24th COBEM - 2017

24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2343
REDUCTION OF THE DYNAMIC RESPONSE OF TRANSMISSION TOWERS THROUGH THE INSERTION OF VISCOELASTIC MATERIAL

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Abstract. *In a country with continental dimensions such as Brazil, energy distribution networks are of the utmost importance. These networks are composed of transmission towers of various sizes and characteristics. Accidents with these structures can cause several disorders, as well as endangering the lives of many people. Therefore, the study of the dynamics of these structures is fundamental. This work aims to study the natural frequencies of a tower model (suspension tower) and its behavior when inserting viscoelastic materials into the structure, in the column connections thereof, to introduce damping in the structure. The study was carried out using the finite element method (FEM) through commercial software SAP2000, considering a transmission tower modeled as a space trellis. The use of viscoelastic material at the junction of the tower columns is efficient in terms of the damping introduced into the structure.*

Keywords: *Transmission Towers, Natural Frequencies, FEM, Viscoelastic Material.*

1. INTRODUCTION

The great change in the demographic profile of Brazil, which is occurring in recent years, is due to population growth, and it is associated with rapid urban and industrial growth. As a consequence of this growth, the consumption of electric energy has increased, necessitating a greater supply of this energy in the cities. To meet this demand, it is necessary to expand the power transmission lines (Cargnin, 2014; Carlos, 2015).

In addition, there is the fact that Brazil has large extensions, and the distances between sources of electricity, such as hydroelectric, thermoelectric, nuclear or wind farms, up to consumption points, are very large. In order for this transmission of electric energy to exist, transmission lines are used, which are large structures. Therefore, it should be ensured that the transmission of energy through the transmission lines occurs in a safe, efficient and economical way, maintaining a regularity and continuity (Argenta, 2007; Cargnin, 2014; Carlos, 2015).

Transmission lines have a number of elements, such as conductive cables that are suspended in the chains of insulators and transmit power. The chains of insulators, in turn, become attached to the structures of supports known as towers of electric power transmission lines. The transmission lines are further composed of lightning rods cables, grounding, foundations, fittings and accessories (Cargnin, 2014; Carlos, 2015).

The failure of any of the elements of the transmission lines leads to a loss of the system's power transmission capacity, which interrupts the transportation of electric energy and, therefore, the supply to consumers (Carlos, 2015).

Several factors may cause malfunction or ruin of transmission towers, among them it is possible to cite wind gusts, storms, impact of objects, inadequate sizing and even, indirectly, the action of vandals. Accidents with towers can promote numerous disorders, ranging from reconstruction expenditures to losses with lack of energy in affected sites (Argenta, 2007; Pinto *et al.*, 2013).

Although the national system is efficient in maintaining the power supply in the case of downfall of transmission line towers, this event brings numerous inconveniences and damages to the cities and industries that are affected (Argenta, 2007).

In the execution of a tower project, the most recurring doubts are related to the loading to be considered. The prediction of the behavior of the structure before loading and sizing must be well defined so that it is durable, safe, functional, has a good aesthetic and, above all, is economical (Merce *et al.*, 2007).

The towers of transmission lines have a low own weight, these characteristics make that the action of the wind is the main force that acts on them. Therefore it should be carefully analyzed in the design phase (Huang *et al.*, 1996; Merce *et al.*, 2007; Carlos, 2015).

Wind action is a dynamic request in the structure. However, there is a high difficulty in obtaining the dynamic responses of the transmission line towers in the project situations, due to the set of variables involved and their randomness. If this analysis were performed in the design phase, it would increase the level of complexity of the project, making the time invested in modeling, analysis and processing of the structure increase. So when this action is considered in the project the norms indicate that it is used as static equivalent to the action of the wind (Argenta, 2007; Carlos, 2015).

The transportation of electric energy is fundamental for the development of Brazil and requires a vast transmission and distribution system to serve the consumers. Therefore, there is great interest in the study of transmission systems (Carlos, 2015).

In this way, this work has as main objective to verify if there is reduction in the dynamic response of lattice towers of transmission line with the use of a viscoelastic material. Since the dynamic response given by the free vibration of the structure is important to determine the natural frequencies and vibration modes, in order to avoid premature failures of the lattice metal tower, therefore, the dynamic actions present in the structure must not reach the values of the frequencies natural of this, avoiding the phenomenon of resonance, which can cause ruin or flaws in it.

2. TRANSMISSION LINES TOWERS

As already mentioned, among the elements that make up the transmission lines of energy, there are the towers that are the supports of the transmission lines. As laid by Carlos (2015), these structures are responsible for supporting or anchoring conductive cables, which conduct electrical energy along the line, as well as the lightning rods and insulation cables. The term "lattice towers" is used when the support structures are constructed with angle-shaped steel profiles and in the form of a space truss. The uprights (columns) are connected by screwed flanges and in the middle the viscoelastic material, the diagoals are connected by only one screw, hence labeled. They are the most common because of their ease of transport, low cost and installation speed (Pinto *et al.*, 2013; Cargnin, 2014).

Usually the mechanical model adopted in the design for the lattice towers of transmission lines is quite simple. The most commonly used simplification is the use of trellis elements and / or space gantry elements, treating their bonds as indescribable (supports or embellishments). The base is considered as indeslocavÃl'l, crimping, and the diagonals, the elements that make the locks of the tower are labeled. In the columns it is possible to be said that it is a crimping, however in this setting we are placing a material that allows the damping of the structure. However, it is known that many bars are continuous and some of the links between them should be treated as rigid or semi-rigid (Argenta, 2007; Carlos, 2015).

According to the form of transmission of the towers' efforts to the foundations, these can be divided into two groups: self-supporting and stationary. For Carlos (2015), the staked towers are composed of a slender, modulated metal body called a mast. The stability of the staked towers is guaranteed by means of galvanized steel cables, which are so-called stationary, which are normally pre-tensioned or prestressed, and are fixed along the height of the mast. The stakes absorb part of the horizontal forces, generated longitudinally, transversely or in a combined manner in the transmission line. Each of the estais has its respective foundation, which transmits the efforts to the ground. The rest of the forces must be absorbed axially by the tower mast and its foundation must withstand the critical conditions of compression combined with horizontal forces. The self-supporting towers transmit their efforts to the ground by means of four foundations, which provide support to the four pillars of the structure. They are usually composed of a straight part at the top of the tower and a pyramidal part at the base. Its foundations are alternately subjected to compression and pull (pulling) forces, combined with horizontal forces. They are also usually formed by modules (Forti *et al.*, 2006; Pinto *et al.*, 2013; Cargnin, 2014; Carlos, 2015).

The transmission line towers can also be defined from their purpose, which is usually a function of the power installed in the line. A transmission line for high voltage energy, such as that used to transmit from generating plants to consumer centers, is usually made up of metal towers. Being that, in this line there are basically three types of towers. Terminal towers at the beginning and end of the line; the anchor towers, which appear between the terminal towers, in order to give greater rigidity to the line; and the suspension towers, which serve to support the cables of the line (Argenta, 2007). The tower used in this work is a suspension tower.

3. VISCOELASTIC MATERIALS

The viscoelastic materials are natural or synthetic having elastic properties. For this reason its main characteristic is its great deformability and elasticity. It can reach deformation of 1000 % without rupture and recover the original shape, thus allowing to accumulate more energy than any other material (Mendes *et al.*, 2010; Guerreiro, 2003).

They absorb the vertical and horizontal stresses of the structure under which they are. As they are arranged between the structural parts they have the purpose of accommodating boundary conditions, thus transferring the superstructure reactions to the infrastructure, thus fulfilling the design requirements for forces, displacements and rotations.

4. DYNAMICS OF STRUCTURES

Among the essential characteristics that differ the dynamics of structures of the static can be cited the consideration of loads varying in time. Thus, static analysis is a simplification of dynamic analysis, considering only the rigidity of the structure, thus ignoring its inertia and damping (Argenta, 2007).

To perform the dynamic analysis of the tower, the tower can be discretized using Finite Element Method (FEM). According to Soriano (2009) the FEM is a powerful tool and an essential instrument of analysis for practically any application of structural engineering. It consists of reproducing the behavior of a real problem by means of a computational numerical model composed of several elements, where the solution of a system of algebraic equations allows it to be possible to describe the behavior of the problem as a whole (Soriano, 2009).

In other words, the FEM consists of subdividing the domain of the problem into a discrete number of regions that have finite dimensions, these subdivisions are called finite elements. And the unknowns of the problem are expressed in terms of nodal values that are associated with the internal displacements of the element through valid interpolation functions for each element (Argenta, 2007).

It is possible to use free vibration to find the natural frequencies, since this is caused by the initial conditions of displacement and speed, and there is no external force and no damping. This is an idealization, because there is no system that has no damping and vibrates indefinitely. However, its study is very useful because the dynamic characteristics, such as the natural frequencies and the corresponding modes of vibration of the system are determined, that is, the behavior of the problem (Soriano, 2009).

In the dynamic analysis of any discretized structure in finite elements it is possible to separate the temporal variable of the other independent variables in each subdomain called finite element. Thus, it is possible to obtain a global system of differential equations of equilibrium in the time variable, its reduction being an eigenvalue problem or the integration of these equations (Soriano, 2009; da S. Alves, 2015).

We begin with the equation of motion of the structure given by:

$$M\ddot{U} + KU = 0. \tag{1}$$

where K and M are stiffness and mass matrices respectively and have constant coefficients.

Assuming that the movement of free vibration is a simply harmonic movement, that is, this system of differential equations admits harmonic solution. Their displacement in time can be represented by:

$$U = \phi sin(\omega t + \varphi), \tag{2}$$

where ϕ is a vector called the natural mode of vibration (eigenvector), ω is the natural frequency of vibration, and φ is the phase angle.

Substituting the Eq. 2 into the Eq. 1, we obtain:

$$(K - \omega^2 M)\phi = 0. \tag{3}$$

The system of equations above represents a classical problem of eigenvalues and eigenvectors, in which the square root $\sqrt{\omega^2}$ of the eigenvalues represents the natural frequencies, and, associated with these eigenvectors are represented by the modal forms of vibration (ϕ). This system of equations has nontrivial solutions (ω^2, ϕ) only in the case of the matrix of the coefficients of $(K - \omega^2 M)$ to be singular, that is, in case of:

$$det(K - \omega^2 M) = 0. \tag{4}$$

Thus, for each solution ω^2 (which is an eigenvalue and square of the jth natural frequency), the resolution of the system of equations 3 provides an eigenvector ϕ which is the j-th natural mode of vibration or non-damped mode (Soriano, 2009).

In metal towers, for example, their useful life can be reduced due to fatigue and, consequently, the signals of the telecommunications towers can be disturbed due to the vibration, therefore the increase of the natural frequency is justified, because the probability of failures due to fatigue are smaller, as well as that of the estrurura entering into resonance with the wind.

5. NUMERICAL APPLICATION

In this work, a self-supporting lattice tower of steel A36 with 18 meters of height, shown in Fig. 1, is analyzed, sections with three modules are considerate, all of them having 6 meters. The analyzes without and with viscoelastic material, in their joints (in 6 and 12 meters). As shown in Fig. 2.

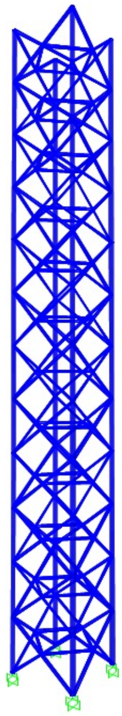

Figure 1. 3d view of the tower

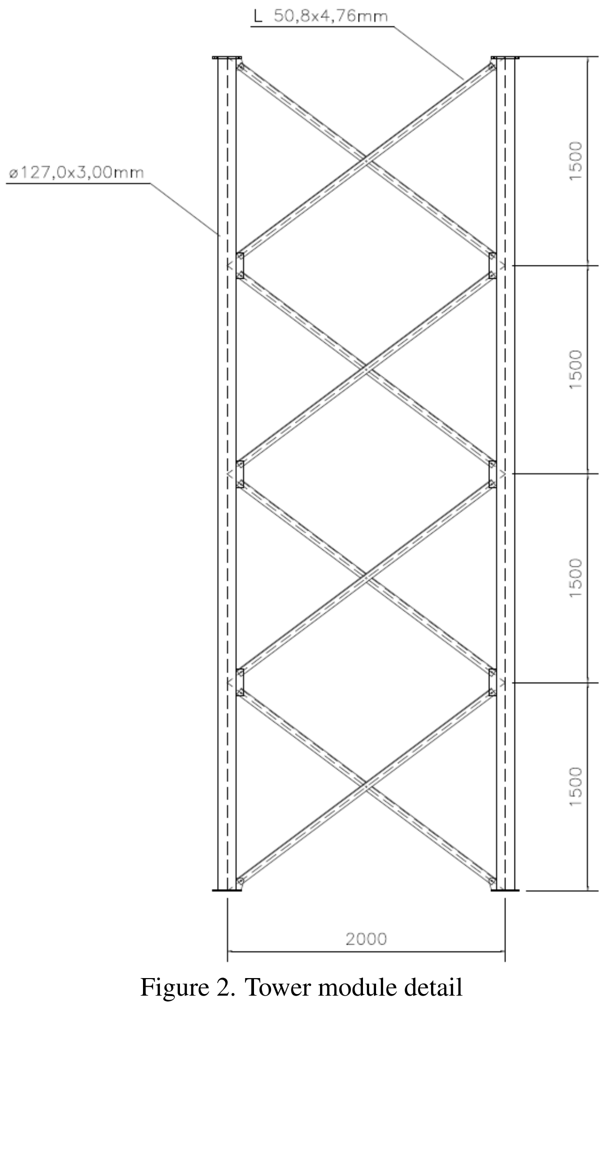

Figure 2. Tower module detail

The modeling of the tower by 3D gantry finite elements was performed through the SAP2000 program. The model was submitted to a dynamic linear three - dimensional analysis, obtaining the natural frequencies and vibration amplitudes of the tower, with and without the viscoelastic material, so that it was possible the comparison with the presence of the viscoelastic material.

6. DESCRIPTION OF THE MODEL

The silhouette of the metal lattice tower used is subdivided into modules, and each module has the same vertical dimension. It has a square section, with sides of 2.0 meters.

Each of the lattice tower modules has circular uprights (columns) of 127.0 mm in diameter and 3.0 mm in thickness. Its diagonals are composed of L profiles of equal flaps of 50.8 mm flap and thickness of 4.76 mm. The modules have a subdivision every 1.5 m, where they present an internal locking in the diagonals encounter (Fig. 2).

The use of the viscoelastic material occurs between the connections of the tower columns at the junctions between the modules. The material has the same dimensions as the flanges of the bond, however, it has a thickness of 5.0 mm and the following properties, which will be used in this case those of Neoprene material:

- σ = 20,5 MPa (Yield stress)
- ε = 588 % (Specific deformation)
- E = 3,53 MPa (Modulus of elasticity)
- ν = 0,49999 (Poisson coefficient)

It is possible to see the detail of the Neoprene position in Fig. **??**.

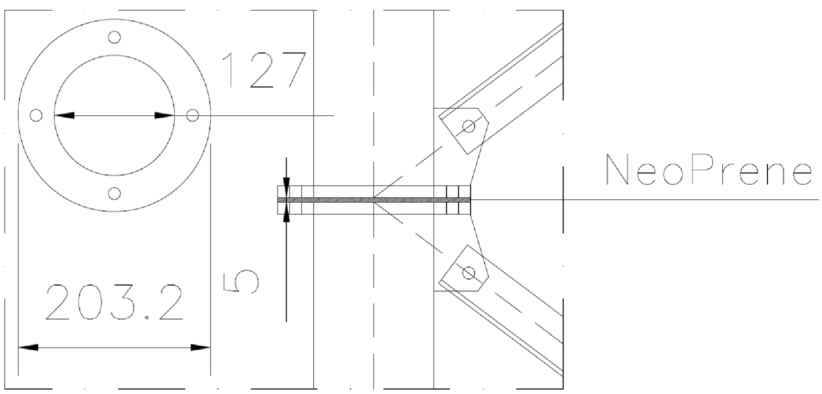

Figure 3. Neoprene Position Detail

7. NUMERICAL ANALYSIS

In the metallic tower its elements were discretized as 3D portico formed by bars. Each bar of the structure was subdivided into four finite elements. This subdivision aims to give greater precision to the consideration of second order local effects. Thus, a total of 1008 finite elements were obtained. The base of the tower is labeled.

Using the labeled bonds, only local frequency were obtained, frequencies were obtained the diagonal ones, of which only two, which were of flexion in X and Y, showed differences with the use of the viscoelastic material. In the others the same values were obtained, even after the use of viscoelastic material.

In order to carry out an overall analysis, the rigidity of the structure was high in all connections. With this, new 12 first frequencies were obtained. All the frequencies obtained after the stiffening of the structure are shown in Tab. 1.

From these new ones, five global frequencies were found, being the first and second of flexion with a point of inflection, two frequencies of flexion with two points of inflection and one of twist, respectively. The others represent natural frequencies of the diagonals used in the structure locking, so similar frequencies of vibration modes from 6 to 12.

In the same table also the frequencies after the addition of the viscoelastic material between the connections of the uprights are presented.

Table 1. Frequencies obtained

Vibrate mode	Frequencies (Hz)		Relation (%)
	Original	With viscoelastic material	
1	0,196917	0,288275	46,39
2	0,196917	0,288275	46,39
3	0,053802	0,055209	2,62
4	0,042559	0,055209	29,72
5	0,039448	0,054005	36,90
6	0,039448	0,042960	8,90
7	0,038635	0,040339	4,41
8	0,034841	0,040141	15,21
9	0,032363	0,036695	13,39
10	0,030865	0,033774	9,42
11	0,029941	0,032362	8,09
12	0,029413	0,030798	4,68

Modes 1 and 2 generate flexion with one point, one mode in the X direction and the other in the Y direction. Modes 3 and 4 generate flexion with two points, also one mode in the X direction and the other in the Y direction. the mode 5 generates twisting in the structure. The motion generated by these modes is possible to be observed in Fig. 4, 5 and 6.

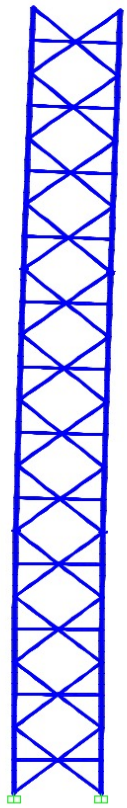

Figure 4. Vibrate mode of frames 1 and 2

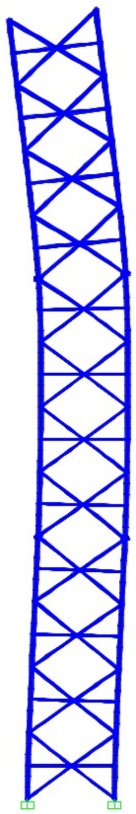

Figure 5. Vibrate mode of frames 3 and 4

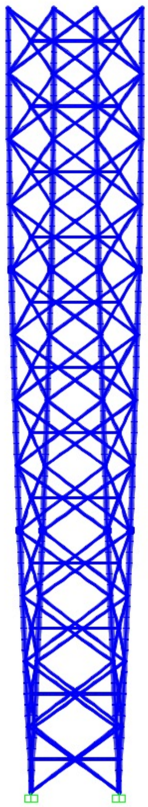

Figure 6. Vibrate mode of frames 5

8. CONCLUSIONS

The towers of transmission lines are structures considered fundamental for the supply of electric energy. Since they serve as support for cables that conduct power.

It can be observed during the numerical analysis construction process that leaving the bars labeled the results obtained were simply local, and their values did not change with the use of the viscoelastic material, because if the bar was not in contact with it, no there would be a difference in the use of the viscoelastic material for the local analysis of the same. Therefore, it became necessary to stiffen the entire structure, thus obtaining new frequencies, being now the first five global.

From the obtained frequencies it is possible to observe that the viscoelastic material can be used as an auxiliary so that the natural frequencies related to the neighboring regions where it is found are increased.

The other frequencies that had little change with the use of viscoelastic material are far from their location.

Improving the natural frequency means that the fatigue loads reduce, consequently the useful life of the structure is extended. The higher the frequency, the less likely the structure to resonate with the insider's view on it, and with the transmission line cable.

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