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Linear Analysis of Guyed Mast Subjected to Wind, Ice and Seismic Loading

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ABSTRACT
Masts are, tall structures designed to support antennas for telecommunication, broadcasting and television. They are among the tallest man-made structures. The telecommunication guyed mast towers are the kind of towers which are not self-supporting and requires external support of guys to stand. In the present work structure has been modeled with two node space truss element. Equivalent static wind loads has been calculated as per IS 875-1987 (part3).This paper aims at investigating the, linear time history, structural non linearity of the structure subjected to the influence of wind, ice and earthquake loading. For the purpose of research activity, a 100m mast tower has been analyzed using SAP2000V14. Loads will be calculated and the structure will be modeled using SAP2000v14.
Keywords - Guyed mast, linear analysis, wind load, ice load, natural frequencies.

I. Introduction

Guyed towers are almost exclusively used for communication purposes and structural reliability of guyed communication towers is becoming an important factor in the ever-increasing demand for wireless communication technologies. The major loads acting on the structure are wind load, wind gusting load, equivalent static earthquake and transient analysis. In this paper the attention is focused mainly on wind loading. A guyed tower is generally a non-linear structure in which the mast, typically consisting of multiple truss members and of triangular or square cross section is supported laterally at several points by inclined guy cables. In our present study a linear static analysis of guyed mast are considered for its structural response. Masts supported laterally by guy cables usually provide a more economical solution for taller towers.

The cables are anchored to the ground and are always pretensioned. Due to overall flexibility, slenderness and lightweight, guyed masts are susceptible to large deflections and also exhibit high dynamic sensitivity to turbulent winds. As a result, dynamic analysis is considered imperative for calculating the peak axial forces in the mast. A suitable structural dimension of the model is identified and the wind forces acting on the structure is calculated at different guy levels. The standard approach for the equivalent static analysis of line-like structures, based on the gust factor, is reviewed, with special reference to the case of systems with intermediate elastic supports, like cable-stayed masts. A new analysis method, based on the definition of a gust function variable along the height is proposed and applied to a case study. The loads will be calculated as per IS 875-1987 (part3).The linear static analysis will be carried out using SAP2000V14.

The preliminary design is done. The dimensions of mast is fixed by trial and error method. The height of the mast is fixed as 100m. Base width of the mast is 1m. prestressed cable diameter as 20mm. Most research has been undertaken into the modeling of a guyed mast as an equivalent beam element. The self-weight of a lattice truss is substantially different to that of a beam element with similar behavioral properties.

In order to control the dead load and mass of the mast, the self-weight and mass of the mast (calculated from section properties of the equivalent beam) were set to zero. The correct values, calculated from the original lattice mast were then applied as additional loadings and masses to the mast. The equivalent beam stiffness for the masts used in this research had already been calculated. In order to accurately model the masts a number of initial assumptions needed to be made and validated.

II. Linear analysis

Any practical structure having mass and elasticity tends to vibrate on application of external loading. Analysis of the structure is conducted to determine the distribution of forces and deformation induced in the structure by the ground shaking. Linear procedure is applicable to the structure that responds in an elastic manner. The linear static analysis is done.

Wind load is calculated by using IS875 (part 3)-1987. Apply the load on one face of the mast. Analyze the mast and deflection at top is obtained. Validate the journal for analysis and design of guyed transmission towers-case study in Kuwait (H. A. EI-Ghazaly and H. A. AL-Khaiat,1993).

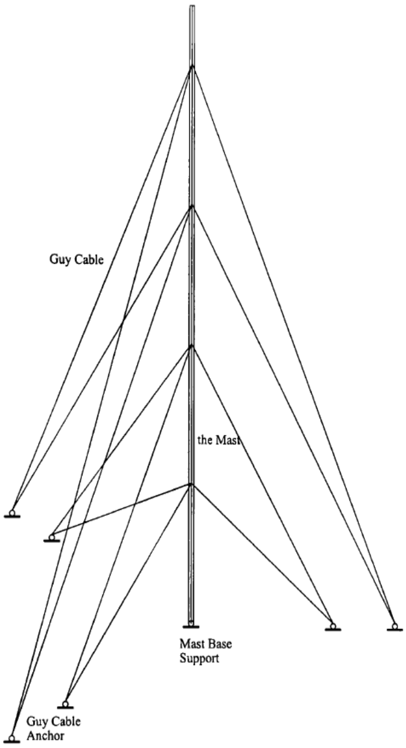

Fig.1: Structural model of a typical guyed mast

A two-dimensional guyed tower was analysed. The tower is modelled using three beam-column elements, pinned at base and supported at the three levels by prestressed elastic guys. The guys are considered as straight elastic cable element. The deflection value of guyed mast at top guy level (ie.at 96m) as $7.5x10^{-5}$m.

III. Finite Element Analysis

For analysis of guyed mast the mast is modelled as frame element and cables are modelled as truss element. The Fig.3 shows the plan view of guyed mast. FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

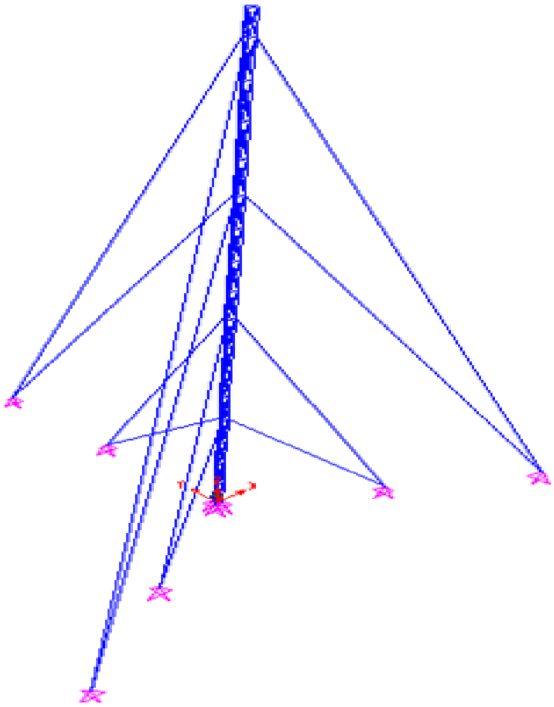

Fig.2: 3-D view of 100m guyed mast

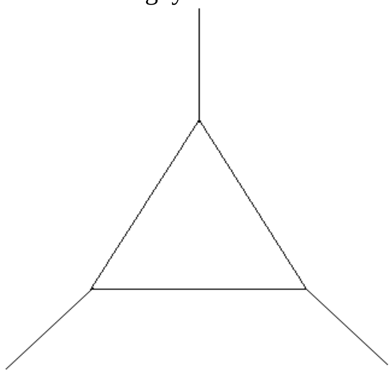

Fig.3: Plan View of a guyed mast

Table 1.Wind data from code

Data	Design Values
Wind zone	2
Wind speed	39m/s
Area of tower	20.106m^2

Table 2.Wind loads at each guy level of the mast

Applied Wind Load	Load (kN)
24m	2.58
48m	6.27
72m	7.98
	9.25

96m	

IV. Analysis Under Wind Gust Loading

The wind gust load is calculated by using IS875 (part 3)-1987 that specifies the steps for the construction of a static load. Some modifications are introduced in order to take into account the dynamics of the wind velocity, modeled by the following equation. The standard defines the static wind gust load as:

$$F = q_z \text{ x } G \text{ x } C_f \text{ x } A_f \qquad (1)$$

Where, F= magnitude of the wind load; G=gust coefficient; A_f =exposed area of the mast; C_f is a coefficient which takes into account the shape of the structure.

Validate the journal for parametric studies of guyed towers under wind and seismic loads (Jorge S. Ballaben and Alberto M. Guzman, 2011). A 120m, three-dimensional guyed tower was analyzed. The tower is modeled using three beam-column elements, pinned at base and supported at the four levels by pre-stressed truss element. The deflection value of guyed mast at top guy level(ie.at 96m) as 0.0175m.

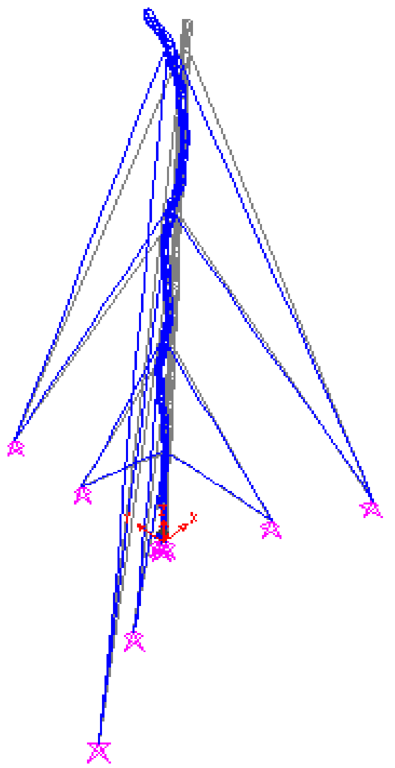

Fig.4: Deflection Diagram for static wind loading

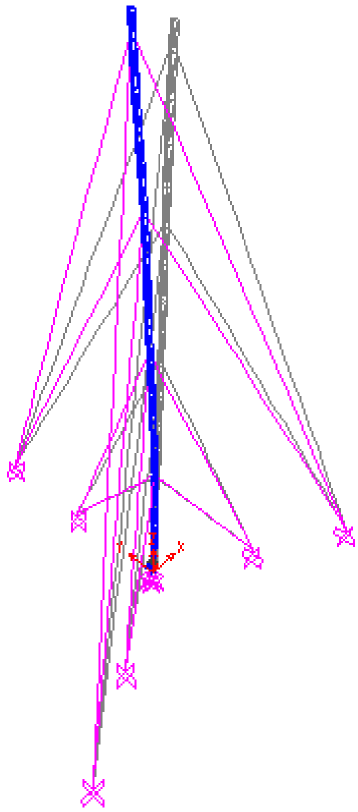

Fig.5: Deflection Diagram for wind gusting

Table 3.Wind gusting at each guy level of the mast

Applied Wind Load	Load (kN)
24m	0.64
48m	1.98
72m	2.76
	2.98
96m	

V. Ice Loads

Ice accumulation on a structure increases both the area and weight, resulting in additional force. Increased surface area captures more wind, equating to more wind force on the tower and appurtenances. In reality, Ice and Wind with Ice may be the culprit in a significant number of tower failures. Logic tells us that if proper considerations had been made, following published guidelines during design, fabrication and installation, the cause of tower failure may not be Ice or Wind with Ice.Mass density of ice = 0.90 g/cm^3.

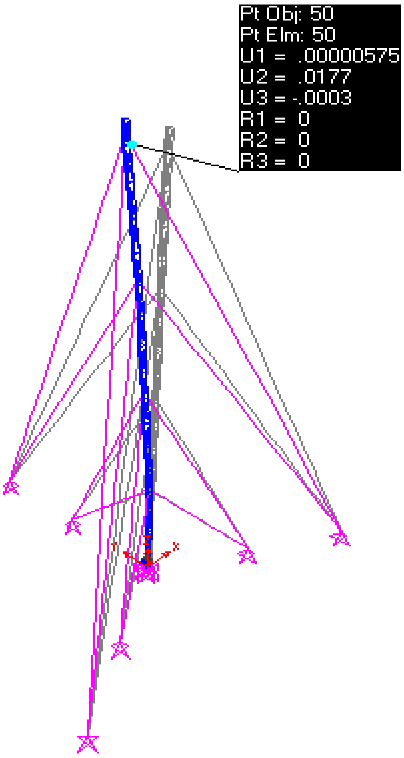

Fig.6: Deflection Diagram for combination of wind and ice load

VI. Analysis Under Equivalent Static Earthquake Loading

Seismic data for mast

1. Zone factor = 0.16(zone III)
2. Soil type = medium soil
3. Response reduction factor(R)=5(steel frame with eccentric bracing)
4. Importance factor (I) = 1.5
5. Damping = 5 %

Sample calculation:

At 24m, the loads are calculated by,

T= 0.3594 sec

$V_B = A_h \times W$

Where, V_B= Design seismic base shear

W=Seismic weight of the structure

$$A_h = \frac{Z\,I\,S_a}{2\,R\,g}$$

$$= \frac{0.16 \times 1 \times 2.5}{2 \times 4} = 0.05$$

Where, A_h = Design horizontal seismic coefficient

Z = Zone factor (Table 2, IS 1893(Part 1:2002))

I = Importance factor (Table 6, IS 1893(Part 1:2002))

R = Response reduction factor (Table 7, IS 1893(Part 1:2002))

S_a/g= Average response acceleration coefficient

V_B= 0.901kN

$Q_i = V_B \times (w_i h_i^2 / w_j h_j^2)$

= 0.03098kN

Where, Q_i= Design lateral force at floor i.

w_i= Seismic weight of floor i.

h_i= Height of floor i measured from base.

VII. Ground Motion

The characteristics (intensity, duration etc..) of seismic ground vibrations expected at any location depends upon the magnitude of earthquake, its depth of focus, distance from the epicenter, characteristics of the path through which the seismic waves travel, and the soil Strata on which the structure stands.

The time histories of these events were downloaded from the Pacific Engineering and Earthquake Council's website (PEER 2005), where records are maintained from practically all large seismic events that have been recorded. The records are resolved into three orthogonal components, two horizontal and one vertical, and tabular forms of the acceleration, velocity, and displacement time histories are available, as well as the acceleration response spectra at different levels of damping. Earthquake causes impulsive ground motions, which are complex and irregular in character, changing in period and amplitude each lasting for a small duration. Therefore, resonance of the type as visualized under steady-state sinusoidal excitations, will not occur as it would need time to buildup such amplitudes.

The Northridge earthquakes were chosen for the analysis. Time histories in all three directions were available for these two earthquakes. The choosen accellogram is Northridge, January 17th, 1994, 24514 Sylmar - Olive View Med FF, horizontal component Syl360, magnitude of 6.7, duration 20 s, PGA 0.843 g.

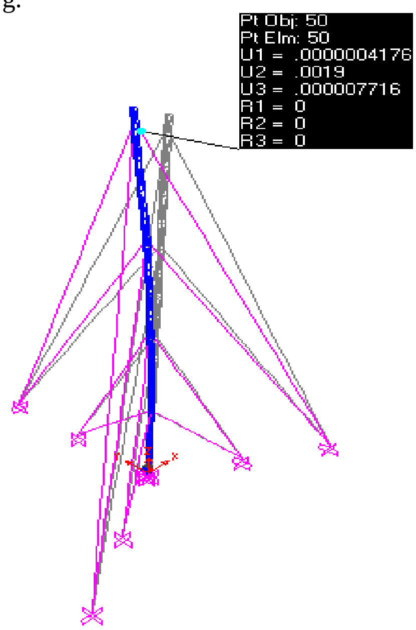

Fig.7: Deflection Diagram of mast subjected to equivalent static earthquake for 100m

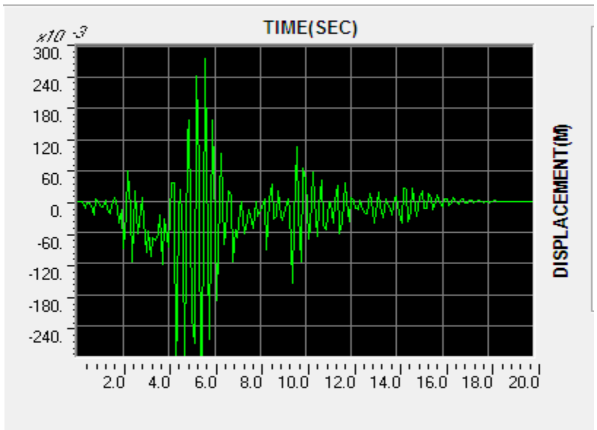

Fig.8: Results of 100m mast subjected linear transient analysis (at top guy level).

VIII. Conclusion

The static wind load of a 100 m tall guyed mast is analytically determined. In the present study the wind load is considered as a static load only, whereas at high wind loads dynamic effects may also be considered. In the analysis, the displacement on the top of the mast, a significant decrease is present when pretension increases. In the wind case, the tower becomes stiffer as the pretension is increased.

Results obtained from 3D models suggest the following conclusions: A finite element based methodology was successfully applied to determine natural frequencies and mode shapes of guyed towers. Steel guyed masts may be designed specifically to meet the requirements of regional, national and international communications.

Guyed towers are generally very tall. As a result, the self-weight of tower imposes a considerable axial load on the lower portion of tower mast. It was found that the tower self-weight affects the first few natural frequencies of a tower mast. As such, self-weight effects were considered in the analysis. Geometric non-linear dynamic response of the guyed mast was examined and it was found that none of the chord members failed. If proper considerations and guidelines are considered during design, fabrication and installation of guyed mast, the cause of tower failure can be avoided.

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