Modelling and Analysis of Lattice Towers for Wind Turbines

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Abstract: ***Towers are the fundamental support structures for wind turbines which give them the suitable height to capture wind. Lattice towers are freestanding framework towers which have found applications in transmission towers, cellular towers, radio towers, observation towers and wind turbine towers. This paper discusses about both guyed and freestanding lattice towers. The lattice towers are modelled in three different shapes and two different sections (Pipe and Angle). The models are designed and analysed under static and dynamic conditions in STAAD Pro software. The objective is to produce a safe, stable and optimum design. The results are compared and suitable conclusions drawn.***

Keywords: Lattice tower, STAAD Pro, Pipe section, Angle section, Structural analysis

1. Introduction

Wind energy is one of the fast growing potentials in the field of renewable energy. The prevailing disadvantage of fossil fuels and the technological saturation in solar energy has pushed humanity to look for better and sustainable sources of energy. Wind energy provides a tremendous opportunity in this regard. Until date, there have been many successful approaches to extract power from wind and it is categorized in form of Large Wind systems and Small Wind systems. Wind turbines have to be placed at optimum heights so that they can capture sufficient energy from wind. This leads to the involvement of towers, which position the turbines at required height, absorb vibrations and act as a support structure. Towers come in many configurations like Tubular, Lattice, Guyed Pole and Hybrid. Lattice towers have the advantage of easy fabrication, less capital costs, ease of transportation, flexible erection and lesser effect on ecology.

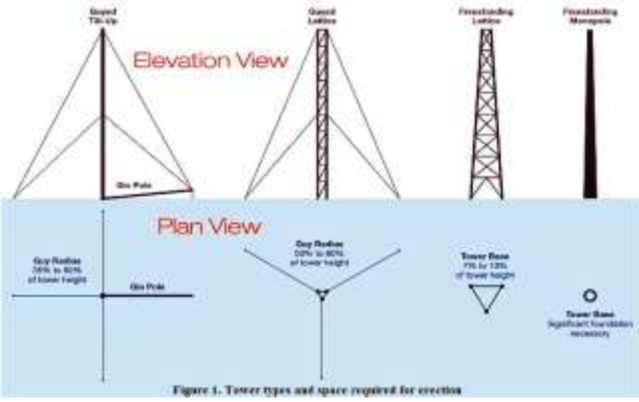

Figure 1: Tower types and space required for erection.

This paper presents three shapes of lattice structure i.e. triangular, rectangular and trapezoidal. These three shapes are modelled as Pipe and Angle sections separately. The Pipe sections are given guy wire supports and Angle sections are kept as freestanding. The tower base area is kept same for all models. The height of the tower is 20m. Wind loads are calculated on basis of IS 875: Part 3 and other loads on basis of IEC 61400-2. The tower is designed for a small wind system of approximately 300 kg. The models are subjected to static and dynamic loading conditions. The models are optimised to obtain a safe design and the obtained results are compared.

2. Design Methodology

A wind turbine tower has to encounter many loads during its lifetime, which must be considered in order to start the design process. The following figure presents a generalised view of the predominant forces acting on the tower.

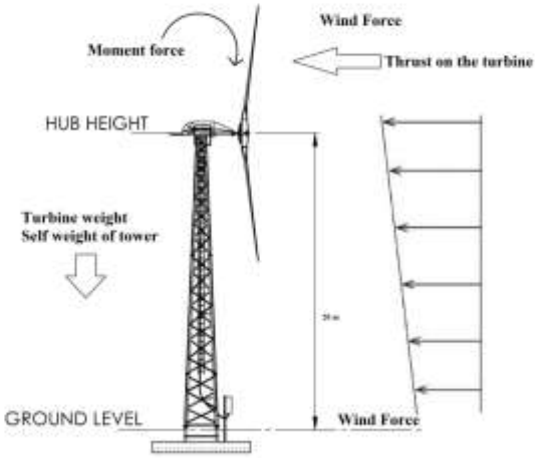

Figure 2: Forces on a tower.

Turbine weight (tower top weight) = 300 kg.
The wind loads are calculated according to IS 875.
Design Wind Speed (V_z) = V_b x k_1 x k_2 x k_3
V_b = Basic Wind Speed.
k_1 = probability factor (risk coefficient).
k_2 = terrain, height and structure size factor.
k_3 = topography factor.
The basic wind speed is obtained from basic wind speed map of India.

Basic Wind Speed (V_b) = 39 m/s.
k_1 = 1.06 (Mean probable design life of structure is 100 years).
k_2 = 1.1 (Terrain category 1, Class B).
k_3 = 1 (Flat topography)
V_z = 45.474 m/s
Design Wind Pressure (P_z) = 0.6 x V^2_z
P_z = 1240.73 N/m^2
The thrust force and the moment force are calculated to be 2120 N and 524 Nm.

The model of towers is as follows:

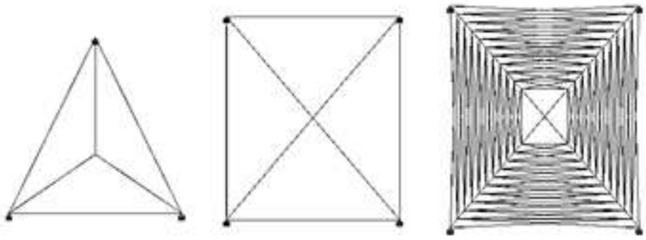

Figure 3: Top view of the models

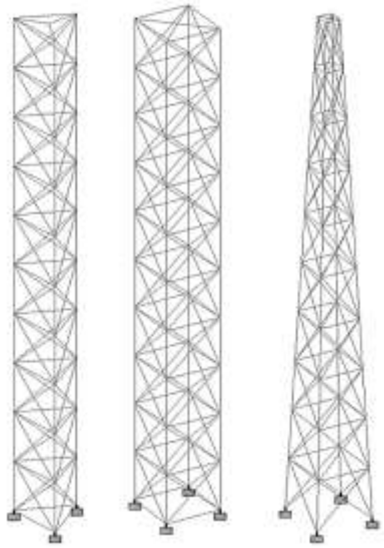

Figure 4: Front view of the models

The height of the tower is 20m and base area is 4m^2 for all models. In order to reach an optimum level of cost and safety, the section size has been varied throughout the models. The model was divided into 3 partitions [0-6] m, [6-12] m, [12-20] m. The section size was more at the initial partition and it was reduced with height. The model creation was of 6 types, 3 guyed pipe type sections and 3 self-supporting angle type sections. The models were analysed in STAAD Pro v8i software as per loads calculated. The section size values were varied continuously to achieve the optimum shape size which is based on unity ratio of design members. The structural members upon reaching values ≤ 1 were deemed to be safe. The optimum shape here indicates a safe design with minimum possible weight. The guy wire supports were given a uniform dimension of 1 cm diameter. The emphasis was on the variance in relation to the shape of the structures. The dimensions for 6 models are as follows:

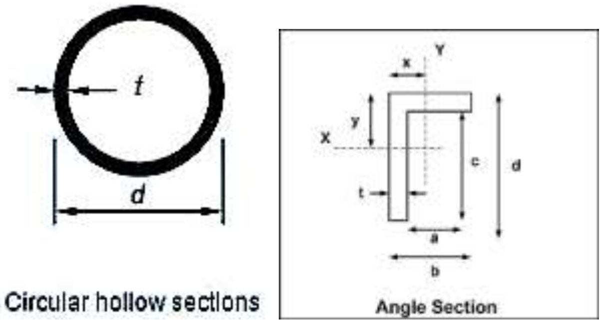

Figure 5: Type of sections used in design.

Table 1: Pipe section triangular tower specifications

Triangular Tower (Pipe)		
Horizontal and Vertical Members		
OD (cm)	ID (cm)	Height (m)
7	6.5	0-6
5.5	5	6-12
4	3.5	12-20
Cross Bracings		
3	2.7	0-6
2.7	2.4	6-20

Table 2: Pipe section rectangular tower specifications

Rectangular Tower (Pipe)		
Horizontal and Vertical Members		
OD (cm)	ID (cm)	Height (m)
7	6.5	0-6
5.5	5	6-12
4	3.5	12-20
Cross Bracings		
5	4.5	0-6
4.7	4.2	6-20

Table 3: Pipe section conical tower specifications

Conical Tower (Pipe)		
Horizontal and Vertical Members		
OD (cm)	ID (cm)	Height (m)
6.5	6	0-6
5.5	5	6-12
4	3.5	12-20
Cross Bracings		
5	4.5	0-6
4.5	4	6-12
4	3.5	12-20

Table 4: Angle section triangular tower specifications

Triangular Tower			
Horizontal and Vertical Members			
	D (cm)	B(cm)	T(cm)
ISA110X110X12	11	11	1.2
ISA80X80X12	8	8	1.2
ISA65X65X6	6.5	6.5	0.6
Cross Bracings			
ISA90X90X6	9	9	0.6

Table 5: Angle section rectangular tower specifications

Rectangular Tower
Horizontal and Vertical Members

	D (cm)	B(cm)	T(cm)
ISA100X100X12	10.00	10.00	1.20
ISA75X75X10	7.50	7.50	1.00
ISA60X60X8	6.00	6.00	0.80
Cross Bracings			
ISA90X90X6	9	9	0.6

Table 6: Angle section conical tower specifications

Conical Tower			
Horizontal and Vertical Members			
	D (cm)	B(cm)	T(cm)
ISA100X100X12	10.00	10.00	1.20
ISA75X75X10	7.50	7.50	1.00
ISA60X60X10	6.00	6.00	1.00
Cross Bracings			
ISA90X90X6	9	9	0.6

3. Results and Discussion

The analysis of the above models is as follows:

Table 7: Maximum Resultant Displacements

Maximum Resultant Displacement (mm)	
Pipe section triangular tower	24.2
Pipe section rectangular tower	29.543
Pipe section conical tower	19.522
Angle section triangular tower	56.802
Angle section rectangular tower	31.257
Angle section conical tower	41.664

This is the displacement occurring at top levels of the tower. The pipe sections have guy wire supports and angle sections are free standing. It can be seen from above values that guy wire supports act efficiently to restrict the degrees of freedom as compared to free standing towers, hence lower values of displacement.

IS800 gives deflection limits for buildings and building components under serviceability loads. The tower is a cantilever member under live loads with no cladding. The maximum deflection can be taken as (Span/150) which is 133.33 mm. We can observe that the obtained results are below the maximum deflection value.

The stresses and force reactions are not emphasized in this paper, but suitable results have obtained.

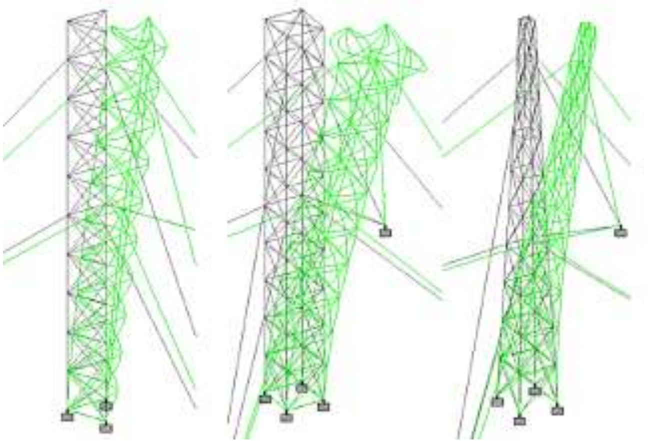

Figure 6: Pipe section displacements

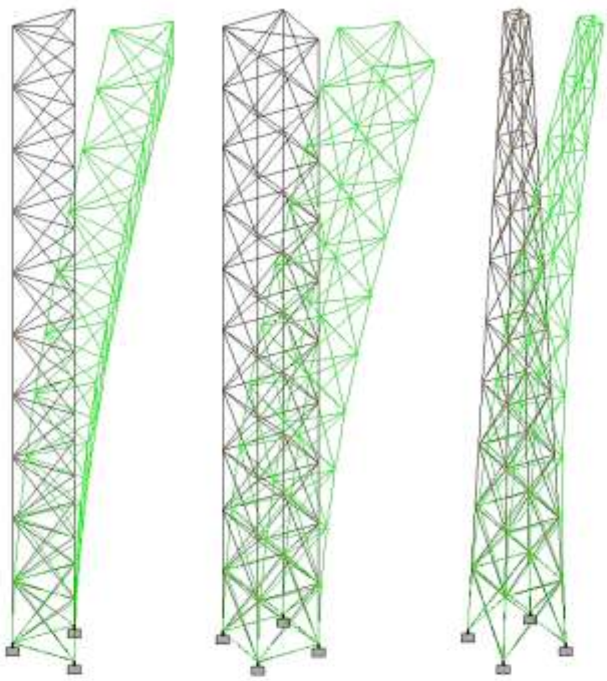

Figure 7: Angle section displacements

Wind is essentially a random phenomenon both in time and space, hence is dynamic in nature. When the natural vibration frequencies of structures are low enough to be excited by the turbulence in the natural wind, the structures are considered to be dynamically wind sensitive. Since we have a rotating machine on the top of the tower, the vibrations generated by it should not match the fundamental frequency of the tower. The rated RPM of the turnine is 300, so the forcing frequency from the running turbine is f = 5 Hz (RPM/60). This is normally called 1f vibration frequency or shaft frequency. The wind turbine consists of 3 blades, so the (n)f values comes to 15 Hz which is exciting frequency for a '3'bladed rotor under well balanced operating conditons.

The frequencies of the models are summarised as:

Table 8: Frequencies of Pipe Sections

Pipe Sections				
Triangular Tower				
Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %
1	5.097	0.196	0	36.624
2	7.176	0.14	95.854	0
3	8.346	0.12	3.69	0
4	44.322	0.023	0	49.94
5	82.365	0.012	0	0
Rectangular tower				
Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %
1	3.537	0.283	0	21.768
2	4.589	0.218	6.184	0
3	4.995	0.2	93.678	0
4	33.43	0.03	0	43.401
5	37.691	0.027	0.002	0.057
6	37.912	0.026	0	0.139
Conical tower				

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %
1	7.223	0.138	98.269	0
2	10.704	0.093	1.496	0
3	20.771	0.048	0	41.119
4	52.33	0.019	0	46.792

The towers can be classified based on frequency as:
1. Soft-Soft tower (F_1 < f)
2. Soft-Stiff tower (f < F_1 <(n)f)
3. Stiff-Stiff tower (F > (n)f)

The natural frequency (F_1) of the tower should not coincide with the excitation frequencies. Soft-soft towers are cheaper but they tend to oscillate more. Stiff-Stiff are more resilient but may not be cost effective to build.

Table 9: Frequencies of Angle Sections

Angle Sections				
Triangular Tower				
Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %
1	6.053	0.165	97.644	0
2	9.176	0.109	0	11.912
3	12.056	0.083	0.322	0
4	37.589	0.027	0	40.692
5	39.449	0.025	0	1.062
6	42.038	0.024	0.002	0.03
Rectangular Tower				
Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %
1	1.149	0.87	0	0
2	5.926	0.169	0	8.397
3	7.506	0.133	97.07	0
4	38.657	0.026	0.002	0
5	41.402	0.024	0	69.346
6	77.542	0.013	2.373	0
Conical Tower				
Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %
1	3.499	0.286	0.032	0
2	6.811	0.147	98.983	0
3	38.009	0.026	0	50.782
4	58.288	0.017	0	32.046
5	66.329	0.015	0	0

The total weights of the different models are:

Table 10: Weight of Tower Models

Weight of Model (kg)	
Pipe section triangular tower	567.3
Pipe section rectangular tower	1253.73
Pipe section conical tower	981.55
Angle section triangular tower	2966.92
Angle section rectangular tower	3771.94
Angle section conical tower	3599.14

The rectangular sections consume more steel, hence are heaviest. The triangular sections are lightest.

The following comparisons are obtained for the above models:

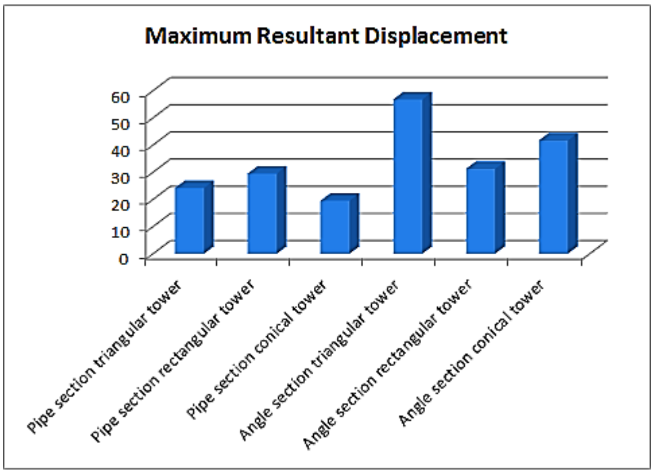

Figure 8: Comparison of Resultant Displacements of models

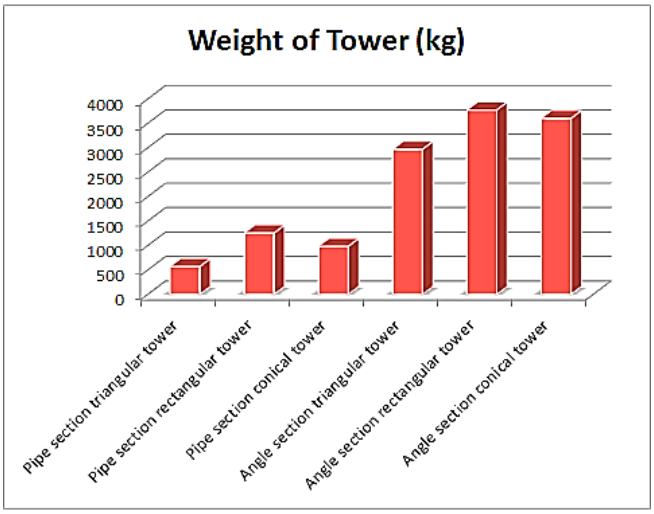

Figure 9: Comparison of tower weights

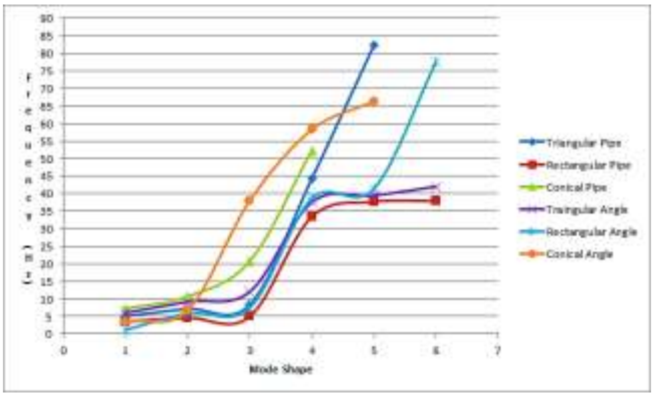

Figure 10: Comparison of frequencies and mode shapes

4. Conclusions

The paper presents a comparison regarding the structural analysis of different shapes of lattice towers. It is noticed that heavier towers are costlier, have low displacement and frequency values. Guy wire supported pipe towers are lighter than angle sections and have low displacement values. Triangular models are cost effective but less stiff while rectangular models are stiffer and costly. Conical models provide equality of cost and stiffness. Angle sections have low frequency values as compared to pipe sections. Generally, the triangular and rectangular sections are preferred for masts and small turbines. The conical towers are meant for large turbines.

There are various parameters involved in design process. Attempts can be made to design models of different shapes and observe their behaviour under the action of loads. Further changing parameters like base area, bracings etc. may give lighter, stiffer and cost effective designs.

5. Acknowledgment

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