Aerodynamic damping of telecommunication lattice towers

Ileana Calotescu [a], Daniel Bîtcă [b], Giovanni Solari [c]

[a] *Technical University of Civil Engineering Bucharest, Lacul Tei 122-124, Bucharest, Romania*
[b] *Technical University of Civil Engineering Bucharest, Lacul Tei 122-124, Bucharest, Romania*
[c] *DICCA, Polytechnic School, University of Genoa, Via Montallegro 1, Genoa, Italy*

ABSTRACT: Lattice towers are structures generally considered to be sensitive to wind loading, mainly due to their low mass. However, low mass structures possess considerable aerodynamic damping which has a reduction effect on the along-wind induced dynamic response. The main purpose of the study is to investigate the effect of various parameters such as the force coefficient and the design velocity pressure on the aerodynamic damping of antennae towers. As such, a parametric study consisting in the design of seven towers of various heights, i.e. 90m, 80m, 70m, 60m, 50m, 40m and 30m to along-wind loading has been conducted. All towers have a triangular in-plane section. Circular cross-sections were used for leg members whereas both circular as well as angle cross-sections were used for diagonal, horizontal and secondary members. All towers have been considered to be equipped with both ancillaries as well as antennae, the same configuration being used for all the design cases. Similar values of aerodynamic damping were obtained for towers of similar heights, irrespective of the cross-section of bracing members. Also, results show that the reference velocity pressure used in design has little influence on the aerodynamic damping value.

KEYWORDS: aerodynamic damping, free-standing lattice towers, along-wind loading

1 INTRODUCTION

Free-standing lattice towers are lightweight modular structures used in a variety of fields in order to support necessary equipment to certain heights. Due to their purpose, lattice towers may reach considerable heights which, together with their reduced mass may render the structure sensitive to dynamic along-wind loading. However, lightweight structures possess aerodynamic damping which, for free-standing lattice towers is larger than structural damping resulting in a significant increase of total damping and thus a reduction of structural response to along-wind loads.

This paper investigates the effect of aerodynamic damping on the sensitivity of lattice towers to wind loading by means of a parametric study. Seven triangular antennae lattice towers denoted hereinafter as T90, T80, T70, T60, T50, T40 and T30 according to their heights, have been designed based on the Romanian wind code [1] to a reference velocity pressure of 0,5kPa. Moreover, tower T90 was further designed under three other reference velocity pressures, i.e. 0,4kPa, 0,6kPa and 0,7kPa, values taken in accordance with the wind hazard zoning map of Romania [1]. In total, the parametric study consisted in seventeen design cases, out of which fourteen represent the seven towers designed considering both circular as well as angle cross-sections for the bracings and three cases represent the design of tower T90 with circular cross-sections for all members under the additional reference wind velocity pressures stated above.

The towers were considered to be equipped with both ancillaries as well as antennae, the same antennae configuration being used in all design cases. The force coefficients for each design case were evaluated according to [2]. Only wind forces corresponding to wind direction orthogonal to one face were considered for design and no ice loading was taken into account for the purpose of this study.

2 DAMPING OF LATTICE TOWERS

Damping represents the ability of a structural system to dissipate vibrational energy and it mainly consists of three components: structural damping, aerodynamic damping and damping due to special devices.

Structural damping depends on several parameters such as material, structural configuration, connections of elements as well as frequency of vibration. In general, structural damping is assumed to be of viscous-type and is expressed as the logarithmic decrement of damping (δ_s) or the damping ratio (ξ_s) which may be obtained from experimental tests using various methods such as the logarithmic decrement technique or the half-power bandwidth technique. Full-scale tests performed on free-standing lattice towers show, for example, values of the damping ratio ξ_s = 0.003-0.005 [3] or ξ_s = 0.0025-0.01 [4]. In design codes, the damping ratio for steel towers is given according to the element connections with values such as: $\xi_s = 0.003 \div 0.005$ [1] and $\xi_s = 0.0015 \div 0.005$ [5].

Aerodynamic damping is caused by the relative velocity of the structure to that of the air flow. For lightweight structures, aerodynamic damping in the along-wind direction is considerably larger than structural damping leading to a reduction of wind-induced response. The aerodynamic damping ratio corresponding to the fundamental mode of vibration depends of parameters such as velocity, mass and force coefficient and is expressed as [1]:

$$\xi_a = \frac{c_f \rho v_m(z_s)}{4\pi n_1 m_e} \tag{1}$$

where c_f is the force coefficient, ρ is air density, v_m is the mean wind velocity, z_s is the reference height, n_1 is the fundamental frequency of the structure and m_e is the equivalent mass per unit length of the fundamental mode given by:

$$m_e = \frac{\int_0^l m(s)\Phi_1^2(s)\,ds}{\int_0^l \Phi_1^2(s)\,ds} \tag{2}$$

where m is the mass per unit length and l is the height of the structure.

3 PARAMETRIC STUDY

Seven free-standing triangular lattice towers have been designed for the purpose of this parametric study with heights varying from 30m up to 90m. The bracing pattern of diagonals was chosen in correspondence with the height of each tower as seen in Figure 1.

All the towers have been designed using Finite Element Analysis. The wind field parameters were evaluated according to the Romanian wind code [1] whereas the total wind force coefficients were determined according to [2] based on the guidance for special cases which takes into account both the structural as well as the ancillary components of the force coefficients. The geometrical characteristics along with the fundamental frequencies and equivalent mass per unit length of the fundamental mode for all towers designed under wind velocity pressure 0,5kPa are presented in Table 1. Tower T90 was further designed under velocity pressure 0,4kPa, 0,6kPa and 0,7kPa resulting in fundamental frequencies 0,98Hz, 1,11Hz and 1,15Hz respectively and corresponding equivalent masses 196,3kg/m, 216kg/m and 224,7kg/m respectively.

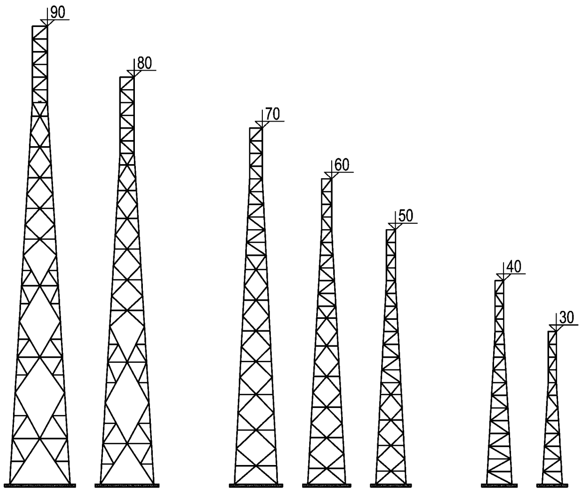


Figure 1. Tower configurations used in the parametric study

Table 1. Geometric and dynamic characteristics of the lattice towers for reference velocity pressure 0,5kPa

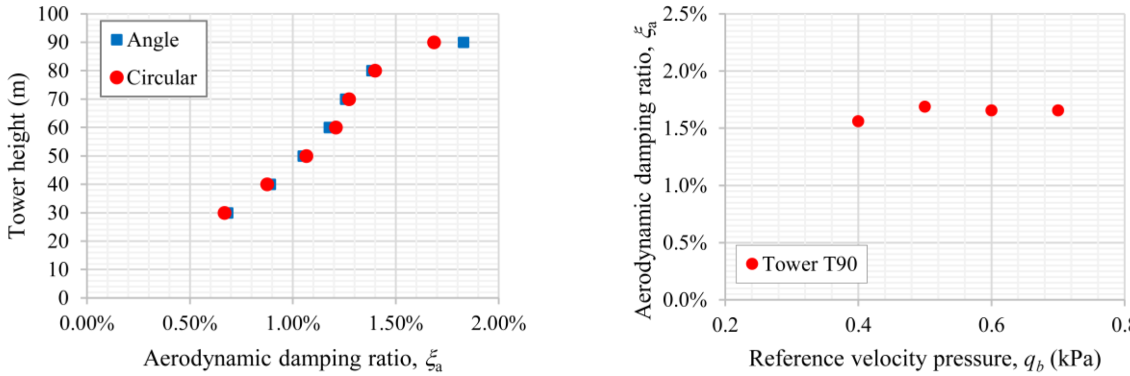
Tower	Height (m)	Base width (m)	Top width (m)	n_1 (Hz)		m_e (kg/m)	
				Circular	Angle	Circular	Angle
T90	90	12,00	3,00	1,02	1,10	208,92	228,31
T80	80	10,60	2,80	1,12	1,10	201,51	258,76
T70	70	8,50	2,50	1,24	1,16	189,81	251,31
T60	60	7,50	2,00	1,27	1,25	174,47	223,65
T50	50	6,00	1,80	1,38	1,37	171,75	204,95
T40	40	5,00	1,70	1,55	1,59	175,35	197,88
T30	30	4,00	1,60	1,88	1,83	180,63	209,86

4 RESULTS

The main purpose of the parametric study presented in this paper was to investigate the influence of several parameters on the aerodynamic damping of lattice towers. As such, two parameters were considered, i.e. the force coefficient and the design velocity pressure. For the influence of the force coefficient on the aerodynamic damping, the seven towers were designed under two geometrical hypotheses: (a) both leg and bracing members with circular cross-sections and (b) leg members with circular cross-sections and bracing members with angle cross-sections. Figure 2a shows the variation of the aerodynamic ratio with height for both cases. As it may be seen, all towers present very similar values of aerodynamic damping with percentage differences in the range 1%-3% except for tower T90 where a 9% percentage difference was obtained. An almost linear increase of damping ratio with height may also be observed which may be useful in a rough evaluation of aerodynamic damping for lattice towers.

The influence of the basic wind velocity pressure on the aerodynamic damping was investigated by designing tower T90 having circular cross-sections for all members under four velocity pressures 0,4kPa, 0,5kPa, 0,6kPa and 0,7kPa. At it may be seen in Figure 2a, the value of the aerodynamic damping ratio is very similar irrespective of the reference velocity pressure.

In order to investigate the reduction effect of aerodynamic damping on the wind-induced response of lattice towers, Table 2 shows values of the dynamic factor for all the design cases corresponding to reference velocity pressure 0,5kPa as evaluated according to the Romanian wind code [1] without and with taking into consideration the aerodynamic damping ratio. As it may be seen an approximately 10% reduction of the dynamic coefficient is reported in all cases.



a) b)

Figure 2. Variation of aerodynamic damping with a) tower height and b) reference velocity pressure

Table 2. Influence of aerodynamic damping on the dynamic factor

Tower	c_d (ξ_s)		c_d (ξ_s+ξ_a)		% Reduction	
	Circular	Angle	Circular	Angle	Circular	Angle
T90	1.033	1.019	0.924	0.918	10.6%	9.9%
T80	1.039	1.044	0.936	0.938	9.9%	10.2%
T70	1.048	1.051	0.946	0.946	9.7%	10.0%
T60	1.062	1.065	0.955	0.957	10.1%	10.1%
T50	1.083	1.083	0.972	0.972	10.2%	10.2%
T40	1.091	1.091	0.988	0.987	9.4%	9.5%
T30	1.105	1.113	1.011	1.014	8.5%	8.9%

5 CONCLUSIONS

In this paper a parametric study has been conducted on the sensitivity of lattice towers to along-wind loading which may be considered to be governed by the aerodynamic damping. Results show an approximately 10% reduction of along-wind induced forces when aerodynamic damping is taken into account. Moreover, for the investigated towers, both the total force coefficient as well as the basic velocity pressure used for design seem to have a small influence on the amount of aerodynamic damping when towers are properly designed to withstand the forces corresponding to these parameters. Due to the complex evaluation method, structural engineers usually neglect the aerodynamic damping in calculations, missing thus the possibility of reducing the load by approximately 10%. However, in reality, there is also a tendency to miss calculating the dynamic coefficient which is luckily compensated by the aerodynamic damping neglection.

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