PARAMETRIC COMPARISON OF COMMUNICATION TOWERS WITH DIFFERENT BRACINGS

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ABSTRACT

Recent advances in communication engineering have posed a challenge on Civil Engineers with respect to economical design of communication towers. Communication towers are generally pin jointed space frames built of steel sections for holding transmitters and receivers. In addition to self-weight, wind forces are critical for these towers. In this study, the towers are analysed for 6 different basic wind speeds that are considered according to IS 875: 2015 (PART 3). This project is aimed at comparing a four legged communication towers with different bracing systems for different wind zones in India. Towers are designed as per IS: 800-2007 using STAAD.Pro and the wind forces are calculated as per IS: 875 Part-III. From this study, it can be concluded that for a 24m height four legged tele-communication tower, angular cross section with K-bracing pattern is found to be most effective and economical among all considered basic wind speeds (i.e. 33 m/sec, 39 m/sec, 44 m/sec, 47 m/sec, 50 m/sec and 55 m/sec).

Key words: Pipe, Tubular Configurations, Bracings, Wind Loads, Quantity of Steel Required, Lateral Displacements.
1. INTRODUCTION

Telecommunication is an economic miracle that has transformed the lives of millions and contributed immensely towards India’s socio-economic development. Telecommunication towers are tall structures designed for supporting parabolic antennas installed at a specific height. The telecommunication industry plays a great role in the present societies and thus more attention is now being paid to telecommunication towers compared to the past. The direction and height of tower along with the antennas mounted on it is completely governed by the functional requirements. Communication towers act as vertical trusses and resists wind load by cantilever action. The bracing members are arranged in many forms, that carry only tension, or alternatively tension and compression. The bracing is made up of crossed diagonals, when it is designed to resist only tension. Based on the direction of wind, one diagonal takes all the tension while the other diagonal is assumed to remain inactive. Tensile bracing is smaller in cross-section and is usually made up of a back-to back channel or angle sections. Communication Towers are classified under three categories, i.e. guyed masts, monopole, and self-supporting tower. Self-supporting towers are generally preferred since they require less base area. There are different types of bracing systems that are commonly adopted such as Single diagonal bracing, double diagonal (X-X) bracing, (X-B) bracing, (X-B-X) bracing, arch bracing, subdivided V bracing, diamond lattice system of bracing, K, Y, W, X bracing etc.

Types of wind forces on buildings

- Shear Load – Wind pressure that is horizontal and could make a building tilt.
- Lateral Load – A pulling and pushing horizontal pressure that can cause a building to move off its foundation.
- Uplift Load – Pressures from wind flow that causes lifting effects.

1.1. Objective

The objective of this work is to reduce the Displacements and steel quantity of the communication tower in the event of wind load effects by considering most suitable bracing system.

1.2. Scope

Four legged Telecommunication towers of height 24m designed with both Pipe and Angular cross sections considering four types of bracing patterns at different basic wind speeds (33m/sec, 39m/sec, 44m/sec, 47m/sec, 50m/sec and 55m/sec), have been modeled to evaluate the performance of different bracing system in different wind zones.

2. REVIEW OF LITERATURE

Many analytical works have been conducted and published worldwide in the area of Analysis and Design of Steel Towers. Chiu and Taoka et al. 1973 [1] performed an experimental and theoretical study on the dynamic response of lattice self-supporting telecommunication towers under real and simulated wind forces. The study revealed that the tower response to wind-induced forces was dominated by the fundamental mode of vibration. Konno and Kimura et al.
1973 [2] researched on the effects of earthquake loads on lattice telecommunication towers mounted on top of buildings. It was observed that in some member forces due to earthquake were greater than those due to wind. Badruddin Ahmed et al. 1984 [3] discussed on behavior of self-supporting towers under wind loads by analysing some existing towers and compared the results with measured data. Mikus et al. 1994 [4] investigated the seismic response of six 3-legged, 20m to 90m height self-supporting telecommunication towers with heights ranging from 20 to 90 meters. It was concluded that modal superposition with the lowest four modes of vibration would ascertain sufficient precision. Galvez et. al. 2004 [5] performed additional studies to introduce simplifying methods for the seismic analysis of telecommunication towers.

It was concluded that contribution of second and third transversal modes of vibration on the maximum acceleration at the top of the towers, depending on the tower type, varies from 15% to 50%. Silva et al. 2005 [6] researched on an alternative structural analysis modeling strategy for the steel tower design considering all the actual structural forces and moments combining 3D beam and truss finite elements. Ghodrati Amiri et al. 2007 [7] investigated the seismic sensitivity of 4-legged telecommunication towers based on modal superposition analysis. Empirical relations have been presented to approximate the dynamic response of towers under seismic loadings. Efthymiou et al. 2009 [8] researched on the influence of the wind action on the structural behaviour of the lattice masts and developed the deformation configuration for all the masts. The study was carried out by means of innovative software in order to introduce the wind actions thoroughly. Simulation models have been configured for the masts under investigation incorporating all special geographical parameters and structural arrangements.

Swami et al. 2010 [9] worked out that the steel towers of heights ranging from 50m to 250m are considered for wind load analysis. The variation of wind force with height, geometry and the dynamic properties of the structure are studied. Siddesha et al. 2010 [10] presented on the analysis of microwave antenna tower with Static and Gust factor method and compared the towers with angle and square hollow sections. The towers with different configuration have also been analyzed by removing one-member present in the regular tower in lower panels. Nitin Bhosale et al. 2012 [11] carried out the seismic response of 4 legged telecommunication towers under the effect of design spectrum from the Indian code of practice for zone – IV. The axial forces of the tower member are considered and comparison is made between roof top tower and ground tower. Jesumi et al. 2013 [12] modelled five steel lattice towers with different bracing configurations such as the X-B, single diagonal, X-X, K and Y bracings for a given range of height. The towers are analyzed for wind loads with STAAD Pro. V8i, to compare the maximum joint displacement of each tower. From the results obtained, Y bracing are found to be the most economical bracing system up to a height of 50m. Preeti et al. 2013 [13] analysed a self-supporting transmission line tower with three different types of bracing patterns (W, Y, and XB) to obtain an optimal bracing configuration. Richa Bhatt et al. 2013 [14] discussed on the influence of modeling in lattice mobile communication towers under wind loading. The towers are analysed for gust factor wind displacements, member forces and maximum stress and compared to find out the effect on towers. Wind analysis is carried on antenna towers with static & gust factor method and the displacements at the top of the tower with angle and square sections are recorded. Jithesh Rajasekharan et al. 2014 [15] 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 method. The seismic effect on tower structures by modal analysis and response spectrum analysis for zone II to zone V was also studied. 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. Preetil et al. 2015 [16] explored on the analysis of 4 legged angular self-supporting telecommunication towers is performed. Assessment is done based on modal analysis, by comparing the results of roof top tower and ground based tower. Keshav
Sharma et al. 2015 [17] designed a 45m height self-supporting tower with combination of K and X bracing for seismic along with the wind effect. Specific codes like IS 802 [18], Steel Table IS 808 [19], IS 1893 [20], and IS 800:2007 [21] are used to design a tower.

From the review of Literature, it can be observed that, although researchers have done extensive work on Transmission line and Telecommunication towers, a comparison of 4 legged Transmission line towers with different bracing systems subjected to wind loads needs some additional attention.

3. METHODOLOGY

In this context, Four legged tele-communication towers of height 24m using different types of bracing systems in combination with different types of bracing section configurations (i.e. both pipe and angular sections) are designed and compared. The supports at the base of the structure are also specified as fixed. The structure is subjected to self-weight, dead load values as specified by IS 875 Part 1 [22] and IS 875 Part 2 [23]. The wind load values are generated by STAAD.Pro considering wind intensities at different heights as per the specifications of IS 875 Part 3 [24]. Analysis of the structure is carried out using STAAD.Pro software. The material parameters and load cases/combinations adopted in the STAAD.Pro model are discussed as follows.

3.1 Material Parameters

Steel

Modulus of Elasticity of steel,

\[ E = 200 \text{ G Pa} \]

Poisson’s ratio,

\[ \mu_s = 0.3 \]

Density of steel,

\[ \gamma_{\text{steel}} = 77 \text{ kN/m}^3 \ (7.850 \text{ kg/m}^3) \]

Yield strength of steel,

\[ f_y = 415 \text{ M Pa} \]

Specifications of the Tower

Height of Tower = 24m

Types of Bracings considered = 4 (K, V, X, Y)

No of sections = 2 (Pipe and Angular)

Support condition = fixed.

3.2 Load cases considered for the study

Dead loads

The dead loads acting on the structure include the self-weight of the structural elements like bracings etc. that depends on the type of structural steel used in the tower.

Imposed loads

Live or imposed loads include the platform loads of tower generally at an interval of 10m for towers used for repair purposes.
Wind load

IS: 875 (Part 3) 1987 [24] prescribes basic wind speed in various zones by dividing the country into 6 wind zones. The design wind pressure is given in IS: 875(Part 3)-1987 [24] Clause 5.4 and is computed as,

\[ P_z = 0.6 \times (V_z)^2 \]

Where,

- \( P_z \) = design wind pressure in \( \text{N/mm}^2 \) at a height \( Z \) and
- \( V_z \) = design wind velocity in \( \text{m/s} \) at a height \( Z \).

Calculation of Wind Pressure on the telecommunication tower.

According to IS: 875 (Part 3) 1987 [24] Clause 5.3 the design wind speed ‘\( V_z \)’ is given by

\[ V_z = V_b \times K_1 \times K_2 \times K_3 \times K_4 \]

Where,

- \( V_z \) = Design wind speed at any height in (m/s),
- \( V_b \) = Basic wind speed according to the zone II is 50 m/s
- \( K_1 \) = Probability factor (risk factor), according to clause: 5.3.1 of IS: 875 (Part-3) [24]
- \( K_2 \) = Terrain roughness and height factor, as per Clause 5.3.2 of IS: 875 (Part 3) [24]
- \( K_3 \) = Topography factor, according to clause: 5.3.3 of IS: 875 (Part-3) [24]
- \( K_4 \) = Importance factor for cyclonic region

The following design data is considered in this study.

Design data

Tower height = 24m
Upward wind slope is < 3°
Basic wind speeds considering 33m/s, 39 m/s, 44 m/s, 47 m/s, 50m/s and 55m/s
Risk factor \( K_1 \) for all heights = 1

The value of \( K_1 \) for basic wind speeds for all general buildings and structures is taken from Table 1 of IS: 875 (Part 3)-1987 [24]. The structure falls under category II of terrain classification as per Clause 5.3.2 of IS: 875 (Part 3) 1987 [24]. The height of tower is below 50 meters and hence structure is of class B. Table 1 presents wind pressure in (kN/m²) on structure at different heights

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Wind Pressure (kN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1.92</td>
</tr>
<tr>
<td>25</td>
<td>1.86</td>
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<tr>
<td>21</td>
<td>1.81</td>
</tr>
<tr>
<td>15</td>
<td>1.72</td>
</tr>
<tr>
<td>10</td>
<td>1.68</td>
</tr>
</tbody>
</table>

3.3. Load combinations as per codes IS: 875-1987 [22, 23, 24]

For limit state of collapse
1) 1.5 (Dead Load + Live Load)
2) 1.5 (Dead Load + Wind Load in + X)
3) 1.5 (Dead Load + Wind Load in - X)
4) 1.5 (Dead Load + Wind Load in + Z)
5) 1.5 (Dead Load + Wind Load in + Z)
6) 1.2 (Dead Load + Live Load + Wind Load in + X)
7) 1.2 (Dead Load + Live Load + Wind Load in - X)
8) 1.2 (Dead Load + Live Load + Wind Load in + Z)
9) 1.2 (Dead Load + Live Load + Wind Load in - Z)

*For limit state of serviceability*

1) 1 (Dead Load + Live Load)
2) 1 (Dead Load + Wind Load in + X)
3) 1 (Dead Load + Wind Load in - X)
4) 1 (Dead Load + Wind Load in + Z)
5) 1 (Dead Load + Wind Load in + Z)
6) 1 (Dead Load) + 0.8 (Live Load + Wind Load in + X)
7) 1 (Dead Load) + 0.8 (Live Load + Wind Load in - X)
8) 1 (Dead Load) + 0.8 (Live Load + Wind Load in + Z)
9) 1 (Dead Load) + 0.8 (Live Load + Wind Load in - Z)

3.4. Elevations of typical tower and 4 bracing configurations

Figure 1 shows the bare configuration of the four legged tower and the four bracing patterns considered for this study.

![Figure 1 E elevations of typical tower and 4 bracing configurations](image)

**4. RESULTS AND DISCUSSION**

4.1 Lateral displacements (X-direction) vs. Height of towers at different basic wind speeds for pipe configuration:

4.1.1 Lateral displacements (X-direction) vs. Height of tower at wind speed 33m/sec

Figure 2 shows the lateral displacements (X-direction) vs. Height of tower at wind speed 33m/sec.
From Figure 2, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 25.81%, 16.81%, 25.49% for V-bracing, X-bracing, Y-bracing, for basic wind speed 33m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for V-bracing for wind speeds is of 33m/sec well within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).

4.1.2 Lateral displacements (x-direction) vs. height of tower at wind speed 39m/sec
Figure 3 presents the lateral displacements (x-direction) vs. height of tower at wind speed 39m/sec.

From Figure 3, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 19.70%, 8.75% for V-bracing, Y-bracing, and decrease in percentage of 1.25% for X-bracing for basic wind speed 39m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for V-bracing for wind speeds is of 39m/sec well within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).
4.1.3 Lateral displacements (X-direction) vs. height of tower at wind speed 44m/sec
Figure 4 presents the lateral displacements (x-direction) vs. height of tower at wind speed 44 m/sec.

![Figure 4](image_url)

From Figure 4, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 34.83%, 8.35%, 9.10% for V-bracing, X-bracing, Y-bracing, for basic wind speed 44m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for V-bracing for wind speeds is of 44m/sec well within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).

4.1.4 Lateral displacements (X-direction) vs. height of tower at wind speed 47m/sec
Figure 5 presents the lateral displacements (x-direction) vs. height of tower at wind speed 47 m/sec.

![Figure 5](image_url)

From Figure 5, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 29.93%, 26.06%, 37.59% for V-bracing, X-bracing, Y-bracing, for basic wind speed 47m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for Y-bracing for wind speeds is of 47m/sec well within the permissible limits.
within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).

4.1.5 Lateral displacements (X-direction) vs. height of tower at wind speed 50m/sec
Figure 6 presents the lateral displacements (x-direction) vs. height of tower at wind speed 50m/sec.

![Figure 6](image)

From Figure 6, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 45.97%, 22.41%, 72.22% for V-bracing, X-bracing, Y-bracing, for basic wind speed 50m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for Y-bracing for wind speeds is of 50m/sec well within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).

4.1.6 Lateral displacements (X-direction) vs. height of tower at wind speed 55m/sec
Figure 7 presents the lateral displacements (x-direction) vs. height of tower at wind speed 55m/sec.

![Figure 7](image)
From Figure 7, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 22.55%, 8.58%, 27.79% for V-bracing, X-bracing, Y-bracing, for basic wind speed 55m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for Y-bracing for wind speeds is of 55m/sec well within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).

4.2 Lateral displacements (X-direction) vs. height of towers at different basic wind speeds for angular configuration

4.2.1 Lateral displacements (X-direction) vs. height of tower at wind speed 33m/sec

Figure 8 presents the lateral displacements (X-direction) vs. height of tower at wind speed 33m/sec.

From Figure 8, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 30.98%, 2.08%, 12.13% for V-bracing, X-bracing, Y-bracing, for basic wind speed 33m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for V-bracing for wind speeds is of 33m/sec well within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).

4.2.2 Lateral displacements (X-direction) vs. height of tower at wind speed 39m/sec

Figure 9 shows lateral displacements (X-direction) vs. height of tower at wind speed 39m/sec.

From Figure 9, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 30.53%, 19.00%, 38.49% for V-bracing, X-bracing, Y-bracing for basic wind speed 39m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for Y-bracing for wind speeds is of 39m/sec well within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).
Parametric Comparison of Communication Towers with Different Bracings

4.2.3 Lateral displacements (X-direction) vs. height of tower at wind speed 44m/sec

Figure 10 shows lateral displacements (X-direction) vs. height of tower at wind speed 44m/sec.

From Figure 10, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 31.539%, 10.222%, 10.042% for V-bracing, X-bracing, Y-bracing for basic wind speed 44m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for V-bracing for wind speeds is of 44m/sec well within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).

4.2.4 Lateral displacements (X-direction) vs. height of tower at wind speed 47m/sec:

Figure 11 shows lateral displacements (X-direction) vs. height of tower at wind speed 47m/sec.
From Figure 11, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 41.08%, 10.245% for V-bracing, X-bracing and decrease in percentage of 12.59% for Y-bracing for basic wind speed 47m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for V-bracing for wind speeds is of 47m/sec well within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).

4.2.5 Lateral displacements (X-direction) vs. height of tower at wind speed 50m/sec:

From Figure 12, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 40.13%, 11.93%, 2.01% for V-bracing, X-bracing, Y-bracing for basic wind speed 50m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for V-bracing for wind speeds is of 50m/sec well within the permissible limits.
within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).

4.2.6 Lateral displacements (X-direction) vs. height of tower at wind speed 55m/sec:
Figure 13 shows lateral displacements (X-direction) vs. height of tower at wind speed 55m/sec.

![Figure 13](image)

**Figure 13** Max. X- displacement vs. Height of Tower at 55 m/sec basic wind speed

From Figure 13, it is observed that there is an increase in percentages of lateral X-displacement at 24 m height by 33.67%, 13.06%, 23.32% for V-bracing, X-bracing, Y-bracing for basic wind speed 55m/sec when compared with that of K-bracing. It is also observed that maximum X-displacement is obtained at 24m for V-bracing for wind speeds is of 55m/sec well within the permissible limits. (i.e. 3% of Total height of tower as per ANSI – TIA222 – G., 3/100×24= 0.72m (or) 720 mm).

4.3 Max. X-displacements of tower at different basic wind speeds with pipe section vs. angular section with bracing systems

4.3.1 For Basic wind speed of 33 m/sec:

![Figure 14](image)

**Figure 14** Max X- displacement at 33 m/sec basic wind speed for Pipe vs. Angular section
From Figure 14, an increase in percentage of maximum lateral X-displacement of Pipe configuration at 24 m height by 72.81%, 66.02%, 97.75% and 93.41% for K-bracing, V-bracing, X-bracing and Y-bracing respectively when compared with Angular configuration at 33m/sec basic wind speed is observed.

### 4.3.2 For Basic wind speed of 39 m/sec

[Figure 15](#) Max X- displacement at 39 m/sec basic wind speed for Pipe vs. Angular section

From Figure 15, an increase in percentage of maximum lateral X-displacement of Pipe configuration at 24 m height by 100.59%, 84.62%, 67.03% and 58.07% for K-bracing, V-bracing, X-bracing and Y-bracing respectively when compared with Angular configuration at 39m/sec basic wind speed is observed.

### 4.3.3 For Basic wind speed of 44 m/sec

[Figure 16](#) Max X- displacement at 44 m/sec basic wind speed for Pipe vs. Angular section

From Figure 16, an increase in percentage of maximum lateral X-displacement of Pipe configuration at 24 m height by 69.83%, 74.08%, 66.96% and 66.39% for K-bracing, V-bracing, X-bracing and Y-bracing respectively when compared with Angular configuration at 44m/sec basic wind speed is observed.
bracing, X-bracing and Y-bracing respectively when compared with Angular configuration at 44 m/sec basic wind speed is observed.

**4.3.4 For Basic wind speed of 47 m/sec**

![Figure 17](image1.png)

**Figure 17** Max X- displacement at 47 m/sec basic wind speed for Pipe vs. Angular section

From Figure 17, an increase in percentage of maximum lateral X-displacement of Pipe configuration at 24 m height by 36.99%, 26.11%, 56.58% and 115.57% for K-bracing, V-bracing, X-bracing and Y-bracing respectively when compared with Angular configuration at 47 m/sec basic wind speed is observed.

**4.3.5 For Basic wind speed of 50 m/sec**

![Figure 18](image2.png)

**Figure 18** Max X- displacement at 50 m/sec basic wind speed for Pipe vs. Angular section

From Figure 18, an increase in percentage of maximum lateral X-displacement of Pipe configuration at 24 m height by 37.67%, 43.42%, 50.57% and 132.43% for K-bracing, V-bracing, X-bracing and Y-bracing respectively when compared with Angular configuration at 50 m/sec basic wind speed is observed.
4.3.6. For Basic wind speed of 55 m/sec

From Figure 19, an increase in percentage of maximum lateral X-displacement of Pipe configuration at 24 m height by 84.45%, 69.11%, 77.14% and 91.14% for K-bracing, V-bracing, X-bracing and Y-bracing respectively when compared with Angular configuration at 55m/sec basic wind speed is observed.

4.4 Quantity of steel vs. bracing systems at different basic wind speeds for Pipe section

The following specific results can be obtained based on the study conducted on different bracings of towers. Charts are drawn for different bracings of towers and amount of steel required for different wind speeds and the results are obtained as follows.

From Figure 20, a comparison is made between towers with different bracing systems at different basic wind speeds vs. quantity of steel required. It can be concluded that for 24 m
height four legged tele communication tower with PIPE section, K-bracing pattern requires minimum quantity of steel when compared to other three considered bracing patterns (i.e. V-bracing, X-bracing and Y-bracing) at all considered basic wind speeds. A reduction in the percentage of quantity of steel by 21.54%, 40.48%, 18.97% for V-bracing, X-bracing and Y-bracing towers respectively when compared with K-bracing tower is observed.

4.5. Quantity of steel vs. bracing systems at different basic wind speeds for Angular section

The following specific results can be obtained based on the study conducted on different bracings of towers. Charts are drawn for different bracings of towers and amount of steel required for different wind speeds and the results are obtained as follows.

<table>
<thead>
<tr>
<th>Wind Speed</th>
<th>K-BRACING</th>
<th>V-BRACING</th>
<th>X-BRACING</th>
<th>Y-BRACING</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 m/s</td>
<td>1.878</td>
<td>2.234</td>
<td>3.216</td>
<td>2.711</td>
</tr>
<tr>
<td>39 m/s</td>
<td>1.878</td>
<td>2.655</td>
<td>3.402</td>
<td>3.275</td>
</tr>
<tr>
<td>44 m/s</td>
<td>1.976</td>
<td>3.116</td>
<td>3.402</td>
<td>3.396</td>
</tr>
<tr>
<td>47 m/s</td>
<td>2.432</td>
<td>2.543</td>
<td>3.508</td>
<td>3.411</td>
</tr>
<tr>
<td>50 m/s</td>
<td>2.582</td>
<td>3.016</td>
<td>3.733</td>
<td>3.803</td>
</tr>
<tr>
<td>55 m/s</td>
<td>2.959</td>
<td>3.234</td>
<td>3.869</td>
<td>4.207</td>
</tr>
</tbody>
</table>

![Figure 21](image) Quantity of Steel vs. different bracing systems at different basic wind speeds

From Figure 21, a comparison is made between towers with different bracing systems at different basic wind speeds vs. quantity of steel required. It can be concluded that for 24 m height four legged tele communication tower with ANGULAR section, K-bracing pattern requires minimum quantity of steel when compared to other three considered bracing patterns (i.e. V-bracing, X-bracing and Y-bracing) at all considered basic wind speeds. A reduction in the percentage of quantity of steel by 8.51%, 23.52%, 29.66% for V-bracing, X-bracing and Y-bracing towers is observed.

5. CONCLUSIONS

The following specific conclusions can be arrived based on the study conducted on different bracing patterns of towers with Pipe and Angular sections.

1. From the Comparison made between towers with different bracing systems at different basic wind speeds vs. Maximum X-Displacements, it is concluded that for 24 m height four legged tele communication tower with PIPE section, K-bracing pattern has less lateral displacements when compared to other three considered bracing patterns (i.e. V-bracing, X-bracing and Y-bracing) at all considered basic wind speeds. A reduction in the percentage of lateral displacements in K-bracing tower is 18.405%, 7.88%, 21.75% for V-bracing, X-bracing and Y-bracing towers is observed.
2. From the Comparison made between towers with different bracing systems at different basic wind speeds vs. Maximum X-Displacements, it is concluded that for 24 m height four legged tele communication tower with PIPE section, K-bracing pattern requires minimum quantity of steel when compared to other three considered bracing patterns (i.e. V- bracing, X- bracing and Y- bracing) at all considered basic wind speeds. It is observed that the reduction in the percentage of quantity of steel in K- bracing tower is 21.54%, 40.48%, 18.973% for V- bracing, X-bracing and Y- bracing towers is observed.

3. From the Comparison made between towers with different bracing systems at different basic wind speeds vs. Maximum X-Displacements, it is concluded that for 24 m height four legged tele communication tower with ANGULAR section, K-bracing pattern has less lateral displacements when compared to other three considered bracing patterns (i.e. V- bracing, X-bracing and Y- bracing) at all considered basic wind speeds. A reduction in the percentage of lateral displacements in K- bracing tower is 25.19%, 11.55%, 18.98% for V- bracing, X-bracing and Y- bracing towers is observed.

4. From the Comparison made between towers with different bracing systems at different basic wind speeds vs. Maximum X-Displacements, it is concluded that for 24 m height four legged tele communication tower with ANGULAR section, K-bracing pattern requires minimum quantity of steel when compared to other three considered bracing patterns (i.e. V- bracing, X-bracing and Y- bracing) at all considered basic wind speeds. It is observed that the reduction in the percentage of quantity of steel in K- bracing tower is 8.503%, 23.52%, 29.66% for V-bracing, X-bracing and Y- bracing towers is observed.

From this study finally, it can be concluded that for a 24m height four legged tele communication tower, Angular cross section with K- bracing pattern is found to be most effective and economical at all considered basic wind speeds (i.e. 33 m/sec, 39 m/sec, 44 m/sec, 47 m/sec, 50 m/sec and 55 m/sec).

Future of Scope of Research
The work can be extended to economise the tower by adopting the technique proposed by Markandeya Raju Ponnada and Raghuram Sandeep in their book titled [25] “Performance of Lack of Fit Induced Steel Truss”.

REFERENCES


