Analysis of Guyed Mast Using Gust Factor and Patch Load Method

Srinivas Tanuku and K. Rama Mohana Rao

Abstract Guyed masts have unique structural behaviour among other civil engineering structures due to their height, slenderness, light weight and overall flexibility of mast. Wind is predominant on these structures, are very sensitive to dynamic excitation from gusty wind due to flexibility associated with both mast-slender and guy cables. As per IS 875 (Part 3)-2015, dynamic wind loading shall be considered for such flexible structure using gust factor (G) method which is based on spectral characteristics of wind velocities, first natural frequency and damping ratio of structure, assuming that dynamic response at every point is a simple multiple of its static response of steady winds. Gust factor method is valid for structures with one or two dominant vibration modes, and it is not appropriate for guyed mast where 15–20 vibration modes contribute significantly to the response of structure to turbulent wind. In lieu of dynamic analysis Sparling et al. (J Int Assoc Shell Spatial Struct 37(2):89–106, 1996, [6]) proposed patch load method of analysis that utilizes a series of static load pattern to replicate effects of wind gusts and systematically accounts for the characteristics of mast and wind using empirical scaling factors. In this paper, study of gust factor method and patch load method for 100 m high guyed mast is undertaken through load calculation using gust factor and patch load method with geometrically non-linear analysis using STAAD Pro Advanced Analysis software along with comparison statement presented. From the analysis, gust factor method heavily underestimate leg forces in upper spans and bracing forces in middle of each spans and concluded that patch load method gives better approximation compared to gust factor method for analysis of guyed mast.

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1 Introduction

Guyed mast consists of tall structure laterally supported with pre-tensioned cables providing horizontal supports of greatest possible stiffness at several elevations spaced at equal angle around mast. The stability of guyed mast is influenced by the cross-section area of guy cables, second moment of area of mast cross-section and Guy cable initial tension which has both beneficial and determinantal effect on overall stability.

Wind is predominant load on analysis of guyed mast and due to turbulent nature of wind velocities, the wind loads acting on structure are also highly fluctuating. The back-ground response made up largely low-frequency contribution below the lowest natural frequency vibration is the largest contributor for along wind loading. The resonant contribution becomes more significant, when the lowest natural frequency is less than 1 Hz, will eventually dominate as structure becomes taller in relation to their width. When structure experience resonant dynamic response, Inertia force proportional to mass of structure, Damping and stiffness force proportional to deflection play counteracting structural forces to balance wind forces.

Maximum along wind response of flexible structures is obtained from product of mean static displacement and non-dimensional constant, the gust factor G, which involve spatial correlation and energy spectrum of gusty wind and as well dynamic characteristics of structures such as first natural frequency, damping ratio for the first vibration mode. Gust factor method (G) assumes that dynamic response at every point is a simple multiple of its static response of steady winds and shape of fundamental mode of vibration is a linear function of height. While this assumption is valid for one or two dominant vibration modes, it may not be appropriate for guyed mast where 15–20 vibration modes contribute significantly to the response of structure to turbulent wind.

The significance of non-uniform gust loading on continuous structure like guyed masts has been recognized for some time. As early as 1960, Cohen advocated the use of multiple load patterns to quantify gust effects. In addition to full wind loading on all spans, Cohen (1960) recommended the use of load patterns in which 25% of the wind load was removed from one span at a time while full wind load was applied to remaining spans.

The International Association for Shell and Spatial Structures (IASS) adopted a similar approach in their recommendation for the design and analysis of guyed mast [3]. In the IASS Procedure, the dynamic wind load (Defined as the difference between the gust and mean wind loads) is applied to mast using different load patterns: Load acting on all spans simultaneously, load acting on each span individually and load acting on all but one span for each span in turn. The total response envelope for each point along the mast is then obtained by determining the extreme positive and negative values of dynamic response from the patterned load cases and combining them with the response due to the mean wind load.

Gerstoft (1984) proposed a patch load method based partly on the dynamic analysis approach suggested by Allsop (1983). Gerstoft's method deals specifically with bending moments in the mast and does not address shear or deflections. The approximate back ground response is generated by utilizing two series of patch loads: one series consists of load patches applied to each span individually and is used to produce bending moment at guy support levels, while the second series consists of load patches extending from mid span to mid span of adjacent spans and is used to produce mid span moments. To model the lack of correlation between wind gusts, Gerstoft obtained the resultant back-ground response by combining the load path results as the root-sum-of-squares.

Davenport and Sparling (1992) introduced analysis procedure is an extension of Gerstoft's method. A simple, yet accurate method is provided to quantify the effects of resonant response. In addition, the scope of method is expanded to include shear forces in the mast as well as deflections. The dynamic response of guyed mast is clearly influenced by large number of factors including the structural properties, geometry and drag characteristics of the mast and guys as well as the velocity profile and turbulence characteristics of the wind. Results from a full dynamic analysis typically indicate a response (e.g. Displacement or force) that fluctuates about a mean value.

Davenport and Sparling (1992) divided the fluctuating part in to,

- Back-ground response
- Resonant response.

The back-ground response is slowly varying and occurs at a frequency below the fundamental frequency. Back-ground response will be influenced by the relative magnitude of the mast and support stiffness and by the distribution as well as magnitude of load. Allsop (1983) demonstrated that the shape of a given influence line was determined in part by the relative stiffness of the guys and mast. The back-ground component of dynamic response can be completely defined based on three factors,

- Result from the static patch load analysis
- A scaling factor based on stiffness parameter
- A scaling factor based on the length scale parameters.

The resonant response varies rapidly and includes contribution from a large number of vibration modes, each with distinct modal properties. The relative importance of the various vibration modes will vary from mast to mast and depend on type and location of the response being considered. For the broadest range of application, therefore, it is preferable that parameters used to represent resonant response be independent of modal properties so that they apply equally well to all modes. Allsop (1983) related the resonant response of guyed mast to a dimensionless parameter termed the inertial resistance factor, Q. This factor can be derived from the resonant response equations. Q is useful in that it reflects many of the variable associated with resonant response, including the mass, stiffness, drag characteristics and size of the mast, as well as the strength of the windstorm.

Sparling et al. [6] proposed simplified dynamic analysis by replacing gust factor technique with a method that utilizes a series of static load pattern to replicate the effects of wind gusts and systematically account for characteristics of mast and wind through use of empirical scaling factors. The resulting response eliminate location of zero response that are unavailable in conventional static methods, there by provide better approximation of full dynamic results.

Current paper deals with application of patch load method for parametric study for comparing to gust factor method. Detailed specifications, calculations are presented in subsequent sections.

2 Mast Specifications

A guyed mast of 100 m height with equilateral triangular cross-section is considered in current study to support telecom antenna equipment (3 × GSM + 3 × 1.2 m ø MW) for wind speed of 160 kmph of 3 s duration. Guy wires are connected at three levels spaced at 120° in three radial directions at 75 m radius from centre of mast. Mast is divided in to 17 sections consists of 6 m height except top section of 4.0 m with uniform face width of 1.0 m throughout mast height. Each section contains single lacing bracing pattern closed with horizontal member at every section. All legs are consisting of circular hollow section by considering their higher stiffness for small steel area, lesser wind resistance and bracings are of angular profiles for easy fabrication and installation with bolted connection on gusset plate (Fig. 1; Tables 1 and 2).

3 Load Calculations

Wind is predominant loads on these slender structures, the basic wind speed of 44 m/s, of peak gust velocity averaged over a short time interval of about 3 s with a mean probable structure deign life of 100 years situated in open terrain (Terrain category 1) is considered for analysis. The basic wind speed (V_b) shall be modified to include the effects of importance of structure, terrain roughness and height, local topographical features and cyclonic effects (if any) to obtain design wind speed (V_z) at any height is given by

$$V_z = V_b k_1 k_2 k_3 k_4 \tag{1}$$

3.1 Design Hourly Wind Pressure

The design hourly mean wind speed at height z, for terrain category 1 can be obtained as below.

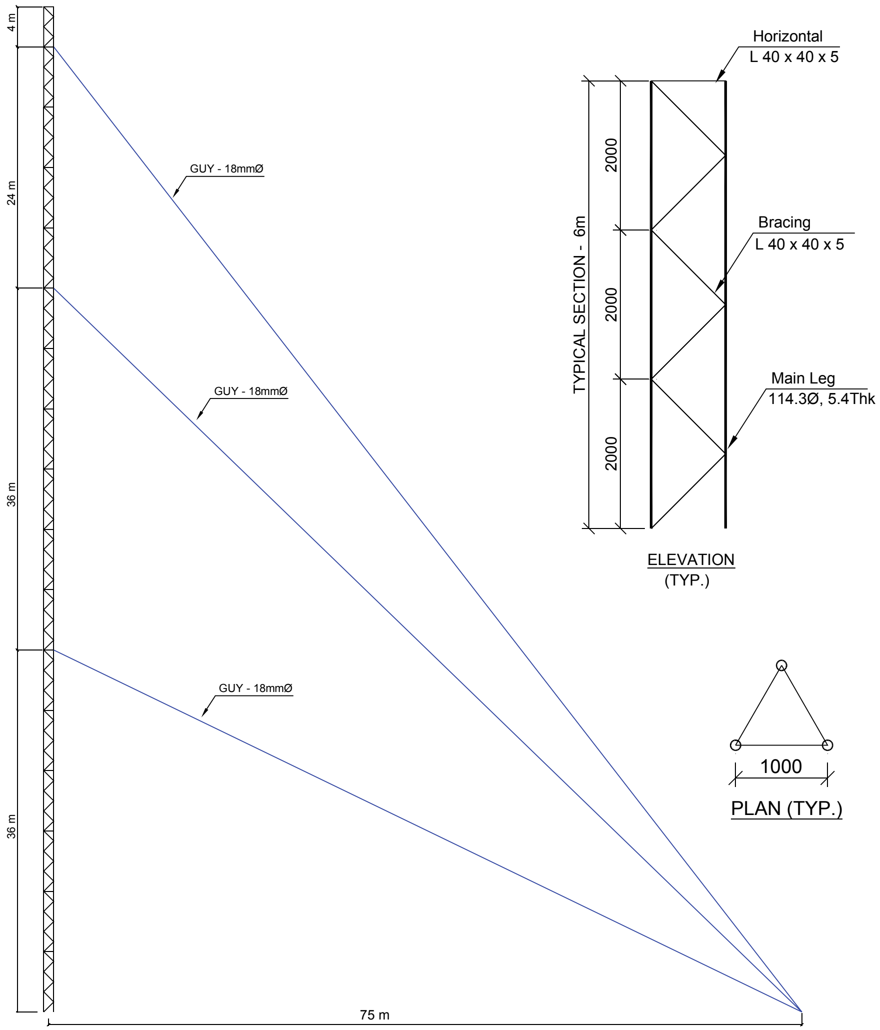


Fig. 1 100 m guyed mast configuration

$$\overline{V}_{z,d} = \overline{V}_b k_1 \overline{k}_{2,i} k_3 k_4 \tag{2}$$

where $\overline{k}_{2,i}$ is hourly mean wind speed factor for terrain category 1 is as follow:

$$\overline{k}_{2,i} = 0.1423\left[In\left(\frac{z}{z_{0,i}}\right)\right]\left(z_{0,i}\right)^{0.0706} \tag{3}$$

k_1 Risk coefficient, 1.07 for 100 years return period

Table 1 Material properties

Description		Legs	Bracings	Horizontal
Grade		S 355	E 250	E 250
Standard		IS 1161	IS 2062	IS 2062
Yield stress	MPa	355	250	250
Ultimate tensile strength	MPa	490	410	410
Cross-sectional area	mm^2	1268	378	378
R_{min}	mm	29.8	7.7	7.7
R_{med}	mm	29.8	12	12
Unit weight per metre	kg/m	9.96	3.0	3.0

Table 2 Guy wire details

Description		Guy 1	Guy 2	Guy 3
Height from base	m	36	72	96
Radius	m	75	75	75
Chord angle	Deg	25.79	44.02	52.19
Chord length	m	82.74	103.61	121.52
Nominal diameter	m	0.018	0.018	0.018
Area	m^2	1.9E−04	1.9E−04	1.9E−04
Weight per metre	kg/m	1.22	1.22	1.22
Modulus of elasticity	KPa	1.65E+08	1.65E+08	1.65E+08
Breaking strength	kN	232	232	232
Initial tension	kN	23.2	23.2	23.2

k_3, k_4 1.00 assuming flat terrain and non-coastal zone respectively.

The design hourly wind pressure at any height (z) is given by (Fig. 2)

$$\overline{p}_d = K_d K_a K_c \left(0.6\, \overline{V}_{z,d}^2\right) \tag{4}$$

3.2 Wind Resistance

Wind resistance is defined as the resistance to the flow of wind offered by the assembled components of tower and by any elements which it supports shall be derived from the force coefficient given in IS 875 (Part 3). The term wind resistance to encompass the combination of area, shielding effects and drag characteristics. For calculation of wind resistance, 100 m guyed mast has been divided in to series of sections to enable

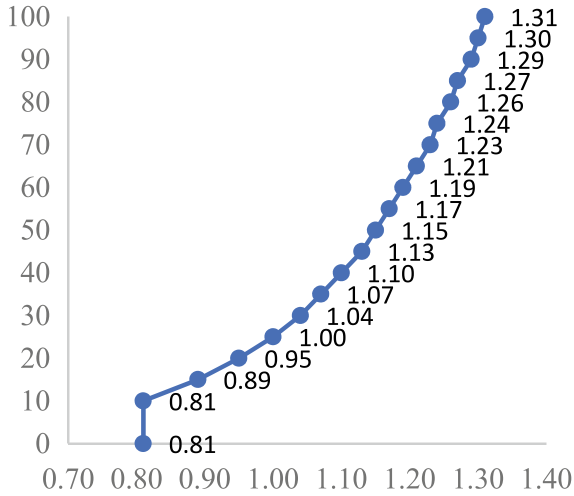


Fig. 2 Mean hourly design wind pressure (kN/m^2)

Table 3 Wind resistance

Mast, 6 m section	m^2	2.95
Linear accessories	m^2/m	0.17
3 × GSM antenna	m^2	2.80
3 × 1.2 m ø MW antenna	m^2	4.28

the wind loading to be adequately represented in analysis. Wind resistance of mast is constant throughout height due to constant cross-section. In addition, wind resistance of linear accessories (non-structural components that extend over several panels such as feeders, ladders) are calculated by assuming single frame and wind resistance of discrete accessories (Non-structural components that is concentrated within a few panels such as dishes, platform) are calculated by assuming individual member and their aspect ratio. Wind resistance of mast, linear and discrete accessories of mast are summarized as below (Table 3).

3.3 Wind Loads—Gust Factor

The design peak wind load on structure at any height is given by,

$$F_z = C_{f,z}\ A_z \overline{p}_d\ G \tag{5}$$

Gust factor (G) is the ratio of the expected peak value of response variable to the mean values, and is dependent on both the overall height and level under consideration. Gust factor accounts for the resonant and non-resonant effects of random wind

Table 4 Basic wind parameter

Aero dynamic roughness height	Z_0	0.002
Peak factor for upwind velocity fluctuation	g_v	3.0
Effective turbulence length scale	L_h	151
Structure first mode frequency	f_a	0.55
Peak factor for resonance	gR	3.98
Damping coefficient	β	0.02
Basic wind speed	V_b	44

pressure. It does not include allowance for a cross-wind loading effects, vortex shedding, instability due to galloping. Gust factor is estimated using following formula as per clause 10.2 of IS 875 (Part 3)-2015 as per notation in the code.

$$G = 1 + r\sqrt{\left[g_{v^2} B_s (1 + \Phi)^2 + \frac{H_s g_{R^2} \mathrm{SE}}{\beta}\right]} \tag{6}$$

Gust factor is reducing with increase in height. Using Eq. 6 and wind parameters as per Table 4 wind parameters, an average value of 2.06 is observed for 100 m high guyed mast.

Wind forces on tower body and linear accessories are distributed in all sectional points at an elevation equally, with a fact that force coefficient has accounted for both wind ward and leeward tower faces including shielding effect and symmetrical location of linear accessories with respect to centre of mast. And wind forces on discrete accessories are distributed to the respective member connecting joints as concentrated vector loads. In Triangular mast, the maximum leg loads occur in the single leg on axis of the tower in the wind direction with wind normal to one face. For bracing members, the maximum forces occur for wind parallel to face in the plane of bracing in wind direction. Therefore, three wind directions, i.e. 0°, 90°, 180° with respect to mast are considered for analysis (Fig. 3).

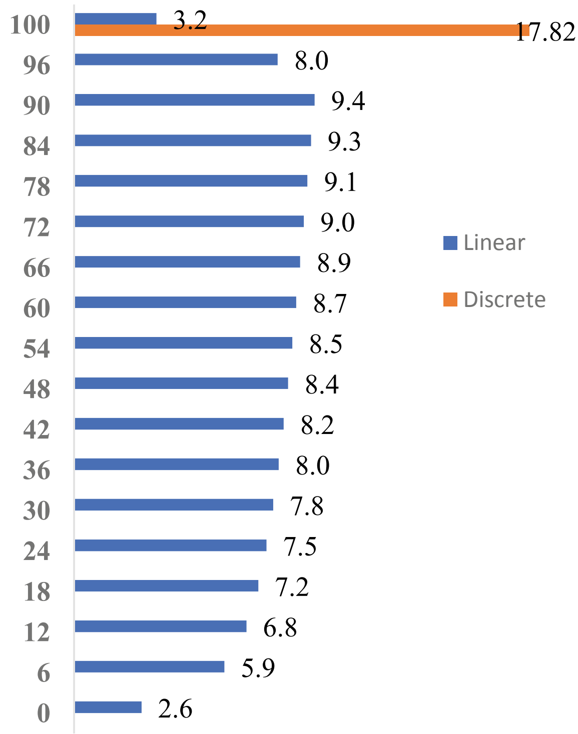
4 Patch Load Method

Patch load method analysis is undertaken in two stages, with the mean wind load effects considered separately from the fluctuating load effects. The design dynamic response $\hat{r}$ may be expressed as,

$$\hat{\mathbf{r}} = \overline{\mathbf{r}} \pm \hat{\mathbf{r}}_{\mathrm{PL}} \tag{7}$$

In which the peak fluctuating response is represented by the effective patch load response, $\hat{r}_{\mathrm{PL}}$. As with simplified procedure, the fluctuating response can be added to or subtracted from the mean response. Minimum criteria—height of cantilever,

Fig. 3 Wind load (kN) at each section by gust factor



tower stiffness and mast drag characteristics shall meet to apply patch load method in lieu of full dynamic analysis of guyed mast.

4.1 Mean Response

The mean component of the wind load is applied to the tower by taking in to account the large displacement effects in the tower, i.e. the non-linear properties of the guys and the second-order (P-Δ) effects associated with axial forces acting on the mast. This displaced position of the system under mean wind load is referred to as the mean equilibrium position. Mean wind speed profile shall be based on design hourly mean wind speed for mast site.

The mean wind load $\overline{F}(z)$ acts simultaneously at all points along the mast as well as on each of the cables and is given by expression

$$\overline{F}(z) = \frac{1}{2}\rho_a C_D(z)\ A(z)\ \overline{v}(z)^2 \tag{8}$$

To simplify calculations, the mean wind load applied to each cable is assumed to be uniform along its length with a magnitude based on the mean wind speed at mid height of cable. The mean equilibrium position of the mast is determined by using iterative Newton–Raphson solution technique. The static solution allows for non-linear guy stiffness characteristics, displacements of the guys due to the mean wind load, the effects of eccentric guy attachment to mast and *P*-Δ effects arising from vertical forces acting on the mast.

4.2 Peak Fluctuating Response

Calculation of the fluctuating response requires that a series of static analyses be performed for each wind direction. Results from the individual analyses are combined in the prescribed manner and scaled to the approximate magnitude using scaling factors.

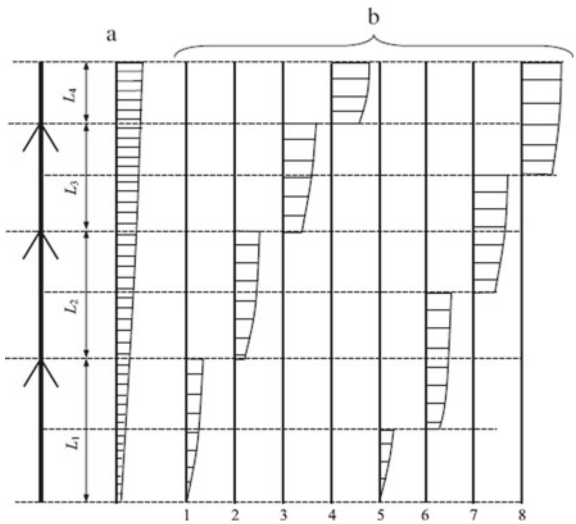
The Magnitude for individual patch load may be calculated as below

$$\overline{F}(z) = 2\, i_o q_0 \tag{9}$$

i_o is a Turbulence intensity, is often related to root-mean-square value of wind speed fluctuations and is depending on site condition, q_0 is mean hourly design wind pressure at a given height. For each load patch, the reference elevation used to calculate q_0 should be taken at mid height of that patch (Fig. 4).

The patch loads should be applied to structure in its equilibrium position under the action of mean wind loading. This may necessitates calculating the response for each

Fig. 4 Patch load cases for guyed mast with three guy levels



patch load as the difference between the response due to the patch load combined with mean wind load and the response due to mean wind load acting alone.

To simulate the lack of correlation in the fluctuating wind loads, the responses due to individual load patches are combined as the root-sum-of-squares as follows:

$$\bar{r}_{\mathrm{PL}} = \sqrt{\sum_{i=1}^{n} r_{\mathrm{PL}i}^{2}} \tag{10}$$

where $\bar{r}_{\mathrm{PL}}$ is the resultant patch load response, $r_{\mathrm{PL}i}$ is the response due to the ith patch load, and n is the total number of load patches that are required. By allowing for the lack of correlation in the gust load, at least in an approximate fashion, the root-sum-of-squares method of combining patch load results generates response pattern that similar to the back-ground component from the full dynamic analysis.

The design fluctuating response $\hat{\boldsymbol{r}}_{\mathbf{PL}}$ is then determined by the expression

$$\hat{r}_{\mathrm{PL}} = \bar{r}_{\mathrm{PL}}\, \lambda_B\, \lambda_R\, \lambda_{\mathrm{TL}}\, g \tag{11}$$

where

λ_B Back-ground scaling factor,
λ_R Resonant magnification factor,
λ_{TL} Turbulent length scale factor,
g Statistical peak factor equal to 4.0.

Using conservative values for scaling factors ($\lambda_B = 0.75$, $\lambda_R = 1.20$, $\lambda_{\mathrm{TL}} = 1.05$), the design fluctuating response $\hat{\boldsymbol{r}}_{\mathbf{PL}}$ can be simplified in to

$$\hat{r}_{\mathrm{PL}} = 3.78\, \bar{r}_{\mathrm{PL}} \tag{12}$$

4.3 Criteria for Use Patch Load Method

(a) The height of cantilever must be less than one-half the distance between the top two guy levels.

$$\text{Height of Cantilever} = 6\text{ m} < 1/2 \times 36\text{ m}, \\ = 6\text{ m} < 18\text{ m, Ok}$$

(b) Stiffness parameter (β_s). The ratio of bending stiffness of mast to the lateral stiffness of guys must be less than 1.0

Table 5 Elastic stiffness of guy wire

		Guy details		
		G1	G2	G3
A_{Gi}	m^2	1.9E−04		
E_G	kPa	1.65E+08		
θ_{Gi}	Deg.	25.79	44.02	52.19
L_{Gi}	m	82.74	103.61	121.52
H_{Gi}	m	36	72	96
K_{Gi}		469	238.9	148.1

Table 6 Calculation of stiffness parameter (β_s)

Elastic modulus of mast	E_m	kPa	2.00E+08
Average moment inertia of mast	I_m	m^4	9.24E-04
Average span length between guy levels	L_s	m	32
Number of guy levels	n	Qty	3
Stiffness parameter	β		**0.254**

$$\beta_s = \frac{4\left(\frac{E_m I_m}{L_s^2}\right)}{\frac{1}{n}\sum_{i=1}^{n} K_{Gi}\ H_{Gi}} \tag{13}$$

Elastic Stiffness of Guy at any level given as (Tables 5 and 6),

$$K_{Gi} = \frac{0.5\ N_i A_{Gi}\ E_{Gi} \cos^2 \theta_{Gi}}{L_{Gi}} \tag{14}$$

(c) Inertial resistance parameter (Q) which measures inertial forces relative to the damping forces must be less than 1.0 (Table 7)

$$Q = \frac{1}{30}\left(\frac{H\overline{V}_H}{D_o}\right)^{\frac{1}{3}}\left(\frac{m_0}{HR}\right)^{\frac{1}{2}} \tag{15}$$

From the above, current mast specification are comply with minimum criteria, hence patch load method can be applicable.

4.4 Mean and Patch Wind Load

See Tables 8 and 9.

Table 7 Mast inertia resistance parameter (Q)

Height of mast	H	m	100
Hourly mean wind speed at top	$\overline{V}_H$	m/s	46.7
Average mast face width	D_o	m	1.0
Average unit mass of mast including ancillaries	m_0	kg/m	117.3
Average wind resistance of the mast	R	m^2/m	0.49

Table 8 Design wind pressure (kN/m^2) for each patch load

Patch	Range (m)	p_a (kg/m^3)	z (m)	$K_{2,i}$	$\overline{v}(z)$	i_o	$\overline{v}_{ref}$	Wind pressure (kN/m^2)
1	0–36	1.22	15	0.82	41.2	0.14	39.3	2.78
2	36–72	1.22	45	0.92	46.2	0.12	39.3	2.56
3	72–96	1.22	75	0.97	48.6	0.11	39.3	2.42
4	96–100	1.22	95	0.99	49.7	0.10	39.3	2.35
5	0–18	1.22	7.5	0.76	38.0	0.16	39.3	2.85
6	18–54	1.22	30	0.88	44.4	0.13	39.3	2.66
7	54–84	1.22	60	0.95	47.6	0.11	39.3	2.49
8	84–100	1.22	88	0.98	49.3	0.10	39.3	2.37

Table 9 Wind Load (kN) at section wise for each patch load

#	Section Ht	Cum. Ht	Only mean (kN)	Mean load + respective patch load (kN)							
				P1	P2	P3	P4	P5	P6	P7	P8
P1	4.0	100.0	3.36	3.36	3.36	3.36	4.03	3.36	3.36	3.36	4.03
P2	6.0	96.0	4.95	4.95	4.95	5.95	4.95	4.95	4.95	4.95	5.95
P3	6.0	90.0	4.89	4.89	4.89	5.89	4.89	4.89	4.89	4.89	5.89
P4	6.0	84.0	4.82	4.82	4.82	5.82	4.82	4.82	4.82	5.83	4.82
P5	6.0	78.0	4.75	4.75	4.75	5.75	4.75	4.75	4.75	5.76	4.75
P6	6.0	72.0	4.68	4.68	5.69	4.68	4.68	4.68	4.68	5.68	4.68
P7	6.0	66.0	4.59	4.59	5.61	4.59	4.59	4.59	4.59	5.60	4.59
P8	6.0	60.0	4.51	4.51	5.52	4.51	4.51	4.51	4.51	5.52	4.51
P9	6.0	54.0	4.41	4.41	5.42	4.41	4.41	4.41	5.42	4.41	4.41
P10	6.0	48.0	4.30	4.30	5.31	4.30	4.30	4.30	5.31	4.30	4.30
P11	6.0	42.0	4.18	4.18	5.19	4.18	4.18	4.18	5.19	4.18	4.18
P12	6.0	36.0	4.04	5.02	4.04	4.04	4.04	4.04	5.05	4.04	4.04
P13	6.0	30.0	3.87	4.86	3.87	3.87	3.87	3.87	4.89	3.87	3.87
P14	6.0	24.0	3.67	4.65	3.67	3.67	3.67	3.67	4.68	3.67	3.67
P15	6.0	18.0	3.41	4.39	3.41	3.41	3.41	4.35	3.41	3.41	3.41
P16	6.0	12.0	3.03	4.01	3.03	3.03	3.03	3.97	3.03	3.03	3.03
P17	6.0	6.0	2.29	3.27	2.29	2.29	2.29	3.23	2.29	2.29	2.29

5 Analysis and Results

A guyed tower is analysed by approximating it as an equivalent continuous beam-column on non-linear elastic support. The initial condition of a structure for analysis taken as that under the un-factored dead load with the guys, at their initial tensions. The analysis is based on second-order theory to take in to account the effects caused by changes in geometry of the shaft and guys due to loading. This ensures that all important influences of the mast's deformation (the variation in guy stiffness depending on their axial stress and applied load, the influence of axial forces on the bending moments) on the distribution of internal forces are taken in to account. STAAD Pro Advanced Analysis software has been used for geometrical non-linear analysis of guyed mast through applying loads as indicated in Sect. 3.3 (Fig. 5).

5.1 Member Forces

See Fig. 6.

5.2 Displacements

See Fig. 7.

6 Summary and Conclusion

From the detailed analysis, following conclusions are drawn using patch load method compared to gust factor method.

- No Difference observed in leg forces at cantilever portion in both methods.
- 50% forces in Top Span and 15–16% increase in middle and bottom span leg forces observed, and 3% forces are increased in bottom most section in patch load method.
- 40% forces are increased in bracings which are located at mid location of each span in patch load method.
- 3%, 13% and 33% increase of guy forces are observed in bottom, middle and Top guy wires, respectively.
- Displacements are reduced in patch load method due to loading pattern and 20% reduction observed in top span while 5–8% observed in remaining spans.

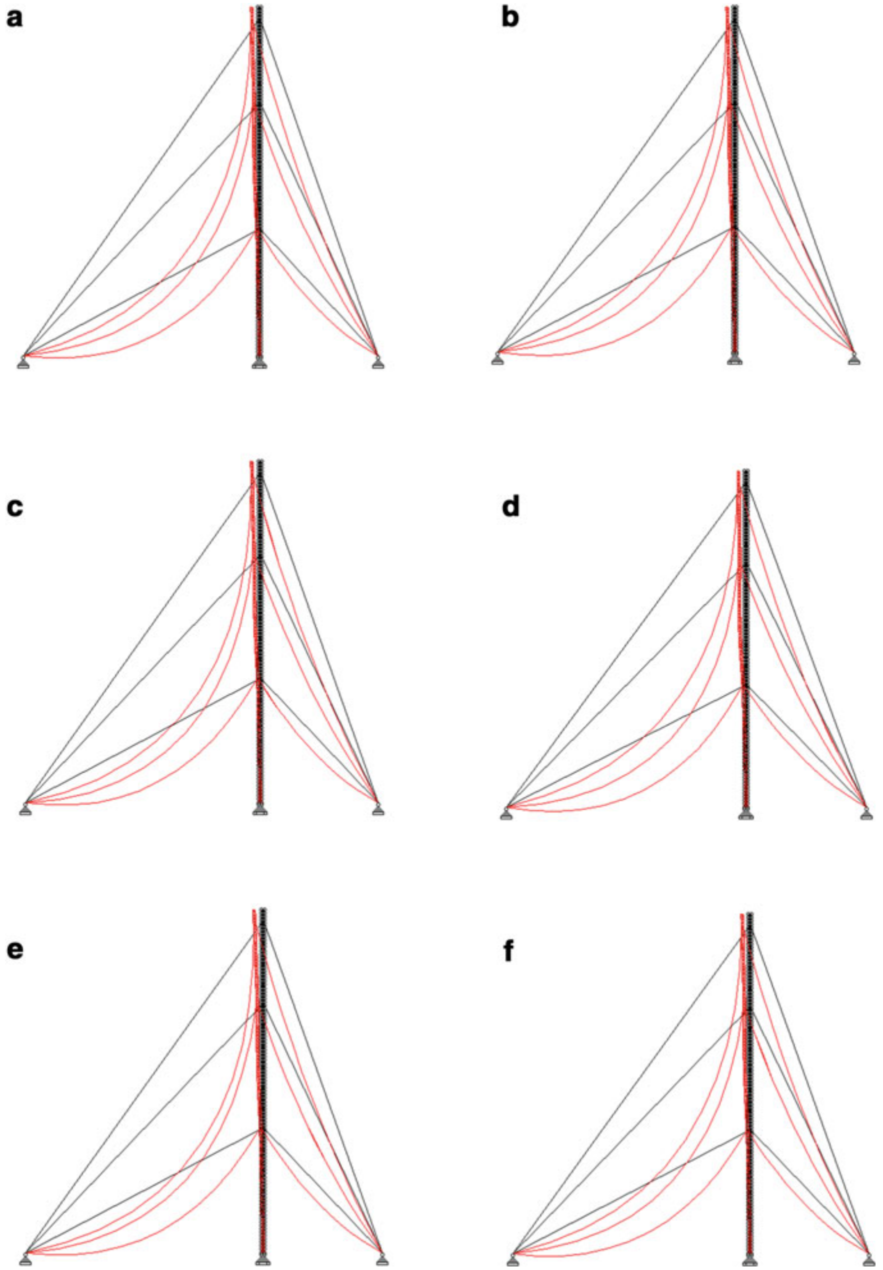


Fig. 5 Deflected profile of guy mast under various load cases. **a** Mean wind. **b** Mean wind + patch 1. **c** Mean wind + patch 2. **d** Mean wind + patch 3. **e** Mean wind + patch 4. **f** Mean wind + patch 5. **g** Mean wind + patch 6. **h** Mean wind + patch 7. **i** Mean wind + patch 8. **j** Gust factor

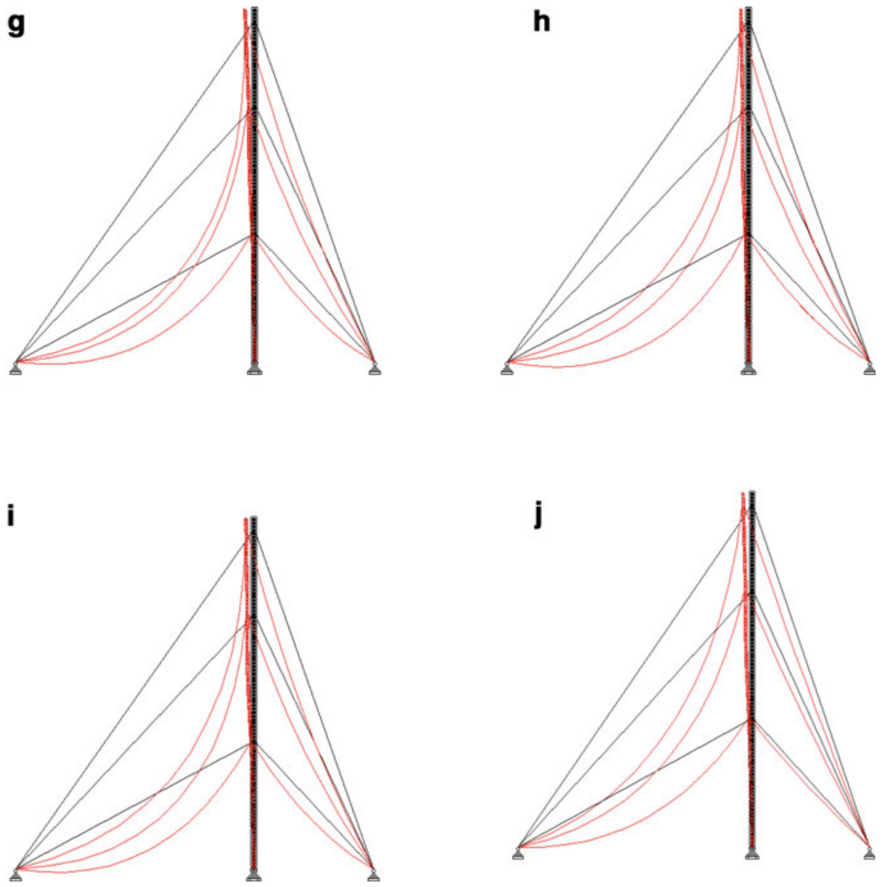


Fig. 5 (continued)

7 Conclusion

From the detailed analysis it is noticed that, gust factor method under estimated leg forces (15% leg up to middle span and 50% in Top Span). Similarly, 40–70% bracing forces are underestimated in middle of each span. Also, Guy Tension in Top Guy location is heavily underestimated. Hence, more emphasize shall be given at top span for main leg force (Huge Variation), bracing forces in middle of each span as well Top Guy Wire while using gust factor method compared to path load method. It is also realized that these variations of forces may vary based on stiffness parameters and Mast Inertia resistance perimeter. Therefore, patch load method gives better approximation of analysis results in lieu of full dynamic analysis compared to gust factor method for guyed mast.

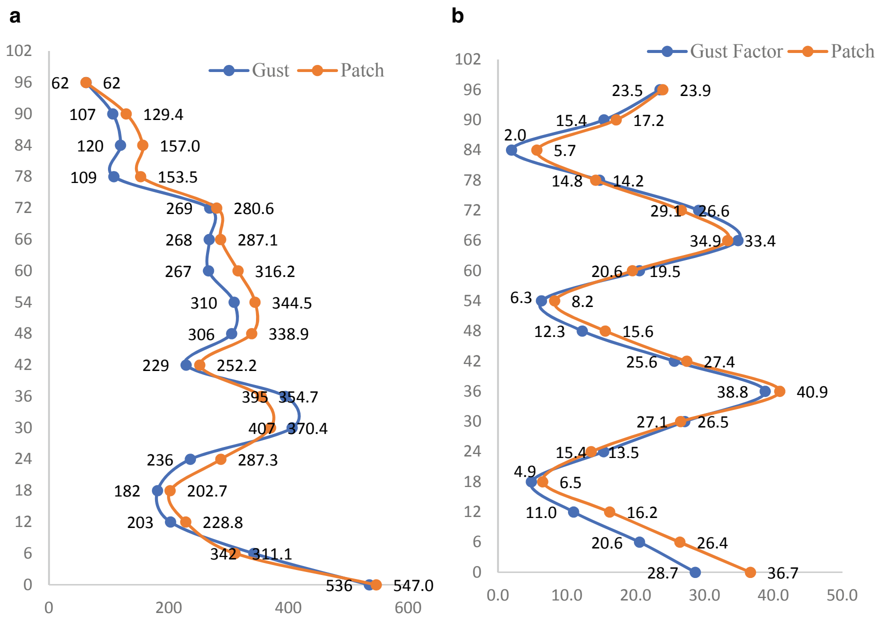


Fig. 6 **a** Leg force comparison. **b** Bracing force comparison

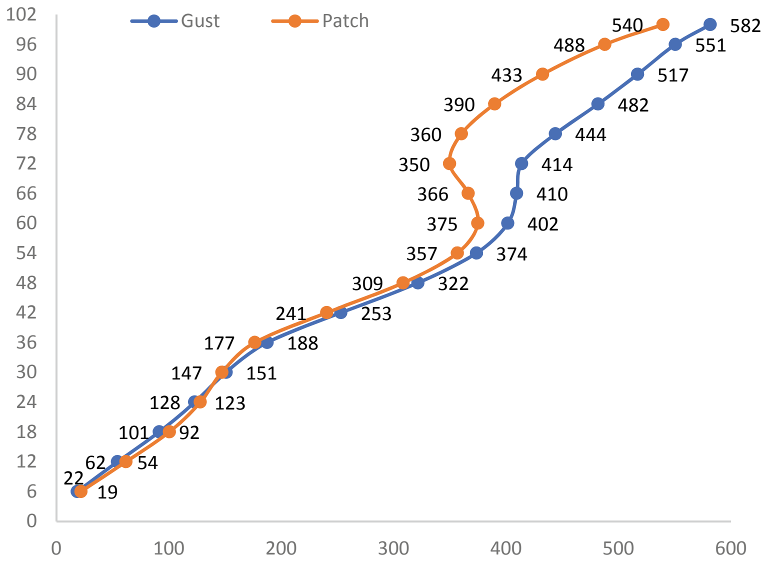


Fig. 7 Maximum displacements (mm) @ service loads, design wind speed

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