EFFECTIVE BRACING SYSTEM FOR TRANSMISSIONLINE TOWERS

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ABSTRAK

Menara talian penghantaran terdedah kepada beban angin yang menjadikan menara tersebut perlu direka supaya ia boleh menahan beban angin. Menara talian penghantaran harus mempunyai ketinggian yang efektif dan system pendakap yang berkesan untuk memberikan prestasi yang lebih baik bagi menahan beban. Dalam kajian ini, menara talian penghantaran sejenis penggantungan ini direka dan dimodelkan menggunakan Staadpro V8i. Terdapat dua jenis system pendakap yang telah diterapkan kepada menara. Menara ini dimodelkan dengan ketinggian 39 m, 49 m, dan 100 m yang akan kendalikan tiga kelajuan iaitu 32.5 m/s, 33.5 m/s dan 40 m/s di dalam Staadpro V8i. Bersadarkan perbandingan yang telah dibuat, system pendakap yang efektif bagi menara berketinggian 39 m dan 49 m adalah pendakap jenis K, manakala menara berketinggian 100 m menunjukkan pendakap jenis X adlah lebih efektif. Dari segi anjakan, menara 39 m dengan sistem pendakap K dengan kelajuan angin 32.5 m/s, 33.5 m/s dan 40 m/s menunjukkan ia berkurang daripada system pendakap jenis X sama seperti menara berketinggian 49 m. Walaubagaimanapun, bagi menara dengan ketinggian 100 m, sistem pendakap K meningkat lebih daripada sistem pendakap X. Kemudian, dari segi beban menara pula, menara berketinggian 39 m dengan kelajuan angin 32.5 m/s, 33.5 m/s dan 40 m/s menunjukkan sistem pendakap K berkuaran daripada sistem pendakap X sama seperti menara berketinggian 49 m. Bagi menara dengan ketinggian 100 m, sistem pendakap K mempunyai beban menara yang lebih tinggi 46% berbanding sistem pendakap X.

ABSTRACT

Transmission line tower which usually affected by the wind load need to be designed to resist the wind load. The transmission line tower should have effective height and effective bracing system in order to give better performance to resist the load. In this research, the transmission line tower was in the form of suspension tower were modelled and designed in Staadpro V8i. Two types of bracing system, K and X system were assigned to the tower. These towers were modeled by considering the effects of tower height which include 39 m, 49 m and 100 m height and were developed with three wind speeds which include 32.5 m/s, 33.5 m/s and 40 m/s in Staadpro V8i. Comparison was made based on the displacement and axial load. It was found that the tower with height 39 m and 49 m gives K bracing system as the effective bracing system and tower with height 100 m showed X bracing system is the effective bracing system. In terms of displacement, 39 m tower with K bracing system that was subjected to 32.5 m/s, 33.5 m/s, and 40 m/s wind speed showed that the displacement was reduced similar to that of 49 m tower height. In contrast, 100 m tower height with K bracing system showed that the displacement increased from the X bracing system. In terms of axial load, 39 m tower subjected to the wind speed of 32.5 m/s, 33.5 m/s, and 40 m/s showed that the K bracing system reduced from the X bracing system, similar to that of 49 m tower. As for the 100 m tower, K bracing system exhibited higher axial load which approximately 46% compared to the X bracing system.

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LIST OF SYMBOLS

P	Design wind pressure
V_{des}	Design wind speed
C_{fig}	Aerodynamic shape factor
C_{dyn}	Dynamic response factor

LIST OF ABBREVIATIONS

STAAD	Structural analysis design

CHAPTER 1

INTRODUCTION

1.1 Background

Transmission line tower is one of the communication towers adapted into the world which use electrical power to generate large transmission over all areas required. The existence of this tower in the communication sector revealed that in the modern era, large power of electricity is needed to supply the communication tower with enough energy. The increasing uses of electricity in this sector give positive impact toward economical industry, which generate electricity being an important part in the sector. Transmission line tower is structure are made of steel with foundation on the ground, which steel structure using economical materials that act as an element of the structure. A steel structure, arrangement using trusses which this kind of structure, arrangement can sustain heavy load from above structure. Trusses using bracing system are usually known as the system that excels in transferring the load from above structure to the ground and it can provide horizontal stability toward structure. The kind of tower structure which widely used are usually square or triangular in shape with different bracing system of the trusses depends on the height and the range of the communication tower. The adoption of different bracing system and different shape of the structure to ensure that the structure can resist the displacement together in the event of wind load toward the structure itself.

Transmission line tower can be classified into two which is suspension and tension towers. The suspension tower is being analysed in the research to have the effective tower with suitable bracing system and effective height to resist the wind load and reduce the displacement effect. The height of the tower and bracing system affect the performance of the communication tower in receiving signal from the cell phones and expand their network. In order to achieve high performance of the tower, height of the tower must suitable with the wind load, bracing system and load that will resist by the tower.

Construction of the transmission line tower must consider the surrounding where the disaster or seismic load that have potential to stuck the area surrounding. All the element that consider during the construction of the tower will give future impact of the structure and the coverage of the communication network. However, the effectiveness of the parameter toward the transmission tower can be modelled using the software of Staadpro V8i which the software will model the structure and depicts the effective parameter required for the tower and the advantage and disadvantages of ivory tower designed. This software helps in analysing the whole structure of the transmission tower with optimum load and strength that can resist by the structure. The most effective and economical tower will give an advantage in the construction industry, which reduce the cost, but increasing the benefit of the construction.

1.2 Problem statement

Wind is known as one of the resistance encountered by the transmission line tower, which subjected to the structure of bracing system implemented in the tower. In order to resist the wind load, several types of bracing system are being analysed to state the most effective bracing system to encounter the wind load. Communication towers are very prone to wind loads such that they are needed to be designed to resist wind loads to make the structure at least for life safe in the event of natural calamities like HUD-HUD(Phanindranath, 2017). Besides the types of bracing system, the height of the tower also being analysed since the height of the towerinfluenced the displacement of the tower. It was observed that from 30m to 40m tower height, the increase in displacement is nearly linear but as the height increases from 40m to 50m there is a steep increase in the displacement in all the zones (Sharma, Duggal, Singh, & Sachan, 2015). The effective height of the tower is analysed within the suitable height of the tower to ensure that the height prone with the displacement in order to get the effective height and the effect of the displacement to the tower.

1.3 Research Objectives

The main objectives of this research include:

i. To determine the displacement effect to the transmission line tower in the event of wind load

ii. To determine the most effective bracing system for communication towers in the event of wind load effects
iii. To identify the most effective height of the transmission line tower with respect to wind zone

1.4 Significance of research

Transmission line tower is one of the communication towers that transmit signal through the devices. In order to complete the transmission of signal, the tower must be design prone to the function of the tower. Types of bracing system assigned to the tower are one of the parameters that affect to the effectiveness of the tower function. There are several types of bracing system analysed and compared to find the most effective bracing system which is K and X bracing system. These are bracing system that commonly used in the structural industry to build a communication tower. In order to have the effective bracing system, this research considered only two of the bracing system. The height of the tower that were analysed is within the minimum and maximum height to have the optimum height of tower to act efficiently. The height of the tower also used to identify the effect toward the displacement.

1.5 Scopes of research

The analysis of tower is focused on the suspension transmission line tower. The analysis of the transmission line tower is using two types of different bracing system which is K and X bracing system in order to compare the effectiveness. The different types of bracing system for the substation analysed using Staadpro V8i software. The height of the transmission line tower that analysed is 39 m, 49 m and 100 m. The difference in term of height is to obtain the minimum and the maximum effective height of the tower to carry the electric voltage. The height of the tower affected by external load which is wind load. Wind load become one of the parameters in this research which the wind load that acted on the tower is 33.5 m/s, 32.5 m/s and 40.0 m/s. The wind load is taken from zone I and zone II and maximum wind speed which to see if the tower can resist the maximum wind load with different types of bracing system and different height. Transmission line tower can be designed using three legged tower and four legged towers. In this research four legged towers were chosen to determine the effectiveness of the bracing system. The transmission line modelled is suspension transmission line tower which only considered the lateral force acting on the tower.

1.6 Overview of research

Chapter one introduced the background of the transmission line tower and the structures are being adapted in the tower. In this chapter also described the problem faces by the designer to build the effective communication tower in the industry. Two others subtopic included in the chapter one are scope of the research and the significance of the research.

Chapter two which is literature review, which review previous findings and investigations. This chapter discussed about the research in the journal and the effect of the research based on the structural, sizes and system required to build the tower toward the effectiveness of the communication tower. Subsequently, the different types of system and sizing of the research are discussed further to ensure the suitability of the system to the communication tower. Lastly, the result of the analysis of the communication tower from the Staadpro software is being discussed in this chapter.

Chapter three discussed the research methodology which described the method used to implement and conduct the analysis of the tower. The models were analysed after all the parameters involved have been confirmed, then abstract the result of the data and justify the result of the research also clearly stated in this chapter.

Chapter four presented about the data and results obtained from the research methodology based on the summary result from the analysis of data for transmission line tower communication. Staadpro v8i software depicts the 3D view of the structure that designing the international code of design which is British Standard code.

Chapter five is the conclusion and recommendation, which the recommendation to improve the research after the result obtained. Considered as the last chapter, conclusion included the effectiveness of the parameter involved toward the transmission line tower.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to types of bracing system

In constructing the transmission line tower communication in certain places, the structural system of the structure must be considered in order to resist the load toward the tower. A bracing system known as the system provided to design the transmission line tower. K, V, X, and Y bracing system are the bracing system that commonly used in the industry based on the load resists, the area of the tower and the transmission signal of the tower provided. All types of bracing system are analyses with different height to test the efficient height with suitable bracing system. Therefore, (Sharma *et al.*, 2015) state in the journal that Y bracing system depicts that the most economical bracing system up to height 50m. The Y bracing system is identified as the economical again in the research of (Phanindranath, 2017) which it has been found that Y bracing system and X bracing system perform in resisting various types of wind load.

Based on the X and Y bracing system perform well in various wind speed of 33m/s. 39 m/s, 44m/s, 47m/s, 50m/s and 55m/s when its coming to angular section. In the research, at wind speed 47m/s the displacement of the Y bracing system increased 114%, at the speed 50m/s the displacement increased to 107%, at the speed 55m/s the displacement increase to the 107% compared to the X bracing system (Phanindranath, 2017).

Towers were modelled, analysed and designed according to the ASCE 10 code14 (Towers *et al.*, 2017) . Seven different types of bracing system consist of K, KD, Y, YD, D, XB and X are considering for rectangular base telecommunication towers with a height of 60, 50 and 40 m. Four different bracing systems consist of K, D, XB and X for triangular base telecommunication towers are also studied.

Eventually, in the (S and Sowjanya, 2015) research only covered 2 types of bracing system which is K and X types of bracing system. Compared to the (Sharma *et al.*, 2015) research the towers are provided with 5-different types of bracings: K type, XBX-type, V-type, W-type, XX-type for lower portion and X-Bracing for upper portion of the tower.

There are 3 sections in the bracing system panel, which is angular section, pipe section and multi section. The database section must be taken based on the country that we locate the structure or building.

2.2 Wind load

Wind load effect is being considered of any building with more than 3 storey and a tower with height more than 6m. Wind load effect has different speed different for various zones in Malaysia. There is 3 wind zone in Malaysia which is zone I, zone II and zone III. By referring to Malaysian Standard 1553:2002 Code of practice of wind loading for building structure, zone I wind speed is 33.5 m/s, the zone II wind speed is 32.5 m/s and zone III wind speed is m/s. The area cover by every zone is being shown by the figure X. The various kinds of wind load are analysed to the simulation of the transmission line tower communication where is zone I and zone II.

Figure 2.1: Zone of wind load

Source: Google Image

Transmission line tower subjected to the wind loading since the load controlled the structural actions, resultant forces, bending moment, cable tension, deflections and accelerations. Wind load has become the main issues in the structural building since it is one of the safety factor.

For a lattice structure like tower, three wind force effect is being considered which is vertical uplift, downward thrust, and drug force. (Dhoopam, 2015) state that the wind load from the 45 degree and 0 degree directions are considered in the square tower. Those combinations of wind load being used for analysis of the tower. The research also included the seismic load for the tower and obtained the shape of the mode of the natural frequency. Wind induced vibration control is the method suggested in (Tian *et al.*, 2013) since in 2002 and 2005 the transmission tower damaged because of the wind vibration which in 2005 is the serious damaged occurred.

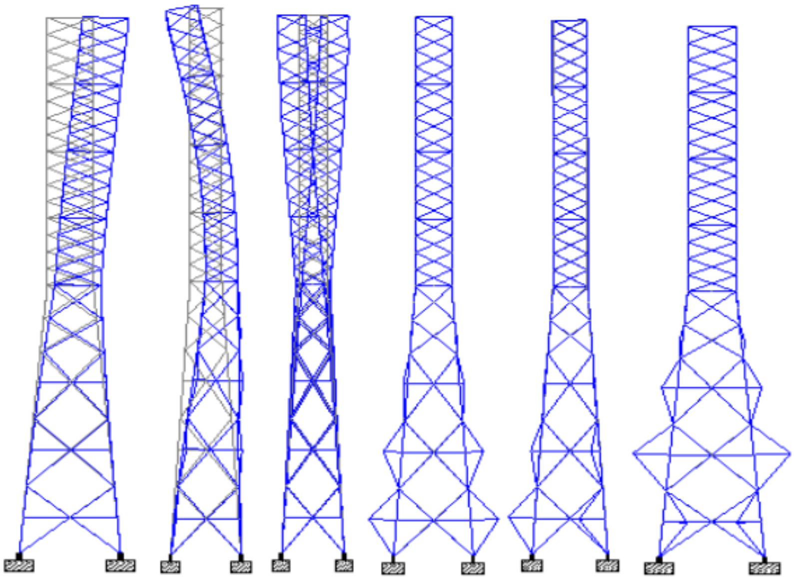


Figure 2.2: Natural frequency and mode shape one of the tower

Source: (Dhoopam, 2015)

The wind load effect has been considered since transmission line tower is classified in the high rise structure. In the (Kumar and Reynold, 2018) research, it stated that the analysed tower of height 40 m and 60 m vary approximately with same trend. The wind load applied in the model of (Sharma *et al.*, 2015) is between 5 zone in that area which is 33 m/s, 39 m/s, 44 m/s, 47 m/s, 50 m/s, and 55 m/s.

The wind load effect is analysis by zone I with 33 m/s, zone II with 39 m/s, zone III with 44 m/s, zone IV with 47 m/s and zone V with 55m/s speed of wind (Sharma *et al.*, 2015) . The wind zone analysis subjected to different types of bracing system which is K, XBX, V, W, and XX bracing system to see the effect toward displacement and stress. The tower also analyses with different height of 25 m, 35 m, and 45 m. The result shows that the displacement increase with the wind zone I until zone V and maximum for W bracing and minimum for K bracing. The variations of the displacement in different types of bracing system shows in this research. The effect to stress, increase from zone I until zone V and maximum for K bracing and the minimum for the XX bracing system. The research of (Sharma *et al.*, 2015) analysed the tower for seismic load such as natural frequency which the result depicts the mode shape of the tower.

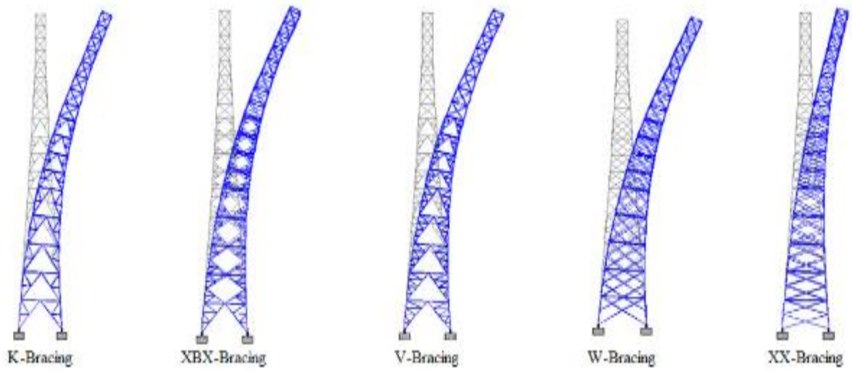


Figure 2.3: Mode shape of the tower after seismic load
Source: (Sharma *et al.*, 2015)

In a few research the loading only applied after the wind speed is calculated. Procedure of calculating the wind speed shown in the research clearly. In the (Methodology, 2015), the research depict the calculation of wind load based on the transverse load based on the G.W level, transverse load at conductor level (1,14), longitudinal load (1,14), vertical load (1,14) and torsional load (1,14). The wind load is calculated under three conditions which is the normal condition, ground wire broken, and top left conductor broken.

2.3 Displacement

Displacement of the tower influenced by the types of bracing system together with the height of the transmission line tower. Displacement defined as the movement of the structure from its original places. Displacement occurred due to the resistance in which wind or other load resist by the tower itself. In (Phanindranath, 2017) research, the displacement of the structure being analysed with different types of the section to identified most of the efficient bracing system to worked well with the types of section.

The displacement of the tower also being analysed by (Kumar and Reynold, 2018) which in the research depict the maximum displacement percentages for static, dynamic, offshore dynamic for 40 m tower is 76%, 103%, 403%, and 478% and for 60m high tower, the displacement of all three element is 75%, 101%, 225% and 309%. The maximum percentage of displacement for 40 m and 60 m are 244% and 309%. The increasing height of the tower contribute to the high percentage of displacement. Based on the (Sharma *et al.*, 2015), it analysed the displacement at the top of the transmission line tower. A different bracing system with various wind speeds do not depict much different in term of the displacement with tower high between 25 m to 35 m. Maximum percentages of displacement for a tower with a height from 35 m to 45 m for a tower with K and W bracing system which the speed of wind is 33 m/s to 47 m/s. The V bracing system gives the minimum value for the displacement. The W bracing system gives maximum value of displacement for tower height 35 m to 45 m with wind speed 50 m/s to 55 m/s. It was concluded in the research that K bracing increase the stress with variation of wind speed and XX bracing gives the minimum value of displacement.

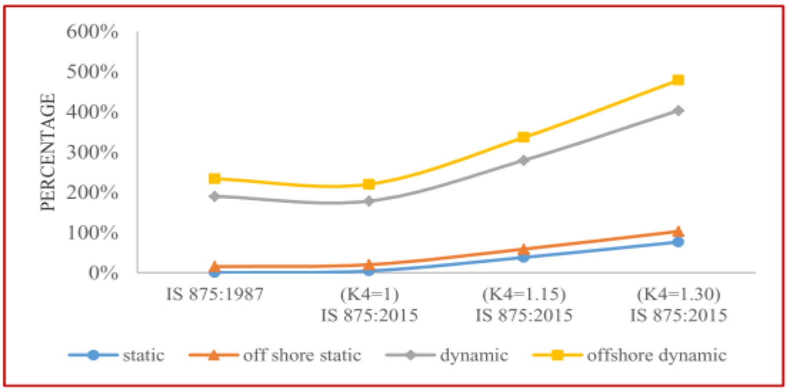


Figure 2.4: Varitions of displacement for 40 m

Source: (Kumar and Reynold, 2018)

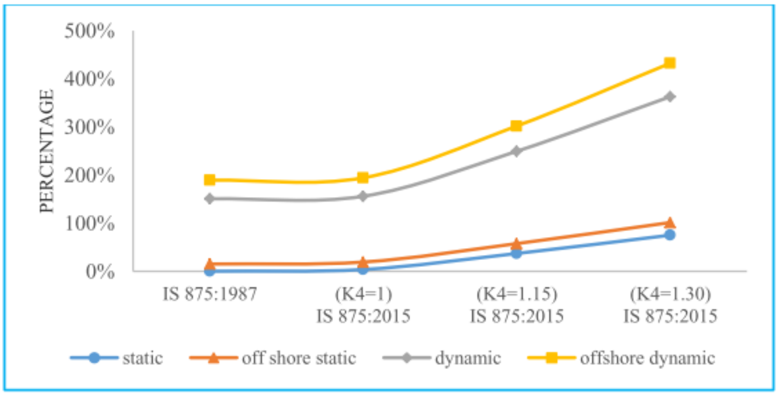


Figure 2.5: Variations of displacement for 60 m

Source: (Kumar and Reynold, 2018)

Eventually, this researchused the optimum high in order to identify the optimization displacement for the transmission line tower.

In term of displacement, the research stated it also analyse the effect of displacement which the tower with 25 m and 35 m with different bracing system types show less effect (Sharma *et al.*, 2015). Tower with height 35 m to 45 m having K and W bracing system gives maximum displacement and the V bracing system gives minimum displacement. The result of displacement shown in the graph in which the pattern of displacement effect can be seen with different height that the research analyse.

2.4 Types of communication tower

There are several types of communication tower that are commonly adapted in the industrial depending on the how much power that the structure carried and the signal that it transmit through the coverage. In this research transmission line tower will be a model which the structure of the transmission line tower is different from the usual communication tower design. Transmission line tower carries heavy transmission conductor at sufficient height in order to perform well. The efficient height increase the performance of the transmission line tower and the safety factor because of the flow of power is dangerous to people.

Every transmission line tower carries a huge amount of electrical power to perform its function. Electrical power is being the most power usage in the world since the maximum usage of the electrical power is being identified in each company. Technically, demand of electrical power is higher in the transmission line tower based on the distance and currency of the transmission. State in the (Reddy, Rasagnya and Gokul, 2016) that the regular transmission system in certain country is with voltages ± 600 KV DC and some countries introduced in using 1000/1100 KV AC or ± 700 KV DC voltages. In Malaysia transmission system with voltage ± 500 KV is operating underground and the medium voltage is 132 KV and the smallest will carry 33 KV.

The types of the tower that used to analysed is four legged square shaped 132 KV Circuit steel Transmission Line Tower (Methodology, 2015) . The tower has 6 conductors and 1 ground wire. Six cross-arms are provided to carry the conductors and clamp of the tower carries the ground wire. The tower is a freestanding/Self-supported single cantilever structure fixed at the base meaning that no guys are used to support the tower. The tower is assumed as an intermediate, Tangent tower (Angle of deviation with respect to adjacent towers = 0-2 deg.). The X-X bracing system is adopted. The insulators are suspension type insulators.

Then, the (Phanindranath, 2017) analysed the model with different types of steel bracing systems like X, V, K, Y systems were assigned. These bracing systems were modeled by considering 3 different steel sections like Pipe section, angular section and multi section (pipe section for columns, angular section for beams and bracings) 24 models with bracing system have been developed to run for wind analysis at wind speeds of 33 m/s, 39 m/s, 44 m/s, 47 m/s. 50 m/s, 55 m/s.

Model using the Steel Communication tower is designed for heights of 25 m, 35 m and 45 m (Sharma *et al.*, 2015). The towers are provided with 5-different types of bracings: K type, XBX-type, V-type, W-type, XX-type for lower portion and X-Bracing for upper portion of the tower. STAAD Pro. V8i has been used for modeling, analysis and design of the towers.

2.4.1 Suspension transmission line tower

Suspension cable of transmission line tower is one of the transmission line tower types that commonly applied in the industry. There are two types of the suspension tower, which is C types and D types. The suspension cable works differently from every type of the tower. Insulator string is one of the tools that hang in these types of tower. Suspension cable bring the force downward, which known as lateral force. The insulatorhang down from the tower.

2.5 Number of legs for tower

Four legged based towers usually implement in the industry to design the transmission line tower. Two self-supporting 4 legged steel of the communication is designed with 24m and 21m tower tall. These towers is being idealized to a model using frame element in (Sharma *et al.*, 2015). The details of both towers are different in term of height of the straight portion at the top of the tower, height of slant portion, effective base width and top width.

In the research of (Dhoopam, 2015) it stated that the research is conducting based on the three legged and four legged space trusses with height between 30m and 160m. The general angles for three legged towers is 60° angles and 90° angles for four legged towers. It also stated that Chiu and Taoka (1973) is among the first to conduct the research regarding the self-supporting telecommunication tower. The research studied about a 3 legged 46m self-supporting response toward the wind load. In the current research of (Dhoopam, 2015) the four legged tower is being modelled on ground and at mounted on roof top. The conclusion of the research is the presence of a normal size tower on the buildings does not have a noteworthy influence on the building frequencies and mode shapes, it is desirable to use a prediction of the roof acceleration based on the natural frequencies of the building alone. Though the natural frequencies of the towers are greatly affected by the flexible base provided by the building, it is essential to find a simple rational way to predict this frequency shift. The same goes in one of the research of the(Methodology, 2015), it analysed four legged tower design with 132KV Double Circuit Steel Transmission Line Tower.

In this research the four legged Transmission Line Tower is being analysed since the four legged towers commonly used in the industry. Three legged towers are not being considered since it is not being used in the power sector. The four legged towers are being modelled with different height and various wind load speeds.

2.6 Conductor

The conductor is the material that allowed the electric current to pass through its body with different potential. The conductor is made of different types of material which is copper, aluminium and cadmium copper. Conductor from copper material have the high conductivity and tensile strength. Copper conductor has a small cross sectional area which means it can carry more current per unit cross sectional area. It is rarely used in the industry due to the non-availability and higher cost. Meanwhile, the aluminium conductor has a larger diameter compared to copper conductor. Even though the tensile strength of the aluminium conductor is less than the copper, it is widely used because of the cost and availability. The cadmium copper is uneconomical to use in the industry since the cost is very high and efficient for long span of communication tower. There are physical properties of the conductor as a need to perform its function:

- High conductivity
- High tensile strength
- High melting point and thermal stability
- Easy to handle and to transport at the site
- Corrosion resistance

Practically in Malaysia, ACSR Aluminium Conductor Steel Reinforced is commonly used as a conductor in the transmission line tower design. ACSR conductor consists numbers of steel strand that layered and wrapped in the spiral. The core wires in the conductor made up by galvanized coated steel or aluminium coated steel to avoid the strand from corrosion. ACSR conductor has high steel content where this type of conductor widely used for transmission and distribution purposes. Transmission of voltage above 220KV need the bundled conductor.

In the (Methodology, 2015) the conductor used is 30/3.00mm Al + 7/3.00mm Steel ACSR conductor Overall diameter = 21mm; Maximum Working Tension = 3640Kg; Unit Weight = 9.77 N/m. It stated that the conductor used is due to the sagging in hot weather. The height of the tower must consider the maximum sag in the climate. The result of this research depicts that Conductor Broken Condition gave less effect to the tower of 21m in the height range tower. Besides, the type of conductor used in the (Reddy, Rasagnya and Gokul, 2016) is the aluminium has an Ultimate Tensile Strength (U.T.S) of 16 – 20 kg / mm2 where the steel has a U.T.S of about 136 kg/ mm2. By a suitable combination of steel and aluminium the tensile strength of the conductor is increased greatly. Thus, there came into use the Aluminium Conductor Steel Reinforced (ACSR).

2.7 Height of the tower

Height of transmission line tower is one of the main parameters to ensure the efficiency and the stability of the tower to carry the power and transmit the signal. Height of the tower affects the displacement of the tower also since it affects the stability. Due to the wind load at zone I and zone II, the height of the tower considered the highest wind effect. The height applies in this research is 39 m, 49 m and 100 m which this three height considers the minimum, intermediate and maximum based on the compatibility of the tower to the displacement and wind effect.

Research from the (S and Sowjanya, 2015) used the same height but with different types of bracing to analysed the model of the transmission line tower in India. The height used is 30m with square tower, K bracing system and square tower X bracing system. Then, the (Dhoopam, 2015) analysed the tower with the height of 21m, 24m and 16m, 21m for the commercial buildings at mounted of the rooftop. The result from the research is The design of roof top towers cannot be based on the analytical results obtained for a similar configuration situated at ground level. As observed, the axial forces in the rooftop tower are increased approximately by two to three times (max.) with respect to ground tower. The long span of the transmission line tower analysed by the (Tian et al., 2013) using height 122m.

In the research of (Sharma *et al.*, 2015) the height of the tower that used to analyse the model of the transmission line tower is 45m, 35m and 25m with different height off the width and a portion of the tower. Then, the (Dhoopam, 2015) used height of 24m and 21m but with same height of portion and width for both structure.

2.8 The load acting on the tower

Load must be considered during design the tower to ensure the dimension and specification of the structure can resist the load apply to the structure. In some research the consideration of the transverse load, longitudinal load, torsional shear, self weight and wind load is being taken.

In the research of (S and Sowjanya, 2015), all the load above is being considered. The transverse load applied to the tower consists point load from the conductor wire and earth wire which support the tower in parallel direction to the cross arms. Then the load distributed the load to the transverse of the structure. The longitudinal load come from the force break off the ground or earth wire which caused unbalanced pull in longitudinal directions. Vertical load cause by the cross arm together with the ground wire peak. This research considered the torsional shear load when there is unbalanced tension in the conductor on two sides. This action due to the broken wire or dead ending of the conductor on single circuit lines. Wind load being considered at the place that the model is going to be placed. The load combination cases for this research also stated in Table 2.1.

Next, the research of the (Methodology, 2015) applied the combination of load toward the transmission line tower modelled. The combination of load is based on the condition which is the normal condition, the combination between the transverse load and longitudinal load. Next, ground wire broken condition, the combination of vertical, transverse, and longitudinal load at the clamps and third condition is top conductor broken condition which combination of vertical, transverse, and longitudinal load at the top cross arm of the tower. The result of the research shows that the maximum displacement at X = 63.1968m, occurred when the combination of load 1, normal condition is applied. The load combination 2 and 3 gave less effect toward the tower of height 21m height, horizontal length of cross arm of 3m and 2 m hammer width. It also stated in the research that with increase in height, length of cross arm members and hammer with, the twisting action due to conductor broken condition and bending action of the Ground Wire broken condition may affect the structure but bending action due to wind load plays a vital role. Hence, Wind load is a major load for towers. Based on the (Sharma *et al.*, 2015), it includes the dynamic load since the research about to analyse the tower subjected to the dynamic and seismic load.

Table 2.1: Load combination cases

LOADING CASES NUMBER	TYPE OF LOADING CASES
1	(DL+LL)
2	(DL+LL+W_X)
3	(DL+LL+W_Y)
4	(TIME HISTORY)
5	(DL+LL+EQ_X)
6	(DL+LL+EQ_Y)

Source: (S and Sowjanya, 2015)

Different load cases used in the (Phanindranath, 2017) which the load combination for the modeled structure as followed:

- 1.5DL + 1.5PL
- 1.2DL +1.2PL + 1.2WL
- 1.2DL + 1.2LL
- 1.5DL + 1.5WL
- 1.5DL
- 0.9DL

Hence, this research applied the three of the combined loads which at normal condition, ground wire broken and the top conductor broken condition of the tower modelled in the Staadpro with different height and braking system. In order to meet the optimized height that can resist the combinations load, various height applied to the tower.

2.9 Model analysis

The model is analyse using the Staadpro V8i software which the software can compute the result of the tower design. The result of the analysing of the structure depict the failure and success of the designed structure. This research, using the Staadpro since it can be used to analyse the transmission line tower with different bracing system and various load combinations.

Stated in the (Methodology, 2015) that using the software, the research done by using the option of "SELECT OPTIMIZED" to use the optimum section to analyse the tower using Staadpro V6i. The option "STEEL TAKE OF" help to analyse the structure with obtaining the steel sections and details for the whole structure. The conclusion from the research is the tower was designed by Limit State Methodology as per IS: 800-2007 rather than the conventional working stress methodology, both manually and by STAAD PRO V6i, for obtaining an optimized design. Design by IS: 800-1984(WSM) was also carried out in STAAD. The weight of the tower by LSM was 2.5221Metric Tones and by WSM was 2.8341 Metric Tones, resulting in 12% savings by LSM. Thus, the objectives of understanding the behaviour of the tower under wind load in combination with other loads and obtaining optimized design by Limit State methodology, in this study, were realized.

Same goes for the research of (Preeti and Mohan, 2013) which used the STAAD software to analyse the tower.

2.10 Summary

Table 2.2 Findings of literature review for different bracing system

Author	Title	Years	Parameter	Result	Remark
Methodology Limit State	Optimized Design of Steel Transmission Line Tower by Limit State Methodology	2015	• Height and top hammer width of the tower • Wind load + load combination	• Increase in height, cross arm, and hammer width effect the tower • Wind load is the major load on the tower	Optimum height will help to resist the wind load efficiently
C Preeti Sankara Ganesh Dhoopam	COMPARATIVE STUDY OF FOUR LEGGED SELF-SUPPORTED ANGULAR TELECOMMUNICATION TOWER ON GROUND AND MOUNTED ON ROOF TOP	2015	• Height of the tower • Wind load • Size of angular section	• Gradual decline in natural frequency as height of tower increase • Axial forces in all tower members that close to antenna attachment are noticeable high than those in bare tower	Section pf the steel effect the effectiveness of the tower
Siddu Karthik C S G.V. Sowjanya	Static and Dynamic Analysis of Transmission Line Towers under Seismic Loads	2015	• Load combination • Wind load • Types of bracing system	• K types bracing system give less deflection compared to X bracing system • K types bracing system reduce weight of tower compared to X bracing system	K bracing system gave positive effect toward the structure

Author	Title	Years	Parameter	Result	Remark
Kamarudin Siti Aisyah Usman Fathoni Nor Intan Baharuddin Zuliana	Review on analysis and design of lattice steel structure of overhead transmission tower	2018	• Design codes • Wind load • Steel section • p-delta analysis and linear static analysis	• both methods showed a minor different values as for the internal forces and the displacement after that will give ideas for further tower optimization	Steel section gave impact toward the structure
Harika T.S.D. Phanindranath	Selection of Suitable Bracing System for a Communication Tower at Various Wind Zones	2017	• Wind speed • Types of bracing system • Bracing section	• X and Y bracing system perform well at various wind zones • Angular section performed well in al aspect	X and Y bracing system effective when it come to the communication tower

Table 2.2 summarizes 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 researchers are conducted the analysis of the transmission line with different wind speed, different height and different types of bracing system with different steel section. Hence, in this study, it didn't consider the different of the steel section since for all modelled the same steel section were used. In addition, simulation based on the research is analysed in Staadpro software. According to the findings from most of the reviews, majority of the researchers were analysed the tower with different height at different places to obtain the maximum and minimum height for tower to against the wind load.

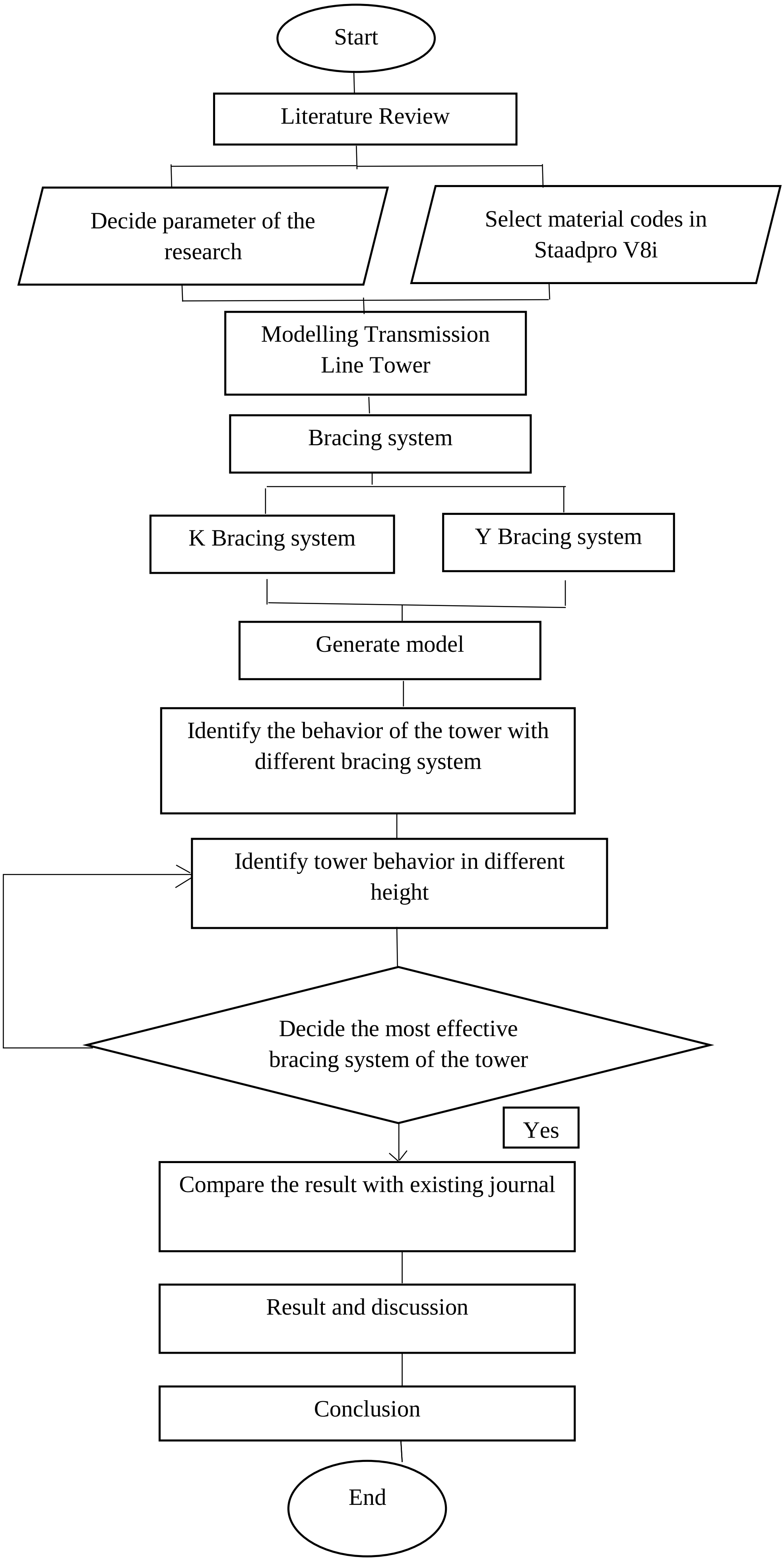
CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter present the step of analysing and design the transmission line tower of height. Mainly the research analysed the transmission line tower with different height and different types of bracing system. The failure of the designed can be identified using this software. The material, specification of the tower and code of practice are all provided in the software. The specification of the transmission line tower designed was provided in this chapter.

3.2 Methodology chart



3.3 Structure geometry and coordinate system

Staadpro V8i implemented two types of the coordinate system to identify the geometry and loading pattern which is global coordinate system and local coordinate system. Global coordinate system specified all the geometry and loading pattern for the structure. Meanwhile, the local coordinate system associated with every member in member end force output. Global coordinate system is being applied in this research for the transmission line tower design.

3.3.1 Global coordinate system

There are three coordinate systems available in the global system which is conventional Cartesian, cylindrical and reverse cylindrical. Practically in this research the Conventional Cartesian coordinate system used as the coordinate system to design the tower. This kind of coordinate system followed the right hand rule system where it can be used to identify the location of the joint and the direction of loading.

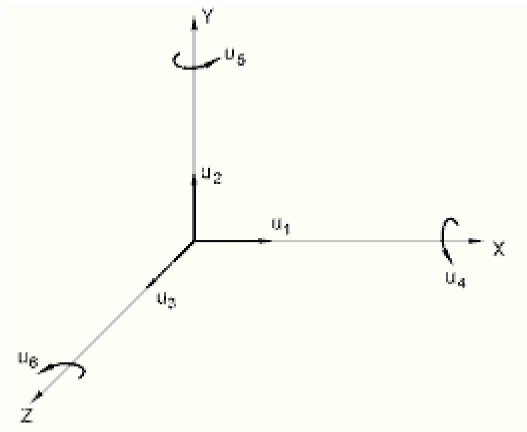


Figure 3.1: Cartesian (Rectangular) Coordinate System
Source: Technical Reference Manual, Staad.Pro V8i Help

Global coordinate system is being at the beginning of designing the transmission line tower, which is K and X bracing system tower. The coordinate system helps to show the direction of the dimension of each tower to be designed.

3.4 Input data

For steel or members of the structure, Staadpro may require data for the properties materials such as:

- Size of the structure
- Assign beam to structure
- Assign support of the structure
- Section database for horizontal, vertical and arm steel
- Load combination resist by the structure

3.5 Bracing system

Staadpro V8i has been used in this study to design and analyse transmission line tower with different types of bracing system. It can be used to design and analysed any structure, including high rise structure which the procedure of design and analysed need to properly do with the right code of practice applied.

Analysed the transmission line tower can be done after few tasks completed. These models were created using commands in the Staadpro after the setting of the Gridline, units, specify the node for the structural frame, assign the support and properties of the steel including the support. Then, a further step was designed the structure based on the types of bracing system as the research demand. The rest of the chapter then discussed about the procedure to design and analyse the model.

3.5.1 Types of bracing system

3.5.1.1 K bracing system

This type of bracing system is being model as in the Figure 3.2. K bracing system depicts that the bracing connected to the column at the mid span of the column. This type of bracing is more flexible and it reduced bending at the floor beams.

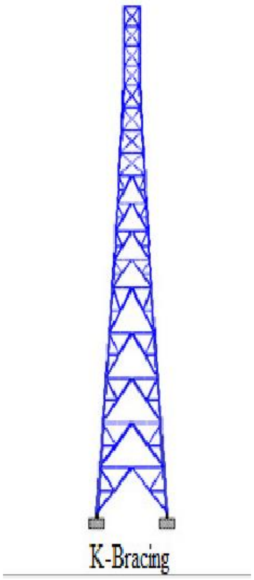


Figure 3.2: K bracing system
Source: (Sharma *et al.*, 2015)

3.5.1.2 X bracing system

This system meet the diagonal of member at the center of the cross member. The cross member is positioned in inclined condition. This kind of bracing system used more steel, but have high strength due to the X bracing condition of membership.

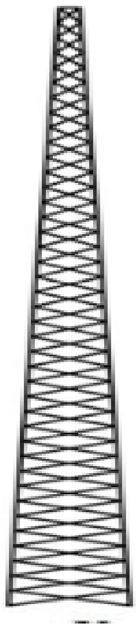


Figure 3.3: X bracing system
Source: (Towers *et al.*, 2017)

3.6 Structure support

The support of the structure assigned according to the compatibility of the structure to be hold by the support. The software allowed to create support using several types of support which is:

- Foundation support
- Inclined,
- Tension/compression only spring,
- Fixed,
- Pinned,
- Fixed but,
- Enforced,
- Enforced but,
- Multi liner spring.

The transmission line tower must have a strength base in order to hold the structure with various kinds of load and different height to reduce the displacement of the tower.

Fixed support assigned to each four leg of the tower and in the restrain condition. The support must be created before assign to the tower to ensure that the support visible in the modelling view. In this research the structural support assigned to all structure is fixed structure after the design has completed.

3.7 Insulator string model

Insulator string was hung down from the tower. The suspension insulator hung down and form a V shape, structure for the forced to be brought downward. Mechanical tension is same for both sides. The insulator string model is used for the transmission line tower, which called as suspension transmission line tower as in this research.

There are 55 types of the insulator string used for the transmission line tower, which is Pin insulator, Suspension insulator, Strain insulator, Stay insulator, and Shackle insulator. In order to resist the high voltage system, the suspension insulator is applied in this research. In order to form a string, the numbers of insulator is formed in series and the most bottom insulator carried the line conductor. The suspension insulator is applied in this research to assure the load is carried downward from the tower. Only vertical force is being considered in this research since the structural analyses are the Suspension transmission line tower. The types of insulator used in the research was in the Figure 3.4.

Figure 3.4: Insulator string
Source: Google images

3.8 Bracing property

In order to design the transmission line tower in the software, three main types of the bracing properties need to be assigned. Assigning the bracing properties help to construct the main frame of the structure with different bracing system. The seven types of the bracing properties are pipe section, angular section, multi section, UB shape, UC shape, JO shape and channel.

All section size is selected in the software before assigning the properties of the structure. The section database in the software can be chosen according to the codes or standard that practices in that particular area which is in this research British standard is being practiced. The steel section is being used in the structure is referring to the BS. The steel section is chosen based on the compression capacity of the members. The steel section used for the horizontal and inclined bracing is 203X102X23 and steel section of 254X146X31 is applied to the main vertical members. Since the transmission line tower has cross arm, the cross arm tower used for the structure is 178X102X19.

3.9 Material of member

Materials of every section and members assigned as the steel types since the transmission line tower used steel as the frame of the tower. The material types of the members help to increase the strength of the tower besides the behavior of the steel are suitable with the transmission line tower. The material of the member assigned to the structure is the steel structure which the dimension has been chosen based on the British standard.

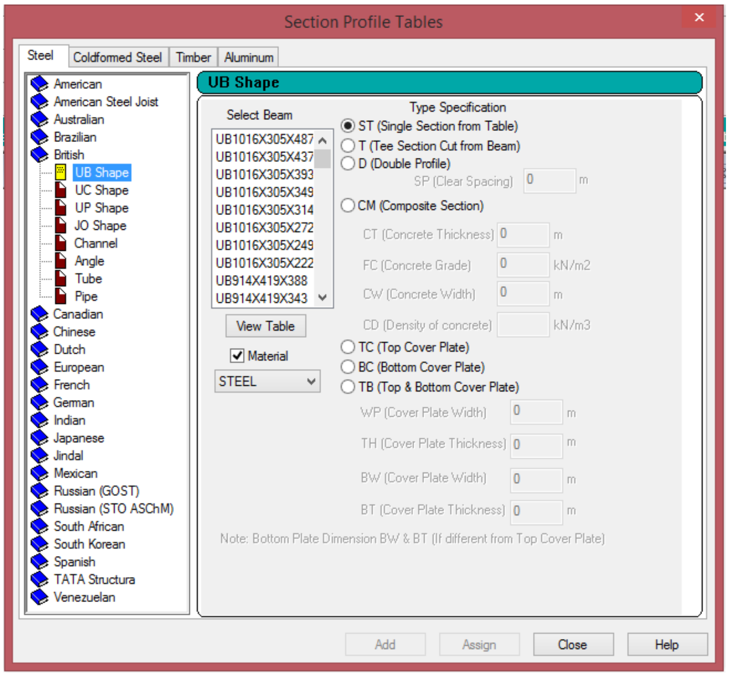


Figure 3.5: Selection of steel size for each member

3.10 Load

3.10.1 Wind load

Load case details need to be confirmed in the software before the wind load intensity is implemented in the model design. The wind that considered in the research is wind speed in three zone in Malaysia which is zone I, zone II and zone III. All those wind load defined with all types of model to identify which model that suitable and convenient for the wind speed at particular zone. The two main wind load applied in this research were Zone I 33.5 m/s and Zone II 32.5 m/s and the highest possible wind load in Malaysia which was 40 m/s. All three wind speed being analysed to three towers with a height of 39 m, 49 m, and 100 m.

In order to apply these load in the Staadpro software, the intensity of load must be converted from the wind speed acquired. Referring to the MS standard 1553: 2002, the wind loads, speed convert to be used in the software. Here it shows the formula used to calculate the intensity of the wind speed:

$$P = 0.613(V_{des})^2 C_{fig} C_{dyn} \quad (3.1)$$

P = Design wind pressure

V_{des} = Design wind speed

C_{fig} = Aerodynamic shape factor

C_{dyn} = Dynamic response factor = 1

In this research, the terrain/height multiplier used was in category 3 since the tower was considered as terrain with numerous large, high (10m to 30m high) and closely spaced obstruction such as large city center and well – developed industrial complexes. The information about the formula was obtained from the MS standard 1553: 2002.

Different height of the tower had different intensity with different wind speed. The 10 different intensities applied to particular tower, which have different height to obtain the effect of wind load toward the tower. The same number of intensity was applied for all research towers to obtain the less the effect of wind load toward the tower.

3.10.2 Dead load and Live Load

Value of dead load is relatively constant for an extended period of time. Dead load assigned to the whole structure. The value of dead load entered in the software showed the force in term of tension and compression that act on the structure itself. The value of dead load and live load included in the modelled was with the combined load that provided in the software. The combination of the load then assigned to the structure to analysed the whole structure.

The dead load factor used in the software is -1Y and the live load factor is 1. The load applies toward the tower together with the suspension load was downward force carried by the insulator. The downward force, then calculated as the weight of the insulator for each tower with different height.

3.11 Model generation

The analysis of the model typically same as the analysis of other structural design in the Staadpro V8i. The different of the modelling only the types of bracing system and height of the tower.

3.11.1 Modelled

The structure was modelled with different types of bracing system and different wind load to identify the convenience structure, and the optimum height that's suitable for every bracing. Two different bracing system of the transmission line tower were tested using the same method. Each of the models tested with different height and various wind speeds. Firstly, the structure was analysed with 39 m height, 49 m height and 100 m height. One type of the bracing system of the structure modelled as Figure 3.6.

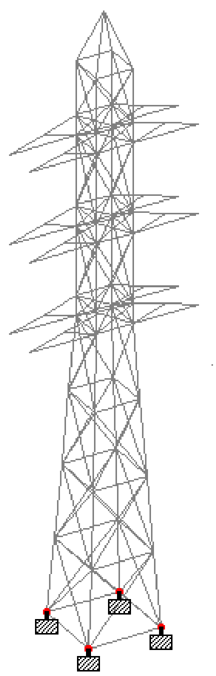


Figure 3.6: Transmission line tower modelling in X bracing system

After designed process, the tower then applied to the steel section database and the differences of each section database shown in the modelling structure. The section database assigned based on the member placed which is horizontal and inclined member, main vertical member and the cross arm member.

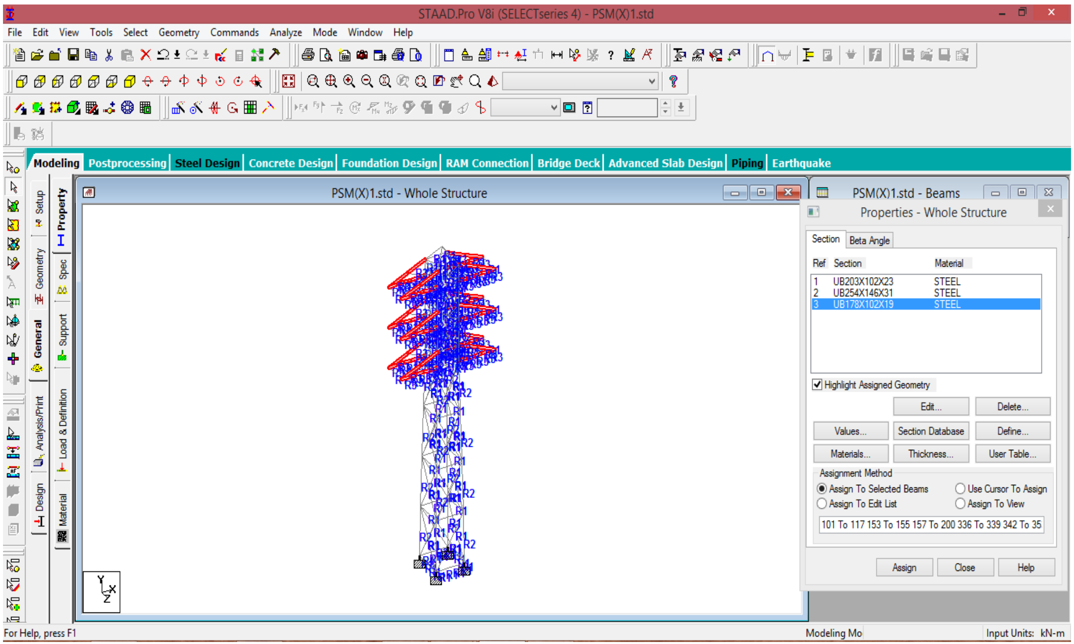


Figure 3.7: The section assigned to the model structure

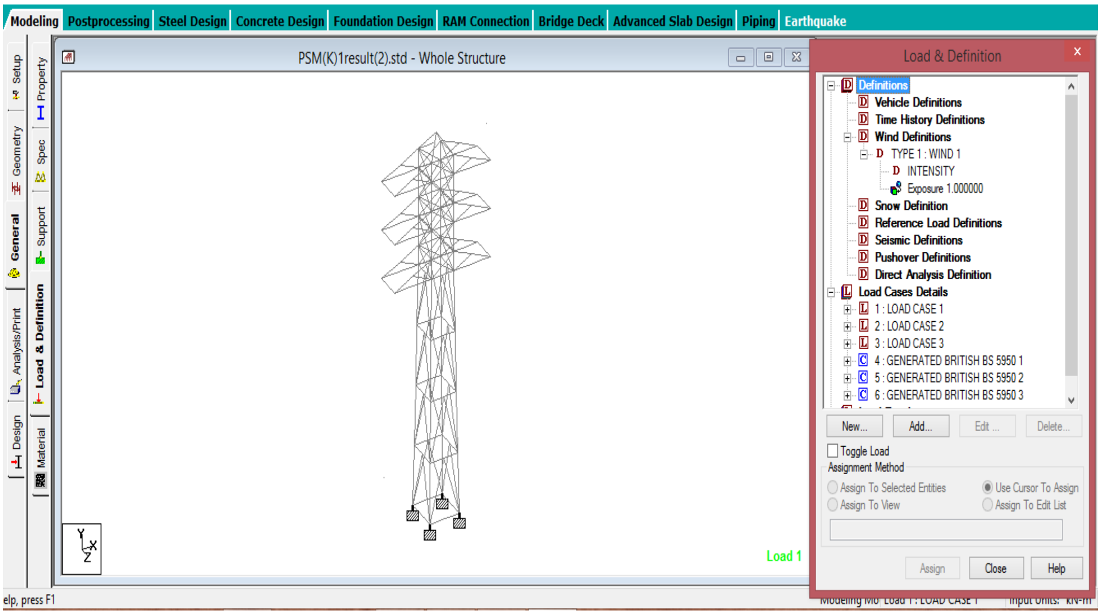


Figure 3.8: Assigning load and load combination of the model structure

3.11.2 Model geometry

The geometry of the beams was modelled then applied with the auto combination load. The combination load was combine with the dead load, live load and wind load. The models were designed with three different heights and different bracing system. Three models were model with height 39 m, 49 m, and 100 m.

3.12 Solution phase

This phase is very important to analyse the structure before generating the results of the post processing phase. This phase is where the structure assigned by forces and load combination. Then, solve the analysis.

3.12.1 Apply load combination

From the menu display selection of the load and definition were required. Then, insert the load that needs to apply to the tower, such as the wind load. Minimum intensity that the research used in this research was 10 value of intensity. The direction of wind speed was determine based on the research. After the confirmation of wind direction, live load, dead load and required load must be applied to the tower as in Figure 3.9.

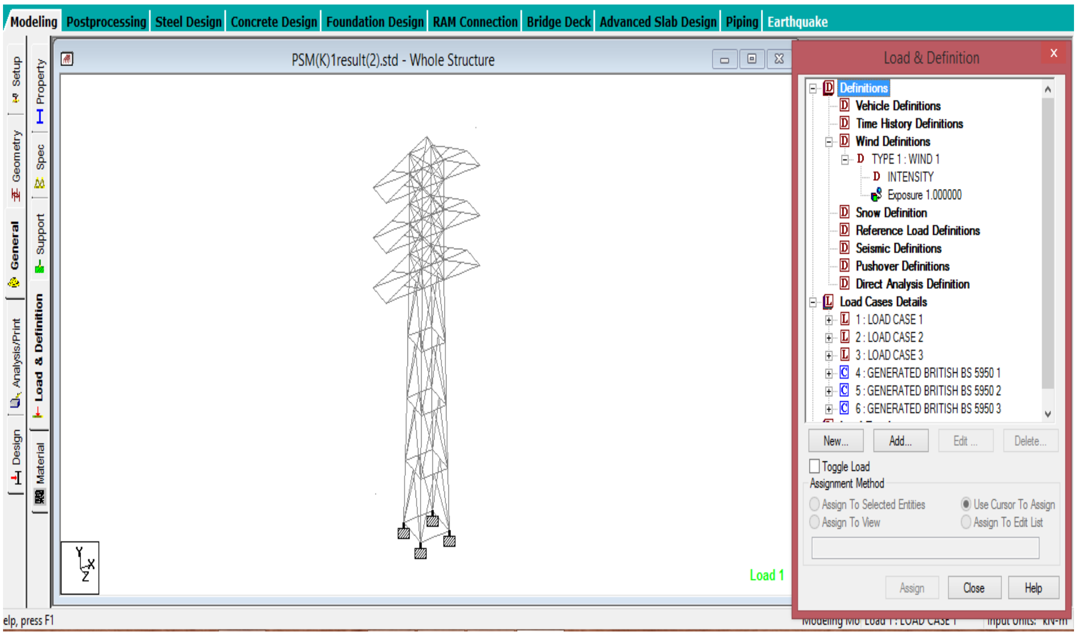


Figure 3.9: Load applied to the tower

3.12.2 Analysed

Each tower designed in this research were analysed after designed and applied load completed. Then, error can be check and modelled can proceed to post processing processed. In some modelled, the error was detected and fixed based on the report perform in the Staadpro.

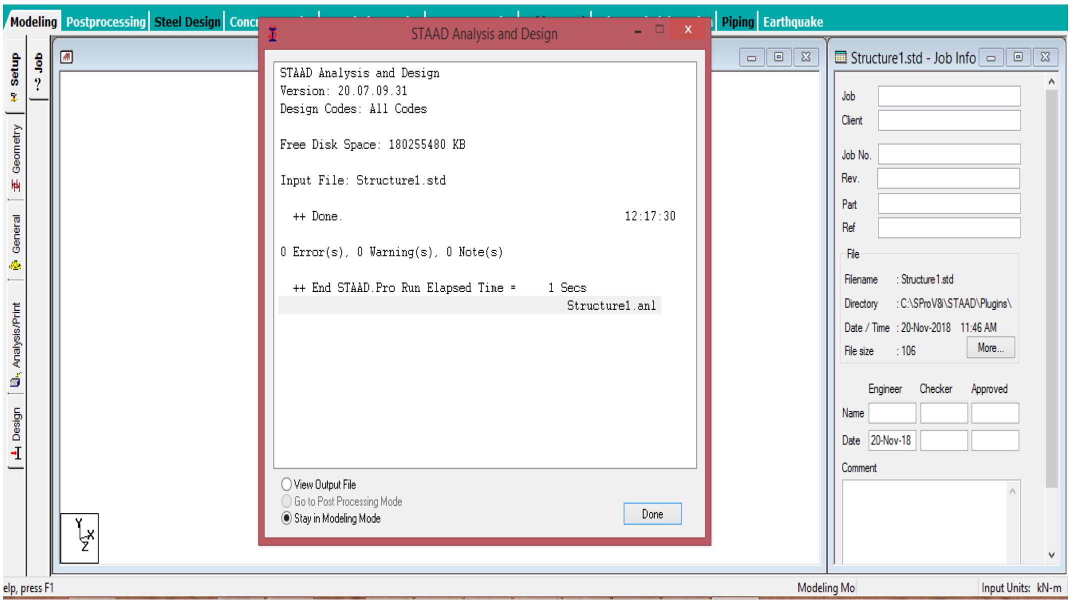


Figure 3.10: Pop up to check error and to post processing mode

3.13 Post processing

In post processing, general results of reaction forces, stress, displacement, and deflection can be checked through general post processing.

3.13.1 Result

The analysis of all the transmission line tower was to obtain the result which is the effectiveness of the tower to transmit signal and to resist the load apply toward the tower. Then, the displacement was observed to determine which types of tower that have less displacement and can resist less if the load apply to it. The displacement, axial load and beam graph was used to analyse the result of towe

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The modelling of the transmission line tower analysis of the suspension tower was built with the dimensions. All models were analysed using Staadpro Vi8 software. The entire model was adopted from the previous journal that being referred together with the tower properties. The properties and types of steel used is important to ensure the effectiveness of the tower toward the loading. In this research, the comparison between types of bracing system, height and wind load have been made. This has been done to identify the most effective bracing system for the transmission line tower.

4.2 Displacement of the tower

In order to obtain the objective of the research, displacement of the structure is being considered. The structure should have less displacement to ensure the effectiveness of the tower to transmit signal. The displacement of the tower effect of the load carries behaviour and the surrounding which is wind load and other natural event. In this research, only wind load is considered. The load combination to the tower is being applied to obtain the displacement each tower. The load combination that applied to the tower included the live load, dead load and wind load.

Table 4.1 to Table 4.3 summarizes the displacement, end member forces and the envelope of end member forces. The summary of these data depicts the highest value of each of the inputs. In the summary of the displacement, the analysis obtained the highest and lowest displacement based on each of the load combinations.

Then, for the end member forces with the envelope, the table shows the Fy, Fx, Fz, My, Mx, and Mz of each node that have been annotated to the structure. The load combination that generates toward the end member forces also there to conclude which load combination gave maximum end forces. Based on the result, the 5 generated British BS 5950 load combination always give the highest impact toward the result.

Table 4.1: Summary of displacement

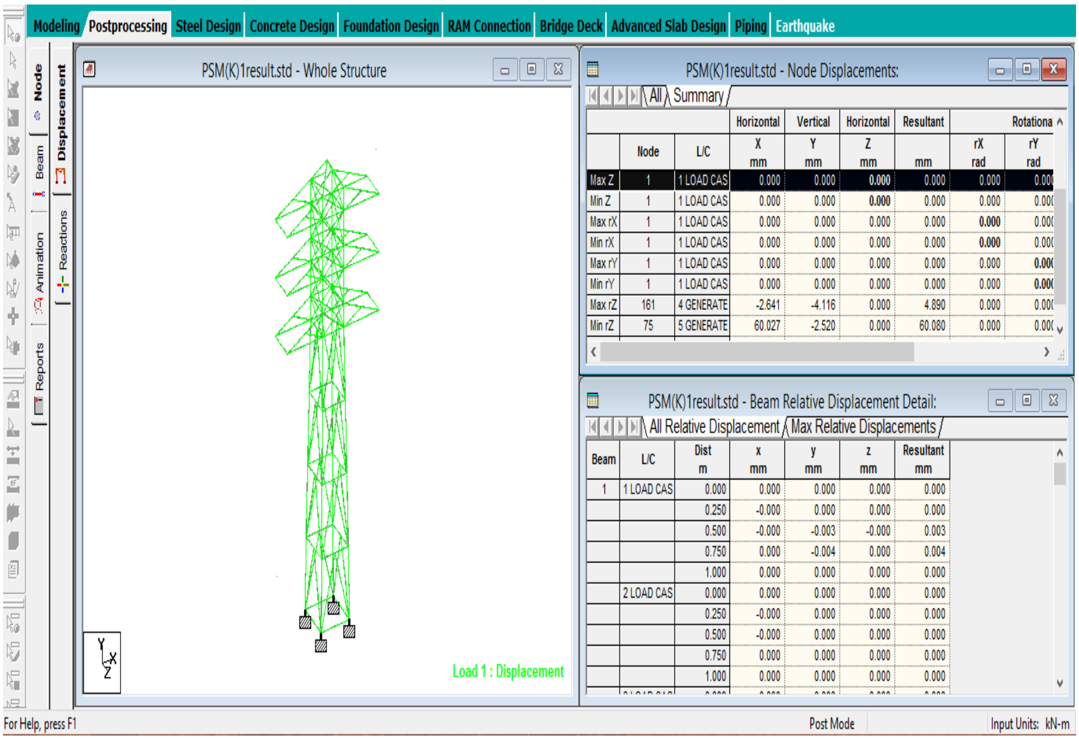


Table 4.2: Summary of end member forces

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	101	5 GENERATE	9	195.609	-0.128	0.007	-0.000	-0.058	-0.464
Min Fx	98	5 GENERATE	82	-121.187	0.100	0.005	-0.000	-0.042	0.590
Max Fy	265	6 GENERATE	208	0.000	4.908	-0.078	-0.000	0.020	1.221
Min Fy	36	6 GENERATE	208	-0.000	-4.941	0.135	0.000	0.034	1.229
Max Fz	181	5 GENERATE	170	0.000	0.255	0.289	0.000	-0.145	0.098
Min Fz	183	5 GENERATE	172	0.000	-0.100	-0.496	0.000	0.248	-0.080
Max Mx	115	5 GENERATE	82	0.000	2.152	0.032	0.001	-0.030	1.914
Min Mx	234	5 GENERATE	197	0.000	-1.811	-0.026	-0.001	0.025	-1.802
Max My	183	5 GENERATE	172	0.000	-0.100	-0.496	0.000	0.248	-0.080
Min My	183	5 GENERATE	173	-0.000	-0.278	-0.496	0.000	-0.248	0.109
Max Mz	35	6 GENERATE	36	-0.000	-4.864	0.135	0.000	0.068	2.407
Min Mz	35	6 GENERATE	35	0.000	-4.712	0.135	0.000	-0.068	-2.382

Table 4.3: Envelope of end member forces

All / Summary / Envelope

Beam	Node	Env	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
1	1	+ve	0.000	0.355	0.000	0.000	0.000	0.148
			-	4 GENERATE	-	-	-	4 GENERATE
		-ve	0.000	0.000	0.000	0.000	0.000	0.000
			-	-	-	-	-	-
1	2	+ve	0.000	0.177	0.000	0.000	0.000	0.000
			-	4 GENERATE	-	-	-	-
		-ve	0.000	0.000	0.000	0.000	0.000	-0.118
			-	-	-	-	-	4 GENERATE
2	2	+ve	0.000	0.177	0.000	0.000	0.000	0.059
			-	4 GENERATE	-	-	-	4 GENERATE
		-ve	0.000	0.000	0.000	0.000	0.000	0.000
			-	-	-	-	-	-
2	3	+ve	0.000	0.000	0.000	0.000	0.000	0.000
			-	4 GENERATE	-	-	-	-
		-ve	0.000	0.000	0.000	0.000	0.000	-0.030
			-	-	-	-	-	4 GENERATE
3	3	+ve	0.000	0.000	0.000	0.000	0.000	0.000
			-	4 GENERATE	-	-	-	-
		-ve	0.000	0.000	0.000	0.000	0.000	-0.030
			-	-	-	-	-	4 GENERATE
3	4	+ve	0.000	0.000	0.000	0.000	0.000	0.059
			-	-	-	-	-	4 GENERATE
		-ve	0.000	-0.177	0.000	0.000	0.000	0.000
			-	4 GENERATE	-	-	-	-
4	4	+ve	0.000	0.000	0.000	0.000	0.000	0.000
			-	-	-	-	-	-
		-ve	0.000	-0.177	0.000	0.000	0.000	-0.118
			-	4 GENERATE	-	-	-	4 GENERATE
4	5	+ve	0.000	0.000	0.000	0.000	0.000	0.148

4.2.1 Displacement of tower with height 39 m

The displacement of the X bracing system with wind speed 32.5 m/s increased 6.7% compared to the K bracing system tower. Then, 13.8% of displacement increased to the structure with the X bracing system compared to the K bracing system at wind speed 33.5 m/s. At wind speed 40 m/s same types of bracing system which is X bracing system depict 9.8% increasing of the displacement compared to the K bracing system. All the result obtained represent in Figure 4.1.

The X bracing shows that in every wind speed, the displacement of the tower increased compared to the K bracing system. This result concludes that for 39 m tower, the K bracing system is more effective to apply for the suspension tower of transmission line.

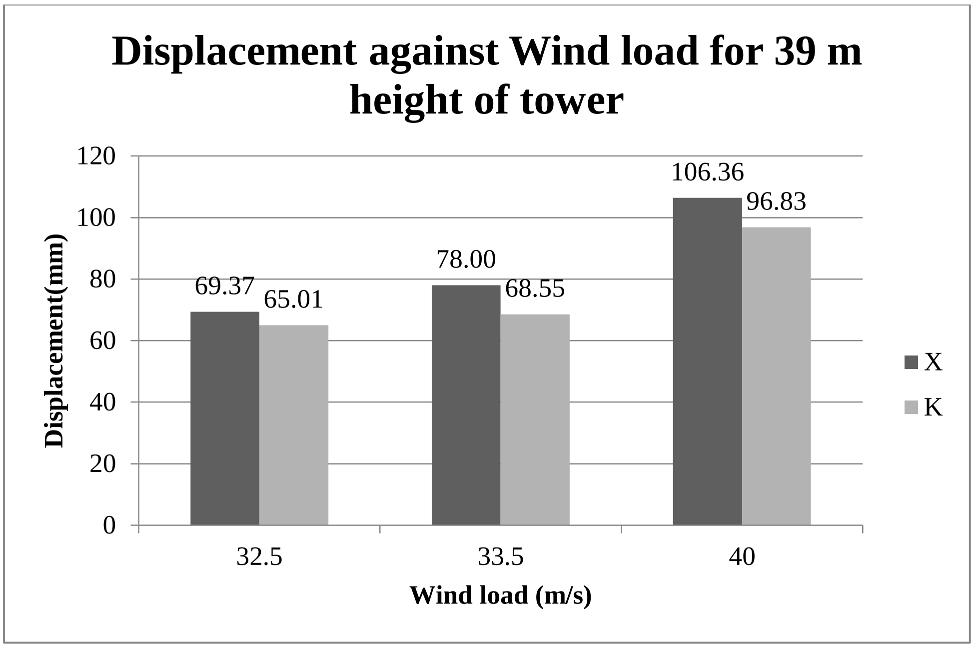


Figure 4.1: Graph of displacement against wind load for 39 m height of tower

Figure 4.2 to Figure 4.7 shows that the displacement of the K bracing system and X bracing system for the 39 m tower height. Figure 4.2 shows the displacement of K bracing system with the wind speed of 32.5 m/s while Figure 4.3 and 4.4 show the displacement with wind load 32.5 m/s and 40 m/s.

As for Figure 4.5 refers to the displacement of X bracing system with the wind speed of 32.5 m/s. Then Figure 4.6 and 4.7 refer to the displacement of X bracing system with wind load 33.5 m/s and 40 m/s.

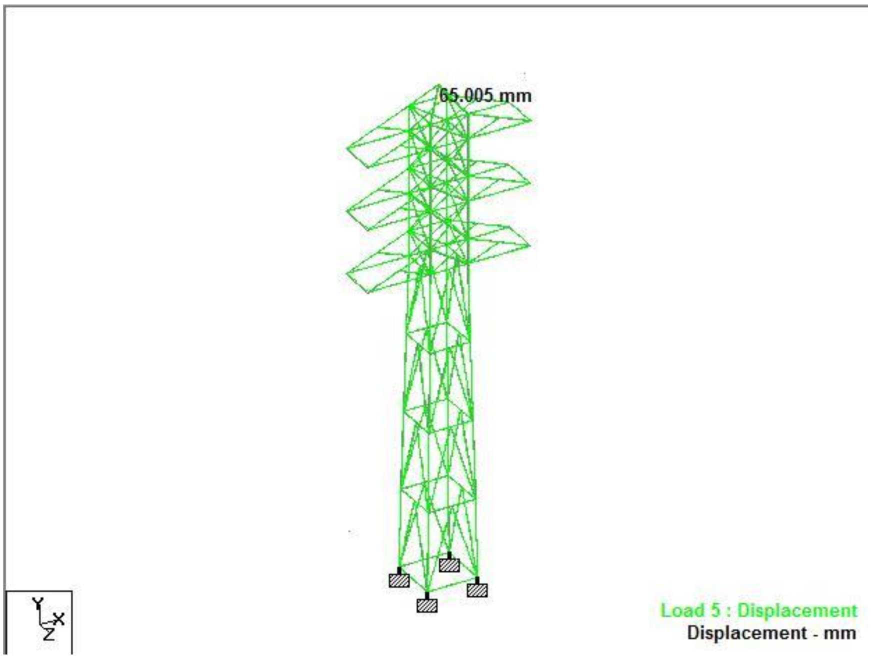


Figure 4.2: Max node speed with wind 32.5 m/s displacement for 39 m K bracing tower

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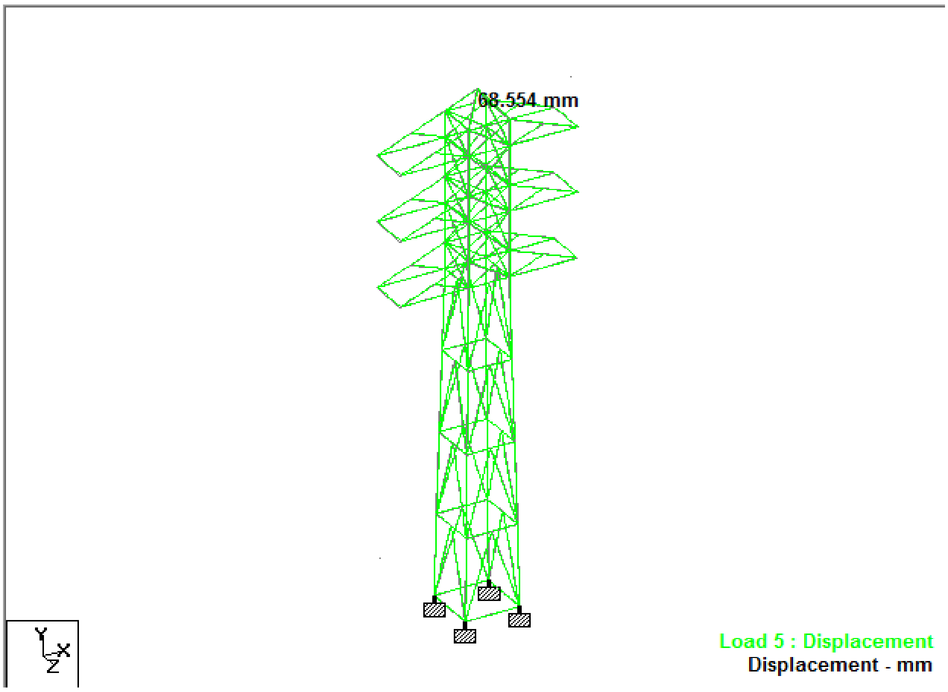

Figure 4.3: Max node displacement for 39 m K bracing tower with wind speed 33.5 m/s

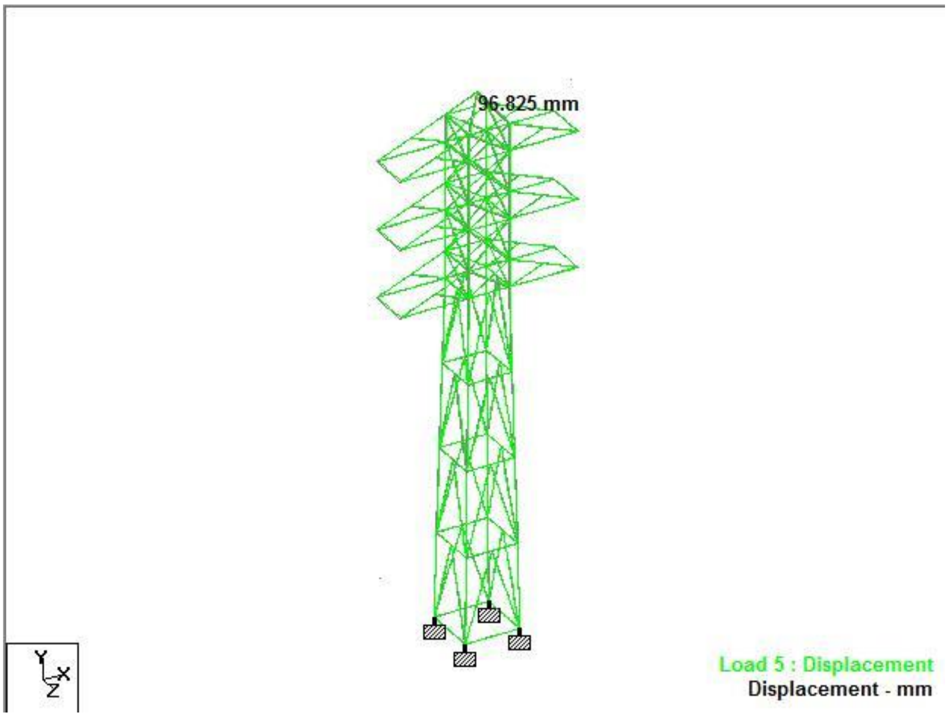

Figure 4.4: Max node displacement for 39 m K bracing tower with wind speed 40 m/s

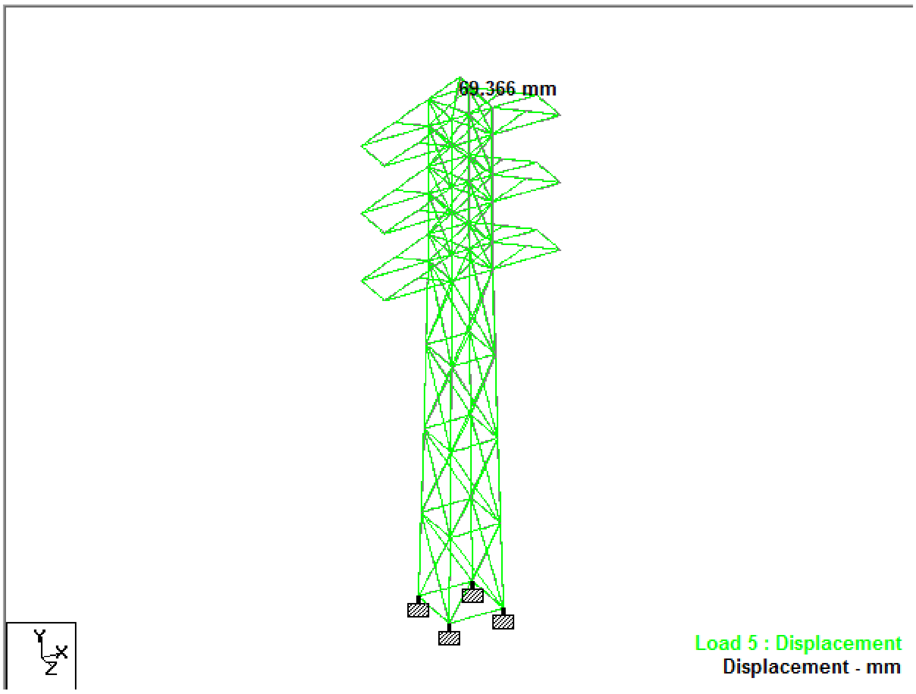

Figure 4.5: Max node displacement for 39 m X bracing tower with wind speed 32.5 m/s

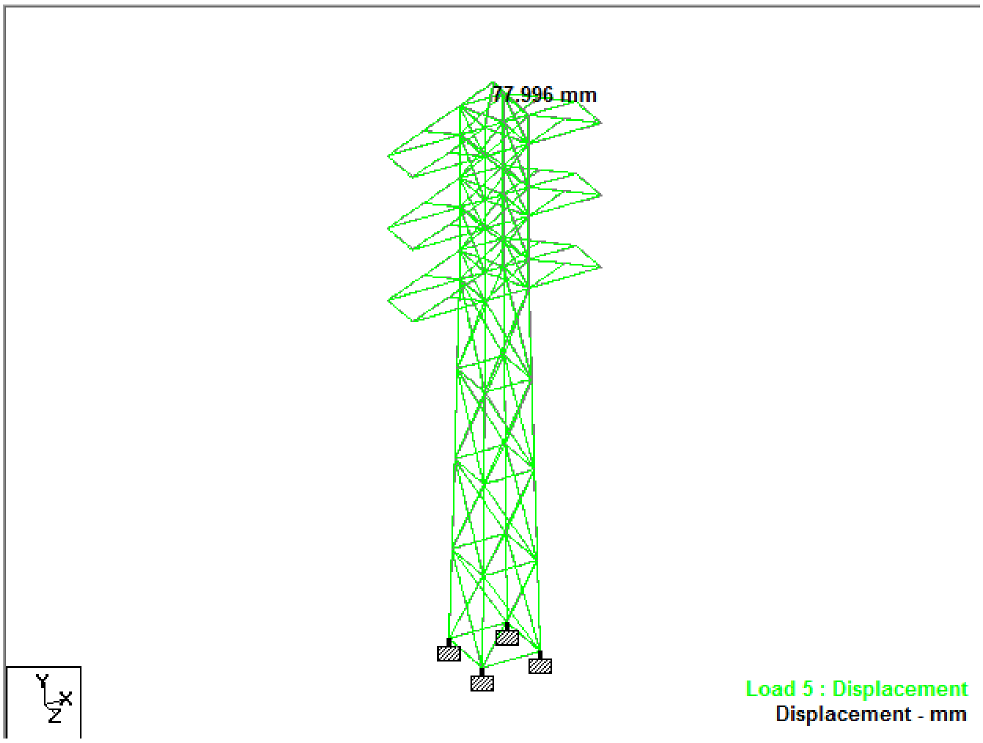

Figure 4.6: Max node displacement for 39 m X bracing tower with wind speed 33.5 m/s

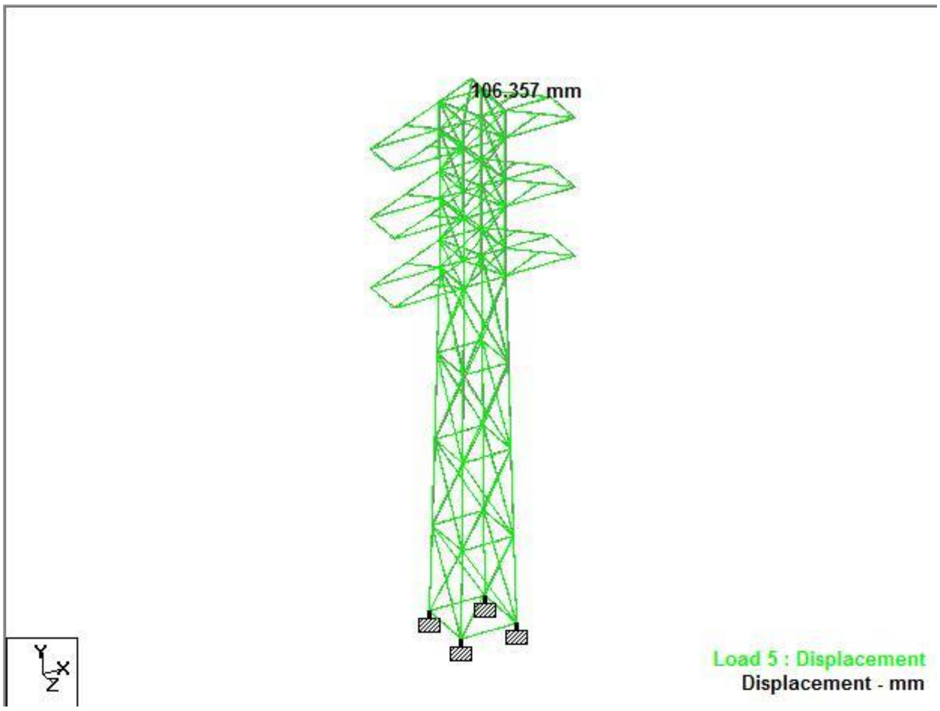

Figure 4.7: Max node displacement for 39 m X bracing tower with wind speed 40 m/s

4.2.2 Displacement of tower with a height 49 m

For wind speed 32.5 m/s the X bracing system increased 84.0% displacement from the K bracing system. Then, 84.8% of displacement of the X bracing system increased from the K bracing system for wind speed 33.5 m/s. Lastly, the X bracing system also shows the increasing 86.4% of displacement from the K bracing system for wind speed 40 m/s. All the result obtained represent in Figure 4.8.

For the tower height of 49 m, the K bracing system shows less displacement compared to the X bracing system prone to the wind speed. Since K bracing obtained less displacement, it is effective to use K bracing system for tower 49 m.

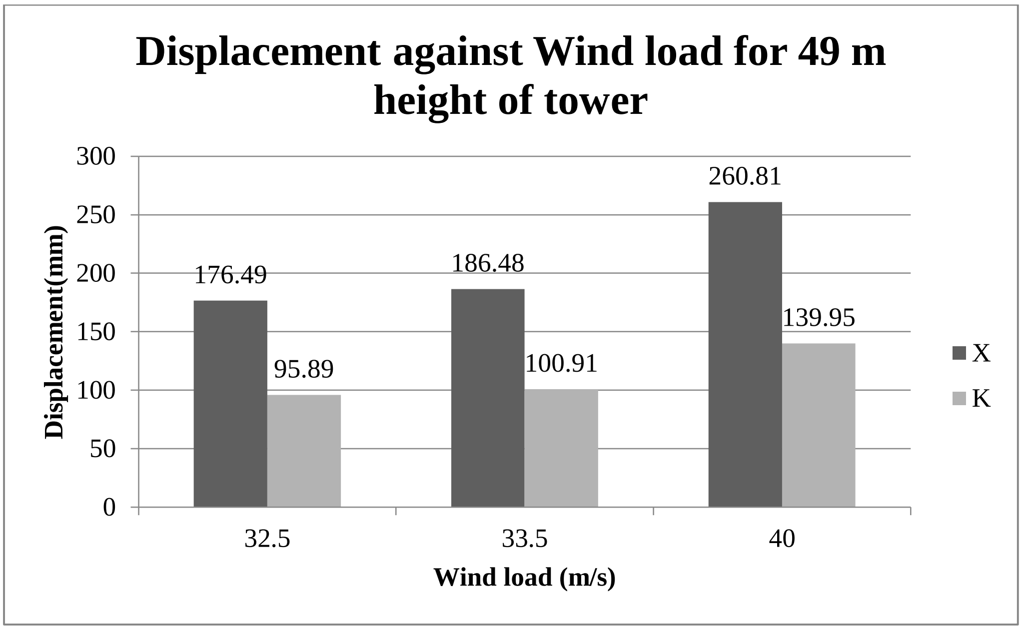

Figure 4.8: Graph of displacement against wind load for 49 m height of tower

Figure 4.9 to Figure 4.14 shows that the displacement of the K bracing system and X bracing system for the 39 m tower height. Figure 4.9 shows the displacement of K bracing system with the wind speed of 32.5 m/s while Figure 4.10 and 4.11 show the displacement with wind load 32.5 m/s and 40 m/s.

As for Figure 4.12 refers to the displacement of X bracing system with the wind speed of 32.5 m/s. Figure 4.13 and 4.14 refer to the displacement of X bracing system with wind load 33.5 m/s and 40 m/s.

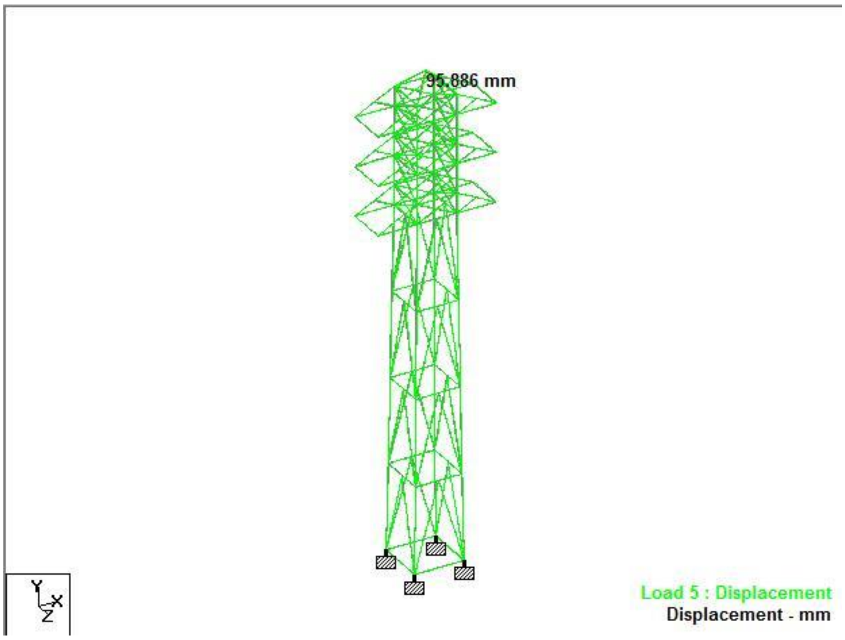

Figure 4.9: Max node displacement for 49 m K bracing tower with wind speed 32.5 m/s

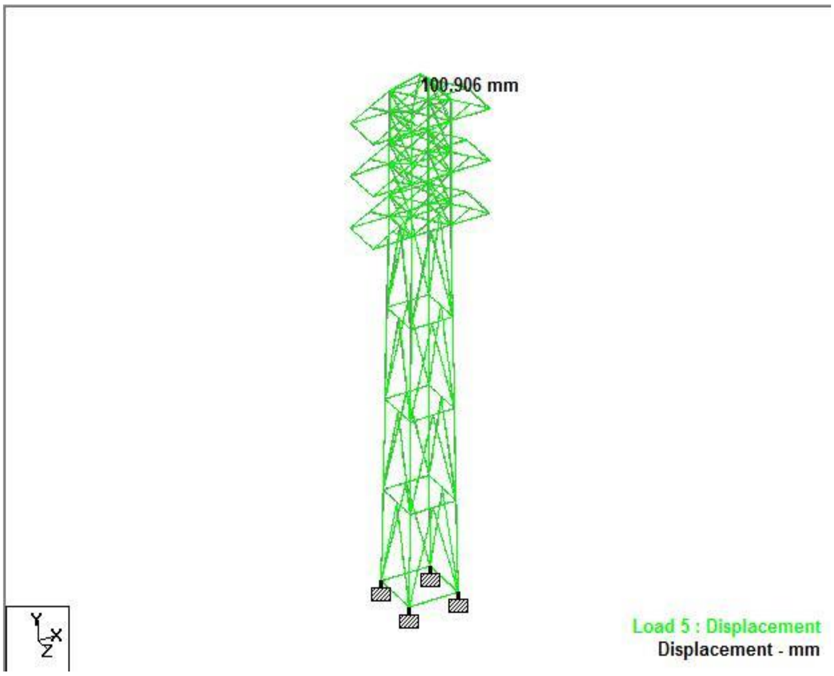

Figure 4.10: Max node displacement for 49 m K bracing tower with wind speed 33.5 m/s

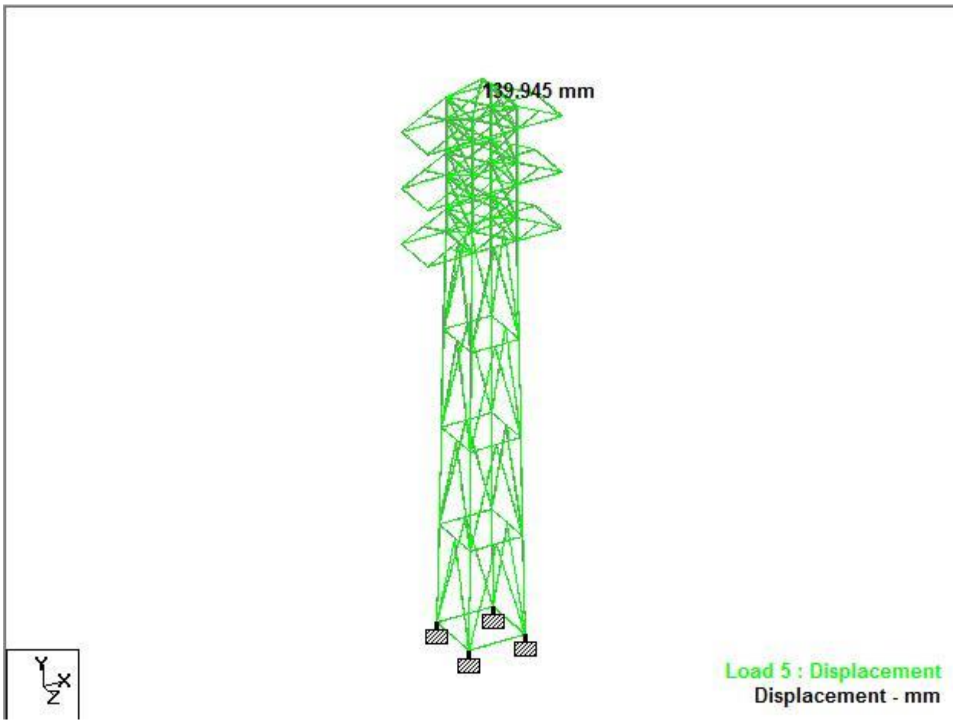

Figure 4.11: Max node displacement for 49 m K bracing tower with wind speed 40 m/s

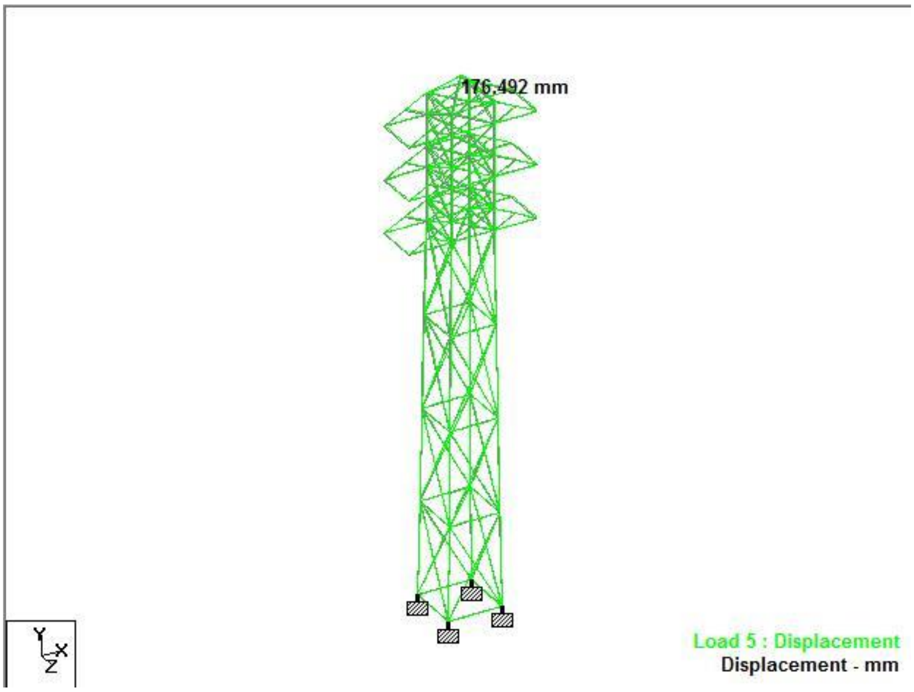

Figure 4.12: Max node displacement for 49 m X bracing tower with wind speed 32.5 m/s

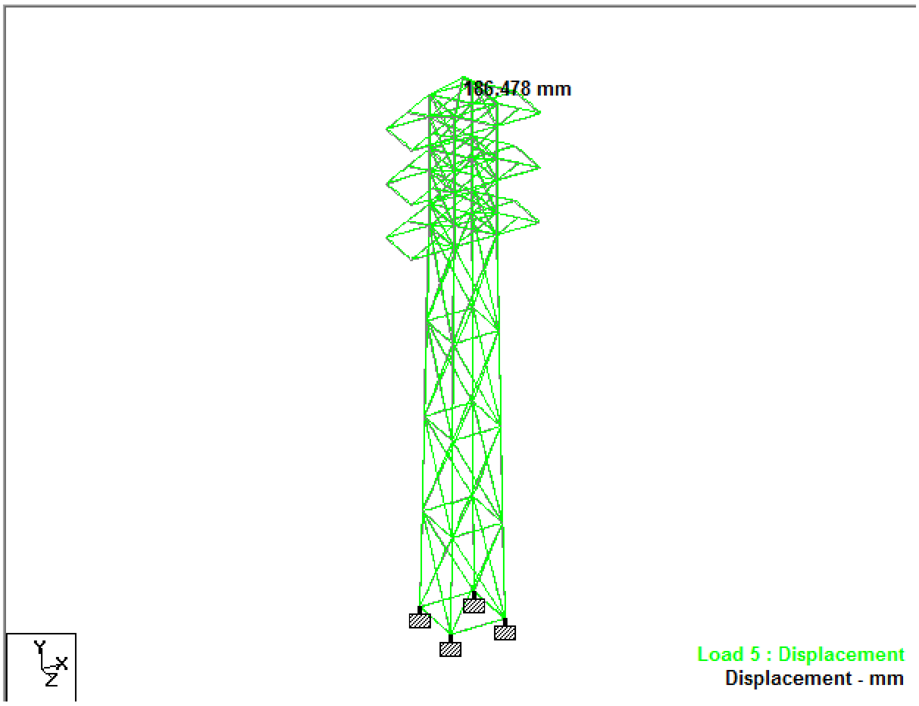

Figure 4.13: Max node displacement for 49 m X bracing tower with wind speed 33.5 m/s

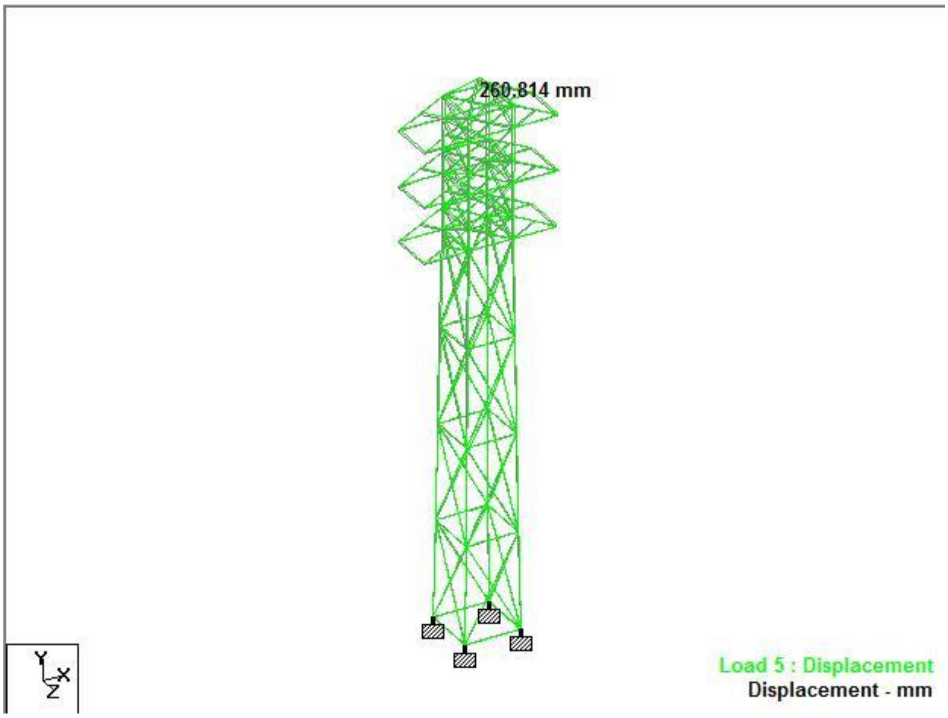

Figure 4.14: Max node displacement for 49 m X bracing tower with wind speed 40 m/s

4.2.3 Displacement of tower with height 100 m

The increasing 108.7% of displacement for the K bracing system from the X bracing system shows for the wind speed 32.5 m/s. Next, the K bracing system increased 109.8% from the X bracing system for wind speed 33.5 m/s. Then, increasing 118.4% of displacement for the K bracing system depict for wind speed 40 m/s. All the result obtained is shown in Figure 4.15.

Tower with 100 m height shows less displacement that depicts that the uses of the X bracing system is effective to the highest tower compared to the 39 m and 49 m tower. The K bracing system has the highest displacement which is less effective to the tower with 100 m height.

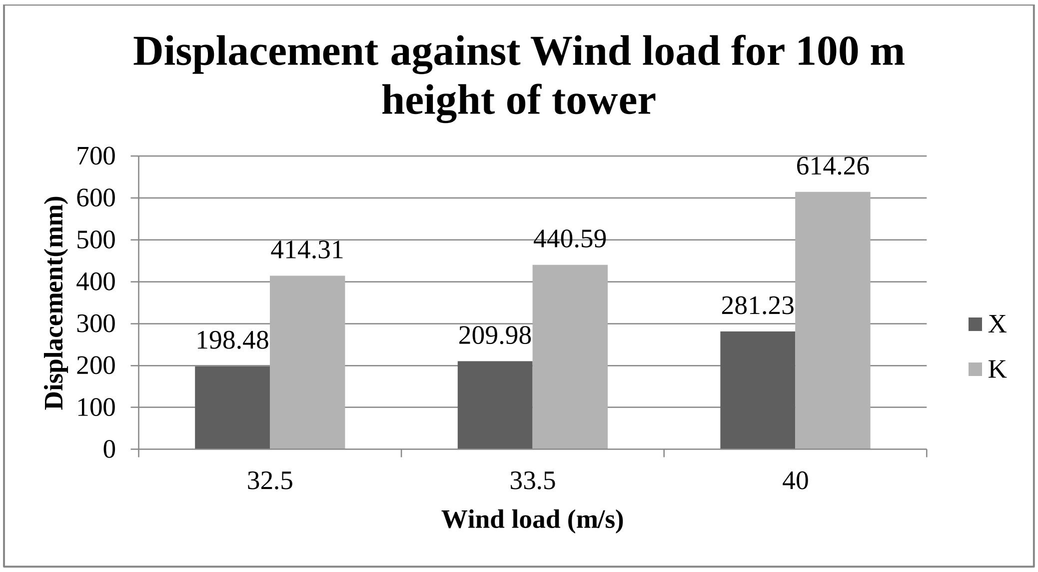

Figure 4.15: Graph of displacement against wind load for 100 m height of tower

Figure 4.16 to Figure 4.21 show that the displacement of the K bracing system and X bracing system for the 39 m tower height. Figure 4.16 shows the displacement of K bracing system with the wind speed of 32.5 m/s while Figure 4.17 and 4.18 show the displacement with wind load 32.5 m/s and 40 m/s.

As for Figure 4.19 refers to the displacement of X bracing system with the wind speed of 32.5 m/s. Figure 4.20 and 4.21 refer to the displacement of X bracing system with wind load 33.5 m/s and 40 m/s.

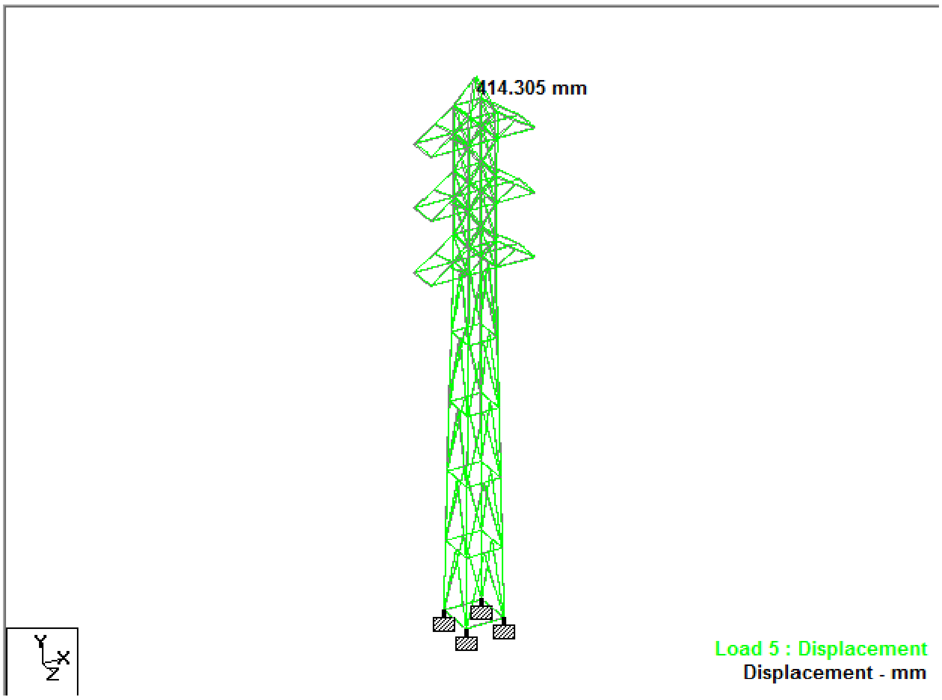

Figure 4.16: Max node displacement for 100 m K bracing tower with wind speed 32.5 m/s

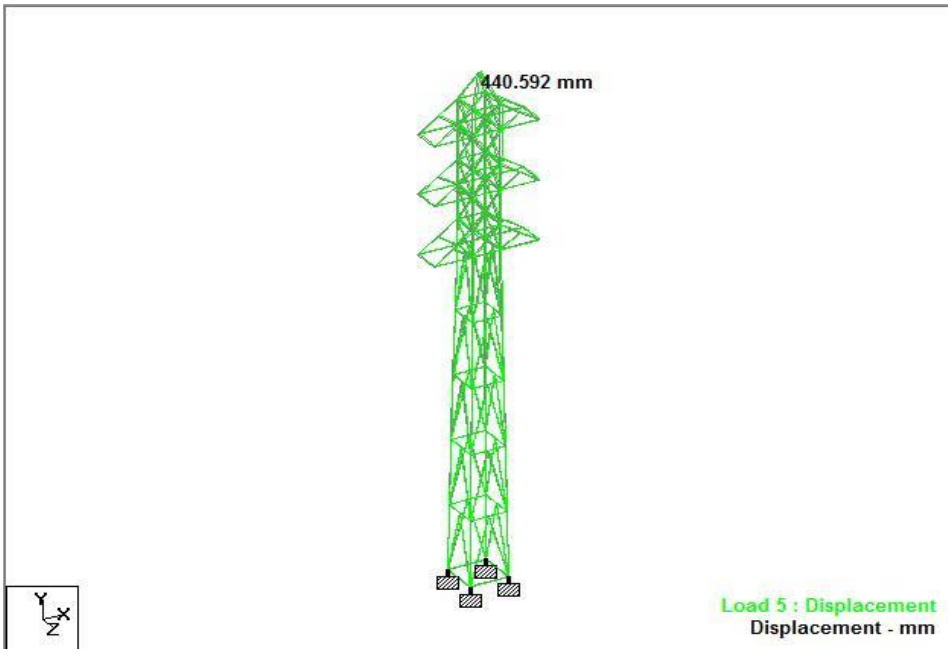

Figure 4.17: Max node displacement for 100 m K bracing tower with wind speed 33.5 m/s

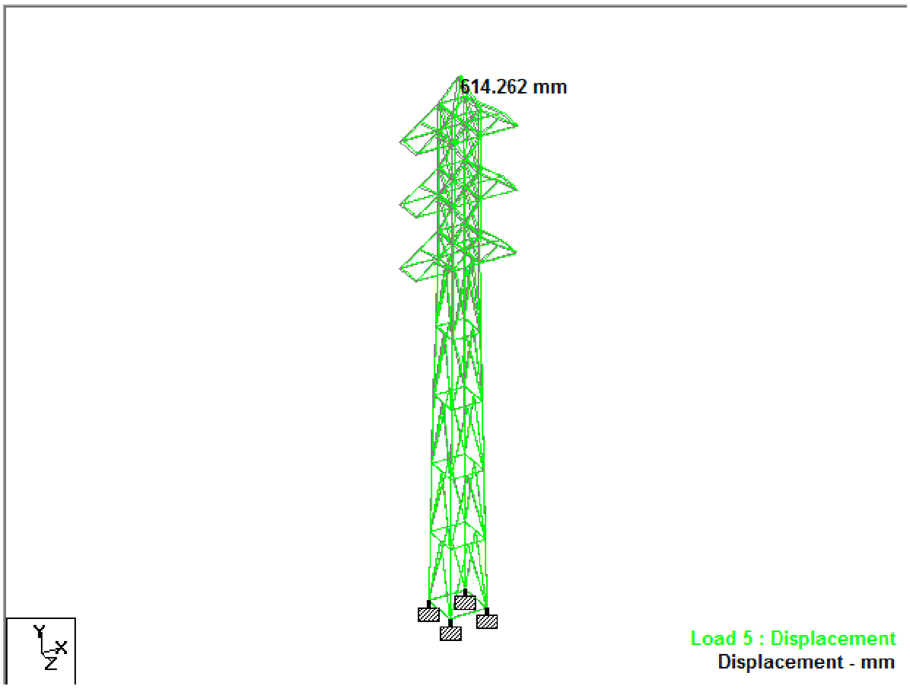

Figure 4.18: Max node displacement for 100 m K bracing tower with wind speed 40 m/s

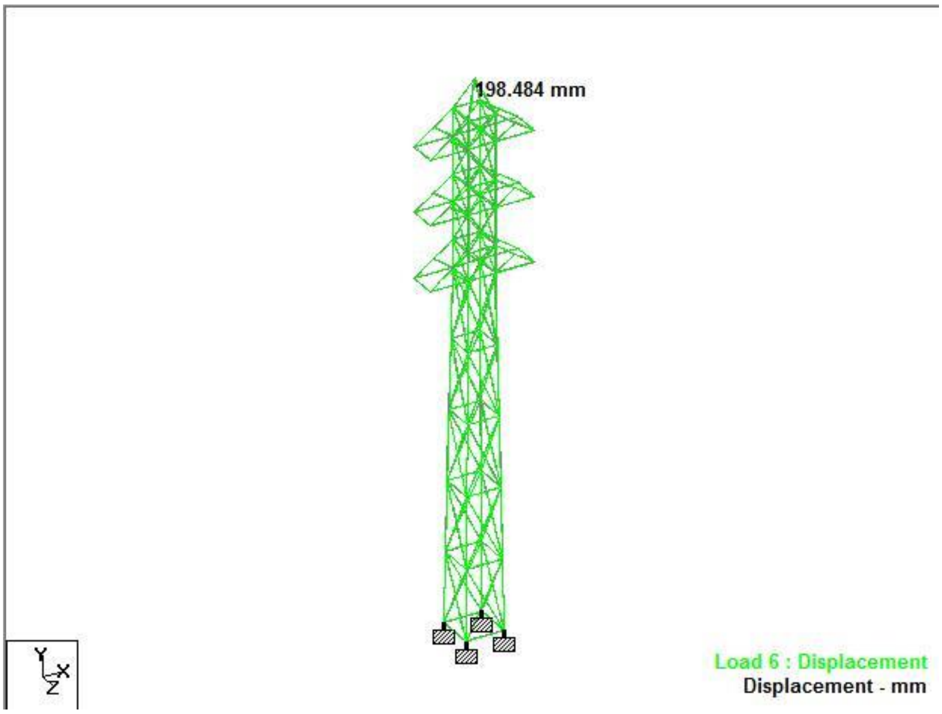

Figure 4.19: Max node displacement for 100 m X bracing tower with wind speed 32.5 m/s

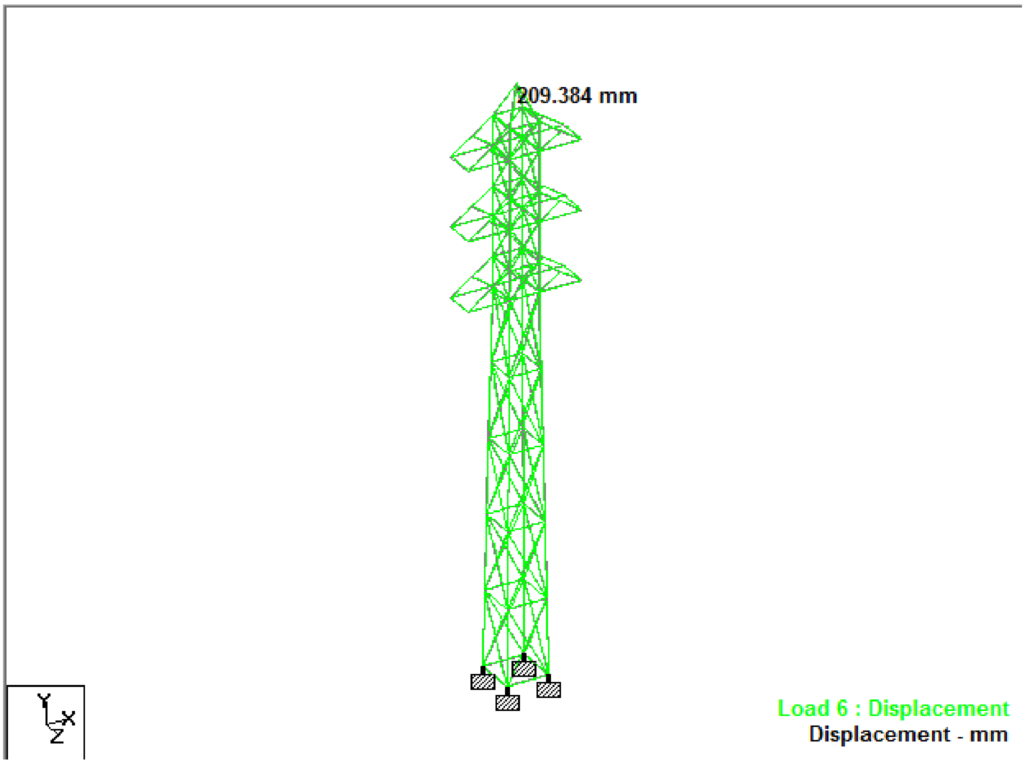

Figure 4.20: Max node displacement for 100 m X bracing tower with wind speed 33.5 m/s

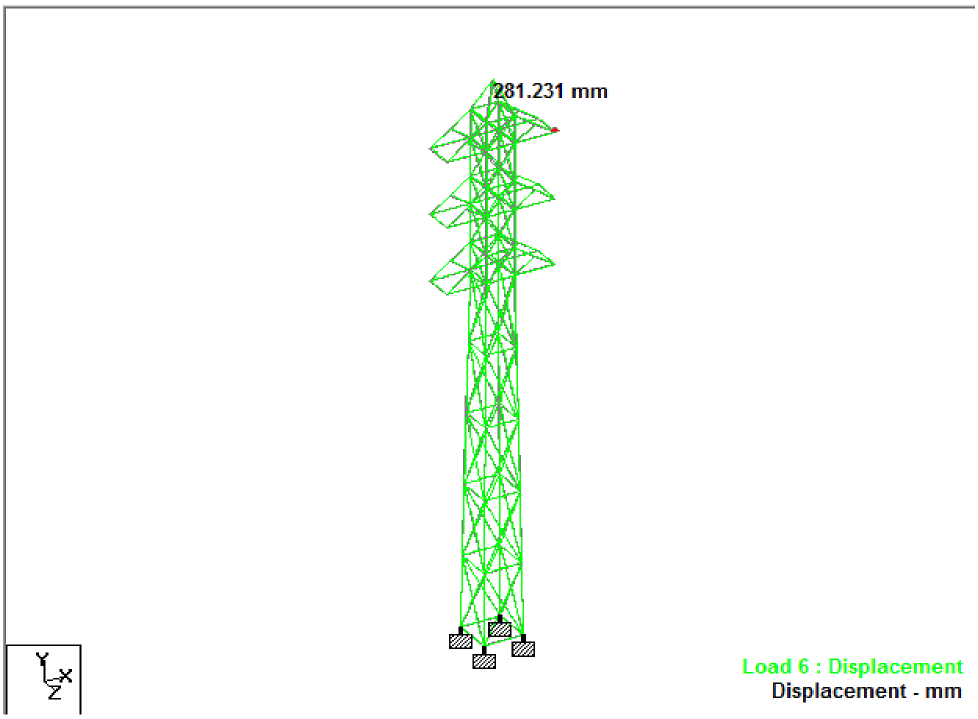

Figure 4.21: Max node displacement for 100 m X bracing tower with wind speed 40 m/s

Tower with 100 m height shows different results compared to the 39 m and 49 m tower. The X bracing system shows less displacement when resists the load toward it.

All figures of the displacement showed the highest displacement for node for each tower with different height and subjected to different wind speed. Each figure shows different displacement at the top structure of the tower. This is based on the different wind speed and steel section of the tower with the load combination applied to each tower. Each figure depicts the displacement of each tower at the maximum displacement. Basically, if refer to the figure of 39 m and 49 m tower, the X bracing system shows highest displacement for each of the towers for every wind speed subjected to the tower.

The maximum displacement of tower with height 39 m and 49 m shows that within this range of tower height, the displacement of the K bracing tower system is not high as shown by the X bracing system tower. The maximum displacement is highest at the top node which is upper structure of the tower. The top node has a maximum displacement since the wind load considers 9m and above tower height.

4.3 Beam graph

Beam graph is the graph that obtained after the post processing process is done. The graph shown is the shear force diagram and the bending moment diagram of the beam in the structure. Each beam in the structure provided with the beam graph diagram.

Figure 4.22 to Figure 4.39 show the beam graph value in the structure. The value obtained from the shear forces diagram and bending moment diagram is tabulated in Table 4.2, which is the summary of end member forces. The tabulated data help to find the highest forces that resist by the beam after all the load applied to the structure. The Fy direction forces compared with all the structure designed. The 100 m tower, Figure 4.39, the maximum shear forces at the end member forces is 0.09 kN compared to the Figure 4.37, the maximum shear forces at end member forces is 0.086 kN which is lower. The pattern is different with the K bracing system for 100 m tower, which the tower with wind speed 32.5 m/s shows higher end member forces value.

Similar with the 49 m tower, Figure 4.33, the maximum shear forces at the end member forces is 0.683 kN compared to Figure 4.31, the maximum shear forces at the end member forces is 0.588 kN. For the K bracing system for 49 m tower, it shows the same pattern for the X bracing system. Then, for the tower 39 m, Figure 4.27, the maximum shear forces at the end member forces is 0.04 kN compared to the Figure 4.25, the maximum shear forces at the end member forces is 0.113 kN which higher. For the K bracing system for 39 m tower, the pattern is same with the X bracing system. The value of the end member forces of beam is based on the highlight beam structure in the figure.

For the bending moment value, the 100 m tower, Figure 4.18 shows the value is 0.235 kNm compared to the Figure 4.16 the value is 0.22 kNm which is lower. In contrast, for K bracing system shows the higher moment is for 100 tower applied with 32.5 m/s wind speed. Next, for tower with 49 m, Figure 4.33 show the moment value is 0.853 kNm and Figure 4.31 the moment value is 0.659 kNm. It shows the same pattern as in, for the K bracing system tower. Lastly, for the 39 m tower, Figure 4.27 the moment value is -0.213 kNm and Figure 4.25 shows the value of -0.098 kNm. The K bracing system at height 39 m shows the same pattern.

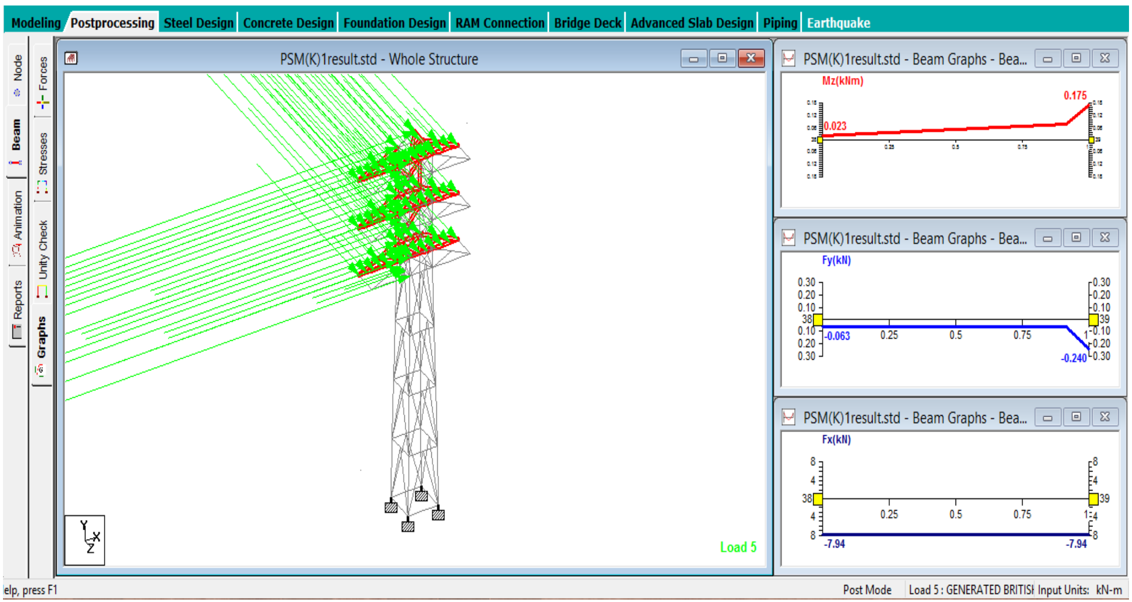

Figure 4.22: Beam graph for 39 m K bracing tower with wind speed 32.5 m/s

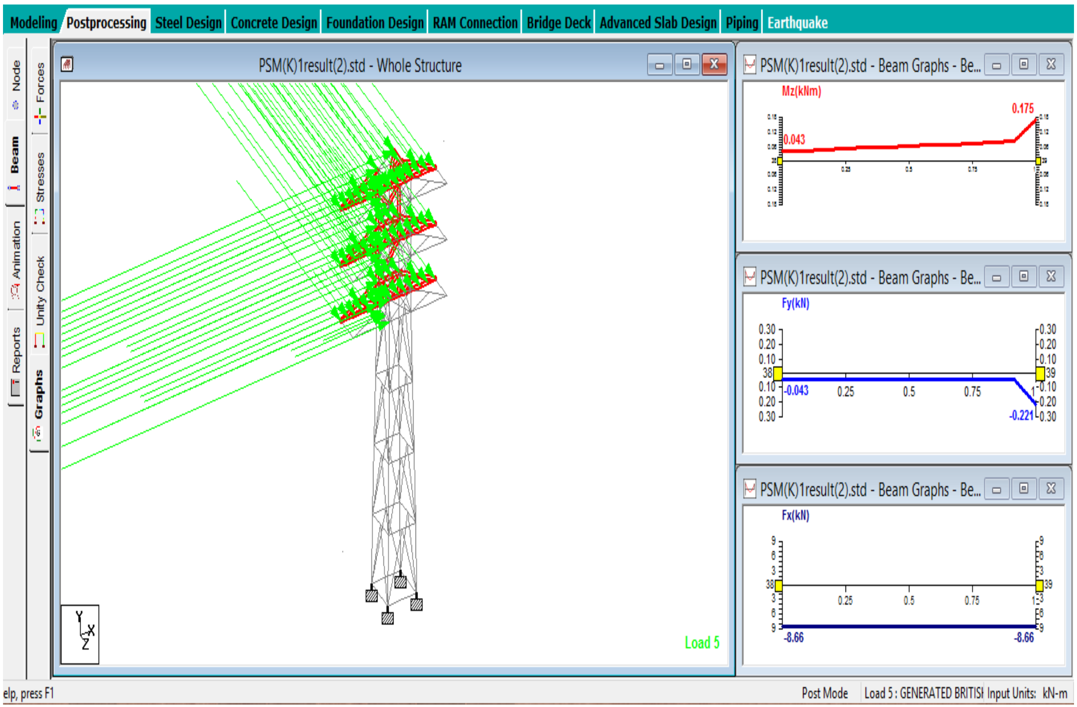

Figure 4.23: Beam graph for 39 m K bracing tower with wind speed 33.5 m/s

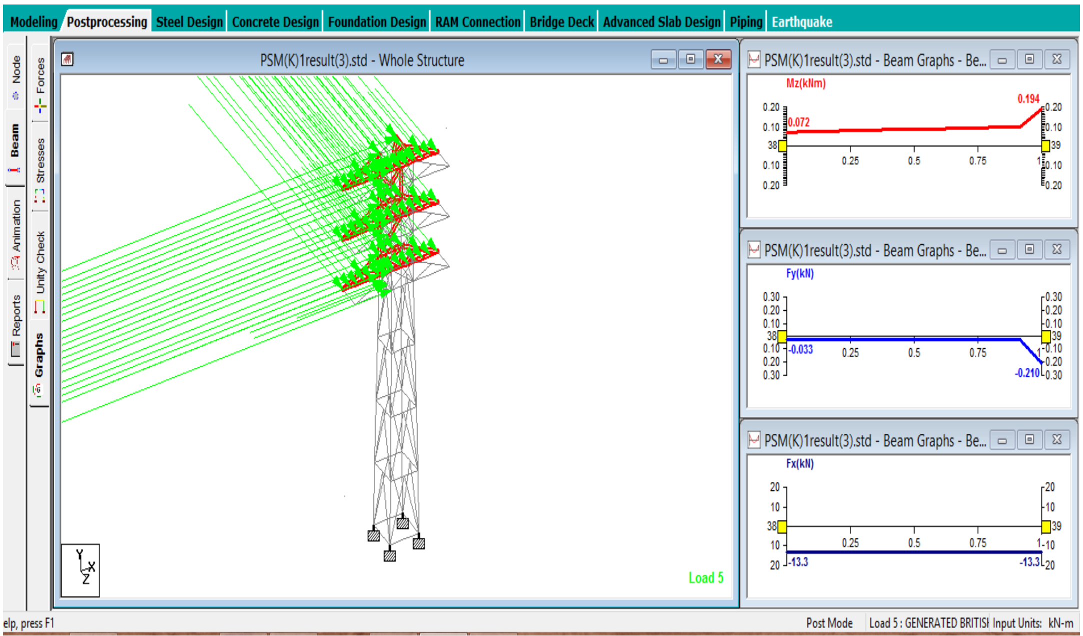

Figure 4.24: Beam graph for 39 m K bracing tower with wind speed 40 m/s

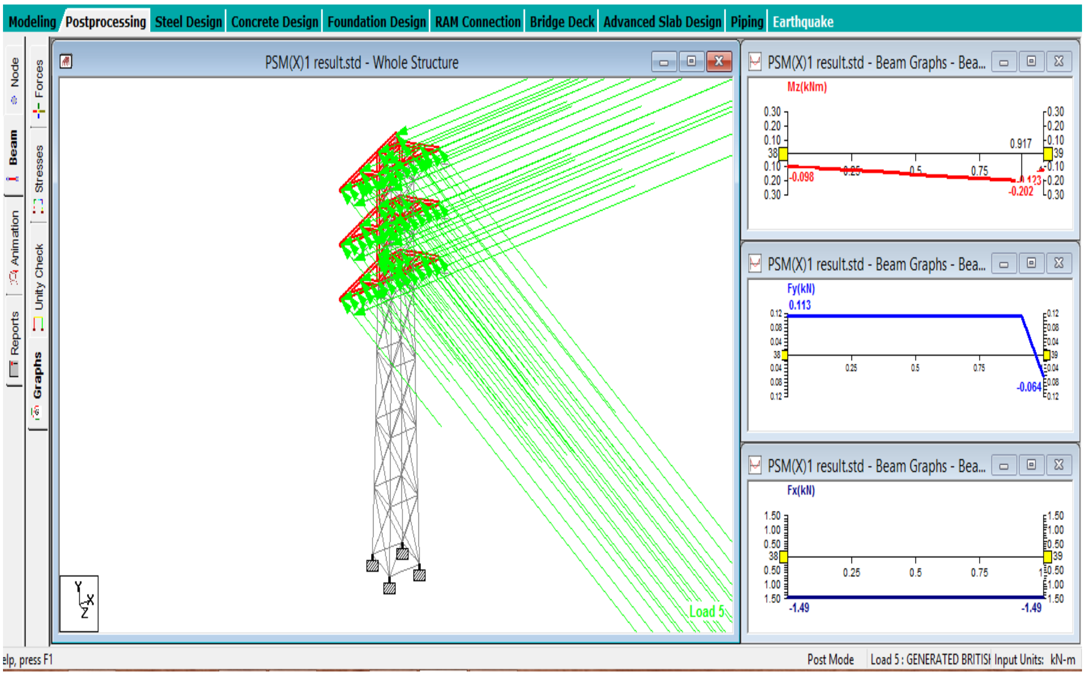

Figure 4.25: Beam graph for 39 m X bracing tower with wind speed 32.5 m/s

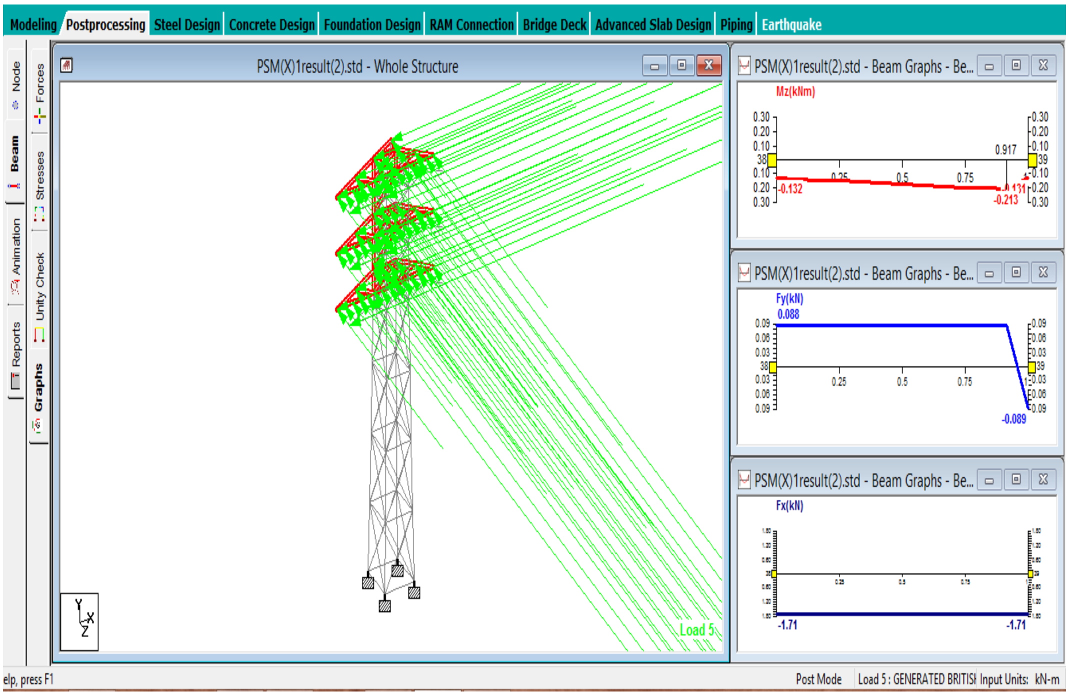

Figure 4.26: Beam graph for 39 m X bracing tower with wind speed 33.5 m/s

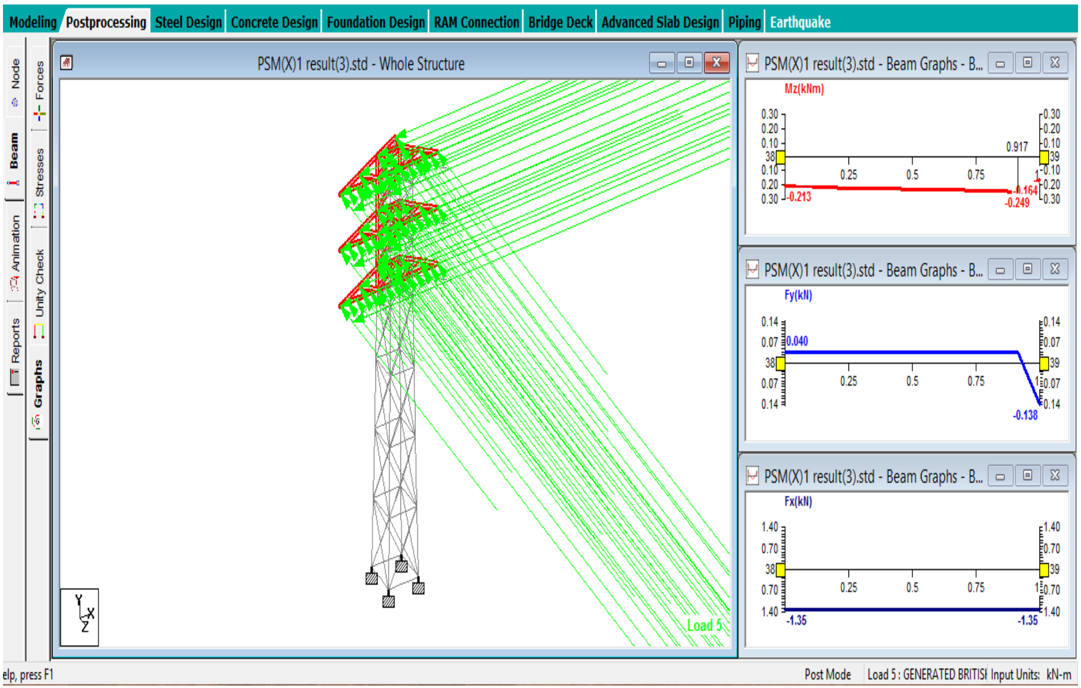

Figure 4.27: Beam graph for 39 m X bracing tower with wind speed 40 m/s

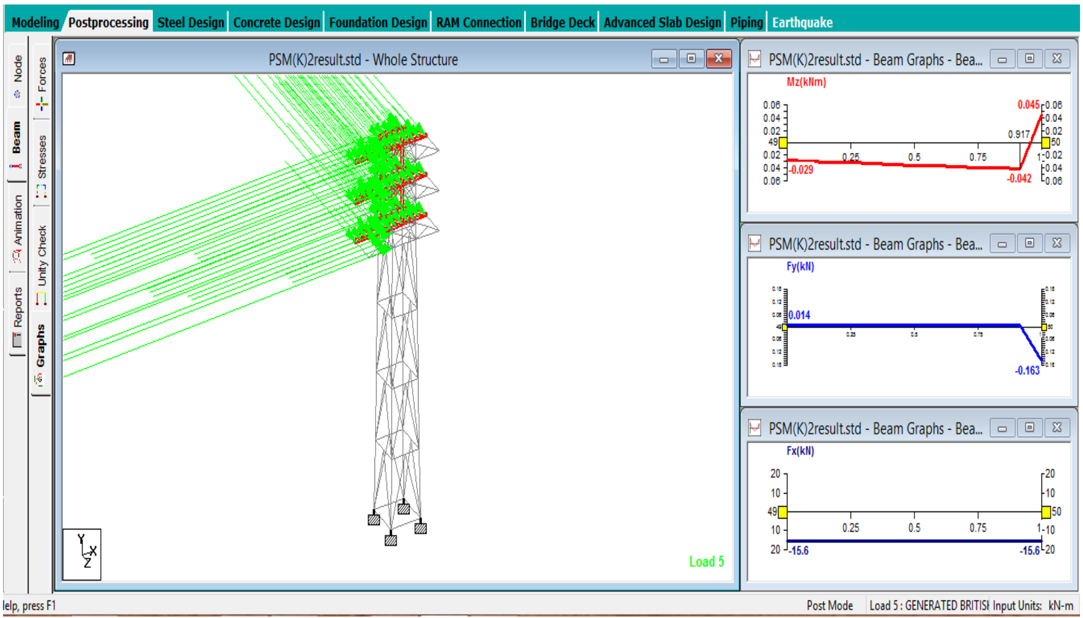

Figure 4.28: Beam graph for 49 m K bracing tower with wind speed 32.5 m/s

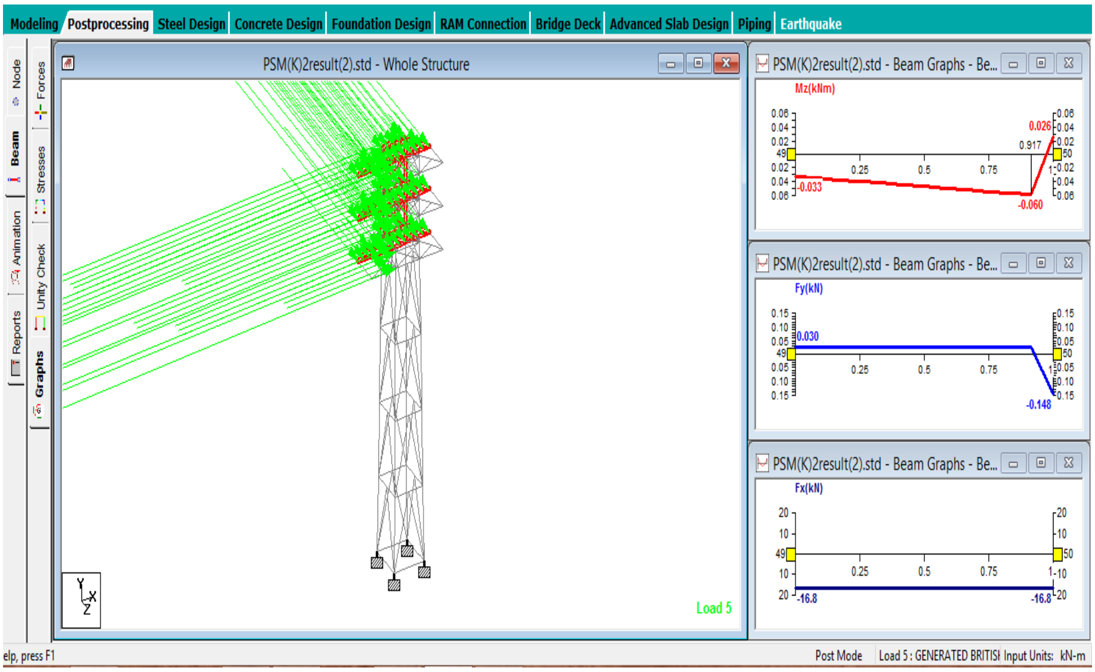

Figure 4.29: Beam graph for 49 m K bracing tower with wind speed 33.5 m/s

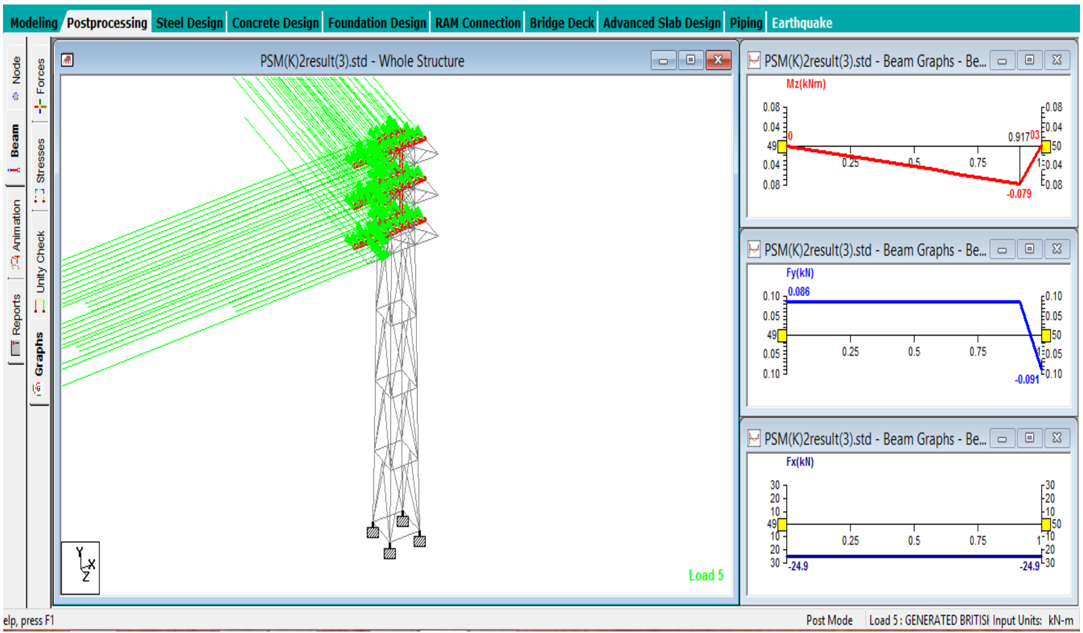

Figure 4.30: Beam graph for 49 m K bracing tower with wind speed 40 m/s

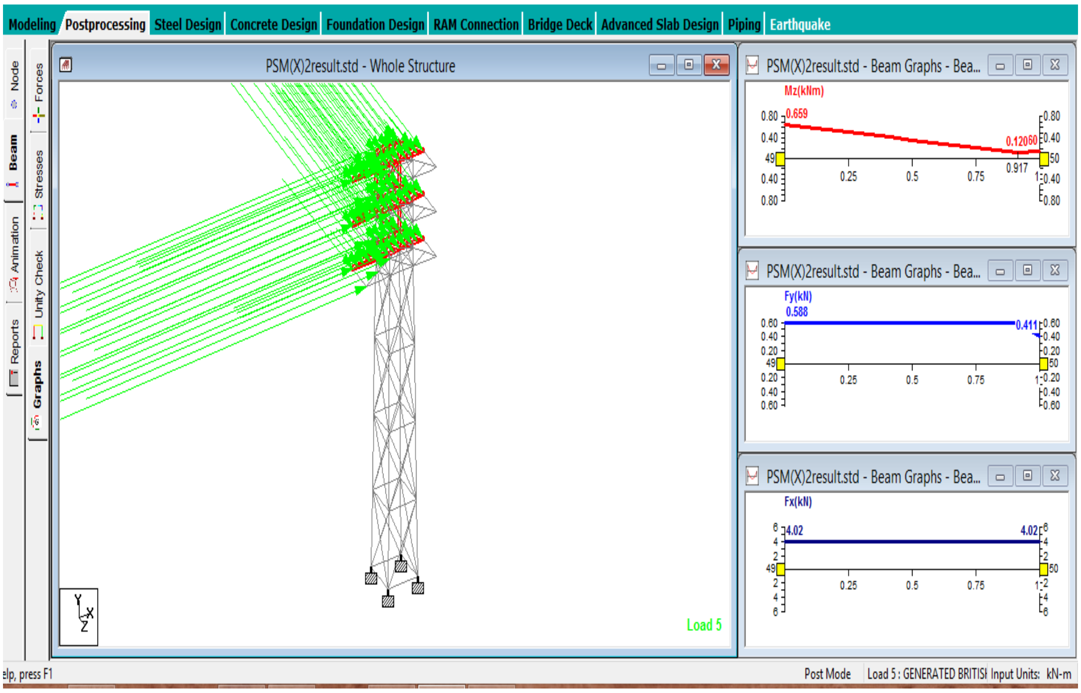

Figure 4.31: Beam graph for 49 m X bracing tower with wind speed 32.5 m/s

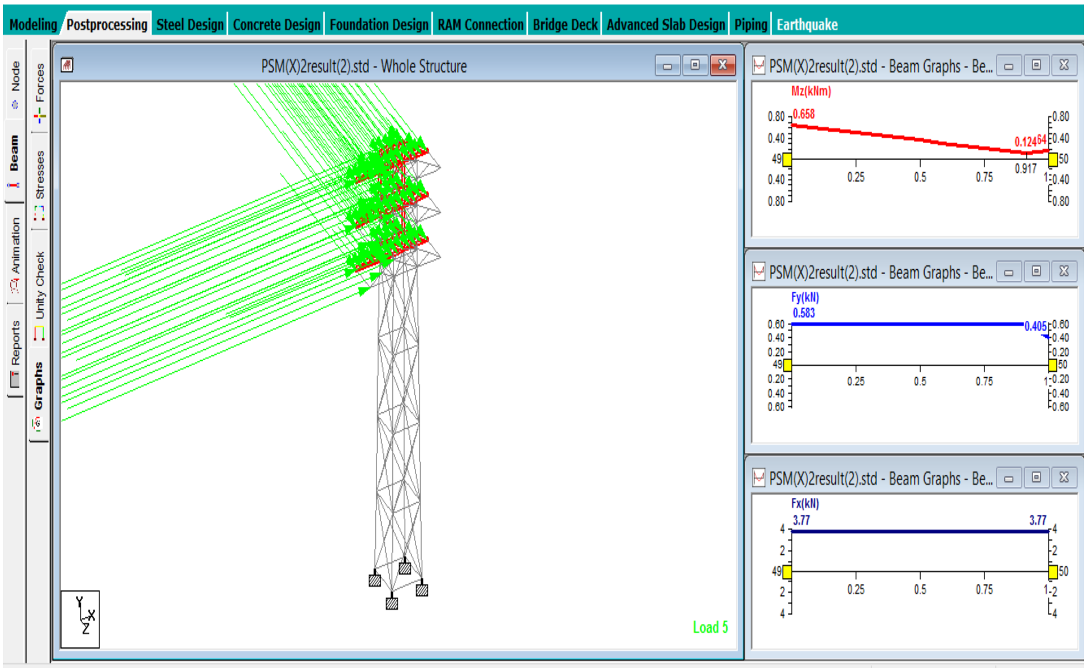

Figure 4.32: Beam graph for 49 m X bracing tower with wind speed 33.5 m/s

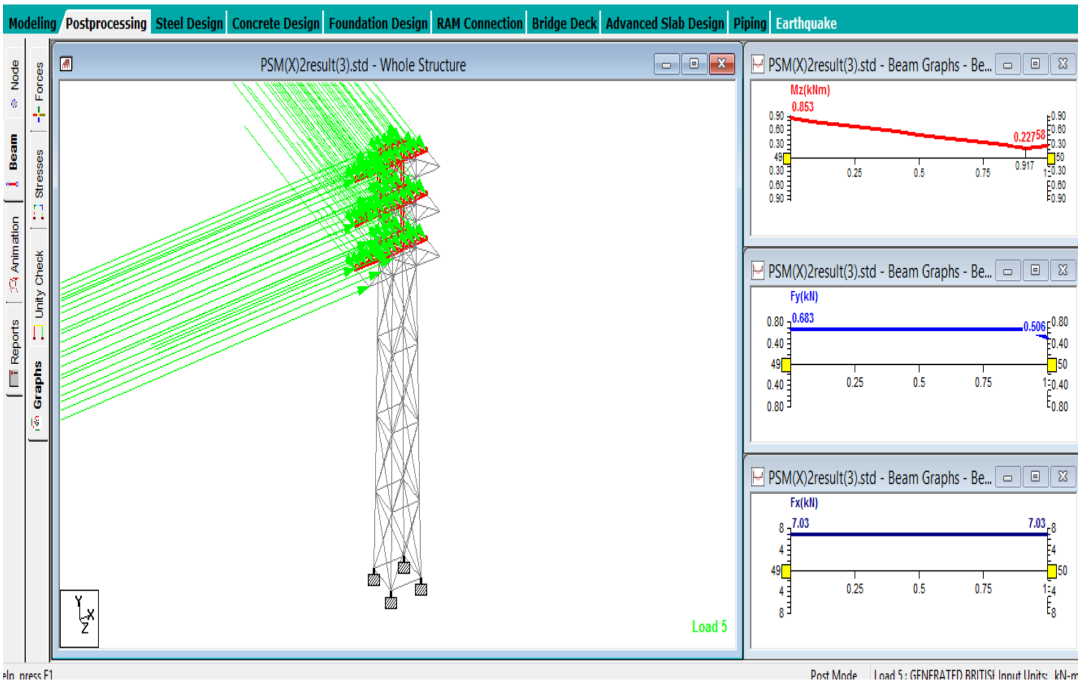

Figure 4.33: Beam graph for 49 m X bracing tower with wind speed 40 m/s

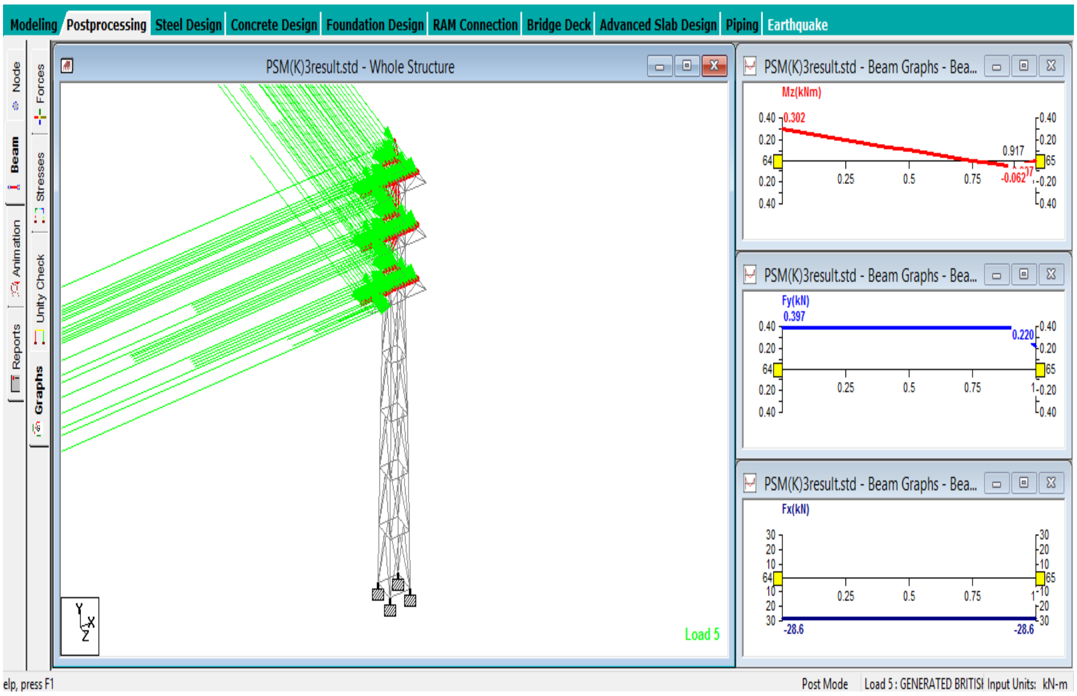

Figure 4.34: Beam graph for 100 m K bracing tower with wind speed 32.5 m/s

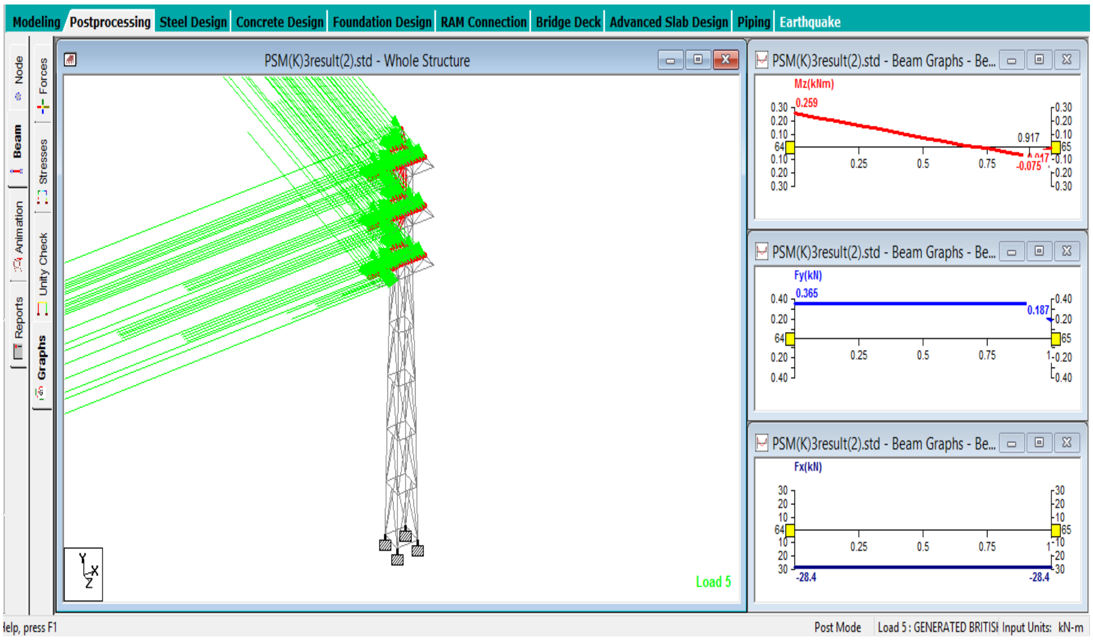

Figure 4.35: Beam graph for 100 m K bracing tower with wind speed 33.5 m/s

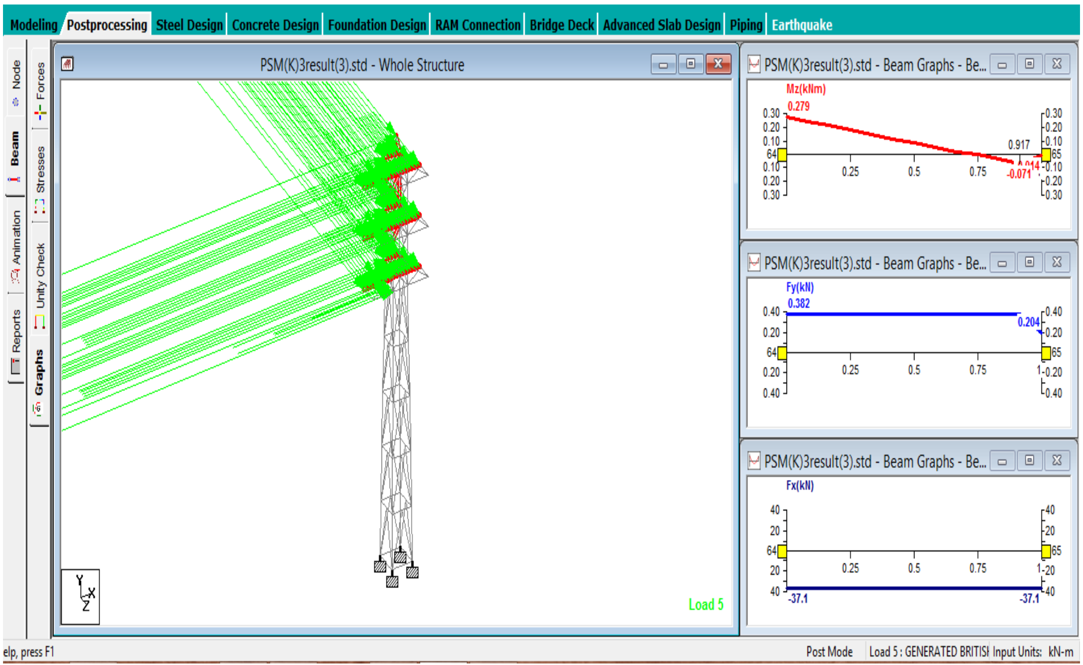

Figure 4.36: Beam graph for 100 m K bracing tower with wind speed 40 m/s

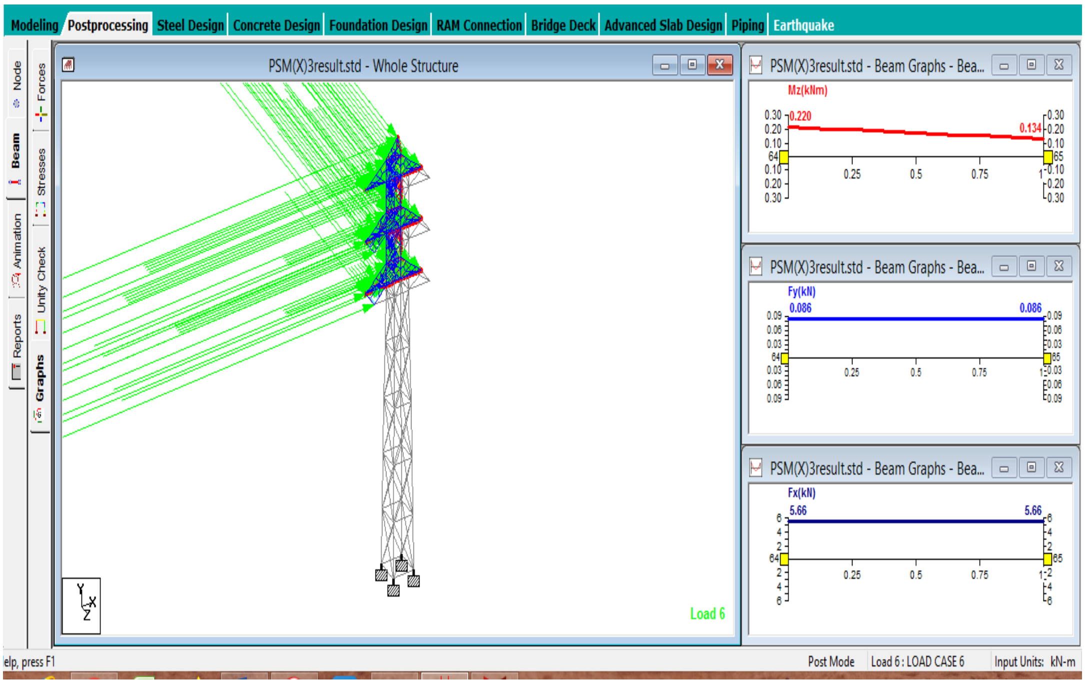

Figure 4.37: Beam graph for 100 m X bracing tower with wind speed 32.5 m/s

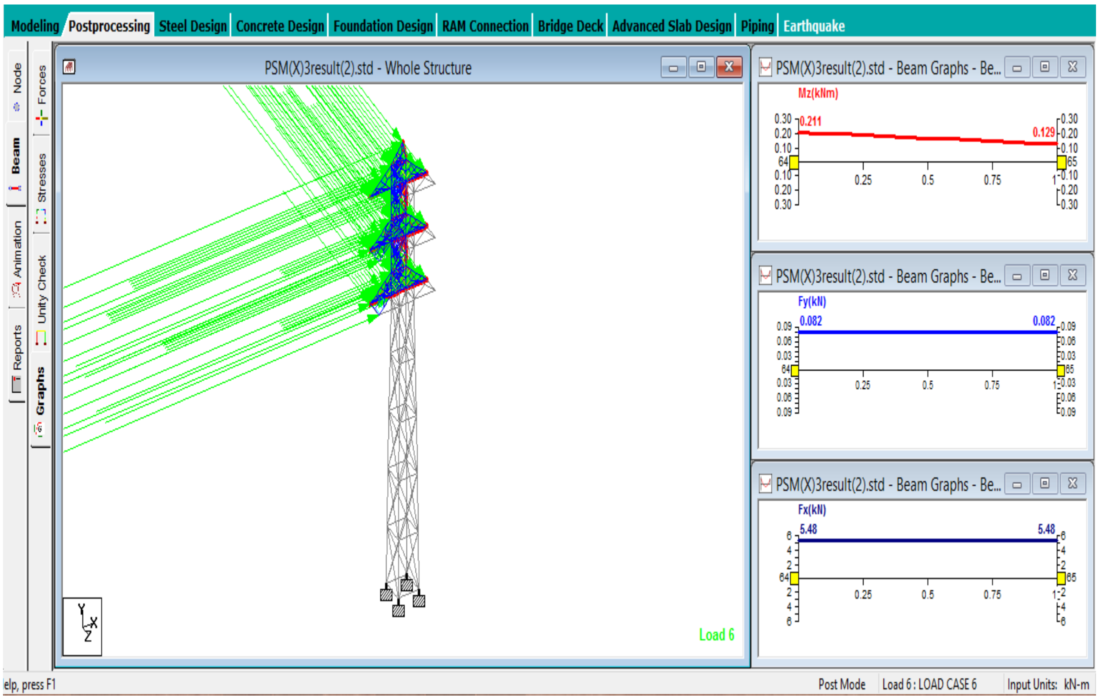

Figure 4.38: Beam graph for 100 m X bracing tower with wind speed 33.5 m/s

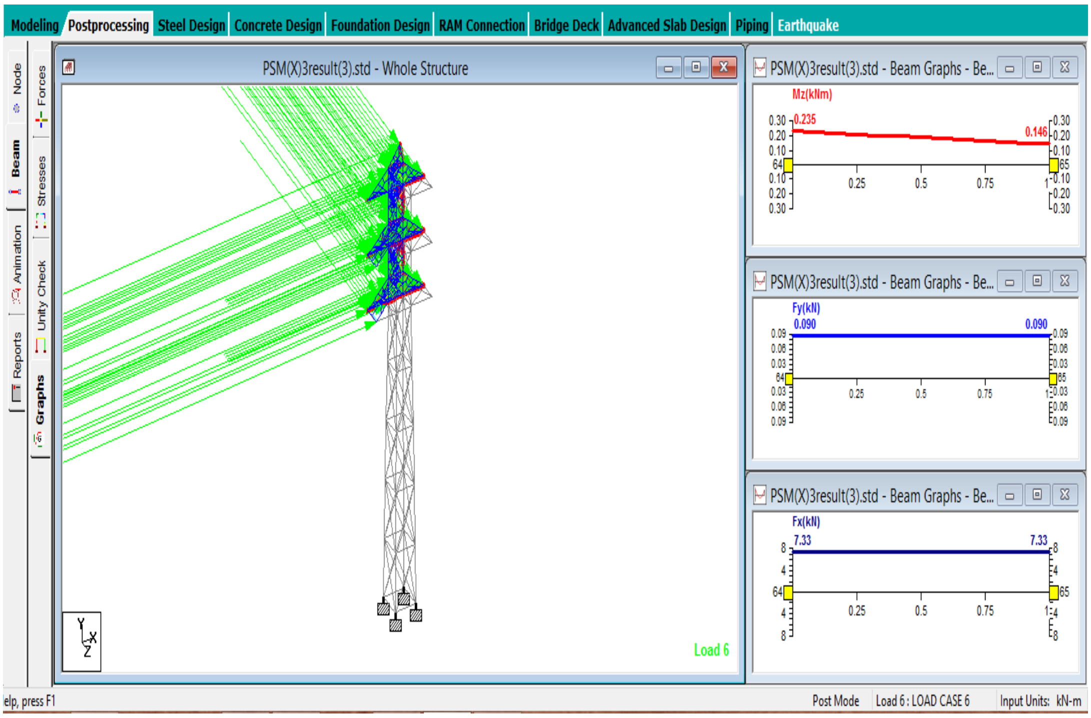

Figure 4.39: Beam graph for 100 m X bracing tower with wind speed 40 m/s

4.4 Maximum axial load

Axial load is the resultant load carried by each of the tower. In order to support the displacement result of this research the axial load result was collected from the Staadpro analysis. The value of axial load shown is the maximum axial load for each of tower modelled.

4.4.1 Axial load of tower with height 39 m

The axial load of the X bracing system tower with wind speed of 32.5 m/s is increasing 20.7% of the K bracing system. Then, for 33.5 m/s wind speed the axial forces of the X bracing system increased 21.1% from the K bracing system. Lastly, increasing of 22.1% axial load of the X bracing system with wind speed 40 m/s from the K bracing system. The result is shown in Figure 4.40.

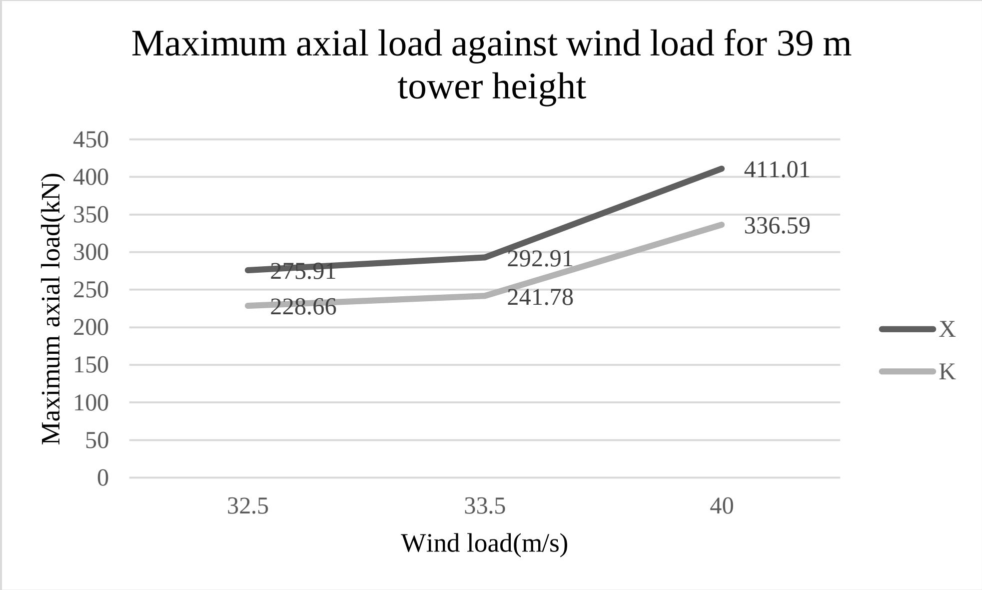

Figure 4.40: Graph of maximum axial load against wind load for 39 m height of tower

4.4.2 Axial load of tower with height 49 m

Increasing 125.3% maximum axial load of the X bracing system for 32.5 m/s wind speed from the K bracing system. For 33.5 m/s, the X bracing system maximum axial load increased 125.6% from the K bracing system. Then, the maximum axial load of the X bracing system increased 127.8% from the K bracing with wind speed 40 m/s. The result is shown in Figure 4.41.

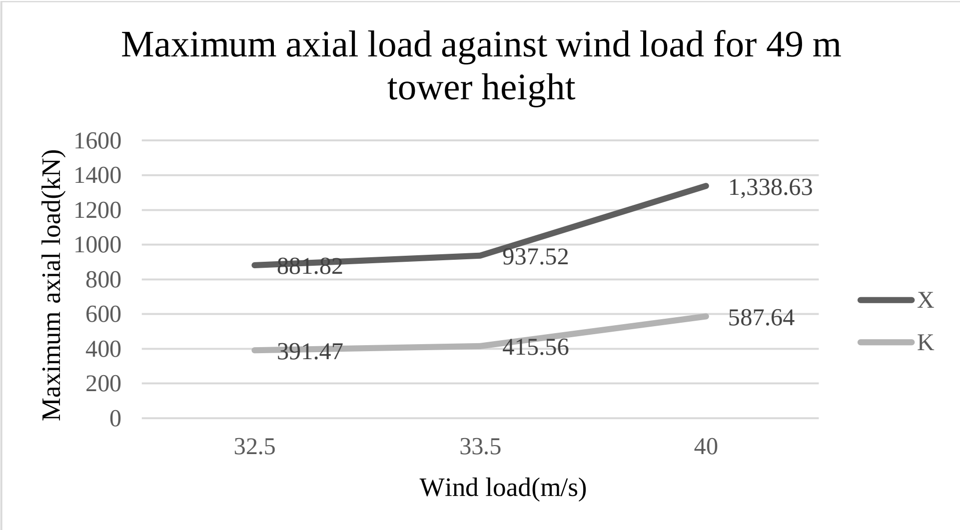

Figure 4.41: Graph of maximum axial load against wind load for 49 m height of tower

4.4.3 Axial load of tower with height 100 m

K bracing system depicts 48.4%, increasing of axial load from the X bracing system with wind speed 32.5 m/s. The axial load of the K bracing system for wind speed 33.5 m/s increased 45.9% from the X bracing system. Lastly the increasing 40.6% of axial load for K bracing system from the X bracing system shows for the wind speed 40 m/s. The result is shown in Figure 4.42.

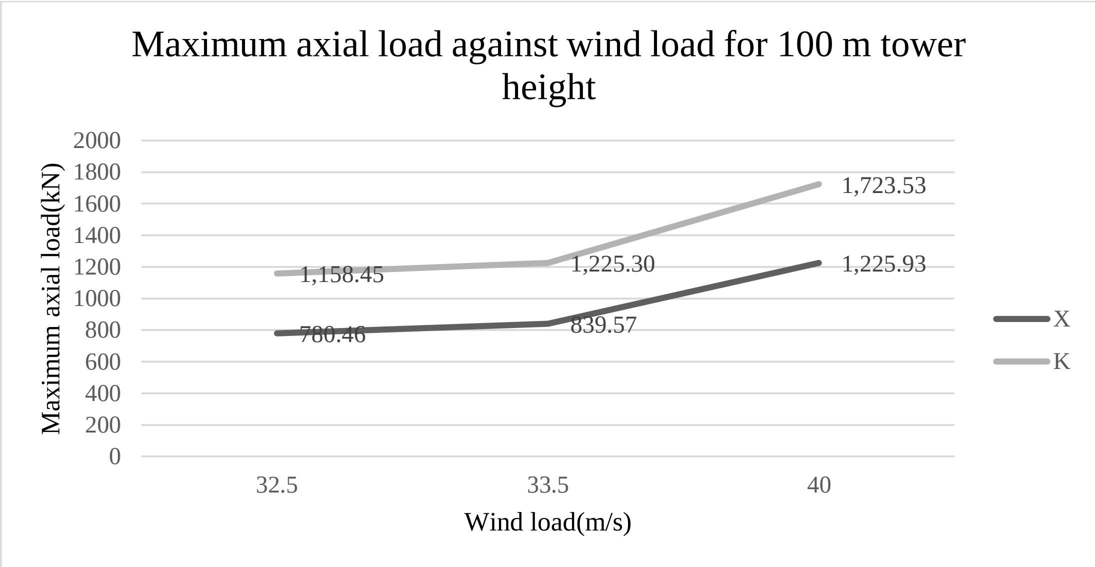

Figure 4.42: Graph of maximum axial load against wind load for 100 m height of tower

4.5 Validation between journal result and experimental result

As mentioned in the previous chapter, three towers with different height of the tower that prone to the different wind speed were model in Staad pro V8i software by (Engineering, 2013). Therefore, the research stated that the tower 40m height with the XX bracing system gave a higher displacement of the joint compared to the K bracing system. The result obtained from this research also same with height of tower 39 m and 49 m. The comparison that can be made from both result is that both results shows that the X bracing system have higher maximum joint displacement which is 91.785 increased from K bracing system when it resist to the wind speed whether in normal wind speed as stated in the (Engineering, 2013). Table 4.4 shows the result obtained from the journal.

Moreover, for the maximum height of the tower, which is 100 m tower the research obtained that the K bracing system gave a higher maximum of joint displacement which is 118.4% higher from the X bracing system.

Table 4.4: Maximum joint displacement of the tower

Height of the tower m	Maximum joint displacement of the tower mm					
	Type of bracing configuration	X-B	SINGLE DIAGONAL	X-X	K	Y
40	Normal wind	197.538	275.352	277.558	262.36	241.258
	Diagonal wind	117.646	159.418	163.514	154.614	143.99
50	Normal wind	128.965	146.838	144.887	139.476	131.649
	Diagonal wind	75.646	80.618	86.22	83.159	79.197

Source: (Engineering, 2013)

4.6 Summary

This research investigated the effect of the wind load toward the tower with different height of transmission line tower. Based on the research, the height and steel section used for each of the transmission line towers either improve the effectiveness of the tower to resist the wind load and reduce the displacement. The displacement of the X bracing tower increased up to 118.4% of the K bracing system tower, which it affect the effectiveness of the transmission line tower. Eventually, the displacement of 39 m tower have less displacement which the minimum is 6.7% from the X bracing system with the K bracing system same goes with the 49 m tower. Tower with height 100 m is different from the other tower when the analysis result shows that the X bracing system have less displacement subjected to all three wind load which is the minimum is 108.7% from the K bracing system. The steel section used is same for each tower, but differences in the horizontal, vertical and cross arm direction of the tower. The axial load does effect the transmission line tower model which the tower modelled with the X bracing system have highest axial load.

In summary, it was found that tower with 39 m and 49 m height have better performance with the K bracing system and for 100 m height the X bracing tower system is more effective compared to the K bracing system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter summarizes the findings based on the result in chapter four. The most effective bracing system for communication tower was identified. In addition, the most effective height of transmission line tower respect to wind zone also identified.

5.2 Conclusions

Based on the results obtained, several conclusions can be drawn with respect to the objectives stated in Chapter 1:

i. Based on the maximum displacement for each tower model, the 39 m and 49 m tower shows that the K bracing system gave 6.7% less displacement from the X bracing system tower. In contrast, tower model with 100 m height shows that the K bracing system gave a 118.4% higher displacement from the X bracing system.

ii. In the event of wind load of 32.5 m/s, 33.5 m/s and 40 m/s the effective bracing system for the tower is a K bracing system for every height. For 100 m tower, the X bracing system shows less displacement compared with the K bracing, but the value of displacement for the X bracing system is higher 86.4% from the 39 m and 49 m tower. In conclusion, the K bracing system relevantly effective for all towers in event of wind load.

iii. In the research, it was found that the effective height for the 32.5 m/s, 33.5 m/s and 40 m/s is 39 m tower since the displacement for this height is 6.7% lesser compared from all model designed.

5.3 Recommendation for Future Research

Based on the analysis conducted during this study, it is found that there is some recommendation could be made for future studies. A number of recommendations are being proposed in order to enhance the whole study and are listed as:

i. To ensure the model produced good results, the model should be compared to the most similar tower model at the same place. For this model the comparison is made within different country which the wind speed is slightly different. To obtain better results, it should be compared with same country research.

ii. Most of parameters that affect is the types of bracing system, wind speed, and height of the tower. For future research, other parameter such as steel section, support reaction and steel quantity can be used to obtain a detailed result structure of the tower.

iii. Moreover, other types of software such as SAP 2000 can be used to analyse and compare the result with previous studies. An analysis can be carried out to compare the result obtained and increase the understanding in the research.

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APPENDIX A
SAMPLE APPENDIX 1

For Appendices Heading, use TITLE AT ROMAN PAGES style.

APPENDIX B
SAMPLE APPENDIX 2

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