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Structural Response of Lattice Steel Masts for Seismic Loading

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ABSTRACT : *The wind excitation induces fluctuating stresses with randomly varying amplitudes around mean deformation states leading to fatigue damage accumulation. For the design of such structures, it is important to study their dynamic behavior and fatigue damage under wind excitation. 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). In the last years, a lot of new issues have been arisen regarding the structural behavior of steel lattice masts which are used either for telecommunication needs or as systems to transfer energy. As environmental effects are becoming more severe and the earthquake phenomenon is taken into account in a more detailed way according to the modern codes for earthquake resistance structures, the thorough investigation of the performance of these structures becomes imperative. The present paper aims at investigating the structural response of these special structures subjected to the influence of wind loading, as well as the combination of wind loading and ice. For the purpose of research activity, 6 types of steel masts have been analyzed, namely 4 masts located on the ground and 2 masts located on buildings.*
Keywords - *structural response, combined effects, Seismic loading, Steel lattice masts, wind loading,*

I. INTRODUCTION

Lattice steel towers are used for a number of diverse purposes, namely, telecommunications, radio and television broadcasting, observation, power transmission and lighting supports, etc. The need to design a lattice tower for resonant dynamic response due to wind load arises when the natural vibration frequency (fundamental frequency) of the structure is low enough to be excited by the turbulence in the natural wind [1]. Although, initially the design wind speeds are obtained by multiplying the mean wind speeds with gust velocity factors to allow for the fluctuations in the wind speed, the neglect of both the dynamic properties and size of the structure could result in an unsafe structure or conservative design of a structure. The structural loads produced by wind gusts depend on the size, natural frequency and damping of the structure. The structural failure which is directly attributable to gust action, emphasizes the importance of these par ammeters in arriving at the gust wind load.

During the past few years there has been increasing interests for the design of radar satellites to operate in medium Earth orbit in order to provide better coverage than low Earth orbit. Such technology will require fewer satellites for global coverage and thus reduce the overall system costs [2]. A radar antenna operating in MEO has to be so large that it could not launch on existing rockets. Inflatable technology is the solution to this problem. While NASA has flown more missions with mechanically deployed systems so far, inflatable structures can be compressed into far smaller packages and offer a solution not currently available using traditional components. Many proposed inflatable designs for space applications consist of truss-like or lattice structures due to their simplicity of construction and large stiffness to mass ratios [3]. Therefore inflatable lattice type structures are a very suitable solution for space applications and there is primary need for understanding the dynamic behavior of such structures. In some cases the financial and social consequences caused by a possible collapse of this kind of structures are considered as damaging as those caused by the collapse of traditionally significant infrastructure, such as bridges. For the purpose of the herein presented research activity, 6 types of steel masts have been analyzed, namely 4 masts located on the ground and 2 masts located on buildings. The study was carried out by means of innovative software in order to introduce the wind actions as thoroughly as possible and simulation models have been configured for the masts under investigation incorporating all special geographical parameters and structural arrangements.

Phill-Seung Leea, Ghyslaine McClureb (2007) they develop a numerical model for simulating ultimate behavior of lattice steel tower structures. They present the elastoplastic large deformation analysis of a lattice steel tower structure using finite element analysis and they compare the numerical results with full-scale destructive tests [5]. A 2-node three-dimensional L-section beam finite element proposed in our previous work is used. The beam finite element can consider eccentricities of loading and boundary conditions as well as material and geometrical nonlinearities. They model a real tower structure section using the beam elements and perform a nonlinear static analysis to obtain the limit behavior of the tower in two different load cases. The numerical results are discussed in detail.

II. ACTIONS ON STEEL LATTICE MASTS

II.1 Permanent actions, imposed loadings and earthquake loading

The basic loads that are considered in the design of a steel telecommunication lattice tower are the dead loads of all the elements, the imposed live loads, the environmental loads and the earthquake action [6]. Regarding the permanent actions on the steel mast, these include the dead load of the structure (the self-weight), the ladder, the several dish reflectors of different diameters that a mast carries and the working platform, located at specific heights of the structure, according to the type of the mast.

II.2 Wind Loading

Wind is air movement relative to the surface of the earth due to pressure differences in the atmosphere. The pressure differences are produced by differential solar heating of the earth's surface and the forces generated by the rotation of the earth. A detailed discussion on wind load on various structures has been given in Chapter II. However, a brief is given here with special reference to towers. The design wind speed V_z (m/s) is given by[7]

$$V_z = V_h \,.\, k_x \,.\, k_1 \,.\, k_i$$

Where V_b = basic wind speed in m/s at 10 m height. k_1 = probability factor (or risk coefficient). k_{II} = terrain, height and structure size factor

K_3 = topography factor, the value of which varies from 1 to 1.4, depending upon the topography; for plain lands, k_3 = 1.

The design wind pressure is given by

$$p_z = 0.6$$

where p_z = design wind pressure (N/m^{II}) and V_z is the design wind speed (m/s).

The wind force on any member is given by

$$F = AC_f\, p_z$$

$$V_z^2$$

A = effective frontal area.

where

C_f = net wind force coefficient, which depends upon solidity ratio = of the tower (Table II.1, II.2 and II.3)

= Solidity ratio = $\dfrac{\text{Obstruction area of the front face}}{\text{Gross area of the front face}}$

For towers, ϕ varies from 0.15 to 0.3, and is to be assumed in the beginning of the design. After designing the members, the assumed solidity ratio is compared with the actual solidity ratio to test the adequacy of the structure.[8]

Table II.1 values of net wind force coefficient C_f for towers composed of flat sided members

Solidity ratio = ϕ	C_f for	
	Square towers	Equilateral triangle towers
0.05	4.0	3.3
0.1	2.2	3.1
0.2	1.9	2.7
0.3	1.7	2.3

Table II.2 force coefficient C_f for square towers composed for rounded members

Solidity ratio = ϕ	C_f for			
	$D.V_d \leq 6m^2/s$		$D.V_d \geq 6m^2/s$	
	face	corner	face	corner
0.05	2.4	2.5	1.1	1.2
0.1	2.2	2.3	1.2	1.3
0.2	1.9	2.1	1.3	1.6
0.3	1.7	1.9	1.4	1.6

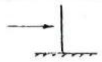
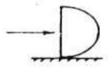
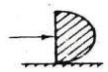
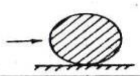
Table II.3 force coefficient C_f for equilateral triangle towers composed for rounded members

Solidity ratio = ϕ	C_f for	
	$D.V_d \leq 6m^2/s$ (all wind direction)	$D.V_d \geq 6m^2/s$ (all wind direction)
0.05	2.5	1.1
0.1	2.3	1.2
0.2	2.1	1.3
0.3	1.9	1.4

Tower Appurtenances the wind loading on tower appurtenances, such as ladders, conduits, elevators etc. shall be calculated using appropriate net pressure coefficients for these elements. Allowance may be made for shielding effect from other elements.

Tower mounting: Usually, towers have mounting such as antenna dishes etc. the pressure on these mounting can be computed by suitably selecting pressure coefficient.

Table II.4.The values of C_f for some limited shapes

Side Elevation	Description of Shape	C_f
	Circular disc	1.2
	Hemispherical Bowl	1.4
	Hemispherical Bowl	0.4
	Hemispherical Solid	1.2
	Spherical Solid	0.5 for $V_d D < 7$ 0.2 for $V_d D \geq 7$,

II.4 Analysis and Designing Lattice Towers:

As stated in the previous article, lattice towers are subjected mainly to two types of loads:

(i) Gravity loads due to self wei g ht etc.

(ii) Lateral loads

(iii) The wind loads, acting a t the panel points have two effects:

(a) Horizontal shear effect due to lateral load :

(b) Vertical .force due to moments due to lateral load.

The lateral load due to wind is resisted mainly by the web members while the gravity loads and the vertical force due to wind moments are resisted by chords or leg members. Since has predominant effect, the wind loads on the exposed area of the windward face and leeward face, including shielding effect should **be** carefully evaluated, as explained in the previous article. Solidity ratio has to the assumed in the beginning, for the computation of wind loads. For the design of legs of a square base tower, the critical wind direction is along the diagonal, as shown in "Fig (1)'' as the Moment due to lateral loads is resisted by only two legs *B* and *D* . At any level under consideration, let W_g be the gravity load and M_w be the moment due lateral loads.[9]

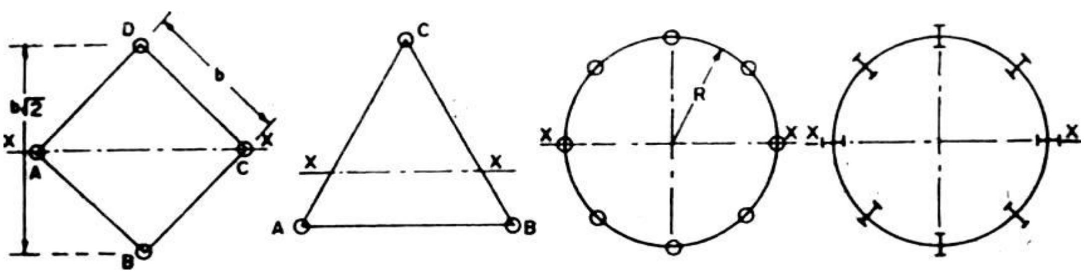


Fig.1.Maximum vertical force in posts.

(A) SQUARE **(B) TRIANGULAR** **(C) MULTI-POST**

The lateral load (i.e. wind shear) is resisted by the web member in tension at the section. In the analysis, the effect of compression web members is known. The leg members are designed as compression members while the web members are designed as tension members. The width of base is taken equal to 1/8 to 1/12 of the height while the inclination or pitch of the sides is kept between 1/16 to 1/40.

III. STUDY OF THE STEEL LATTICE MASTS: ANALYSIS AND RESULTS

The present paper deals with the study of the four most commonly used types of steel lattice telecommunication towers located on ground as well as with two masts located on top on buildings, and focuses on their behavior especially regarding the influence of the environmental actions and the combined effects on their structural capacity. [10]

Table III.1: Cross-sections of the steel masts under investigation

Dimension	Legs Horizontal	face members	Main bracings
0.50m x 0.50m	L80x8	L70x7	L45x5
1.40m x 1.40m	L80x10	L60x6	L60x6
2.50m x 2.50m	L80x10	L70x7	L60x6
4.30m x 4.00m	L110x10 L120x12	L70x7	L60x6

All special features of the material, the used bolts, as well as the geometrical parameters and local conditions were incorporated in the simulation models. The basic loads considered in the study of the masts were the dead loads of all the elements, the imposed live loads, the environmental loads and the earthquake action. Regarding the permanent actions on the steel mast, these included the dead load of the structure (the cross-sections used), the ladders, the antennas and the platforms. As far as the imposed live loading is concerned, the calculation was carried out taking into account the variable loads of the staircase and the working deck.

III.1 Comparative study

III.1.1 Results Due To Wind

The bending moment and shear force are computed for wind and seismic loading with the help of IS 875: PART III. [11]

Example	Solidity ratio	By theoretical calculation		By software calculation	
		Max B.M.(KN.m)	Max shear force (KN)	Max B.M.(KN.m)	Max shear force (KN)
6m mast	0.15	23.08	3.5	23.87	3.39
8m mast	0.24	533.25	18	540.52	18.09
12m mast	0.28	3454.95	172	3450.22	171.36
18m mast	0.33	5437.42	261	5440.33	263.44
12m mast on 15m building	0.28	8563.47	987.56	8595.46	994.36
18m mast on 17.5m building	0.33	10466.54	1626.5	10898.44	1663.44

III.1.2 Results due to seismic load

Structure	Mode	Frequency	Period	Base Shear	Displacement
6m	1	0.178	0.561785	0.29	0.584
	2	0.2	0.99724		
	3	2.118	0.04725		
8m	1	0.082	0.2819	3.90	0.976
	2	0.344	0.21509		
	3	3.301	0.09355		
12m	1	3.547	0.3595	5.38	1.105
	2	4.649	0.2879		
	3	10.690	0.10513		
18m	1	2.781	1.1783	7.44	1.756
	2	3.347	2.90663		
	3	9.512	0.3127		

IV. CONCLUSIVE REMARKS

In the present report, analysis of a steel tower has been presented using finite element method. Three dimensional configuration of the truss has been considered and computer code has been developed for finding the joint deflections, member forces and support reactions due to equivalent static wind load. Some of the conclusions arrived at the present study are as follows Spectral density of the displacement of the member shows peak values at the natural frequencies of the tower. According to the assessment of sample of steel lattice telecommunication masts, the shear in seismic analysis is very less as compared to wind analysis so wind load is main governing load is considered for design. In case of masts with small relative height, the performance of structure is not affected. However, as the height increases, the seismic combination causes more effect. With respect to deformations developing at the top of the steel lattice masts in example, the maximum values of the horizontal displacements are showing. It is observed that the maximum displacement caused due to the combined effect with respect to wind combination and the height of masts increases, the displacement increases.

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