# Comparative study of wind and ice loads on telecommunication towers in hilly terrain

*Gokul Gayatri[1], B. Tirumala Reddy[2], B. Narender[3],*

[1]M.Tech, Structural Engineering, Anurag University, Hyderabad, Telangana, India,
[2]Senior Consultant-Engineering, Ramboll India PVT. Ltd, Hyderabad, Telangana, India, btr@ramboll.in
[3]Structural Engineering departement, Anurag University, Hyderabad, Telangana, India

**Abstract.** Telecommunication structures are usually defined as steel lattice towers on which they mount microwave dish antennas. These are slender, tall, highly optimised structures and the loading conditions that control their performance are extreme cold, snowfall, and strong winds. Strong winds combined with ice accumulation on the structure's members and dishes are the primary reasons of collapse. This comparative study is to investigate the effect of ice loads combined with wind load analysis of triangular tower configuration comprising of height 60m located in hilly terrain (specially dealt with cold region) having wind zones 39mps and 55mps. By referring specialized standards for analysis of lattice towers, reduction of wind load shall be considered when ice loads are accounted for analysis. Initial design is performed for full wind load of the tower configuration through space truss analysis using STAAD.Pro V22 software and same is checked with combined wind and ice loads as per appropriate standards. A comparison statement is derived on effect of ice loads on analysis of structure – leg forces, bracing forces and deflection for tower configuration considered in parametric study.

**Keywords**: Telecommunication towers, Lattice towers, steel towers, GBT tower, Hilly terrain, ice loads, wind loads.

## 1 Introduction

The construction of telecommunication towers, which are used to mount a radio wave antenna at elevated locations from the ground, is growing daily as a result of rapid expansion in the telecommunication system. The demand has expanded the use of wireless communication from every corner of the world as there are rising demands from 2G to 5G. Similar trends may be seen in the increase in steel production needed to build more telecom tower.

Lattice towers are more commonly used for wind load research studies and are less in weight. Lattice towers are mostly square and triangular shaped in structure supported by bracings, redundants and horizontals. Self-weight, antenna, cables, ladder loads, and other equipment are among the loads operating on the tower's structure.

**Ahti et.al (1982)** analysed the three separate observations on rime formation, i.e., a) relationship between ice accumulation and precipitation, b) dependency of rime formation rate on wind speed and air temperature, and c) study of transitions from rime to glaze development, to compute ice loads. The study by **Makkonen et al. (1995)** addressed significant design requirements for TV towers and communications towers in cold regions. According to the findings, the elevation of the site terrain has a bigger influence on rime ice loads than does its height above sea level. In this study by **Makkonen et al. (1995)**, it was found that the combined ice and wind loads acting on antenna towers were the only factor in 14 of the 16 tower collapses. The findings indicate that more attention is needed when calculating the drag coefficient of an iced structure. In investigations by **Sundin et al. (1998)**, ice loads on towers were compared using information from meteorological stations and on-site temperature measurements, demonstrating that tower breakdowns occur in colder areas. The findings demonstrate the need of using temperature data collected on-site to forecast cumulative ice loads over long time periods.

**Thomas Allen (2006)** conducted research on the impact of variable roughness length on flow characteristics over hills and came to the conclusion that while many flow characteristics change as the position of the roughness changes, these changes have little bearing on the general properties used in the terrain drag parameterization approach**. Siddesha.H (2010)** analysed the microwave antenna towers with various sections and configurations were performed and tested against wind loads where the X and M bracings of square hollow sections in the lower first panel have the greatest reduction in displacement compared to square hollow legs and bracings of the tower. **Joze Duhovnik et.al (2012)** presents a survey of different topological designs for steel tower used for communications of antennas mounted on top of the tower subjected to various Loads -Self weight, antenna load, cable load, wind load, ice load, and combinations thereof (wind affects ice towers due to their increased surface area). Higher the tower height, the greater the impact of design topological complexity and thus manufacturing complexity on economic valuation. **Mohammad Javed Iqbal et.al.(2018)** discusses about the importance to understand the effects of new standards on already designed and installed towers using old codes and understanding the provisions of revised standards. **Preeti et al. (2015)** in this study, four-legged, angular, self-supporting communication towers are simulated on the roof and ground of the structure using STAAD Pro finite element software to account for the impacts of wind loads resulting from Indian conditions. Axial forces in rooftop towers are typically two to three times (maximum) greater than those in ground towers.

When designing structures related to ice accumulation, the atmospheric ice loads brought on by freezing rain, snowfall, and in-cloud icing must be taken into account. Site-specific research must be applied in cold climates where historical data or practical experience show that snowfall or in-cloud icing causes greater loads than freezing rain. These help in understanding the site specifications and design accordingly which help in avoiding the structure failures.

In this paper, triangular tower has been compared for wind loading with and without ice loading, and the results are reported. The areas of study that were attempted in this project are as follows:

1. Calculation of 60-meter triangular tower body wind loads according to IS 875(Part3)-2015 including ladders, cables, antennae, and other equipment.
2. Utilising STAAD.Pro software to create models for triangular lattice towers in hilly terrain with wind loads and combined ice and wind loads at both wind speeds (39mps and 55mps).

3. In accordance with the relevant Indian Standards, a comparison of the main leg forces, bracing forces, and deflection of models of wind loads with and without ice loading has been presented.

## 2 Tower and Linear Accessories Specifications

### 2.1 Geometry of Tower:

In this study, a 60m 3-legged self-supporting tower influenced by the topographical factor is analysed. The tower has a base width of 6 metres and a top width of 1.8 metres with top 15 metres of height are straight section, while the rest of the 45 metres are tapered section.

**Table 1.** Tower Details

| | |
|---|---|
| Height of Tower | 60m |
| Bottom Base Width | 6m |
| Top Base width | 1.8m |
| Height of Sloped Portion | 45m |
| Height of vertical Portion | 15m |
| Loading standard | IS 875 (Part 3) – 2015 |

### 2.2 Modelling of Tower:

In the current work, a self-supporting three-legged tower has been modelled using Indian Standard Angles for the bracing and horizontals as shown in fig.1, pipe members for the main legs in tubular model and angular members for the main legs in angular models, respectively.

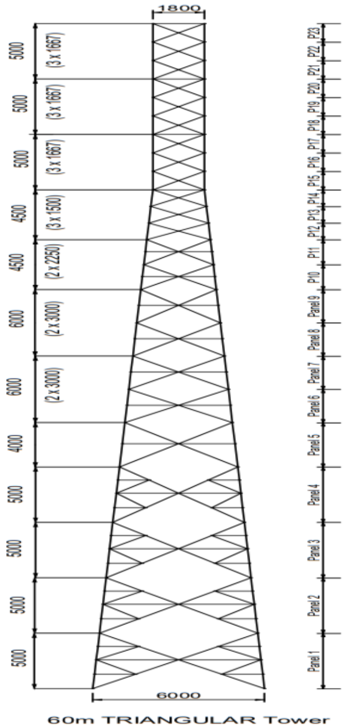


**Fig.1.** Geometry of Three-legged Tower

For the comparative analysis, a 60-meter triangular tower with M-pattern bracing on the bottom four panels, X-pattern with redundant bracing on the next seven panels followed by X-pattern bracing for rest of the panels is taken into consideration. In general, the main legs of towers with four legs and three legs are constructed of 90° angles and 60° angles, respectively. It has been assumed that all of the utilised members are hot-rolled steel angles connected by bolts.

Due to the reason that the tower member is capable of carrying axial force and not moment, member releases are executed for the major legs and member truss is applied for bracing in truss modelling. The calculated wind loads are applied at the proper nodes, and the member forces, bracing forces, and structural deformation as a result of the applied load are investigated.

### 2.3 Linear Accessories Specifications:

Any non-structural elements such as wave guides, feeders, ladders, and pipe work, are referred to as linear accessories. They extend over many panels of the tower. In the study, ladder, cables and antenna like GSM (Global system for mobile communications) and MW (Microwave) antennae are assumed to be along with the tower. The tower antenna loading consists of 9 GSM antennas (size: 2.62m x 0.26m x 0.2m) and 4 standard MW antennas (diameter: 1.2m) with radomes, with cables of 22mm and 10mm diameters running along the height of the tower, respectively. The ladder has a 450mm width, a 20mm diameter solid rod for climbing, two L50x50x5 vertical angles supported, and a horizontal hoop with a 1150mm spacing between the hoops as a safety guard.

The equivalent effective exposed area of the accessories taken into consideration for this study is listed below.

- Antenna area: 2.12 $m^2/m$ (for top panel of tower)
- Ladder area: 0.523 $m^2/m$ (throughout tower height)
- Cables area: 0.111 $m^2/m$ (throughout tower height)

Platforms fall within the category of working and resting platforms. In this model the resting platform is assumed at 20m and working platform is assumed at 40m.

It is assumed that MW antenna is standard antenna with only radome and all the antenna are exposed to win (shielding effect is not considered). Also the ladder is assumed to be placed inside the tower.

## 3 Wind Loads

The analysis of 60m self-supporting triangular model effected by topographical factor, mainly concentrates on 39mps and 55mps wind speed that is prevailing in the Northern part of India, also called the cold region. In such regions, the towers should be analysed for the combined wind and ice loads to prevent the tower failures which causes economic loss.

The tower was developed to withstand wind loads at basic wind speeds of 39mps and 55mps, as the cold northern region is found to be with in there two wind speeds. With terrain category 1 and hilly topography, the average probable design life of a tower is assumed to be 100 years on which risk factor is dependent.

### 3.1 Topography Factor

As the tower is assumed on top of hilly terrain, local topographical characteristics like ridges, hills, valleys and cliffs can have a big impact on how fast the wind blows on structures when compared to flat terrain. If the upwind slope is greater than 3 degrees then topography has a considerable impact on structure. The height of hill is taken as 100m and length is considered as 400m. Accordingly the calculations of tower located on top of hill is as follows.

**Table 2.** Calculation of Topographical Factor ($k_3$)

| **Description** | **60m tower** | | |
|---|---|---|---|
| Height of Hill | Z | (m) | 100 |
| Length of Hill | L | (m) | 400 |
| Slope of Hill | $\theta_s$ | (deg) | 11.32 |
| Effective Horizontal Length | $L_e$ | (m) | 250 |
| Value of C | C | | 0.24 |
| Horizontal distance of tower from crest | X | (m) | 100 |
| Ratio of $X/L_e$ | $X/L_e$ | | 0.40 |
| Height above Mean ground level (Tower Base) | H | (m) | 50 |
| Ratio of $H/L_e$ | bottom | | 0.04 |
| Value of $S_0$ from Fig | bottom | | 0.37 |
| Value of $k_3$=(1+$Cs_0$) | bottom | | 1.088 |
| Average value of $k_3$ | | | **1.09** |

### 3.2 Combined Wind and Ice Loads:

When a structure is covered in ice, it will eventually separate from the structure. Ice can either be completely or partially shredded. Experience has shown that when the temperature rises, ice tends to shatter. It is possible to determine wind action on iced structures utilizing the same formulas used for ice-free structures.

It is possible to generate enough ice forces to cause the structures to fail by combining the geometry of the structure, the size of the ice, and the strength of the ice. Therefore, for any structure that is exposed to ice, careful assessment of ice loading must be made.

The size of structural elements and their drag coefficient do, however, alter. Depending on where the structure is, the thickness of the surrounding ice deposition may be estimated to be 3mm to 10 mm (Clause 5.1 IS: 875 (Part 4) – 1987). The increase in diameter or length caused by ice development must be taken into account when calculating the wind force. In this study, density of ice taken as 900 kg/m$^3$ and thickness of ice is taken as 6 mm for combined wind and ice loads calculation.

All of the tower's structural components (i.e.); main legs, bracing members, redundants and horizontals, the ice thickness is added by increasing the length and breadth in the angular and piped members. For main legs to be piped members the diameter is increased to indicate ice thickness. Calculation of ice on the antenna and linear accessories also by adding the 6mm thickness.

### 3.3 Tower Analysis:

To perform the Analysis on 60m lattice tower, geometry including redundant members are created by using STAAD-Pro V22 software for linear static analysis. Microsoft Excel is used to determine wind loads, and nodal loads are used on the STAAD model. for towers with roughly symmetrical design and loads, three wind directions—$0^0$, $90^0$, and $180^0$—with regard to the tower are taken into consideration.

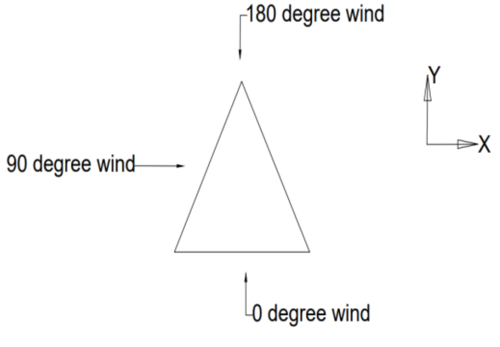


**Fig.2:** Directions considered for Analysis

To analyse a tower for basic wind speed without ice conditions, three variables are used: Dead load + $0^0$ direction wind speed, Dead load + $90^0$ direction wind speed and Dead load + $180^0$ direction basic wind speed. The load combinations considered for analysis of tower are:

- 1.1 Dead Load + 1 Wind Load
- 1.1 Dead Load + 0.5 Wind Load + 1 Snow Load

Taking the reference from ANSI/TIA-222-G, the wind loads are reduced to more or less 50% when combined with ice loads.

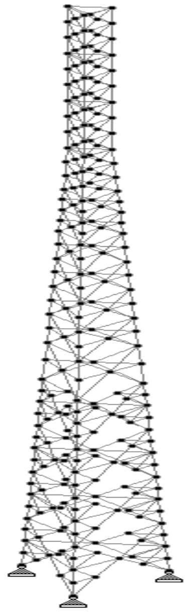

**Fig.3:** 60m Lattice Tower Analysis Model

## 4 Results

The analysis's findings were plotted against each iteration. From the thorough analysis, the following sections provide a comparison of member forces for the Main Leg Force and Bracing Force for each iteration.

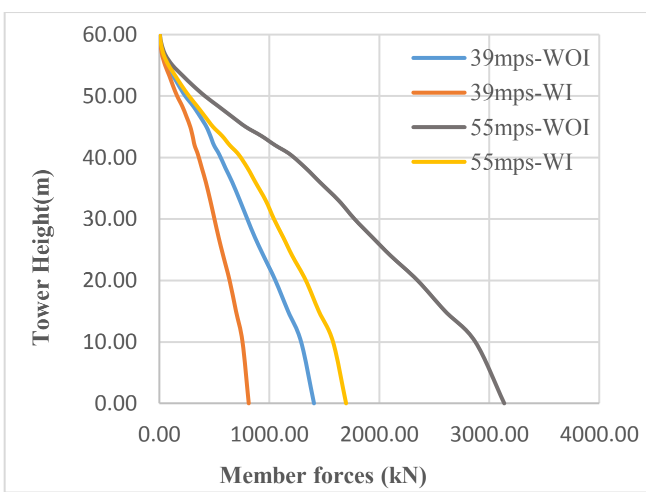


**Fig.4.** Member forces for Angular Tower

From fig.4 the variation of Main leg forces reduces by 65.8% in the bottom 30 metres, 53.1% in the middle portion and up to 31.5% top vertical portion of tower for 39mps wind zone where as in 55mps wind zone the Main leg forces reduce by 76.9% in the bottom 30 metres, 62.3% in the middle and up to 40.9% top vertical portion of tower.

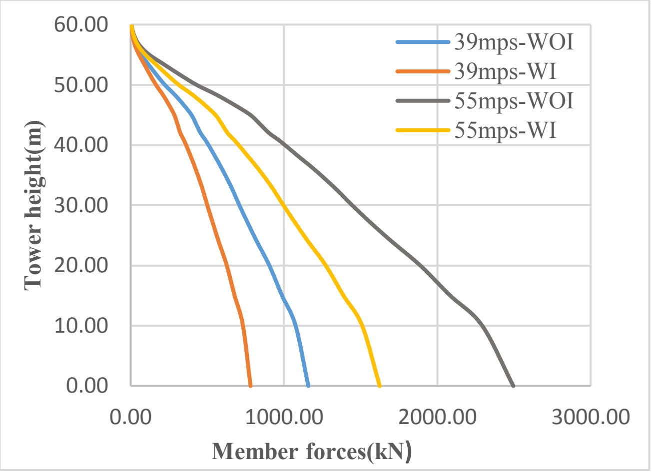


**Fig.5.** Main-Leg forces for Hybrid Tower

From fig.5 the variation of the main-leg forces reduces by 55.6% in the bottom 30 metres, 30% in the middle portion and up to 21.8% top vertical portion of tower for 39mps wind zone where as for 55mps wind zone the main-leg forces reduce by 64.3% in the bottom 30 metres 33.7% in the middle portion and up to 21.7% top vertical portion of tower.

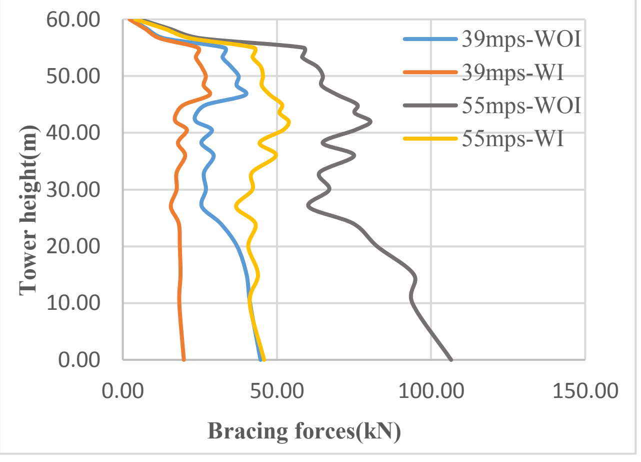


**Fig.6.** Bracing force for Angular Tower

From the fig.6 Bracing forces reduce by 94.3% in the bottom 30 metres, 41.3% in the middle portion and up to 26.7% top vertical portion of tower for 39mps wind zone and forces reduce by 96.6% in the bottom 30 metres, 47% in the middle portion and up to 30.2% top vertical portion of tower for 55mps wind zone.

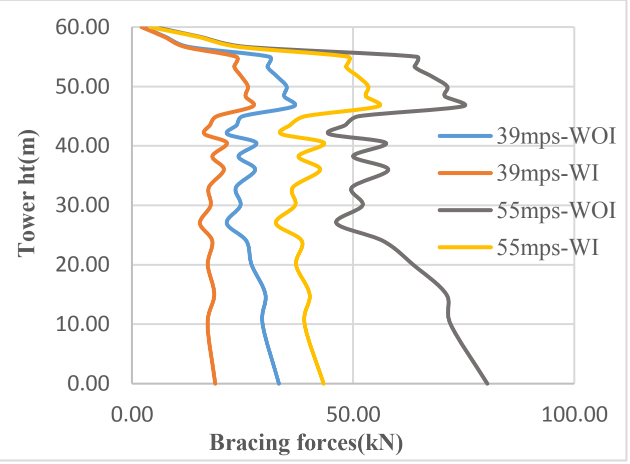


**Fig. 7.** Bracing force for Hybrid Tower

From fig.7 the Bracing forces reduce by 55.6% in the bottom 30 metres, 33% in the middle portion and up to 21.8% top vertical portion of tower for 39mps wind zone and bracing forces reduce by 64.3% in the bottom 30 metres, 33.7% in the middle portion and up to 21.7% top vertical portion of tower for 55mps wind zone.

Graphs show that the member forces and bracing forces are lower for ice loading than for no ice loading. This is because the model experiences less force coefficient with ice loading. The ice makes the angular sections behave like circular smooth sections. Since circular sections have a lower force coefficient (drag force) than angular or flat members, the wind load on the tower is reduced by reducing the forces that must be developed on the members.

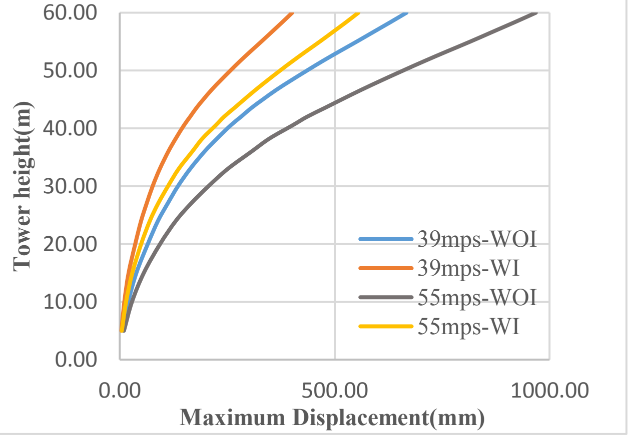


**Fig.8.** Deflection for Angular Tower

From fig.8 the variation in deflection is significantly reduced by 82% for 39mps and deflection is significantly reduced by 74% for 55mps. From fig.9 the variation in deflection is significantly reduced by 49.1% for 39mps deflection is significantly reduced by 51.06% for 55mps.

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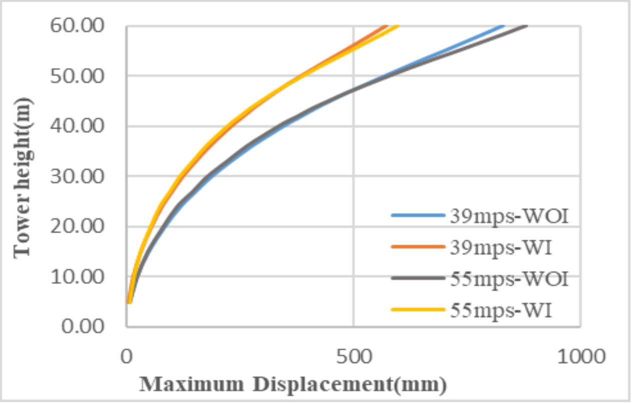


**Fig. 9.** Deflection for Hybrid Tower

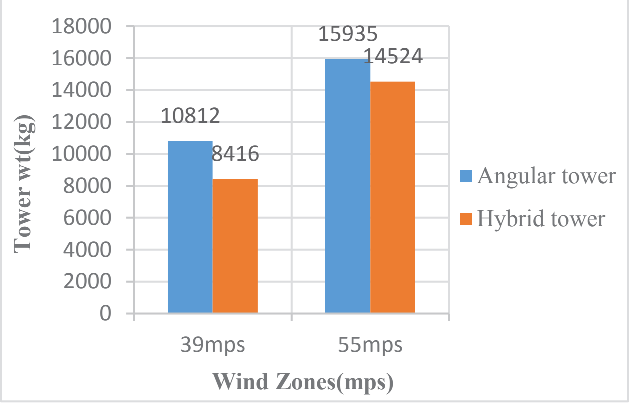


**Fig.10.** Comparison of Angular tower and Hybrid tower

According to the developed model, the structural mass weight of hybrid tower is 28% less than the angular tower in 39mps wind speed and 10% less than the angular tower in 55mps wind speed observed in fig.10.

## 5 CONCLUSIONS

The present study is carried out to evaluate the member forces in lattice tower located at lower and higher wind zones (India) along with ice loads. Based on the Investigations the conclusions are obtained.

It is observed that, even though there is 50% reduction of wind resistance in load combination there is a variation in percentage reduction in member forces and displacement on the overall 60m tower.

- In 3-Legged angular tower model with ice condition for 39mps and 55mps, the Leg forces on an average is decreased by 71% in bottom 30m portion, 57.7% in 30m-45m portion and 36.2% in 45m-60m portion (Top vertical portion) when compared to without ice models.

- In 3-Legged angular tower model with ice condition for 39mps and 55mps, the Bracing forces on an average is decreased by 95% in bottom 30m portion, 44.2% in 30m-45m portion and 28.5% in 45m-60m portion (Top vertical portion) when compared to without ice models.
- In 3-Legged angular tower model with ice condition for 39mps and 55mps, the Deflection on an average is significantly reduced by 78% when compared to without ice models.
- In 3-Legged hybrid tower model with ice condition for 39mps and 55mps, the Leg forces on an average is decreased by 46.8% in bottom 30m portion, 40.4% in 30m-45m portion and 24.3% in 45m-60m portion (Top vertical portion) when compared to without ice models.
- In 3-Legged hybrid tower model with ice condition for 39mps and 55mps, the Bracing forces on an average is decreased by 59.9% in bottom 30m portion, 33.4% in 30m-45m portion and 21.2% in 45m-60m portion (Top vertical portion) when compared to without ice models.
- In 3-Legged hybrid tower model with ice condition for 39mps and 55mps, the Deflection on an average is significantly reduced by 50.11% % when compared to without ice models.
- The hybrid tower model is found to generate less forces than the angular tower model when comparing the two models under ice and without ice conditions, which optimises tower reliability.

In addition to the proposed models, the reduction in structural weights when compared to hybrid and angular models is 28% for 39mps and 10% for 55mps.

This is caused by the wind's sub-critical flow that generates a drag force on the tower, when multiplied by the exposed surface area aids in minimizing the weight of the tower members. Due to the lower forces hybrid towers encounter compared to angular towers, they are economically preferred. As a result, additional antennae are set up in order to accomplish the stated goal of extending communication.

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**Codes**

1. IS 875-4 (1987): Code of Practice for Design Loads (Other Than Earthquake) For Buildings and Structures, Part 4: Snow Loads
2. IS 875-4(2015): Code of Practice for Design Loads (Other Than Earthquake) For Buildings and Structures, Part 3: Wind Loads
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