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Analysis of lateral displacements of a reinforced concrete tower of telecommunication systems under wind action in urban contexts

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Abstract. Most of the existing reinforced concrete towers existing in Brazil intended for supporting telecommunications systems were installed in the 1990s shortly after the "Telebrás" systems were privatized by the Brazilian government. Currently, there is substantial growth expected in the internet sector with the appearance of 5G in the country, and for that, there should be a new demand for the structural engineering involved. In this context, the main objective of this work is to computationally assess the lateral displacements produced by the wind in a reinforced concrete tower considering the geometric nonlinearity and concrete creep. For this, a useful life horizon was defined which allows the structure to age within the estimated time for its operation. A non-linear analysis based on the finite element method is used to operate the calculations. The loading characterizing the problem includes the structure's self-weight and the wind action in urban contexts. The wind forces were obtained through a Computational Fluid Dynamic, which considers the aerodynamics of the structure and existing devices. Herewith, it was possible to evaluate aspects related to the serviceability requirements throughout its useful life and recommend updating existing systems in order to guarantee the quality of the service provided.

Keywords: telecommunication tower, reinforced concrete, analysis, wind, creep.

1 Introduction

The advance of technology and its importance in the modern world is evident, with telecommunications being a tool in constant transformation, essential in the dissemination of this advance. Just as important as the means of communication are the systems involved in making this communication. Thinking about the relevance of the constancy of the communication systems, more specifically telecommunications services, the study of this article analyzes structures designed to support this system. The type of structure under analysis in this paper is a tower used as support of telecommunications devices that have been frequently demanded to increase its loading due to rise of technology, more specifically that of fifth generation technology, also known as 5G, in a process that began in 2018, in the world, with the deployment Brazil occurring since the end of 2019, as we see in Valente [1].

This new technological platform, 5G, is able to transport large amounts of data at high speed, but with limited signal range, requiring a larger number of unit and support states, affirms Teixeira [2]. Given the importance and the need for a larger number of structures for the operation of the telecommunication system, an analysis of the existing structures, which are or will be destined to the 5G system in Brazil, more specifically reinforced concrete towers, is appropriate. Since these towers are in operation and will possibly be required for use for a longer period of time, the analysis of the structure is done for the Serviceability Limit State (SLS), enabling the verification of its support. The Brazilian standard (NBR6118:2014 [3]) defines ELS as a period of use of the structure with limits set for crack formation and/or opening, excessive deformation, decompression or partial decompression,

compression and excessive vibrations. Therefore, it is presented an analysis of a reinforced concrete (RC) tower in ELS that is subjected to the actions of forces of nature, the wind, and lateral forces acting on a one-dimensional structure. In this work is considered the structural element described in Wahrhaftig [4], which is 46 meters high, typically a reinforced concrete tower, with 6 meters of foundation and 40 meters elevated from the surface in a circular profile as described in Fig.1.

The main objective of this work is to perform a preliminary analysis to assess the serviceability limit state of one-dimensional multi-degrees of freedom RC structure intended to support telecommunications devices taking into account the effect of wind in an urban environment and concrete creep. It was possible, in the context of the present work, to exam the effect of wind action on RC towers for similar propose, generalizing the studied problem. For doing that, it was necessary to apply an appropriate mathematical and numerical-computational model of one-dimensional structure representing structures working as support for telecommunications services.

To understand the behavior of structures like these, this study adopted four instants of time after the structure gets into service. The first one is that when the structure is put into use, with zero years of use or twenty-eight days after concrete production (t_0). The next time-instant is adopted for 10 years later (t_1), then 20 years (t_2), and finally when the structure completes 30 years in use (t_3). The structure is assumed to be subjected to the same wind conditions with the concrete proprieties varying over time. The real situation is mathematically simulated by means of the finite element method. That method allowed the solution of the equations involving the structural system, generating computational models with their deformations. The computational platform used in the simulation was the software Ansys Workbench, in the academic version. Finally, the final result from the analysis allowed knowing the displacements resulting from wind actions while the structure is operating.

2 Relevant concepts

A one-dimensional structure subjected to wind action produces a dynamic behavior response as stated by Wahrhaftig [5]. Thus, the analysis of the structure in service must be performed, according to ABNT NBR 6118:2014 [3] "through models that consider the effective stiffness of the sections of the structural element, that is, that take into account the presence of the reinforcement, the existence of cracks in the concrete along this reinforcement and the strain deferred in time" considering the limit state of excessive deformations and vibrations established as adequate by the wind action for the frequent combination.

In turn, the standard for forces due to wind (NBR 6123:1988 [6]) sets the conditions required in the consideration of forces due to static and dynamic wind action, for purposes of building calculations, however we will bring to this study a situation of random wind force on the structure based on Computational Fluid Dynamic (CFD) with parameters representing a urban environment as recommended by Haitham [7].

The modulus of elasticity of the material is intrinsically linked to the deformation of the structure at the time of its effective demand. With the temporal variation in the material properties due to the concrete creep effect, the structure undergoes alterations in the manner it responds to wind action. According to Jiao [8] occurs a loss of load bearing capacity due to several factors involved with the creep of a structural system. Another relevant issue is the slenderness of the examined system, which has a high slenderness index, something around 400. For that reason, the wind action imposed on the analysis is to be done with a nonlinear geometric hypothesis. So, the studied problem has both nonlinear aspects, geometric and material.

The structure is modeled like a unidimensional system clamped at the base and free at the superior extremity. The wind acts on it jointly with the normal force from the structure's self-weight and other loads in service. As pointed out by Wahrhaftig [9] the normal force reduces the structural stiffness, and its inclusion on calculation must be done through the parcel of the geometric stiffness matrix. To perform the present study modeling based on the finite element method was used from non-linear perspectives, the geometric one includes the large displacement theory and geometric stiffness, and the material one considers the creep of concrete.

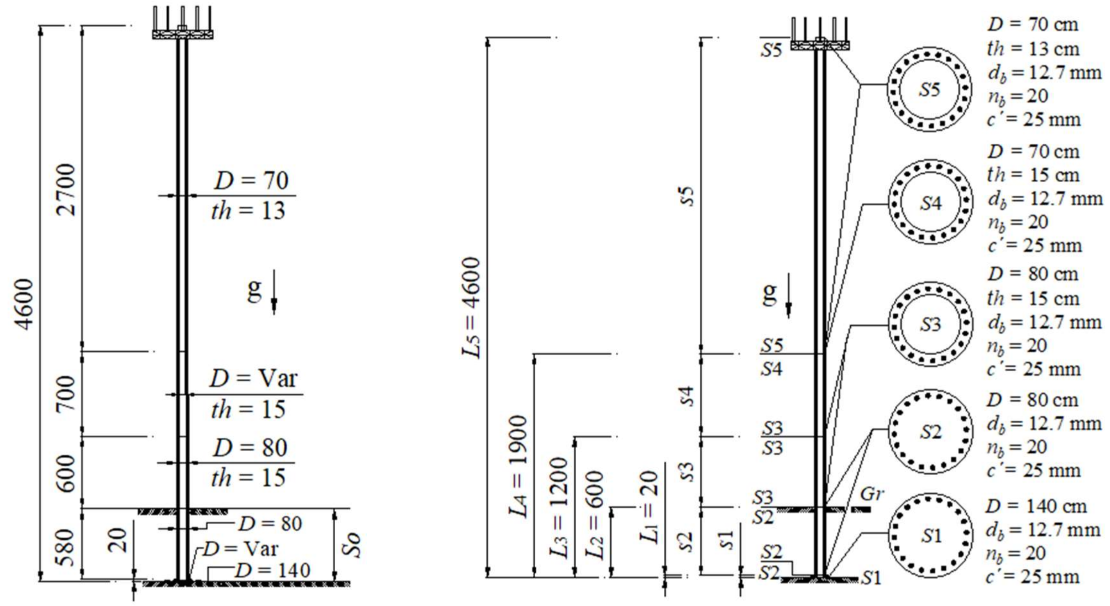
3 Nonlinear structural modeling

A 3-D special non-linear finite element analysis was performed to identify the structural response over time when the system is subjected to the lateral action of wind in both horizontal directions in relation to the flow, *x* (longitudinal) and *y* (transversal), at the same time.

3.1 Object of study

The studied object is a 46 m high reinforced concrete tower, with 6 m of foundation, as shown in Fig. 1. It is described in the Wahrhaftig's work [4]. To substantiate practical considerations of that structure, the tower is considered to be subjected to the effects of the wind forces obtained by a CFD simulation for urban contexts considering the parameters indicated by Haitham [7]. In Fig. 1, L_1 up to L_5 are the height of the respective segments s_1 up to s_5, g is the acceleration of gravity; *S*1, *S*2, *S*3, *S*4, and *S*5 are the cross-sections; *D* and *th* indicate the external diameter and wall thickness of the section, respectively; d_b and n_b represent the diameter and number of reinforcement bars; *c´* is the concrete cover in the respective cross-sections, "Var" represents the variable section in the indicated segment, and *So* indicates the soil zone, that is, the buried part of the structure.

The tower in question, intended for cell phone and internet signal transmission, has a circular hollow cross section with variable segments, a set of antennas and a platform at the tip. Also are included on it a set of cables and a ladder that are installed along its length. Each section is reinforced with steel bars as indicated. Sections *S*1 and *S*2 make up the portion below ground. For this moment, the effects of soil-structure interaction are not considered. So, the structure is clamped along its foundation. As is usual, the creep effects for segments belonging to the foundation are not considered as well.



Geometry   Structural arrangement

Figure 1 – The reinforced concrete tower analyzed

3.2 Adopted conditions

The tower cross-sections are composed of two different materials, steel reinforcement and concrete. In the analysis process, the steel bars of reinforcement were homogenized as concrete by using the parallel axis theorem as part of a simplification. For homogenizing the materials, a time variation was adopted since the homogenizing process involves considering the effects of creep of concrete, a time-dependent phenomenon.

The Brazilian standard NRB6118:2014 [3] defines criteria for determining the creep coefficient of concrete allowing be known the modulus of elasticity of concrete at each instant of interest. For the initial instant of loading of the structure, the standard rule allows estimating its value as 34189.93 MPa. The creep coefficient is calculated by considering an environmental humidity of 70%. Wahrhaftig [4] detailly indicates the procedure for calculating the correction factors of inertia, which correspond to the homogenization of the materials in each cross-section for taking into account the arrangement of the steel bar of reinforcement. Based on the data in Tab.1, the necessary parameters for the homogenization process and loading of the structure are set.

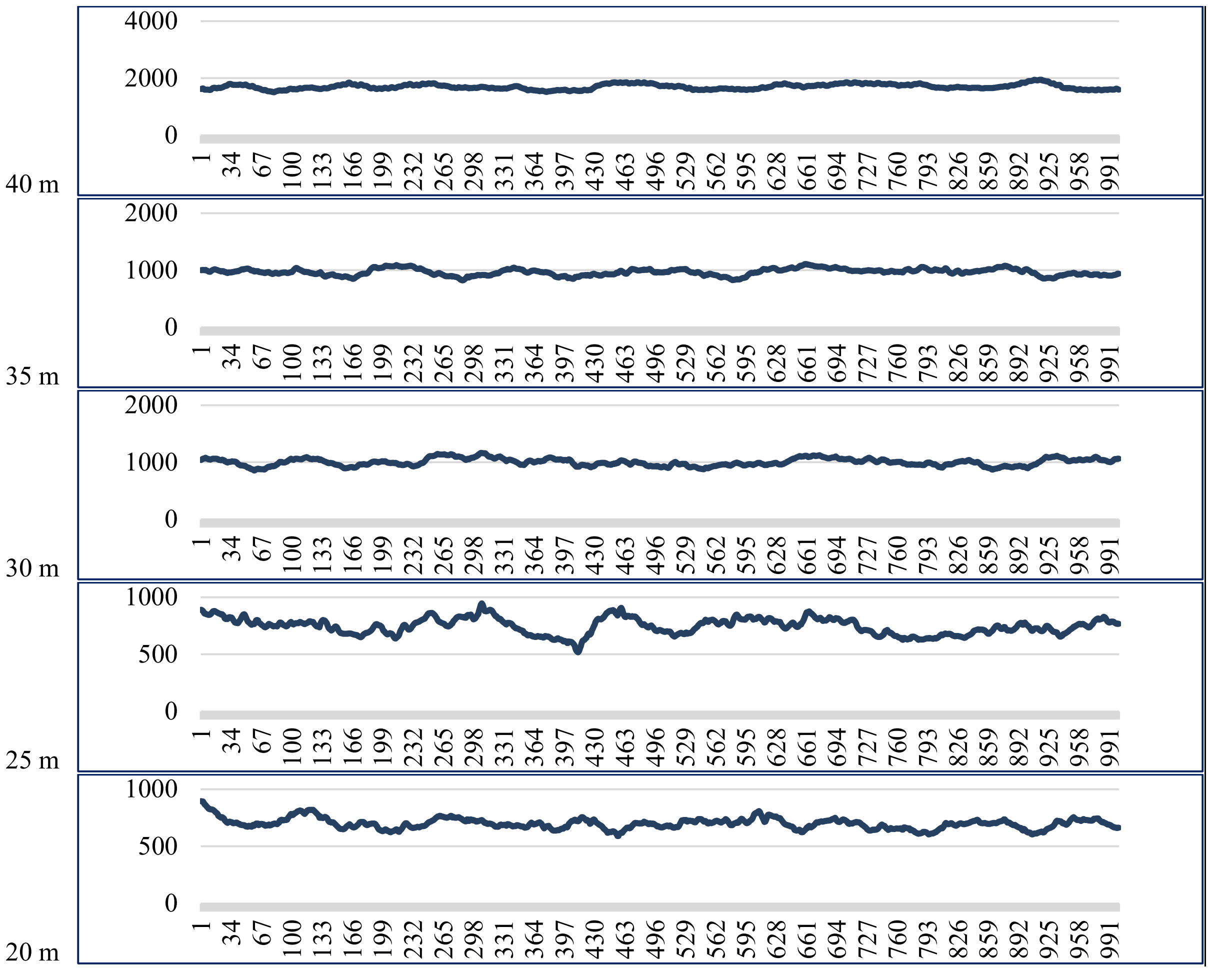
Table 1 – Structural parameters

Parameters	Values
Concrete compressive strength - superstructure	45 MPa
Concrete compressive strength - foundation	20 MPa
Concrete density - superstructure	2600 kg/m³
Concrete density - foundation	2500 kg/m³
Antenna and platform mass	1097.76 kg
Ladder and cable mass	40 kg/m

After the structural parameters are established, the tower is assembled as beams elements, it is clamped at the inferior position below the soil, having the cross-sections *S*1 and *S*2 defined to be fully circular, composing the buried part of the system. On the other hand, the upper extremity is completely released and handles the load of the antennas and platform in form of a point mass on the last section *S*5. In addition to that, the mass and corresponding forces of the ladder and cables are distributed along the superstructure that corresponds to the above-surface portion. Incurring on the segments above the surface, the wind force acts as temporal functions applied to each 5 meters range.

3.3 Analysis process

The wind forces acting on the structure were obtained by using a Computational Fluid Dynamic (CFD) simulation considering an urban exposition. All the forces representing the lateral action of the wind were obtained by taking into account the real aerodynamics of the structural system and existing devices. All of the wind forces are time-dependent because wind fluctuations are also obtained.



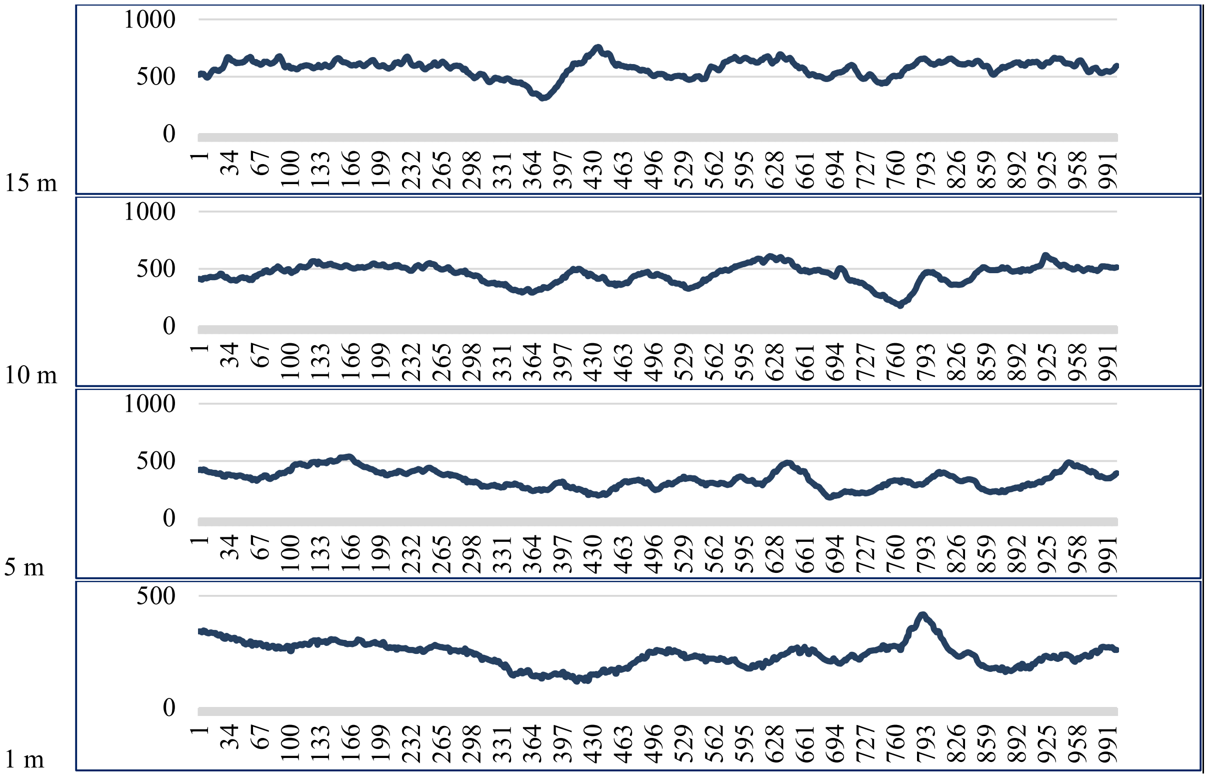
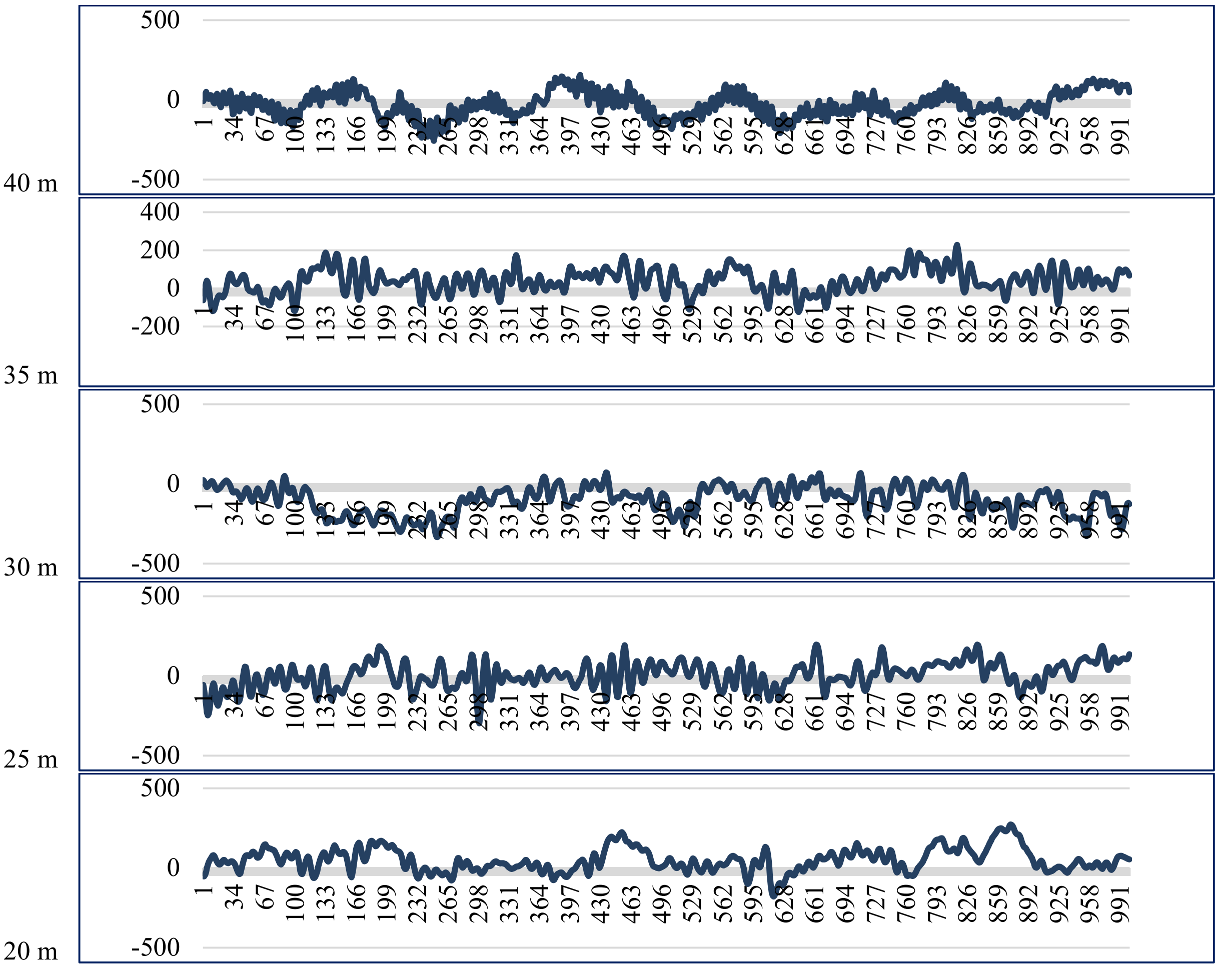


Figure 2 – Horizontal forces due the wind along the structure’s height – *x* direction.



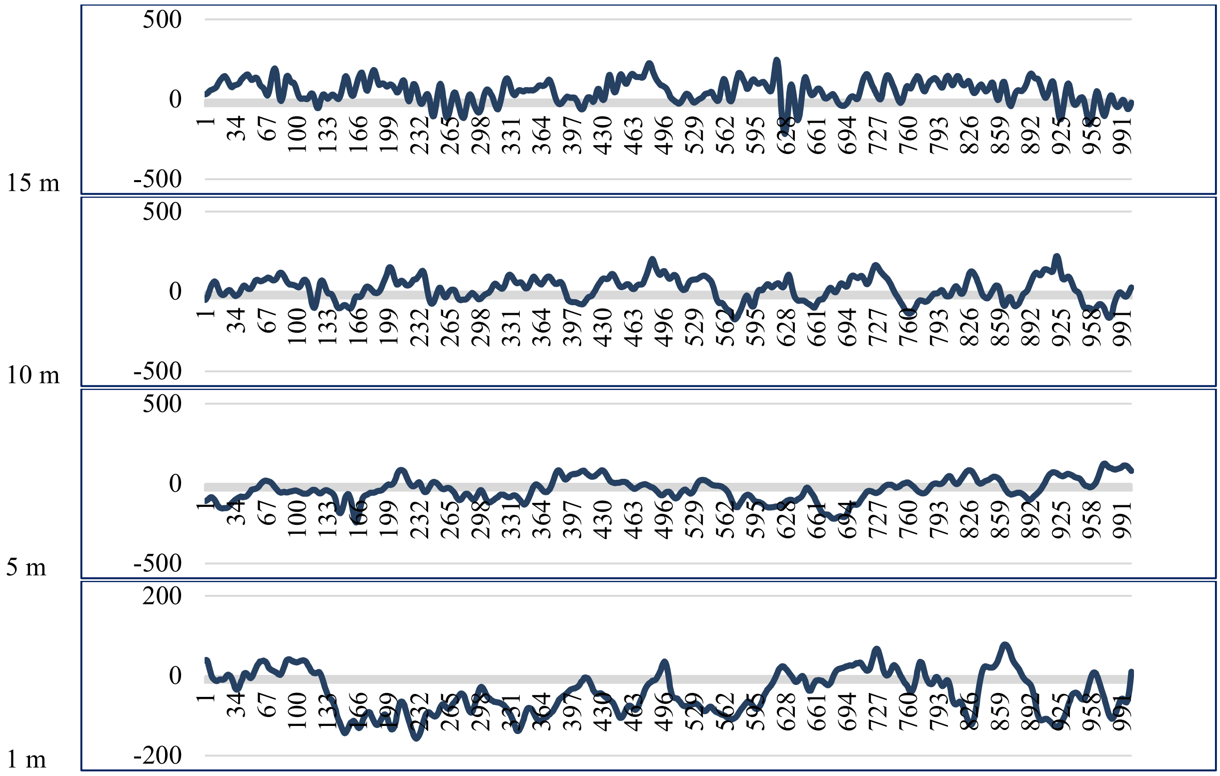
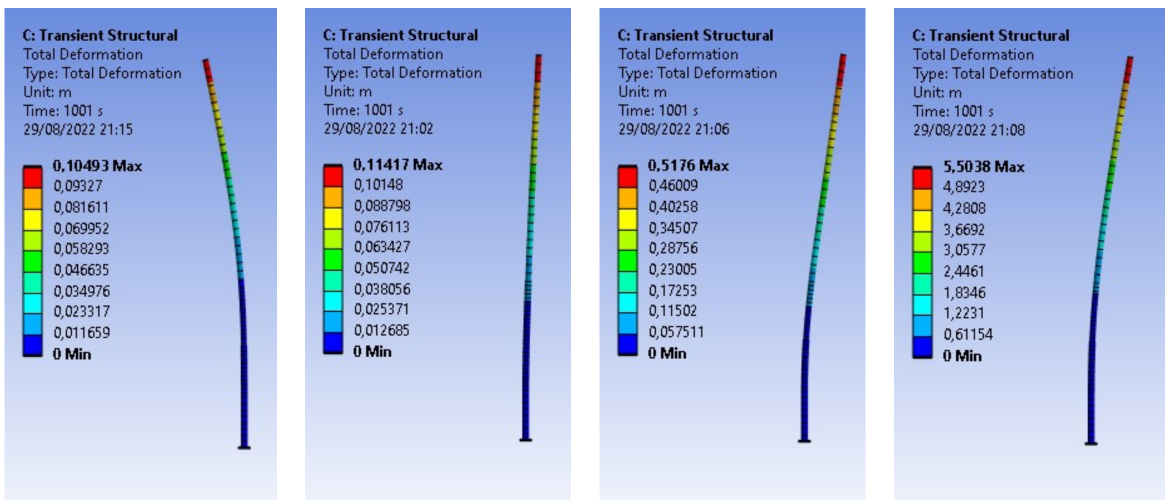


Figure 3 – Horizontal forces due the wind along the structure's height – *y* direction.

4 Results

It can be observed that the tower's behavior depends on the time in which the wind load is applied. This is because of the change occurring in the material properties due to the creep of concrete. The results in terms of displacements can be seen in Fig.3.



t_0 t_1 t_2 t_3

Figure 3 – Structural displacements

It is important to register that the nonlinear analysis was based on a simultaneal consideration of the geometric stiffness and large displacement hypothesis with the equilibrium condition calculated in the deformed position of the structure. The results reveal that the structure presents small displacements until t_2, i.e., up to 20 years old, and passes to present a significant percentual variation when the age of 30 years, t_3, is reached.. Between the initial time of loading t_0 and t_1, 10 years, there was a variation of 8.8%. Between t_2, 20 years the variation reaches 393.4%, and for t_3, 30 years, it goes up significantly to 5146.7% (Tab. 3). In Tab. 3 δ indicates variation in relation to the previous values and Δ indicates variation in relation to the initial value.

Table 2 – Horizontal displacements at the tip

Time instant	Displacement (m)	δ (%)	Δ (%)
t_0	0.1049	-	-
t_1	0.1141	8.8	-
t_2	0.5176	353.6	393.4
t_3	5.5038	963.3	5146.7

5 Conclusions

With the growth in demand for the use of telecommunication towers currently in Brazil due to the arrival of 5G technology, it is pertinent to know how it is the updated capacity of support structures when they are in services, including wind forces. Analyzing the structural deformations, it was possible to observe a significant change on the response of the structure over time. In 10 years, it is 11.42 cm, at the age of 30 years, it is 5.25 m. This configurates a warning for uses these structures.

The obtained results must be observed according to those that may compromise the proper use of the system and must be evaluated under specific operating conditions of the radio transmission system. However, it is possible to verify that when the structure is 30 years old, the presented displacements become extremely huge. This reveals that the analysis of RC towers for supporting telecommunication systems must be done considering the alterations of the material in time due to the creep.

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