The Journal of CPRI,
Vol. 11, No. 1, March 2015 pp. 171-176

Wind load assessment on guyed steel tower with three different codes

Veerendra Kumar Shukla* and Selvaraj M**

Guyed towers are special structures widely used in communication industry as antenna supporting structures. A guyed tower is a nonlinear structural system in which the mast, consisting of single beam-column or multiple members are supported elastically at various points along its height by inclined pretension cables with their ends anchored to the ground. In this paper the wind loads on 120 m tall guyed tower are estimated with three different codes of practices, Indian Code, American Code and British Code. The estimated wind loads are compared and brought out in this paper.

Keywords: *Basic Wind Speed, Dynamic loads, Gust Factor, Guyed Tower, Guy Ropes*

1.0 INTRODUCTION

The design of Transmission Line and Communication Towers are primarily governed by the evaluation of wind loads and responses. The wind velocity varies in a random manner, both in time and space. Steel towers are special steel structures and constructed in such a way that the most efficient and economic use of material is achieved through the use of an open steel system. In this way, the accomplishment of light weight structures with high structural capacity is succeeded and at the same time the modularity of construction is achieved. A lattice tower or truss tower is a free standing framework. They are used for different purposes such as communication, radio transmission, satellite receptions, air traffic controls, television transmission, power transmission, flood light stands, oil drilling tower, meteorological measurements, etc.

With the growth of the telecommunications industry, the demand for taller, more reliable antenna-supporting structures has increased in the past decade. Guyed towers are mostly used for these purposes. Guyed towers are unique civil engineering structures, structurally efficient. High structural efficiency of guyed towers is achieved by the use of pre-tensioned cables and a skeletal design. A guyed mast is a structure with nonlinear behaviour under normal service loads. The nonlinear structural behaviour of a guyed tower is influenced by a number of parameters. The guy cables are the primary source of nonlinearity in guyed towers. Their nonlinear behaviour is due to the change in their stiffness corresponding to change in tension. Many of these taller guyed towers are more flexible and aerodynamically sensitive to the natural wind environment. This results in a nonlinear force deformation relationship for the entire structure. The height of guyed towers can exceed 600 m (Sparling B.F *et.al* (1995) [1], therefore they are extensively used by telecommunication industry. A schematic of guyed tower is shown in Figure 1. The guyed tower is constructed as a triangular space truss with warren or cross-braced configuration. The tower is pinned or fixed at the base while the top

*Senior Research Fellow, Mechanical Engineering Division, Central Power Research Institute, Bengaluru - 560 080, India.
E-mail : vshuklacivil@gmail.com, Mob: +91 9880005991
**Engineering Officer, Mechanical Engg. Division, Central Power Research Institute, Bengaluru - 560 080, India.
E-mail : msraj@cpri.in, Mob: +91 9449851236

usually supports an antenna. Pretension cables, radiating symmetrically from the tower at several elevations, provide lateral support to the tower. Modern tall guyed masts constructed of high-strength and lightweight materials tend to be more flexible and lightly damped than those in the past. The main components of guyed steel masts are legs, bracings, posts, cables and antenna.

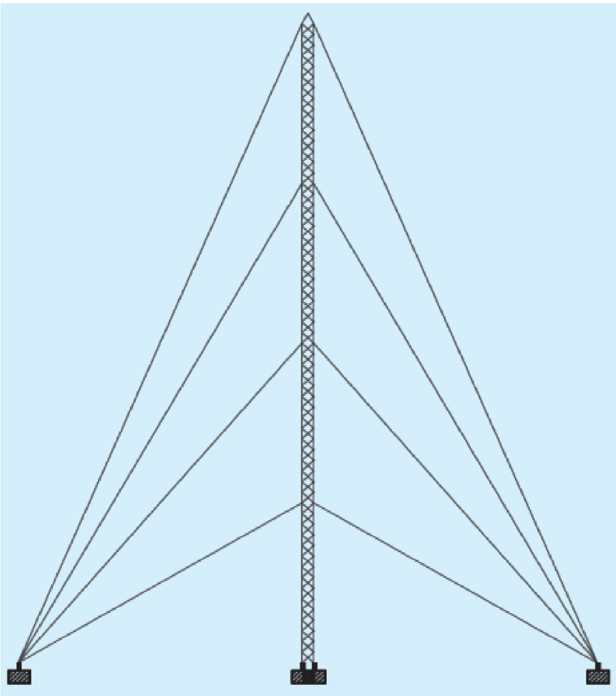

FIG. 1 GUYED TOWER

Mainly the base of these masts is triangular but sometimes square or special type's base is also adopted for suitability. The cables are given initial tensions to resist the lateral force. The different types of bracing system in steel towers are used according to the structural behavior.

2.0 LITERATURE REVIEW

In the past, a lot of work has been done on steel towers to increase their stability; decrease lateral deflections and vibrations and for their better utilization. Some of them are discussed here. Madugula et al. (1998) [2], analyzed the Dynamic response of guyed masts. In this paper the Natural frequencies of guyed masts were determined by modelling the mast as truss elements in one model and as beam-column elements in another model. The experimental results were in good agreement with the results from the finite element analysis Based on the results of these analyses, the influence of ice accretion, guy initial tensions and torsion resistors on the dynamic characteristics of the guyed masts was discussed. Nabil Ben Kahla N (2000) [3], studied the nonlinear dynamic response of a guyed tower due to a sudden guy rupture. In this study the geometrically nonlinear dynamic response of a three dimensional model of a guyed tower, due to the sudden rupture of a selected guy sending an impulsive shock to the entire structure was studied. The sudden rupture was simulated by the instantaneous removal of its end tension, applied as an external force at its mast attachment point. A 500 ft tall tower with three stay levels was analysed. Wahba et al. (1998) [4], evaluated the behaviour of guyed towers, modelling the mast as a lattice truss beam or with beam elements. The finite elements procedure was used to model six existing guyed masts, in order to study the influence of guy initial tensions and torsion resistors on the dynamic response of the structure. Yan-li He et al. (2001) [5], analysed the nonlinear discrete analysis method for random vibration of guyed masts under wind load. Based on the idea of the discrete analysis method of random vibration, the paper studied the wind-induced response of guyed masts; the Gaussian close assumption was adopted to close the mean square equations when taking into account the nonlinearity of cables. The wind load was generated from spatially correlated filtered white noise. The discrete random vibration method can calculate accurate mean and mean square responses. Marcel Isandro R. et al. (2007) [6], studied about the Structural Analysis of Guyed Steel Telecommunication Towers for Radio Antennas. This paper was proposed an alternative structural analysis modelling strategy for guyed steel towers design, considering all the actual structural forces and moments, by using three-dimensional beam and truss finite elements. Comparisons of the above mentioned design models with a third alternative, that models the main structure and the bracing system with 3D beam finite elements, were made for three existing guyed steel telecommunication towers (50m, 70m and 90m high). Jorge S. Ballaben (2011) [7], did the parametric studies of guyed towers under wind and seismic loads. In the paper a typical guyed tower was analyzed with a finite element model in which the lattice mast was represented by an equivalent beam-column element and the guys (or cables) by truss prestressed elements. The wind load was calculated from the design code regarding the height distribution and roughness characteristics. To account for the dynamic loads, a simplified approach is followed.

3.0 GUYED TOWER SPECIFICATION

The square base tower has been considered in this study. Base dimension of the mast is 2m X 2m. Height of the mast is 120m. The panel height is 2m throughout the height of the mast and X-bracing is used in each panel. Angle sections ISA60X60X6 are used for all the leg members and ISA45X45X3 are used for bracings. The mast is prismatic throughout its length. The cable is fastened at every 30m height from ground level. There are four cables at every level. They are fastened at the legs of the mast, after that they are tensioned and fixed at some distance from the base of tower. The diameter of the cable is Φ16 mm. The initial tension in each cable is taken as 35 kN. Figure 2 describes the general specification of present guyed tower. The angles between cable and the vertical mast are shown in the figure mast.

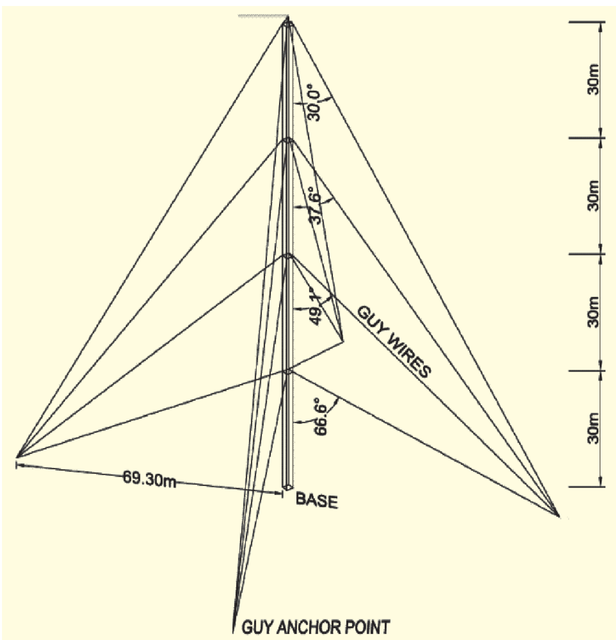

FIG. 2 GUYED TOWER SPECIFICATIONS

4.0 WIND LOAD ASSESSMENT

Due to overall flexibility, slenderness and lightweight, the guyed towers are susceptible to large deflections and also exhibit high dynamic sensitivity to turbulent winds. The magnitude of wind loads on mast is calculated as per three different codes.

4.1 Indian code [8]

Basic wind speed $V_b = 50\ m/s$

Probability factor, $K_1 = 1.08$

Terrain and height factor = K_2

Topography factor $K_3 = 1$ (for flat terrain)

Hourly mean wind speed,

$$V_z = V_b K_1 K_2 K_3$$
$$= 50 \text{ X } 1.08 \text{ X } K_2 \text{ X } 1$$
$$= 54\ K_2$$

So, design pressure,

$$p_z = 0.6 {V_z}^2$$
$$= 0.6 \text{ X } (54\ K_2)^2$$

....(1)

Gust factor,

$$G = 1 + g_f r \sqrt{\left[B(1+\Phi)^2 + \frac{SE}{\beta}\right]}$$

$$= 1 + 0.7 \sqrt{0.65(1+0)^2 + \frac{0.06 * 0.042}{0.020}}$$

$$G = 1.61$$

$$\text{Solidity Ratio} = \frac{\text{Effective area}}{\text{Gross area}}$$

$$\Phi = \frac{2 \text{ X } \left((2 \text{ X } 0.060) + (2.828 \text{ X } 0.045)\right)}{2 \text{ X } 2}$$

$$= \frac{0.49452}{4} = 0.12363$$

From table 30 of IS.875-3,

$C_p = 3.68185$ (For square base)

Effective projected area,

$$A_e = 2\ X\left((2\ X\ 0.060) + (2.828\ X\ 0.045)\right) = 0.49452\ m^2$$

Now, from clause 8.3,

Along wind load on the structure,

$$F_1 = C_p A_e p_z G$$

$$= 3.68185\ X\ 0.49452(0.6\ X\ (54\ K_2)^2)\ X\ 1.61$$

$$F_1 = 5128.2986\ X\ K_2^2 \quad ....(2)$$

4.2 American code [9]

For category II,

Importance factor, $I = 1$

Assume basic wind speed = 50m/s

For open signs and lattice framework,

Wind directionality factor,

$K_d = 0.85$

For height > 15ft and for exposure B,

$$K_z = 2.01\left(\frac{z}{365.76}\right)^{\left(\frac{2}{7}\right)}$$

$$= 0.37226\ X\ z^{\left(\frac{2}{7}\right)} \quad ....(3)$$

From fig. 6-4 of ASCI 7-05,

$K_1 = 0.26$

$K_2 = 0.67$

$K_3 = 0.67$

So,

So,

$$Kzt = (1 + K_1 K_2 K_3)^2$$

$$= (1 + 0.26 \times 0.67 \times 0.67)^2 - 1.247$$

Velocity pressure,

$$q_z = 0.613 K_z K_{zt} K_d V^2 I$$

$$= 0.613\left(0.37226\ X\ z^{\left(\frac{2}{7}\right)}\right)\ X\ 1.247\ X\ 0.85\ X\ 50^2\ X\ 1$$

$$q_z = 604\ X\ z^{\left(\frac{2}{7}\right)} \quad ....(4)$$

$$G = 0.925\left(\frac{1 + 1.7 I_{\bar{z}}\sqrt{g_Q^2 Q^2 + g_R^2 R^2}}{1 + 1.7 g_V I_{\bar{z}}}\right)$$

$$G = 0.8378$$

Solidity Ratio = 0.12363,

Force coefficient,

$$C_f = 4\Phi^2 - 5.9\Phi + 4$$

$$= 4\ X\ 0.12363^2 - 5.9\ X\ 0.12363 + 4$$

$$C_f = 3.33172$$

Effective projected area,

$$A_f = 2\left((2\ X\ 0.060) + (2.828\ X\ 0.045)\right) = 0.49452\ m^2$$

Along wind load on the structure,

$$F_2 = q_z G C_f A_f$$

$$= \left(604\ X\ z^{\left(\frac{2}{7}\right)}\right)\ X\ 0.8378\ X\ 3.33172\ X\ 0.49452$$

$$F_2 = 833.7381\ X\ z^{\left(\frac{2}{7}\right)} \quad ....(5)$$

4.1.3. British code [10]

S_c= Fetch factor, S_t= Turbulence factor, g_t= Gust factor, Sh= Topographic factor, T_c= Fetch adjustment factor and Tt= Turbulence adjustment factor for various heights are obtained. S_b can be calculated from the following formula.

$$= S_c T_c(1 + (g_t S_t T_t) + S_h) \quad ....(6)$$

Now,

$$V_s = V_b\ X\ S_a\ X\ S_d\ X\ S_s\ X\ S_p$$

Basic wind speed, $V_b = 50\ m/s$

Let,

$$S_a = S_d = S_s = S_p = 1$$

Since, Site wind speed 50m/s

Effective wind speed,

$$V_e = V_s S_b$$

$$= 50\left(S_c T_c (1 + (g_t S_t T_t) + S_h)\right) \quad ....(7)$$

Now,

Dynamic pressure,

$$q_s = 0.613 V_e^2$$

$$= 0.613\left(50\left(S_c T_c (1 + (g_t S_t T_t) + S_h)\right)\right)^2 \quad ....(8)$$

Effective projected area,

$$A_e = 2\left((2 \text{ X } 0.060) + (2.828 \text{ X } 0.045)\right)$$

$$= 0.494542 \text{ m}^2$$

For sharp edge tower members,

Pressure Coefficient, $C_p = 2$

So,

Wind force,

$$F_3 = C_p q_s A_e$$

$$F_3 = 2 \text{ X } 0.613\left(50\left(S_c T_c (1 + (g_t S_t T_t) + S_h)\right)\right)^2 0.49452 \quad ....(9)$$

5.0 RESULTS AND DISCUSSION

The equations (2), (5) and (9) are the simplified derived equations to calculate wind load on guyed tower using three different codes. The variables on the right hand side of these equations changes with the height of the tower. The wind loads in each panel of tower is calculated with the help of these equations. For convenience, at every 5 meters, the equivalent magnitude of wind load is calculated. Since there are four joints in each panel of the tower, the calculated wind load is equally distributed at each node is given in Table 1.

TABLE 1

WIND ON TOWER BODY (N)

Height (m)	**Indian F_1**	**American F_2**	**British F_3**
119	1360.152	816.55	1550.739
114	1360.152	806.597	1550.739
109	1360.152	796.327	1550.739
104	1360.152	785.714	1550.739
99	1256.561	774.731	1196.244
94	1256.561	763.344	1196.244
89	1256.561	751.516	1196.244
84	1256.561	739.203	1196.244
79	1256.561	726.354	1196.244
74	1256.561	712.911	1196.244
69	1256.561	698.803	1196.244
64	1256.561	683.944	1196.244
59	1256.561	668.232	1196.244
54	1256.561	651.537	1196.244
49	1108.866	633.698	985.718
44	1108.866	614.508	985.718
39	1108.866	593.689	985.718
34	1108.866	570.867	985.718
29	992.838	545.503	820.567
24	992.839	516.791	820.567
19	992.838	483.423	695.336
14	862.066	443.031	620.133
9	780.014	390.49	502.25
4	780.014	309.732	360.389

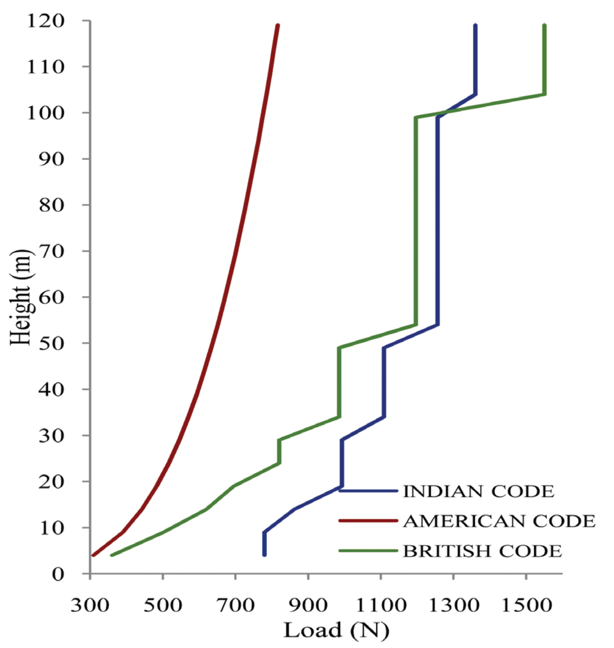

FIG. 3 VARIATION OF WIND LOADS

With the help of Table 1, the graph has been plotted, where the pattern of variation of wind loads with respect to three codes are shown in Figure 3.

It is observed from the above graph, The wind load intensity increases in upward direction. It is minimum at the bottom most point and maximum at top most point. The wind load calculated as per British Code shows maximum up to 100 m, but beyond 100 m the wind load is maximum as per Indian Standard Code.

The wind load calculated as per American code is minimum of three codes throughout the height of the tower. The pattern of wind load variation is almost same as per British and Indian Code, but it is different for American Code.

6.0 CONCLUSION

Based on the above study, following conclusions are made.

As per Indian code and American Code, the gust factor depends upon the solidity ratio, whereas, as per British code it depends upon height of the structures. The guyed tower design as per American Code leads to most economical, because the wind load variation is minimum. The British code gives the maximum load and it depends upon many parameters, it is desirable to consider all the parameters accurately. The Indian Code lies between these two codes.

7.0 REFERENCES

[1] B F Sparling and A G Davenport, "Three dimensional dynamic response of guyed mast to wind turbulence" Paper presented at the meeting of IASS-WG4, Wnnchester England, 1995.

[2] M K S Madugula, Y M F Wahba, G R Monforton, "Dynamic Response of Guyed Masts", Engineering Structures, Vol. 20, N0 12, pp 1097-1101, 1998.

[3] N Nabil Ben Kahla, "Response of a Guyed Tower to a Guy Rupture Under no Wind Pressure", Engineering Structures, Vol. 22, pp. 699-706, 2000.

[4] Y M F Wahba, G R Monforton, "Dynamic Response of Guyed Masts", Engineering Structures, Vol. 20, N0 12, pp 1097-1101, 1998.

[5] He Yan-Li, Wu-Jun Chen, Shi-Lin Dong and Zhao-Min Wang, "the dynamic stability investigation of practical guyed masts under random wind' Techno – press Journal, Volume- 6, 2001.

[6] Marcel Isandro R de Oliveira, "Structural Analysis of Guyed Steel Telecommunication Towers for Radio Antennas", J. of the Braz. Soc. of Mech. Sci. & Eng, 2007.

[7] Jorge S Ballaben, "Parametric studies of guyed towers under wind and seismic loads." 2011.

[8] Indian Standard Code of Practice for design loads (Part-3 Wind Loads) IS: 875 (part 3) – 1987.

[9] American Society of Civil Engineers (ASCE) Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-05).

[10] Loading for buildings-Part-2: Code of practice for wind loads (BS 6399-2:1997).