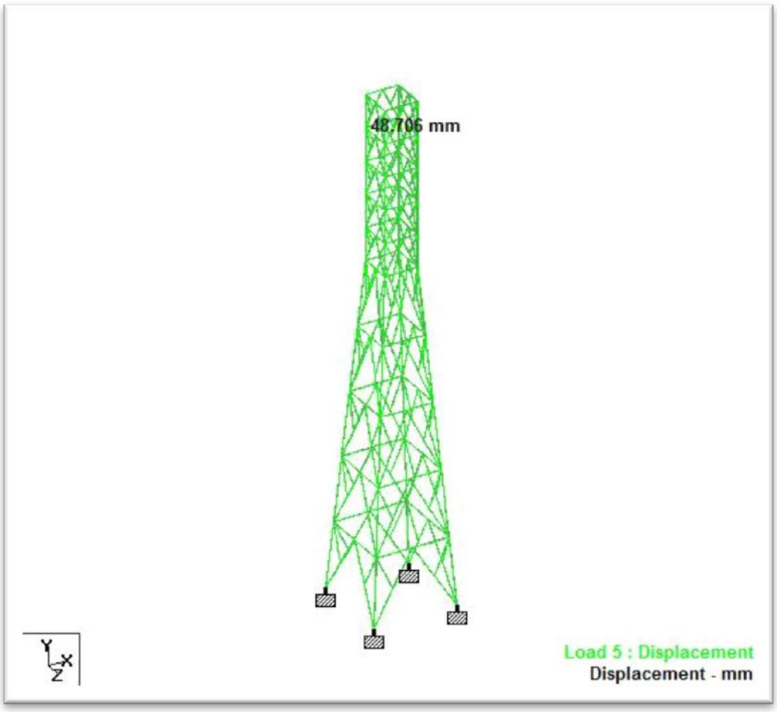


Figure 4.11: Displacement at height 30m of tower with Y bracing

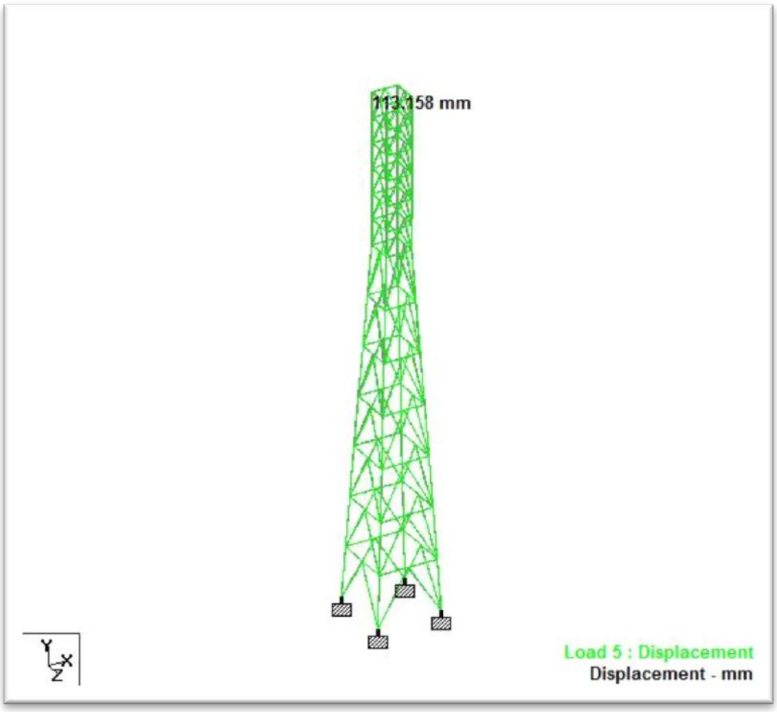


Figure 4.12: Displacement at height 40m of the tower with K bracing

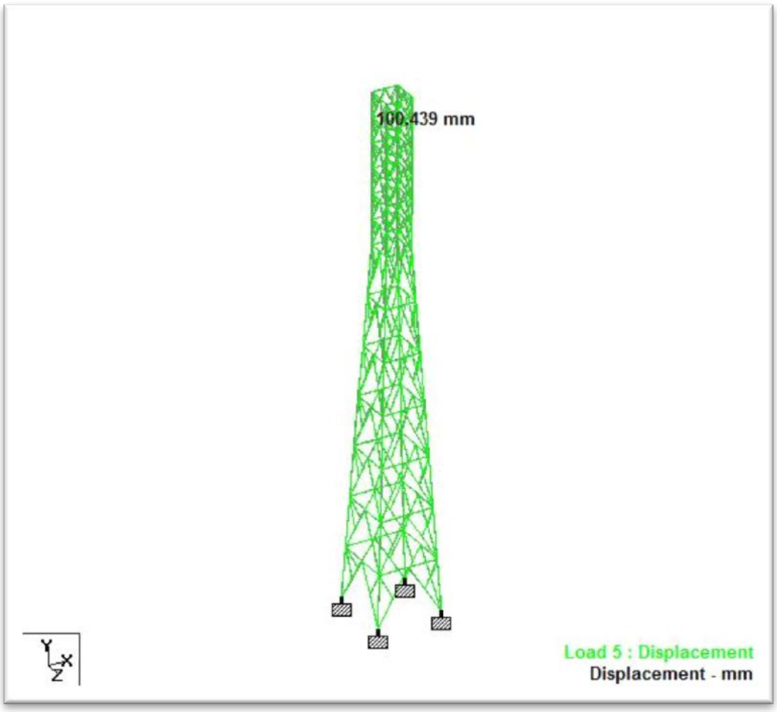


Figure 4.13: Displacement at height 40m of the tower with Y bracing

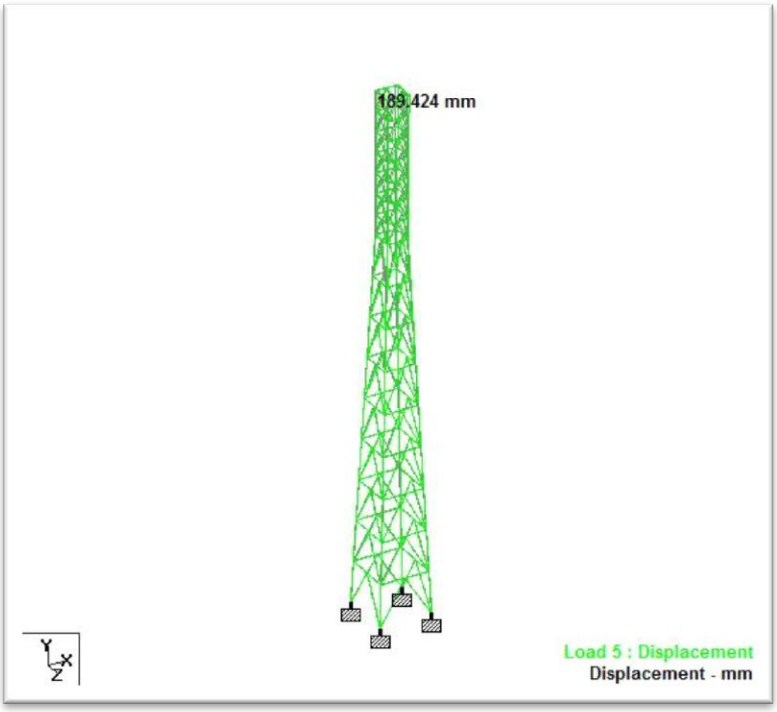


Figure 4.14: Displacement at height 50m of the tower with K bracing

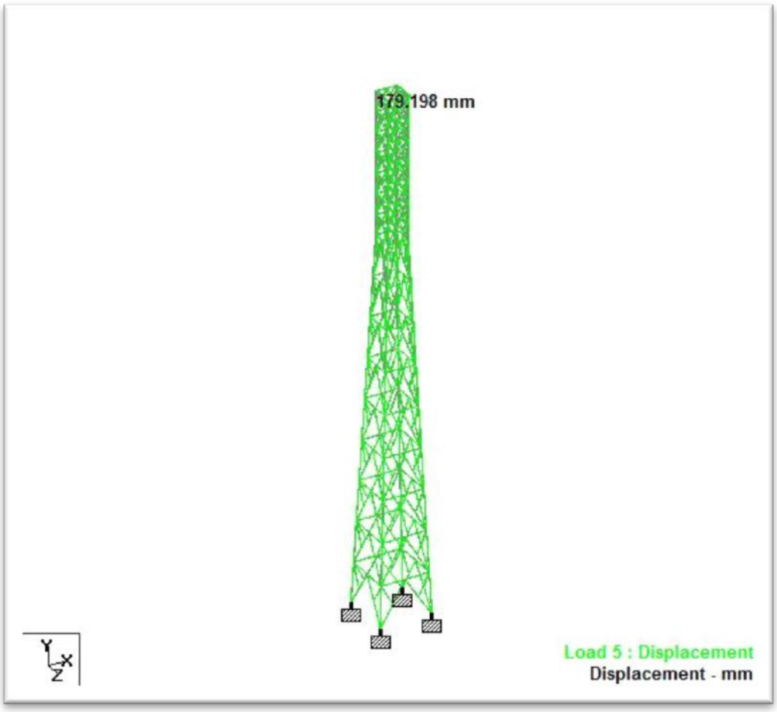


Figure 4.15: Displacement at height 50m of the tower with Y bracing

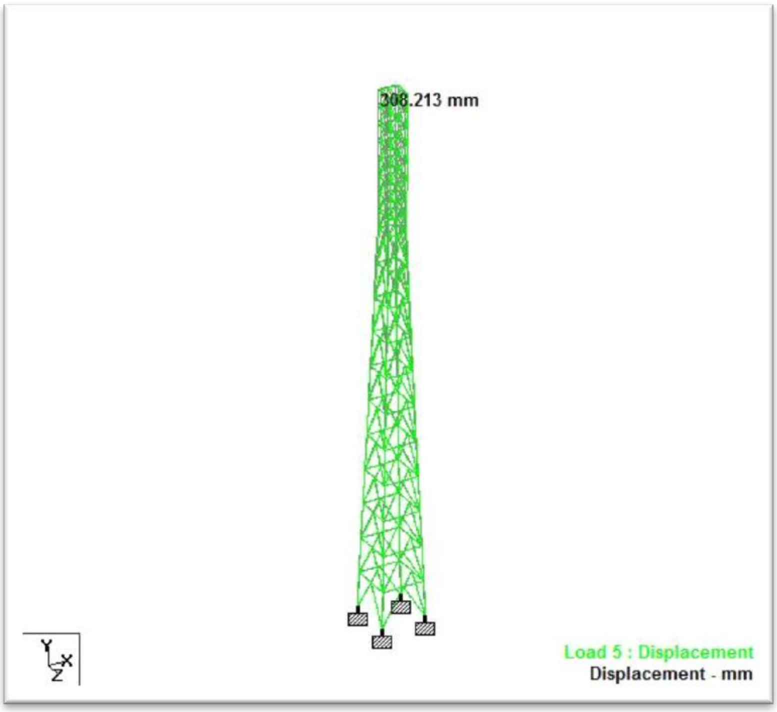


Figure 4.16: Displacement at height 60m of the tower with K bracing

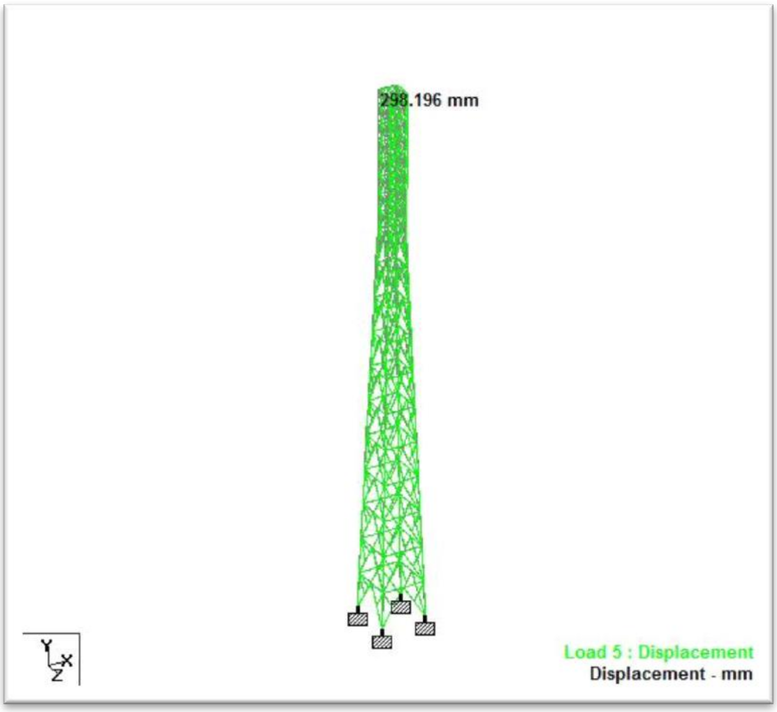


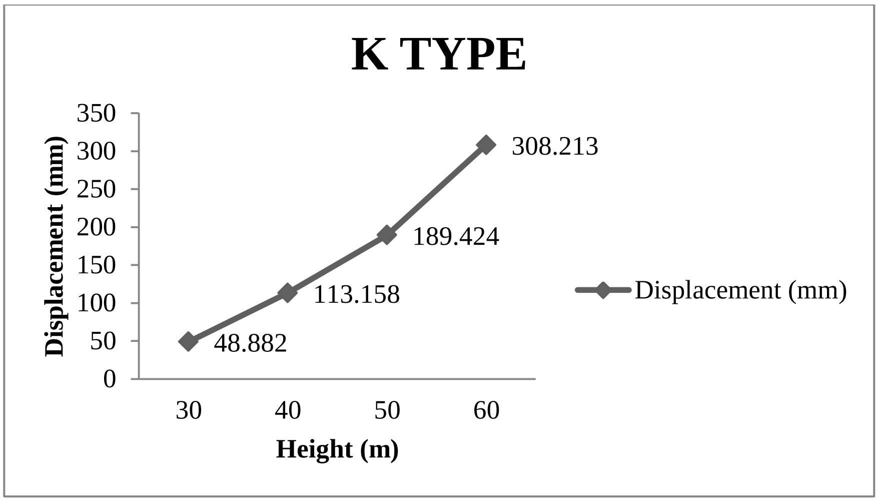
Figure 4.17: Displacement at height 60m of the tower with Y bracing

Table 4.2: Comparison of Displacement

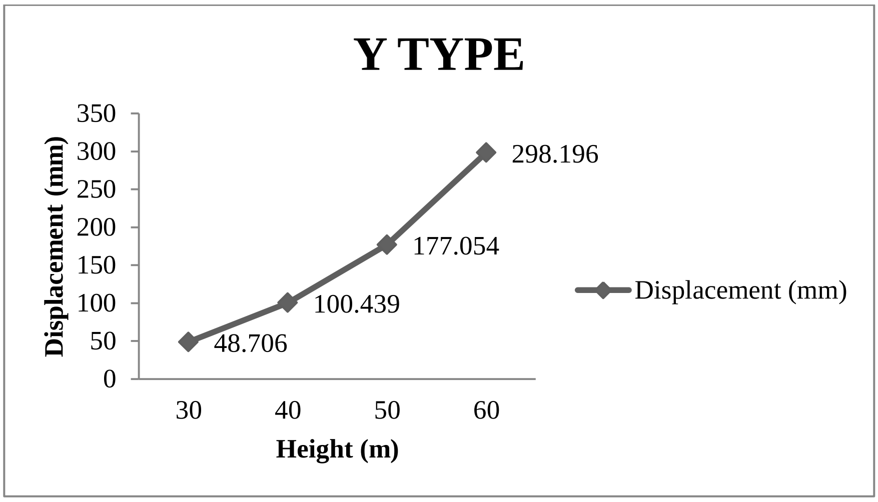
Tower Height (m)	Case 2 (44.0 m/s)	
	Bracing	
	K	Y
30	48.88	48.70
40	113.15	100.43
50	189.42	177.05
60	308.21	298.19

4.3.4 Displacement against Height for Case 2

Figure 4.18(a-b) shows that the displacement increases as the height of tower increase. Based on the graph above, the tower height increase from 30m to 40m the displacement increase by 69% while from 40m to 50m of the tower height, 63% of displacement is produced. Then, at height range 50m to 60m the percentage of displacement become 62%. Y bracing perform well that has less joint displacement whereas K bracing has the highest displacement.



(a)



(b)

Figure 4.18(a-b): Variation of Displacement (mm) at Top for Different Tower

4.3.5 Member Stress of Tower for Case 1

Figure 4.19 until 4.26 shows the variation of member stress at the bottom leg of the tower with different types of height and bracing system. Each tower was carried the same loading which is self-weight, platform load and wind load. For this section, the wind speed that assigns is 33.5 m/s. From there the tower with less member stress at bottom leg can be determined. Table 4.3 shows the result of member stress at the bottom leg of the tower with different types of bracing system. At height 30m of the tower, the tower with K-bracing and Y-bracing produced 24.21 N/mm^2 and 23.97 N/mm^2 of stress respectively. Also, at height 40 m and 50 m of the tower, the steel structure with K-Bracing shows more stress compared to Y-Bracing. Besides, at height 60m, the stress produced by a tower with K-Bracing is greater than Y-Bracing which is 47.90 N/mm^2. This shows that the difference stress between these two bracing about 1.48 N/mm^2.

Table 4.3: Comparison of Member Stress at Bottom Leg

Tower Height (m)	Case 1 (33.5 m/s)	
	Bracing	
	K	Y
30	24.21	23.97
40	32.89	32.36
50	42.78	42.09
60	47.90	46.41

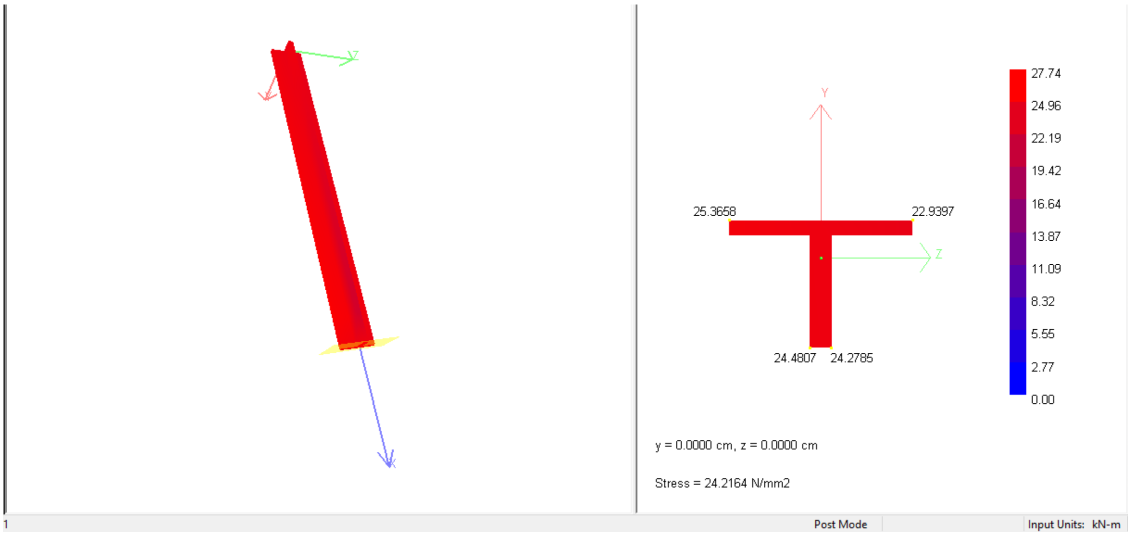


Figure 4.19: Member stress at height 30m with K bracing

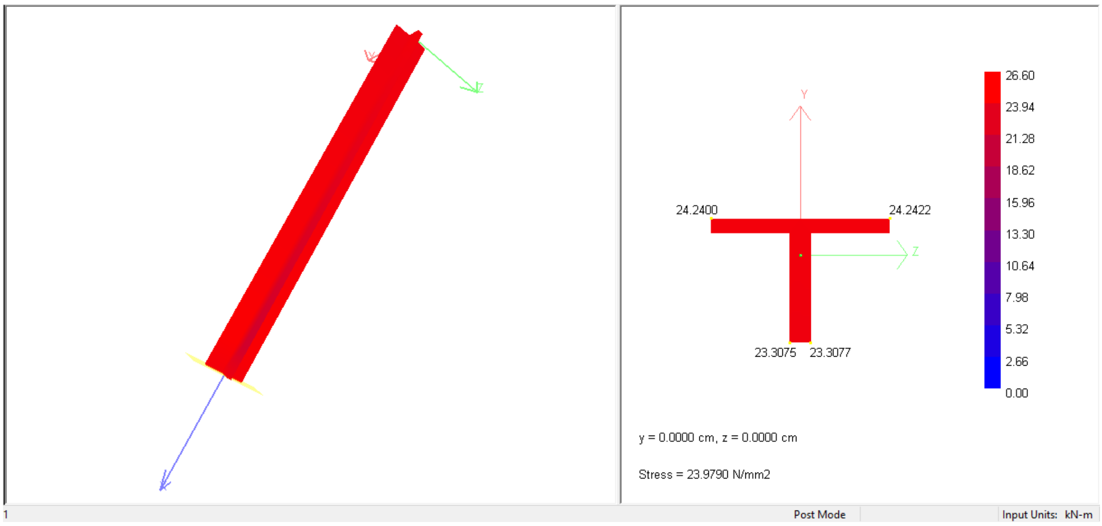


Figure 4.20: Member stress at height 30m with Y bracing

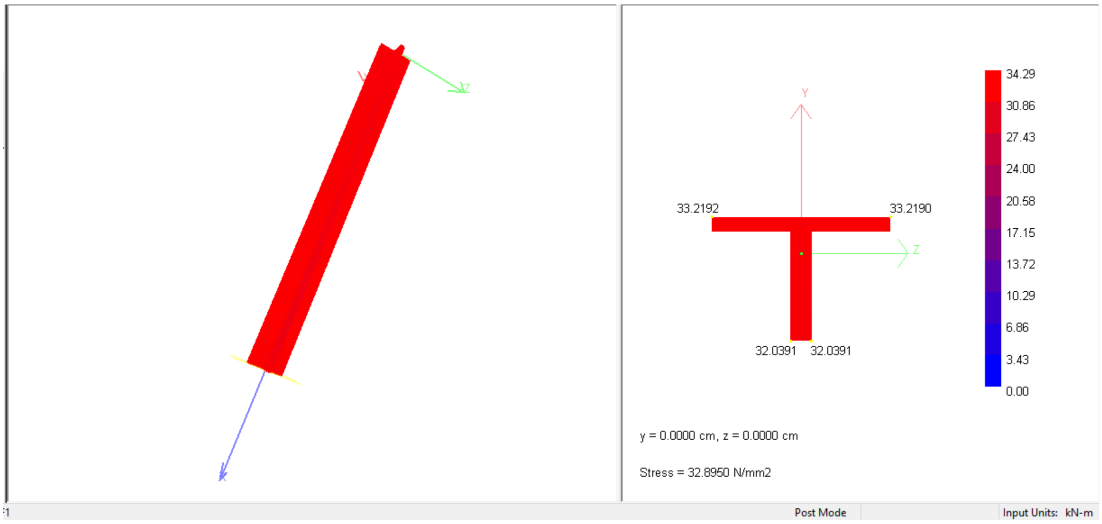


Figure 4.21: Member stress at height 40m with K bracing

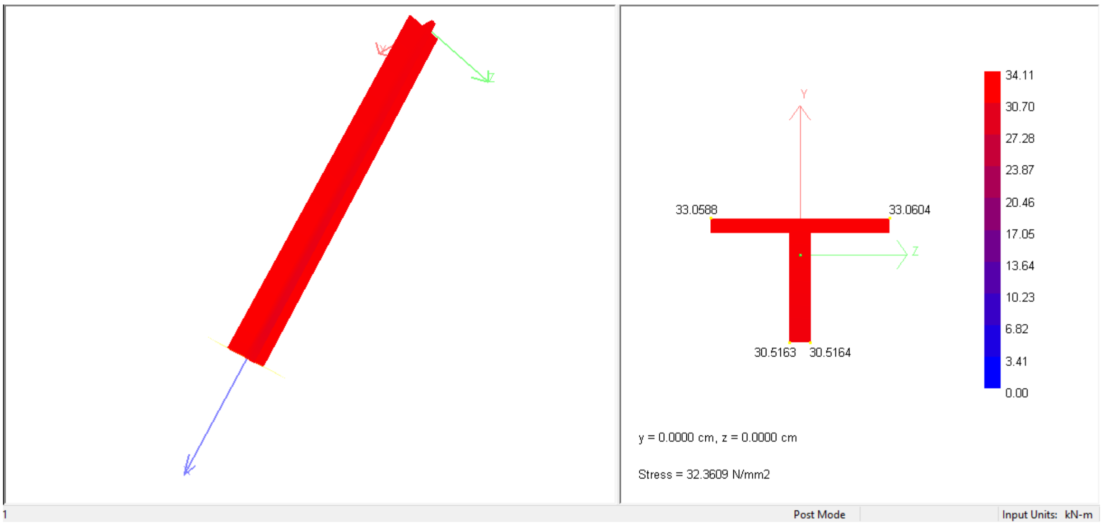


Figure 4.22: Member stress at height 40m with Y bracing

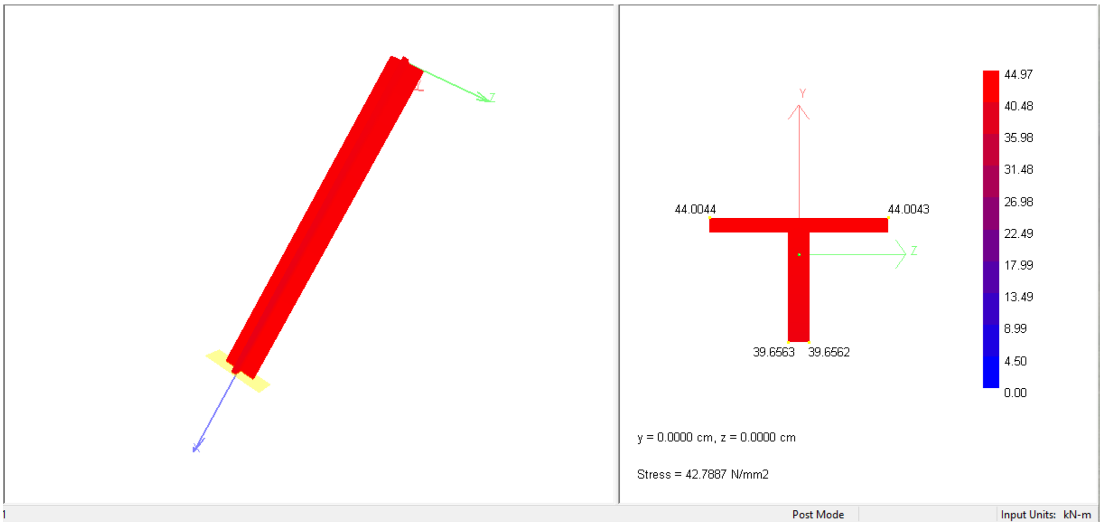


Figure 4.23: Member stress at height 50m with K bracing

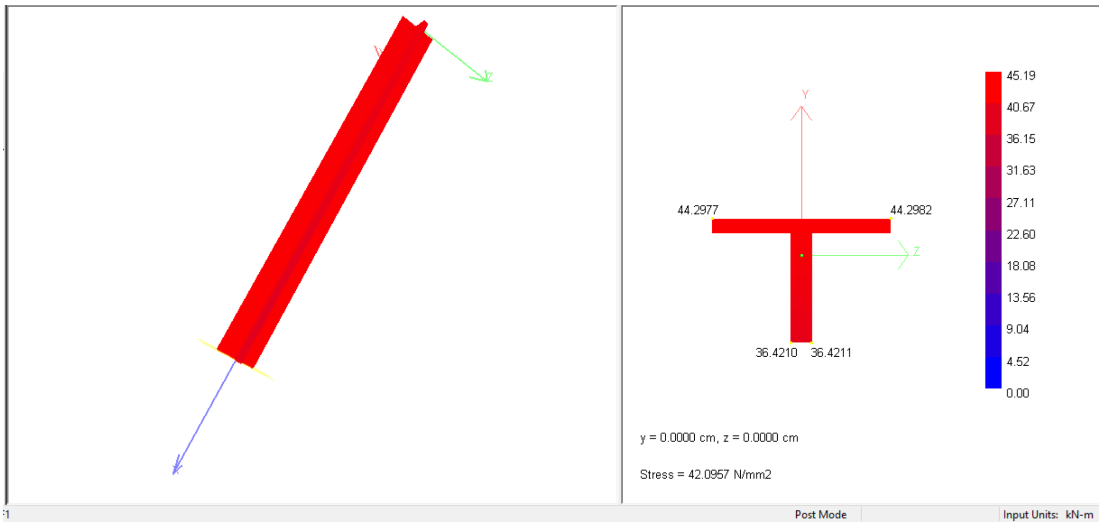


Figure 4.24: Member stress at height 50m with Y bracing

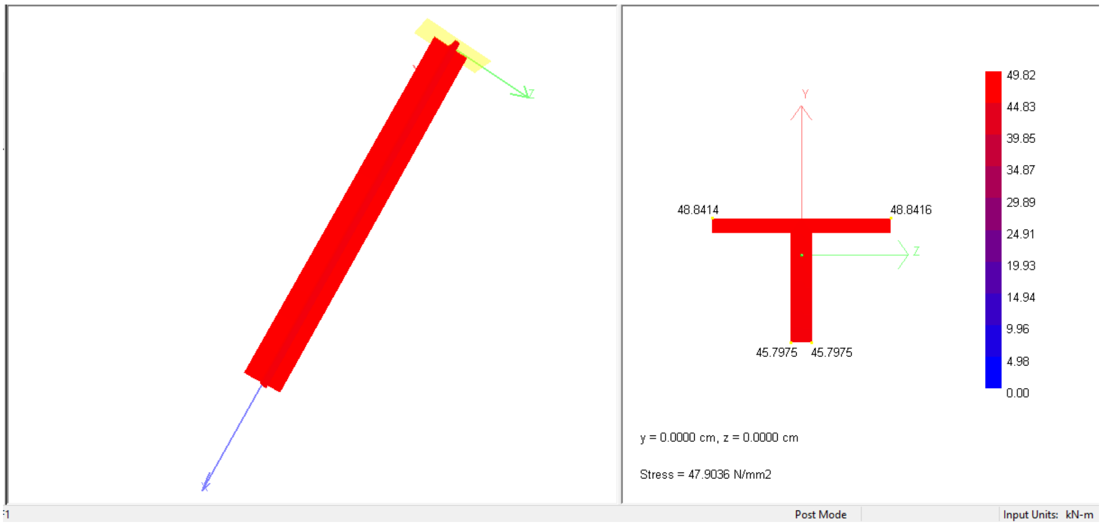


Figure 4.25: Member stress at height 60m with K bracing

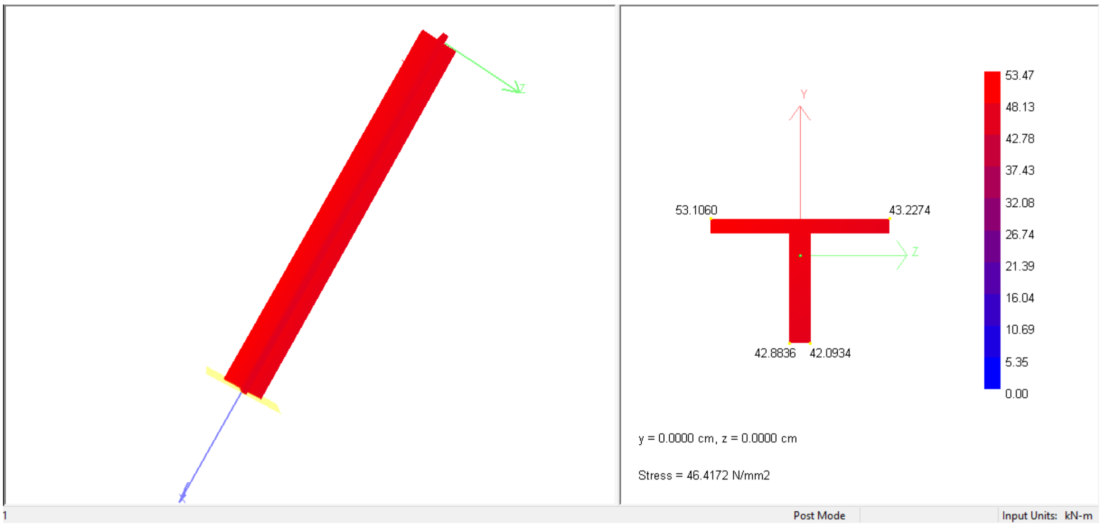
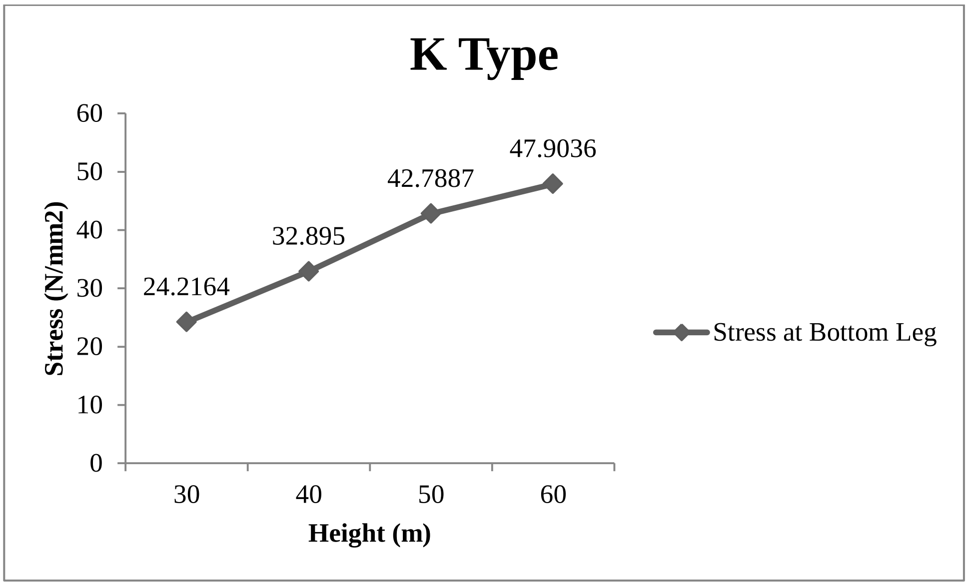


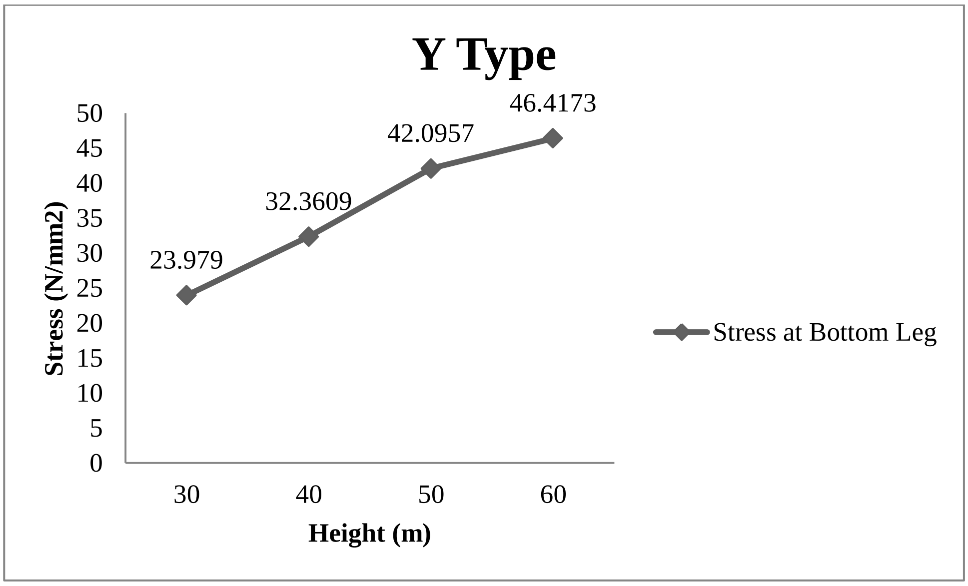
Figure 4.26: Member stress at height 60m with Y bracing

4.3.6 Stress against Height for Case 1

Figure 4.27 (a-b) indicates the variation in the pattern of stress against the height of the tower. The member stress at the bottom leg of K bracing has higher stress compared to Y bracing. Based on the graph that has been plotted, from 30 m to 40 m of tower height the increments in stress about 58% while at tower height from 40m to 50m, the member stress increases almost 56%. Besides, when the height increases from 50m to 60m there is an increase of 53% in member stress at the bottom leg member. At the height from 30 m to 40 m and 40 m to 50 m, Y bracing perform well that has less member stress at bottom leg whereas K bracing has the highest stress. Also, from 50m to 60 m the stress produced by K bracing is greater than Y bracing. Therefore, as the height of tower increase, the members stress at bottom leg increase as well.



(a)



(b)

Figure 4.27 (a-b): The pattern of stress against height

4.3.7 Member Stress of Tower for Case 2

Figure 4.27 until 4.35 indicates the pattern of member stress at the bottom leg of the tower with different types of height and bracing system when the wind load is increased. Each tower was carried the same loading which is self-weight, platform load and wind load. For this section, the wind speed that assigns is 44.0 m/s. From there the tower with less member stress at the bottom leg is determined. Table 4.4 shows the result of member stress at the bottom of the tower with different types of bracing system. At height 30m of the tower, the tower with K-bracing and Y-bracing produced 33.15 N/mm^2 and 32.41 N/mm^2 of stress respectively. Also, at height 40m and 50m of the tower, the steel structure with K-Bracing shows more stress compared to Y-Bracing. Then, at height 60m, the stress produced by a tower with K-Bracing is greater than Y-Bracing which is 60.16 N/mm^2. This shows that the difference stress between these two bracing about 0.66 N/mm^2.

Table 4.4: Comparison of Member Stress at Bottom Leg

Tower Height (m)	Case 2 (44.0 m/s)	
	Bracing	
	K	Y
30	33.15	32.41
40	40.51	40.48
50	43.93	43.17
60	60.16	59.50

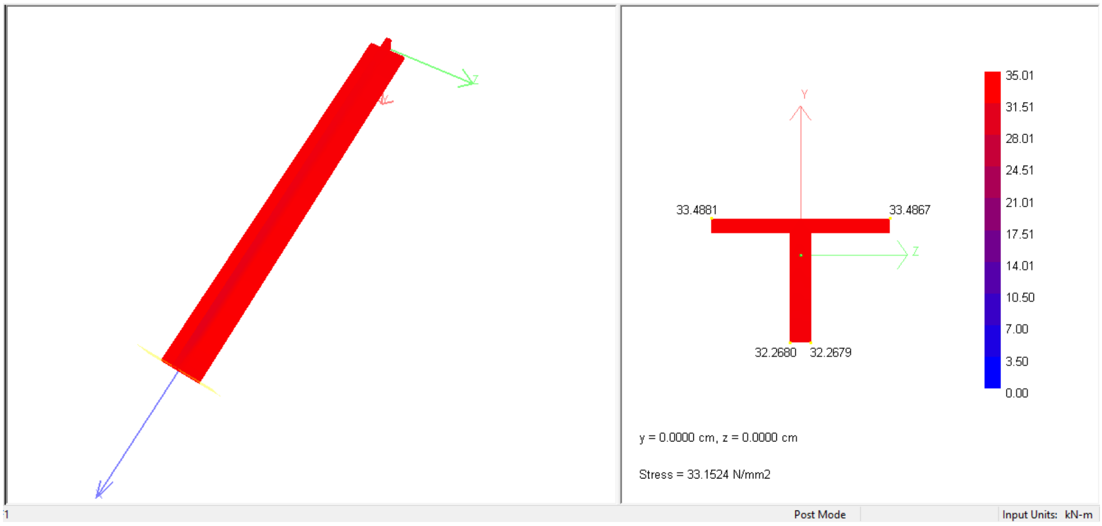


Figure 4.28: Member stress at height 30m with K bracing

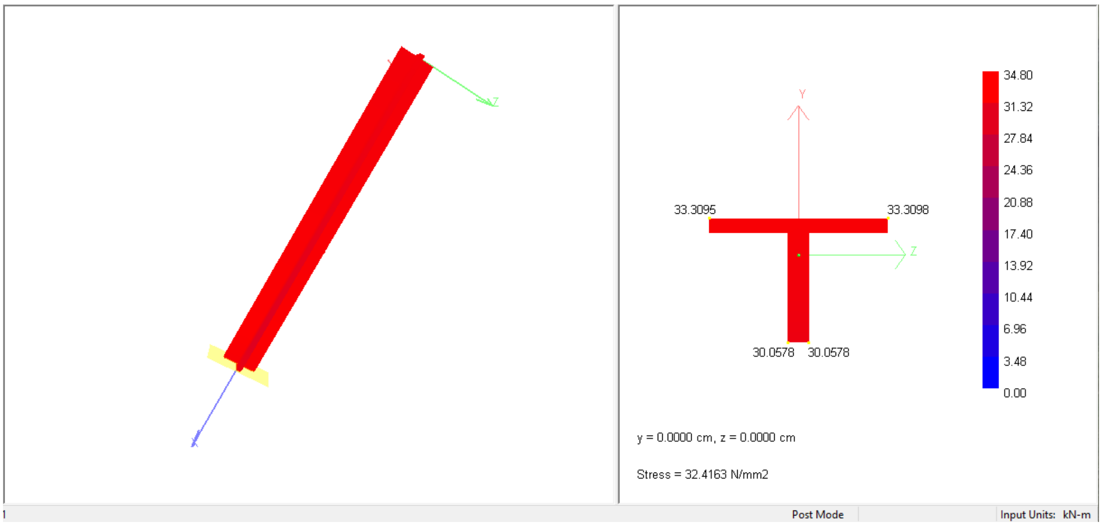


Figure 4.29: Member stress at height 30m with Y bracing

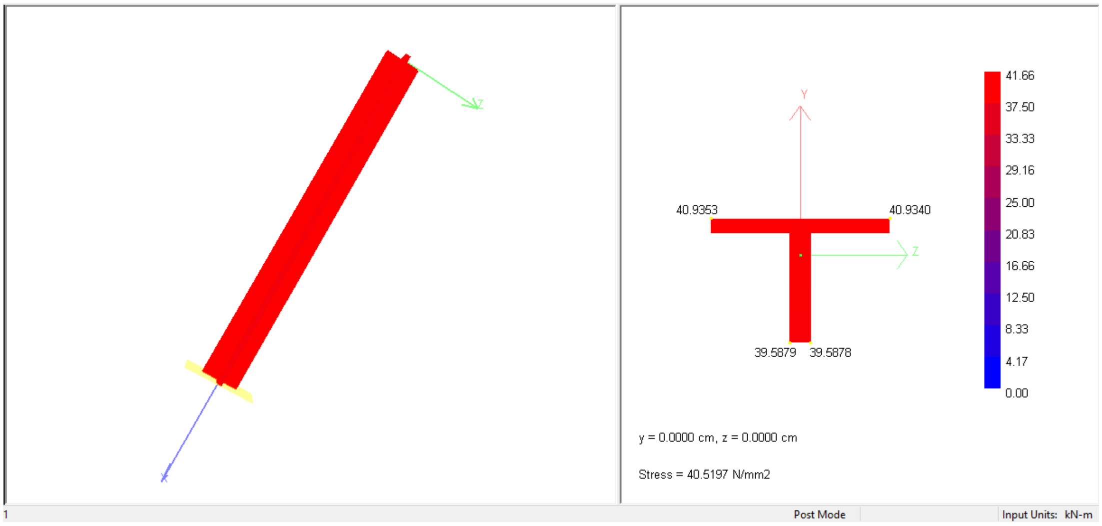


Figure 4.30: Member stress at height 40m with K bracing

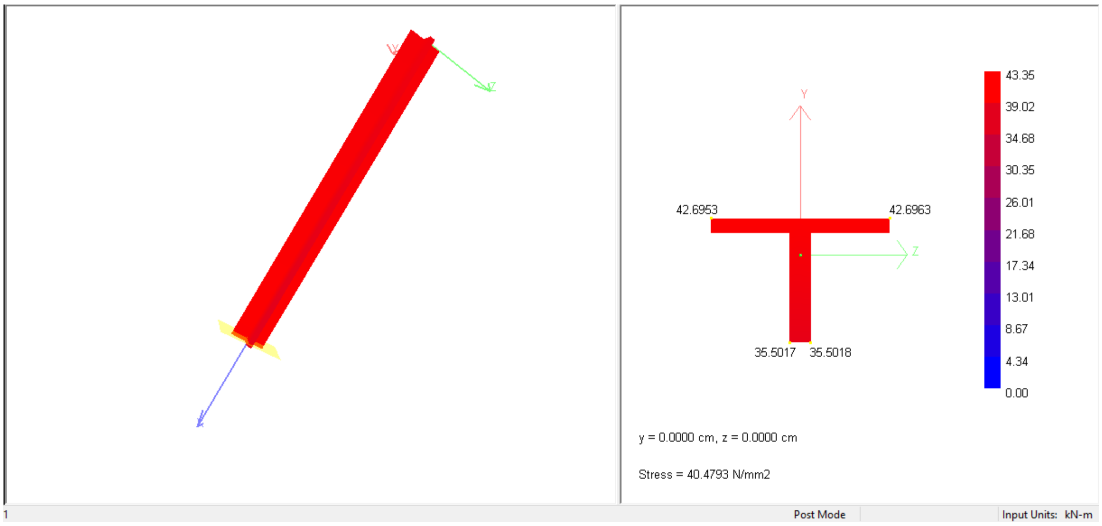


Figure 4.31: Member stress at height 40m with Y bracing

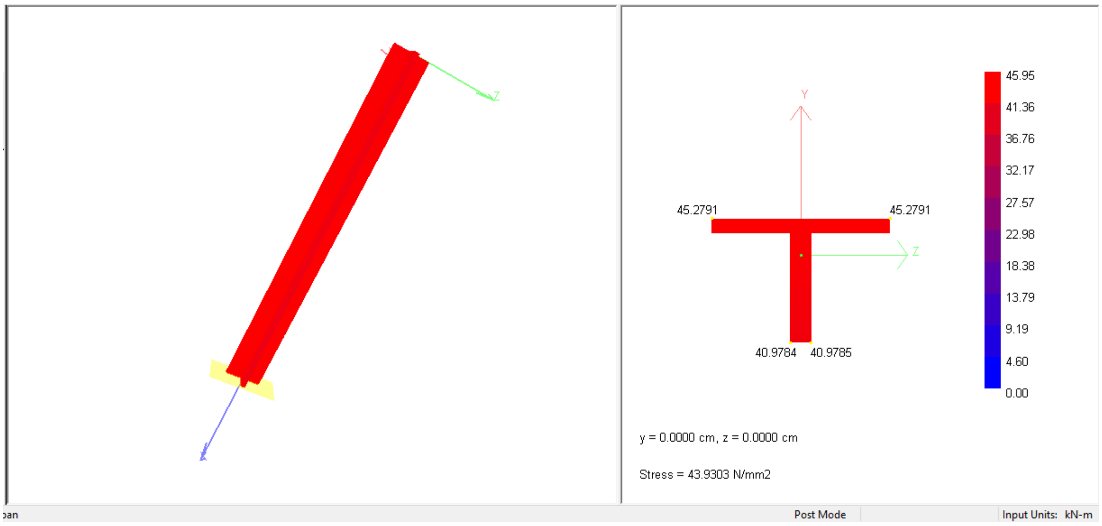


Figure 4.32: Member stress at height 50m with K bracing

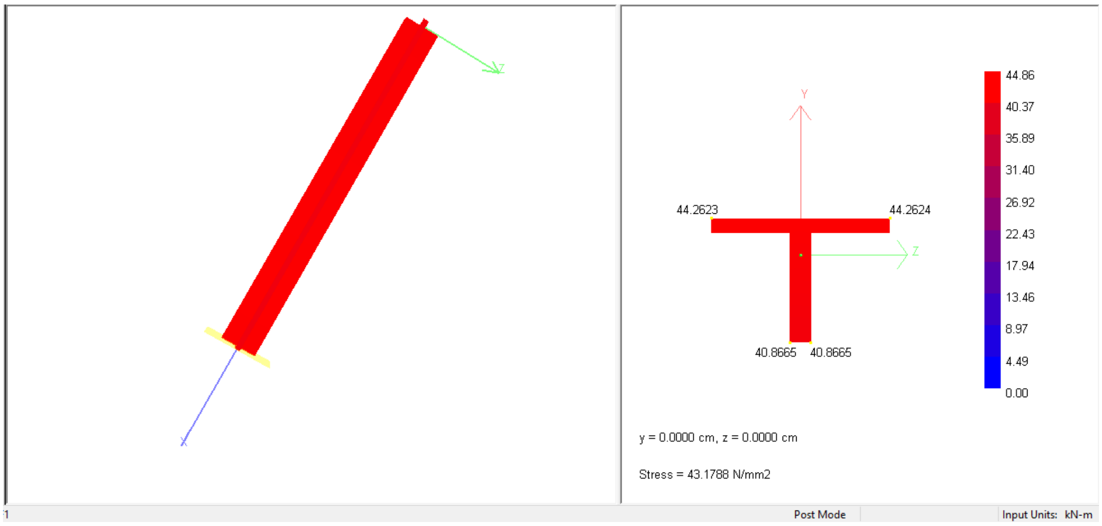


Figure 4.33: Member stress at height 50m with Y bracing

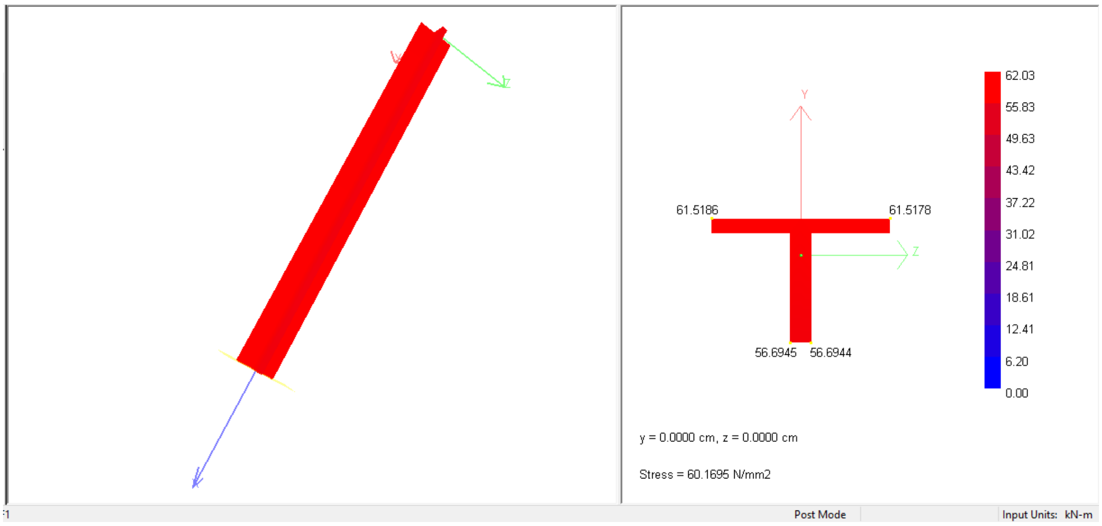


Figure 4.34: Member stress at height 60m with K bracing

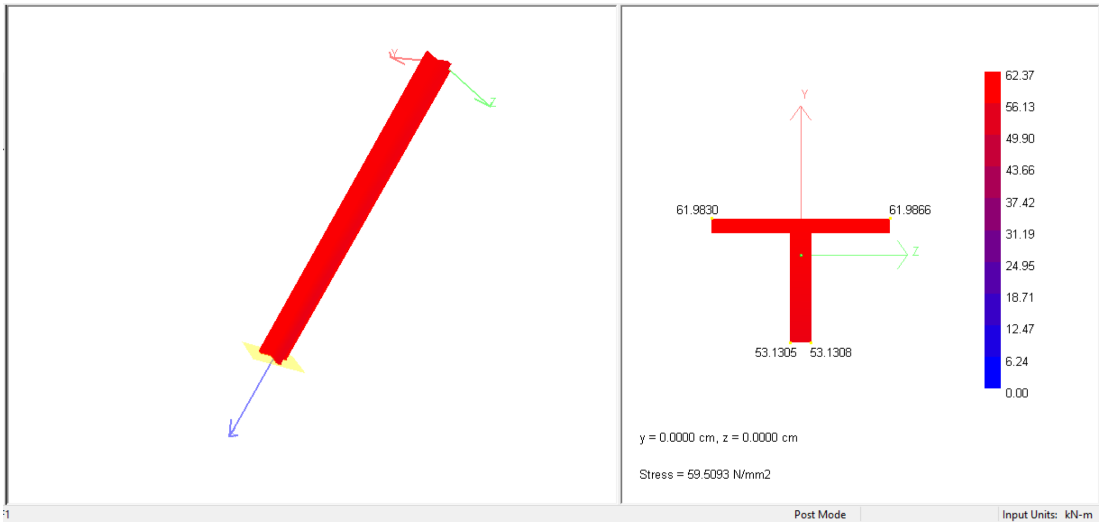
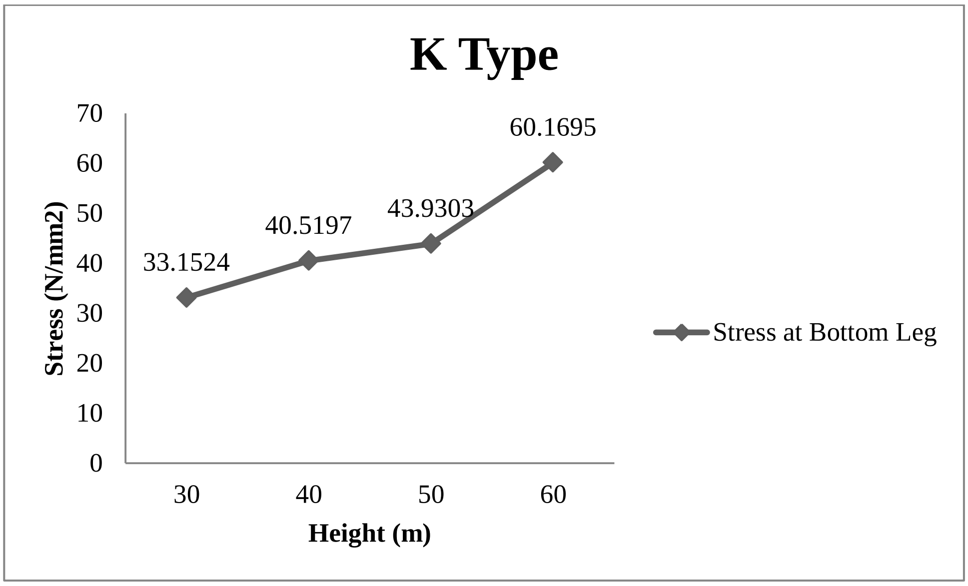


Figure 4.35: Member stress at height 60m with Y bracing

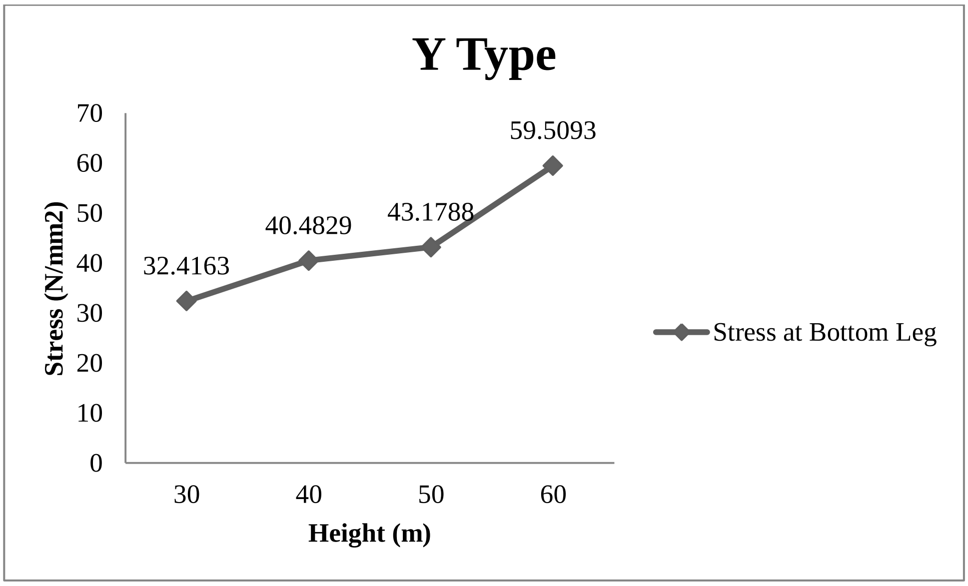
4.3.8 Stress against Height for Case 2

Figure 4.36 (a-b) shows the variation in the pattern of stress against the height of the tower. Based on the graph that has been obtained, the increment in stress is about 55% when the tower height increases from 30 m to 40 m. Also, when the tower height increases from 40 m to 50 m there is an increase of 52% whereas as the height tower increases from 50 m to 60 m, also there is 58% in member stress at the bottom leg member. The tower's height from 30 m to 40 m and 40 m to 50 m with Y bracing perform well that has fewer members stress at bottom leg whereas K bracing has the highest stress. Also, from 50 m to 60 m the stress produced by K bracing is greater than

Y bracing. Therefore, as the height of tower increase, the members stress at bottom leg increase as well.



(a)



(b)

Figure 4.36 (a-b): The pattern of stress against heights

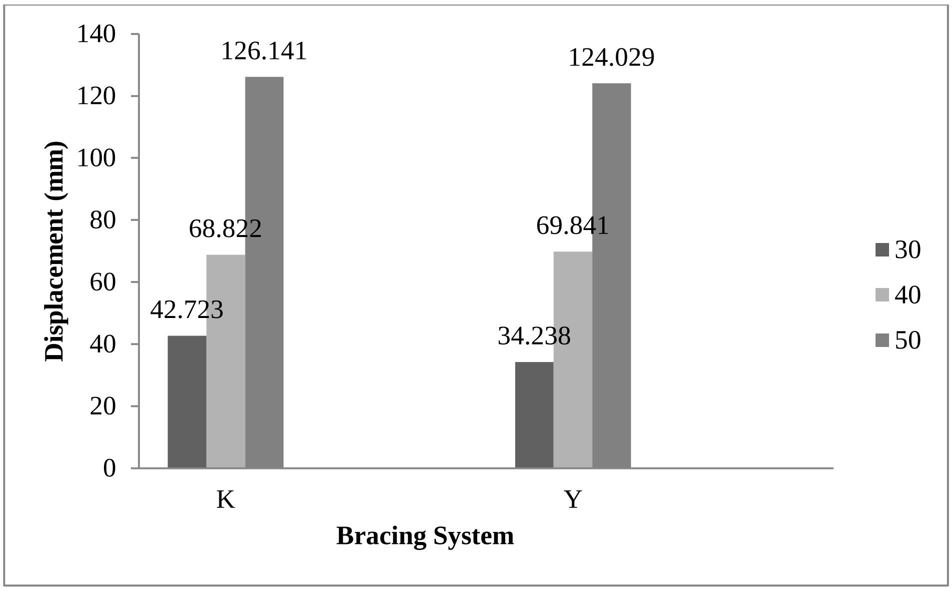
4.4 Validation FEA Results

As stated in the previous chapter, sixteen (16) tower models were modeled in STAAD Pro software and analyzed by FEA. Thus, the FEA results of towers with different height and type of bracing system in various wind zones were compared with the FEA results of displacement and member stress from previous research.

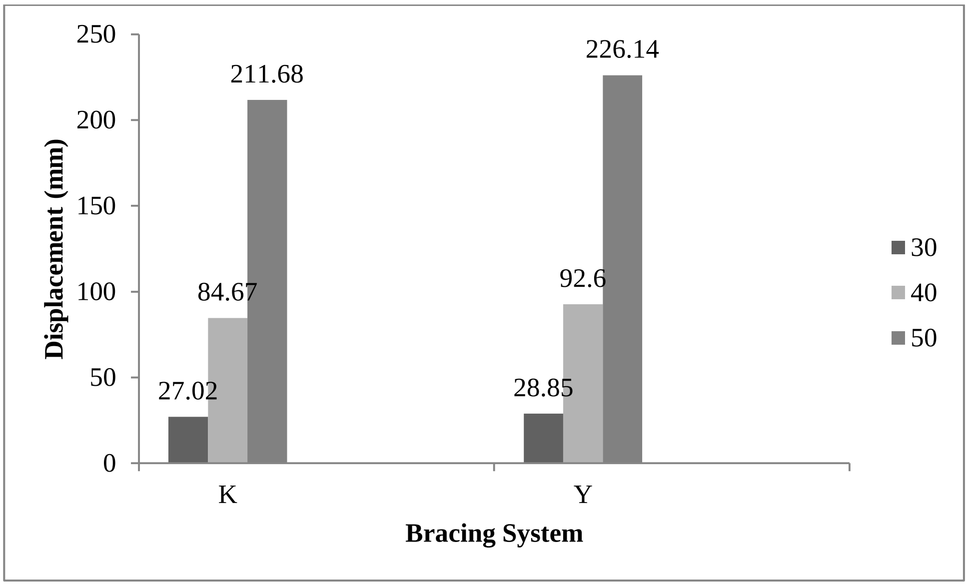
4.4.1 Displacement at Top with Different Bracing

Figure 4.37(a-b) shows the comparison of displacement at the top with different bracing for case 1 between the current result and previous research. In fact, the towers are carried out with basic wind speed. Generally, both of the results indicates that the displacement increase when the height of the tower increase. At the height from 30 m to 40 m, the displacement for the current result and previous research are increased by 64% and 68% respectively. Then, from 40 m to 50 m of the tower height, the displacement for the current result is increased by 64% while 60% for previous research.

Figure 4.38(c-d) is the comparison of displacement at the top with different bracing for case 2 between current result and previous research. Besides, the towers are carried out with a higher intensity of wind speed. Generally, both of the results indicates that the displacement increase when the height of the tower increase. At the height from 30m to 40m, the displacement for the current result and previous research are increased by 69% and 83% respectively. Then, from 40 m to 50 m of the tower height, the displacement for the current result is increased by 63% while 75% for previous research.

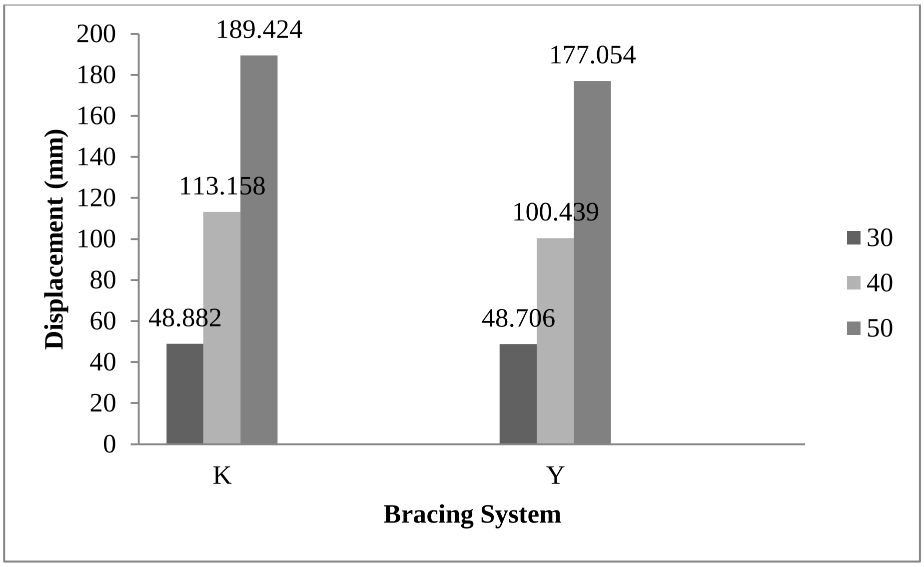


(a)

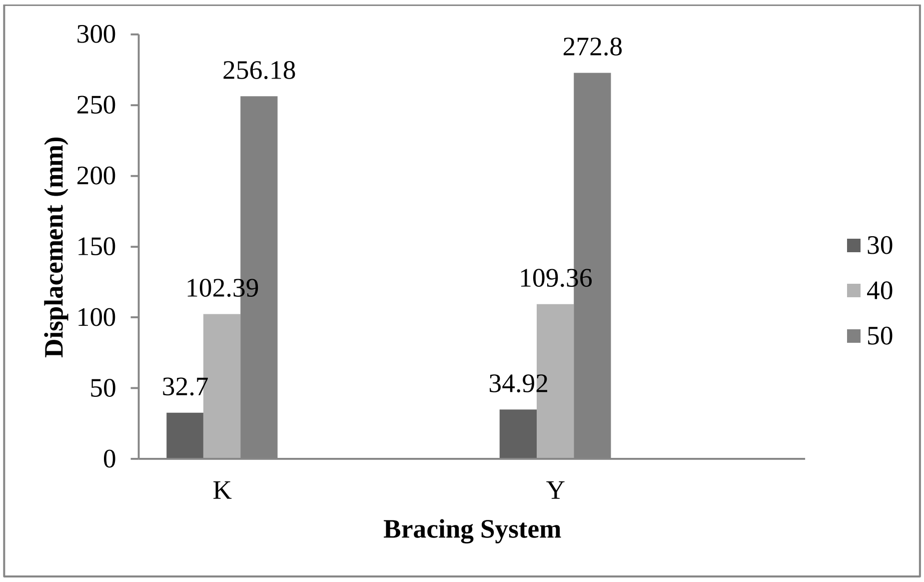


(b)

Figure 4.37 (a-b): Displacement at Top with Different Bracing



(c)



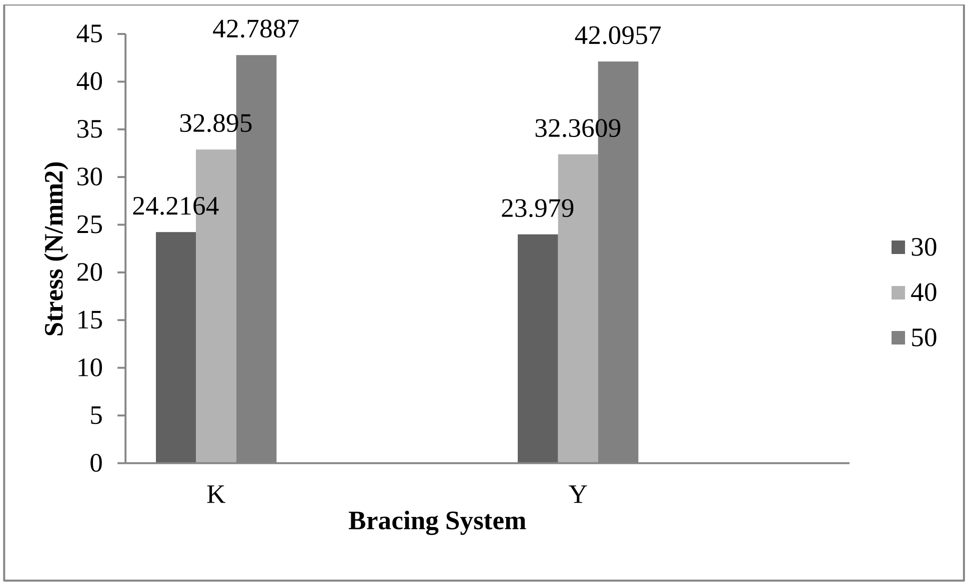
(d)

Figure 4.38 (c-d): Displacement at Top with Different Bracing

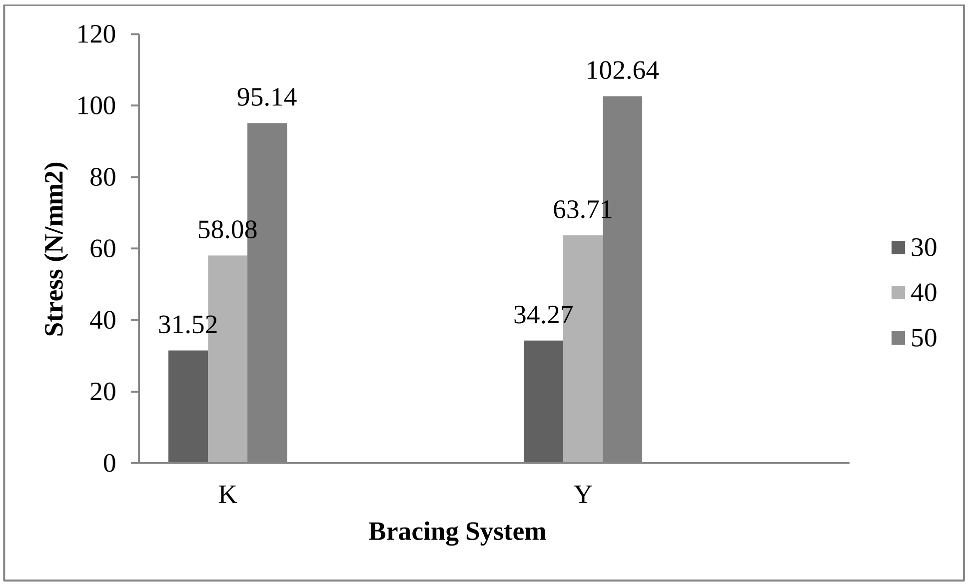
4.4.2 Member Stress at Bottom Leg

Figure 4.39 (a-b) shows the comparison of stress pattern with respect to the height of structure for case 1 between the current result and previous research. The increment in stress about 58% and 45% for current result and previous research respectively when tower height increases from 30m to 40m. Then, as the tower height increases from 40m to 50m the stress also increases which are 56% for the current result and 40% for previous research.

Figure 4.40(c-d) is the comparison of stress pattern at bottom leg with different bracing for case 2 between current result and previous research. Besides, the towers are carried out with a higher intensity of wind speed. Generally, both of the results indicate that the stress increase when the height of the tower increase. At the height from 30m to 40m, the member stress for current result and previous research are increased by 55% and 60% respectively whereas when the tower height increase from 40m to 50m, the stress for the current result is increased by 52% while 55% for previous research.

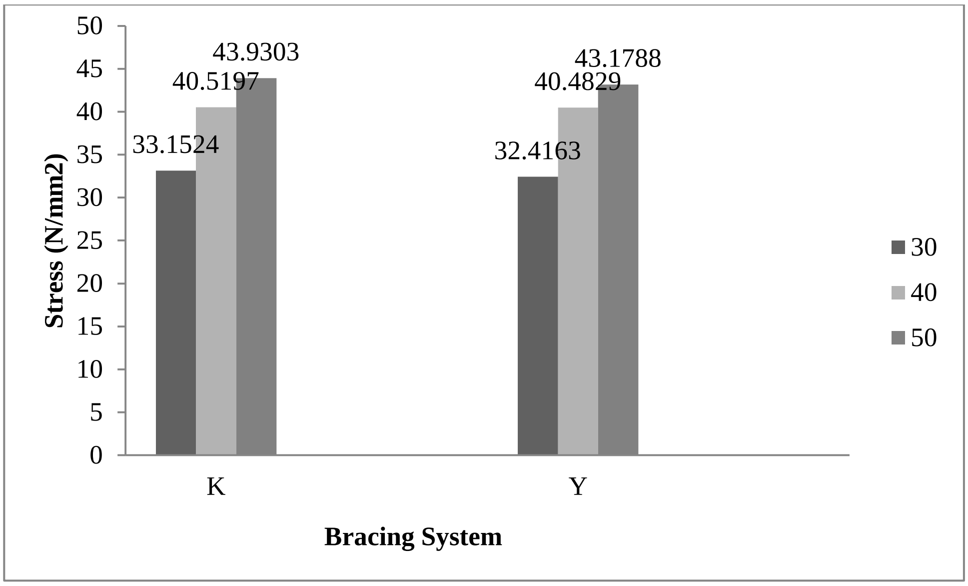


(a)

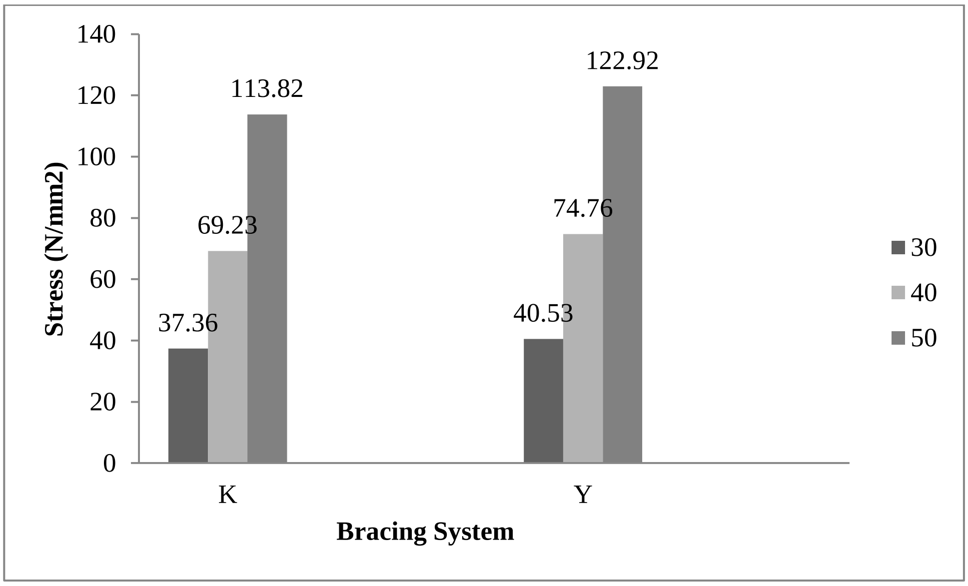


(b)

Figure 4.39 (a-b): Member stresses at Bottom Leg



(c)



(d)

Figure 4.40 (c-d): Member stresses at Bottom Leg

4.5 Summary

The research studies on the behavior of telecommunication tower in terms of displacement at top and member stress at the bottom leg of the tower. Each tower has different height and bracing systems at various wind zones.

Based on the finding of the research, it can be summarized that when the tower height increases, the displacement at top and stress at bottom leg increase as well. Besides, the increment in the intensity of wind load also will increase the displacement and stress of member since the tower very prone to the presence of wind load.

Then, it was found that the tower with Y bracing performs well at a higher intensity of wind load due to least displacement at top and member stress at the bottom. Also, the tower height from 50m to 60m is suite to be used in higher wind load since the displacement produced by the tower is not exceeds the limitation of displacement.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This main objective of this research is to determine the displacement effect to the telecommunication tower in various events of wind load. Several models of towers were modeled in STAAD Pro and were analyzed with Finite Element Analysis. Based on the results stated in chapter four, the most effective height, economical bracing system for telecommunication tower in the event of wind load were identified.

5.2 Conclusions

Based on the result obtained, several major conclusions can be drawn:

i. The wind load has noticeable effects on the towers when the displacement increases from wind speed 33.5 m/s to wind speed 44.0 m/s.

ii. 60 m height is considered to be the most effective height of telecommunication tower as the displacement does not exceed the limitation which is 1 m.

iii. Tower with Y bracing system was found to be the most economical bracing system up to a height of 60 m.

5.3 Recommendation for Future Research

From this research, several recommendations were identified which needed to be considered for future study in order to provide more reliable data as follows:

i. The study will be carried out for towers of greater height and other combination types of bracing system or pattern.

ii. The work can be extended to economize the tower by adopting the relevant and latest technique.

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