

COBEM-2023-1620

DEVELOPMENT OF MECHANICAL AND STRUCTURAL DESIGN OF A TRANSMISSION TOWER APPLIED ENERGY FOR STRUCTURAL HEALTH MONITORING

Victor Emanuel Ribeiro de Santana

Mechanical Engineering Department, Federal University of Sergipe, Av. Marechal Rondon, São Cristóvão/SE
e-mail: victoreng@academico.ufs.br

José Mascarenhas Lima Neto

Mechanical Engineering Department, Federal University of Sergipe, Av. Marechal Rondon, São Cristóvão/SE
e-mail: mascneto@academico.ufs.br

Dr. Rodrigo Borges Santos

Federal University of Grande Dourados, Faculty of Engineering, Department of Mechanical Engineering, Dourados/MS
e-mail: rodrigobsantos@ufgd.edu.br

Dr. José Aguiar dos Santos Jr.

Mechanical Engineering Department, Federal University of Sergipe, Av. Marechal Rondon, São Cristóvão/SE
e-mail: aguiar@academico.ufs.br

Dr. Alexandre Carlos Rodrigues Ramos

Mechanical Engineering Department, Federal University of Sergipe, Av. Marechal Rondon, São Cristóvão/SE
e-mail: alexandre.ramos@academico.ufs.br

Abstract. *The implementation of Industry 4.0 in Brazil could result in annual savings of R\$ 35 billion in repairs, R\$ 31 billion with productive efficiency and R\$ 7 billion with energy savings, totaling a saving of R\$ 73 billion per year. The Brazilian Agenda for Industry 4.0 to prepare the country to embrace this trend and not lose the potential economic benefits that it brings. Structure maintenance can benefit from the innovations brought by Industry 4.0 by replacing costly preventive maintenance, in which specialists are called based on a prior schedule, with predictive maintenance, in which a monitoring system verifies the condition of the structure in an automated way and experts they are only triggered when there are indications of damage or potential failure. This project proposes the creation of mechanical design in CAD based on the DFMA and structural analyses by CAE of a small-scale virtual power transmission tower aimed at developing customized structural health condition monitoring solutions. It is expected that the tools to be developed in this project will help in the management of the power grid of Brazil, contributing to the improvement of the key indicators of maintenance performance.*

Keywords: *Transmission Towers, Structural Health Monitoring (SHM), Structural Analysis*

1. INTRODUCTION

The availability of electricity is what enables the economic and social advances of a society. The absence of it means chaos since society is extremely dependent on this resource to keep itself functioning. This state of chaos is perceived in the first hours without power, since energy is needed to pump water, keep food frozen, keep machines running, among countless other situations in which electricity is indispensable. Having electricity available means having potential for development in the most different areas (GOLDEMBERG; VILLANUEVA, 2003). Brazil is a developing country that needs electricity to continue to develop. The challenges in generation, transmission and distribution are great. A recent example was the energy crisis of 2021, caused, among other reasons, by the strong dependence on the energy generated by hydroelectric plants, which had their reservoirs empty because of the water crisis. (BORGES, 2021)

The growth of electricity consumption is a reality and to keep up with this growth it is necessary to work with intelligent and more effective, safe, and reliable ways to generate, transmit and distribute energy. The object of study of this work are the transmission towers. These are critical structures, under constant stress and exposed to environmental factors such as variations in temperature, humidity, rain, salinity, and winds. Brazil, being one of the largest countries in the world, has the challenge of transmitting energy over long distances is overcome with many costs, because it is necessary a greater number of towers, these towers being high due to the high voltage necessary to avoid losses in transmission. Given these excessive costs, the choice of the type of tower and the maintenance of these impacts on the price of the transmitted energy.

The Brazilian Agency for Industrial Development (ABDI) projected that the adoption of Industry 4.0 in Brazil could yield significant economic benefits. According to their estimations, the implementation of Industry 4.0 technologies has the potential to generate annual savings of R\$ 35 billion in repairs, R\$ 31 billion in productive efficiency, and R\$ 7 billion in energy savings, culminating in a total savings of R\$ 73 billion per year. Industry 4.0 has brought to the energy sector more efficient ways to inspect towers. The analysis of the integrity of the towers that was previously done in loco by a trained professional, today can be done in less time using drones and even at a distance through a constant monitoring of data collected by sensors that serve as indicators to assess the integrity of the tower. This form of real-time monitoring of structures is called structural health monitoring (SHM).

The possible parameters to be used in SHM techniques are corrosion, cracks, displacement, fatigue, force, repression, deformation, temperature, inclination, vibration, water level and wind (SONBUL; RASHID, 2023). Combined, these parameters can provide important information about the variation of the stresses on the structure and indicate fatigue failures in the tower and cables. Each tower will be exposed to different environmental factors, knowing the relationship between the modes of vibration of the structure it will be possible to perceive the increase in the fatigue cycles of one tower in relation to the others and with this direct the maintenance before the failure occurs. (CARLOS, 2015; GIAGOPOULOS et al., 2019). This technique has two different approaches. Data-driven, data is collected through sensors installed in the structure and model-driven, a computational model is used. Currently the combination of both techniques can be done for best results (ROSAFALCO, Luca et al., 2022)

The creation of a computer model of the tower to be monitored is essential, because from the model it is possible to estimate the behavior of the real tower against different loads. With the modeling of the geometry of the tower in the CAD software and analyses made precisely applying the finite element method, data are obtained that will serve as a parameter to evaluate the integrity of the tower. The better the model, the closer to reality the results will be. With the processing of all this data it is possible to estimate the occurrence of failures in the structure and with this it becomes possible to apply an advanced method of maintenance, the so-called prescriptive maintenance. Unlike corrective maintenance, which is commonly applied, prescriptive maintenance of towers reduces maintenance cost and downtime for repairs.

2. TRANSMISSION TOWER

Among the different types of high-voltage electric transmission towers, the most economically advantageous option has been shown to be the single-mast cable-stayed tower. These towers are easier to build, are lighter and are cheaper compared to self-supporting tower options. Its disadvantage lies in the greater need for maintenance, for this reason SHM is an essential technique for these towers to be the cheapest choice. (JING, Wu et al. 2021)

Due to its flexibility the single mast guyed towers are widely used in power grids. We propose a construction and instrumentation of a tower in a 1/10 scale, made by common materials like aluminum, easily found. The manufacture of the tower is being carried out by scientific initiation students linked to the FAPITEC research project, using 6060 T5 aluminum materials in the form of an angle bracket L-1" E-1/8", profile T L-1" A-1 "E-1/8", bars L-1/2", E-1/8", parts in impressions in additive manufacturing, in polylactic acid material (PLA), steel cables of 1/8" in diameter and unions riveted with AD-440-S rivet, as shown in Figure 1.

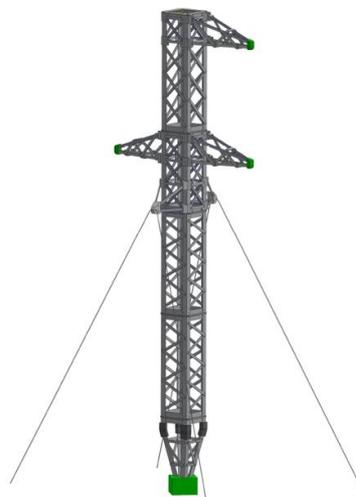


Figure 1. Single mast transmission tower in 1/10 scale. Source: Author

Faced with the need to have a small-scale tower that would fit in the laboratory and that would be easy to build, some parts were changed from the original design. The most relevant changes were the number of layers of the module that was reduced from 4 to 3, the pyramidal base with angle with greater angle in relation to the vertical and the peak that was removed from the tower.

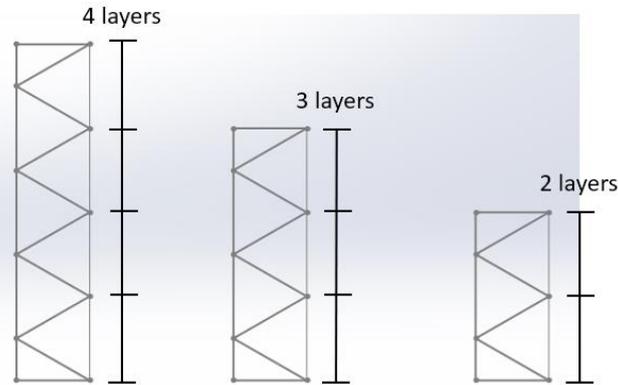


Figure 2. Number of layers per module. Source: Author

3. MATERIALS AND METHODS

3.1 Design and manufacturing

Computers present in the Mechanical Engineering Department of the Federal University of Sergipe were used, which have a good processing power and have the necessary software to create the model. For the CAD model, the Solidworks software was used, while the Ansys software was used for the static and dynamic analyses.

The CAD model was made recognizing the limitations of the design, since simply reducing the scale of the original design of a tower would not be workable due to the small dimensions of some components such as bolts and nuts, and the difficulty of welding small aluminum parts. This limitation was solved by creating precise connections in 3D printing.

For the construction of the tower were used aluminum profiles, rivets, screws and nuts and 3d printed parts made in the laboratory. In addition to the 3D printer, other equipment was used for the machining of aluminum profiles and assembly, such as bench drill, grinder, riveter. The entire process was conducted with the correct use of personal protective equipment.

3.2 Structural analysis

In order to obtain information about the resistance of the tower to its own weight and the load imposed by the stays, a simplified structural analysis by finite elements was performed using the Ansys software, with the use of an academic license. In this sense, the structure was modeled using beam-type elements.

As boundary conditions, the existence of crimping at the base were considered; gravitational force action; and the existence of stress equal to 36,6MPa in the cables, which resulted in 2 symmetrical loads with a value of 26,4kgf each at each of the anchorage points.

Initially, a mesh with 2153 elements was adopted. Aiming to carry out a convergence analysis of the results, new meshes were made, these being more refined (3028 elements and 5832 nodes), until a final maximum stress value was obtained in the structure regardless of the adoption of smaller elements.

3.3 Dynamic analysis

In order to characterize the dynamic response of the tower and to provide subsidies to its instrumentation and to the subsequent experimental investigations that will have to be made from the manufactured prototype, such as fatigue performance, a modal analysis of the structure was also conducted through the use of computational simulation.

In this sense, this survey was carried out based on the same geometric model and with the consideration of the boundary condition “crimping” at the base of the tower. In this case, the option of not using a free-free analysis was due to the consideration that such restriction has the potential to change the rigidity of the set.

Given the lack of empirical data regarding the dissipation of mechanical energy in the structure, an initial damping value equal to 5% was adopted.

4. RESULTS

4.1 Stress and deformation

With use of the process described in section 3.2, the maximum value for stress in the structure was identified as approximately 12MPa at the location indicated in Figure 3, which corresponds to a safety factor that allows for security regarding the structural integrity of the tower due to static loads. It is worth mentioning that the analysis carried out, being preliminary, was restricted only to the bars that make up the tower, so that loads on the joining elements (rivets) and connections made in PLA were not analyzed, which, however, must be done in the following steps.

Concerning deformations, was identified a maximum value of 0.13mm at the location indicated in Figure 4, which can be seen as within acceptable limits for the purpose of this project.

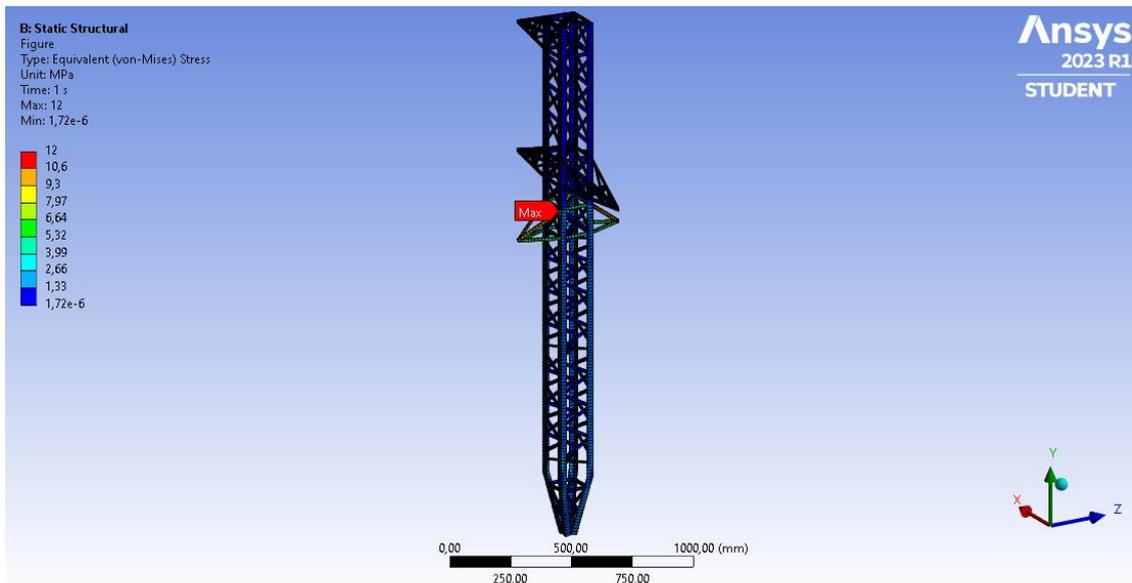


Figure 3. Stress results of static analysis of the tower made in Ansys Software. Source: Author

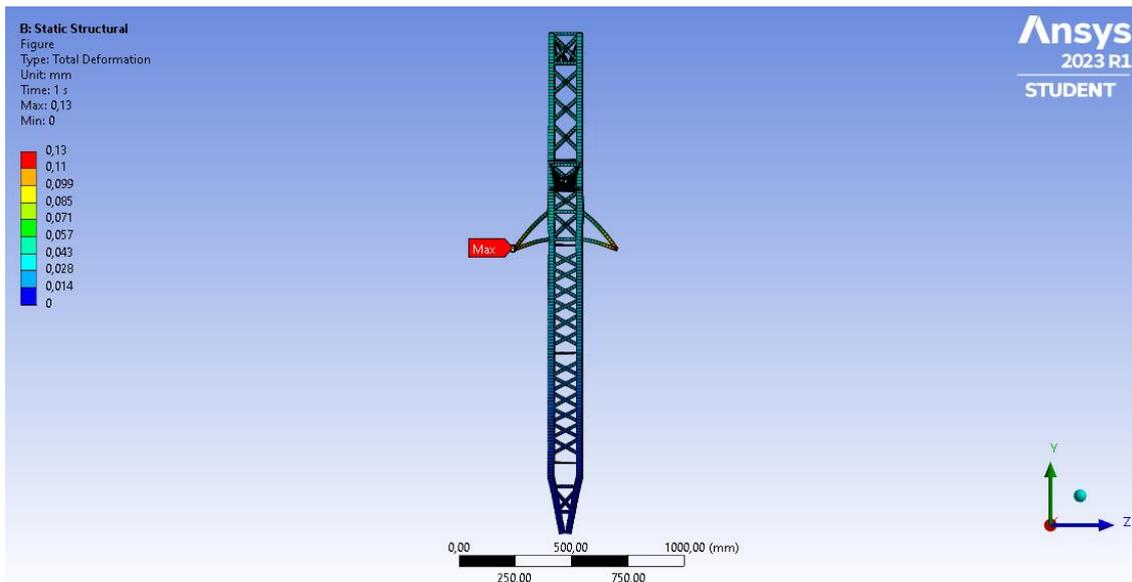


Figure 3. Deformation results of static analysis of the tower made in Ansys Software. Source: Author

4.2 Natural frequencies and normal modes of vibration

The data obtained using the methodology described in section 3.3 indicate that the tower must manifest its first normal mode at a frequency of 11,2Hz. The analysis of the corresponding form of vibration allows classifying such mode as being of bending (Figure 4). At the frequency of 37,9Hz, the tower must exhibit its second normal mode, the corresponding movement being classified as bending as well (Figure 5). Finally, at the frequency of 99,9 Hz, the third normal mode of the tower must be present, which can be seen as torsion (Figure 6).

The following modes, with higher frequency, were not recorded because it was considered that these would not be relevant given the environmental context in which the structure was used.

It is also intended, in the next steps, to carry out a fluid dynamic analysis of the tower in order to know the excitation frequencies resulting from the action of the wind and, in this way, to compare them with the natural frequencies of the structure in order to take note the possibility of structural damage associated with the occurrence of resonances.

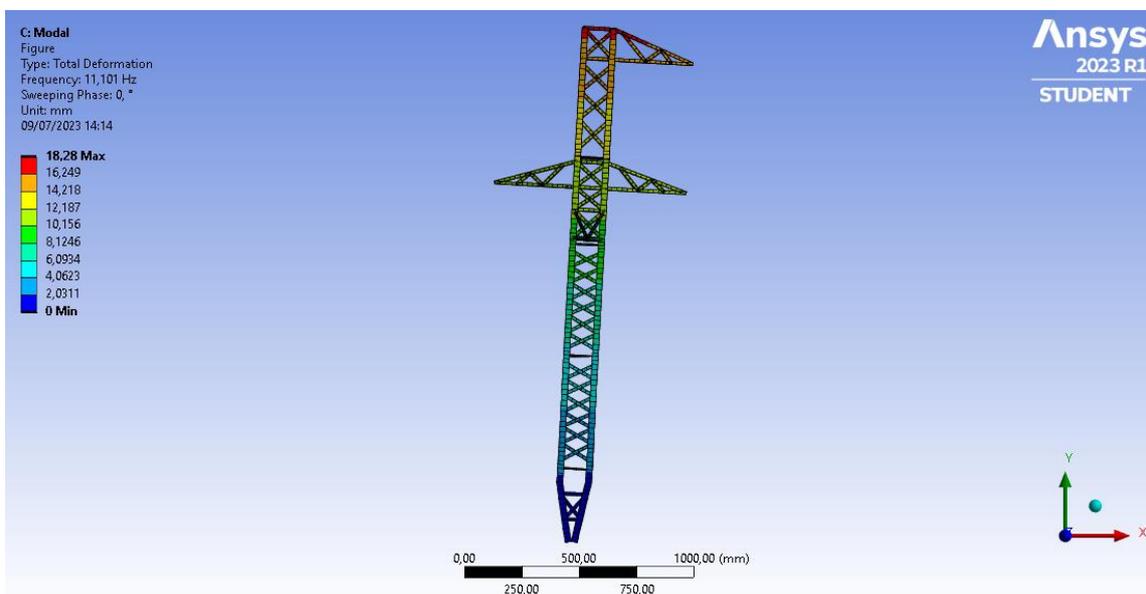


Figure 4. First vibration mode (bending) of the tower made in Ansys Software. Source: Author

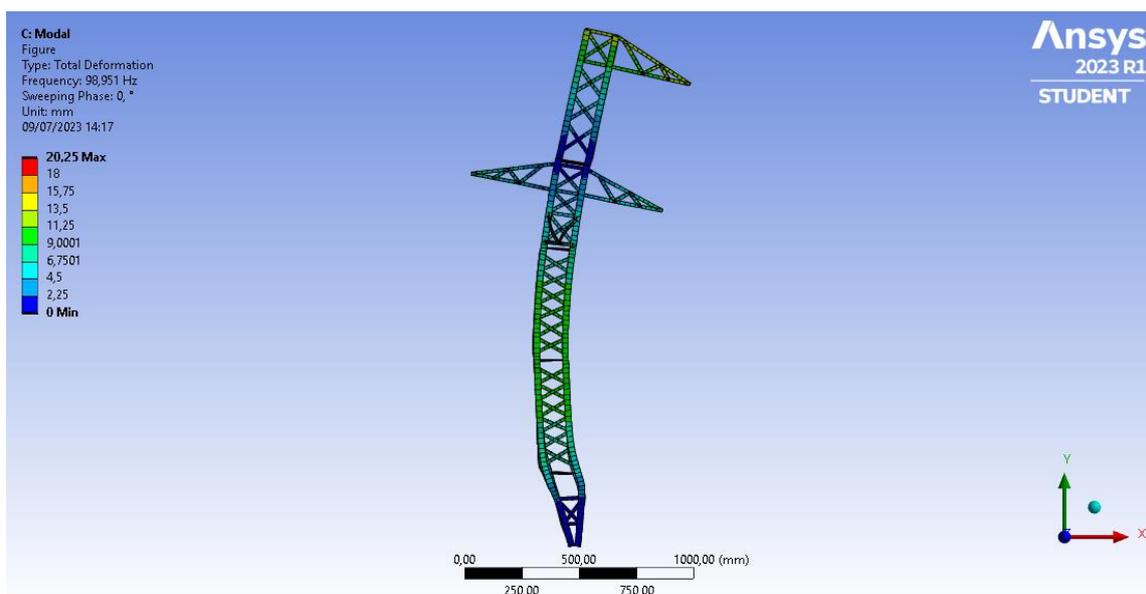


Figure 5. Second vibration mode (bending) of the tower made in Ansys Software. Source: Author

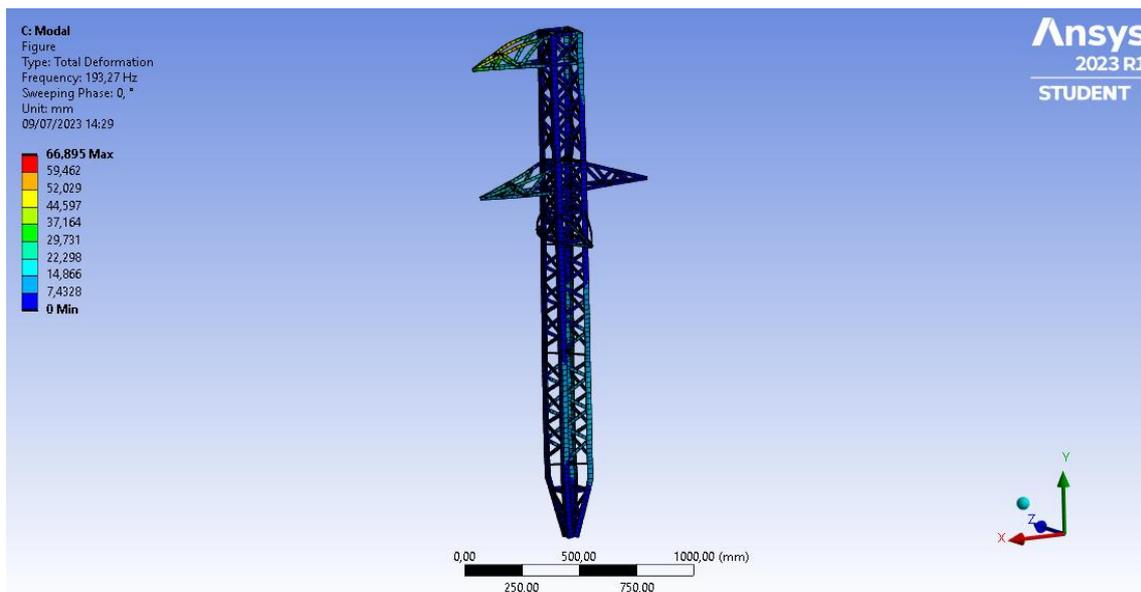


Figure 6. Third vibration mode (torsion) of the tower made in Ansys Software. Source: Author

5. CONCLUSION

The project is still in progress, but it is intended with this work to detect ways to design safer cable-stayed towers in relation to the durability of the structure and cables, considering the reduction of this useful life by fatigue cycles originated mainly by winds that cause the tower to vibrate at certain frequencies that accelerates the failure process. Whether by detecting and monitoring the integrity of the tower followed by maintenance, or depending on the wind regime of each region, it is still possible to modify the design of the tower within certain limits to be discussed, such as the height of the tower, from the addition of modules or removal, when possible. These modifications would not hinder the industrial-scale manufacturing required to install the large number of towers throughout the country, since they are modules.

6. ACKNOWLEDGEMENTS

The authors acknowledge the financial assistance of the Fundação de Apoio à Pesquisa e à Inovação Tecnológica do Estado de Sergipe – FAPITEC (EDITAL FAPITEC/SE/FUNTEC Nº 06/2022).

7. REFERENCES

- ABDI, 2017, Indústria 4.0 pode economizar R\$ 73 bilhões ao ano para o Brasil, ABDI, 20 12 2017. <https://www.abdi.com.br/industria-4-0-pode-economizar-r-73-bilhoes-ao-ano-para-o-brasil/>. Accessed 22 October 2023.
- BORGES, Fabricio Quadros. Crise de energia elétrica no Brasil-uma breve reflexão sobre a dinâmica de suas origens e resultados. RECIMA21-Revista Científica Multidisciplinar-ISSN 2675-6218, v. 2, n. 10, p. e210809-e210809, 2021.
- CARLOS, T. Análise dinâmica de torres estaiadas de transmissão submetidas à ruptura de cabo. Dissertação de Mestrado (Pós-graduação em Engenharia Civil) - Universidade Federal de Santa Maria. Santa Maria, p. 218, 2015.
- CHENG, X. X. et al. Structural Health Monitoring-Oriented Finite-Element Model for a Large Transmission Tower. International Journal of Civil Engineering, v. 16, n. 1, p. 79–92, 1 jan. 2018.
- GIAGOPOULOS, D. et al. Structural health monitoring and fatigue damage estimation using vibration measurements and finite element model updating. Structural Health Monitoring, v. 18, n. 4, p. 1189–1206, 1 jul. 2019.
- GOLDEMBERG, José; VILLANUEVA, Luz Dondero. Energia, meio ambiente e desenvolvimento. São Paulo: Edusp, 2003.
- ROSAFALCO, Luca et al. A Self-adaptive Hybrid Model/data-Driven Approach to SHM Based on Model Order Reduction and Deep Learning. Structural Health Monitoring Based on Data Science Techniques, p. 165-184, 2022.
- SONBUL, O. S.; RASHID, M. Algorithms and Techniques for the Structural Health Monitoring of Bridges: Systematic Literature Review. Sensors MDPI, 1 maio 2023, <https://www.mdpi.com/1424-8220/23/9/4230>. Accessed 29 June 2023.
- JING, Wu et al. Structural Optimization and Experimental Research of High-rise Guyed Tower. In: E3S Web of Conferences. EDP Sciences, 2021. p. 02006.

- TROIAN, Sandro Pieta. Sobre a resposta estrutural dinâmica de uma torre estaiada de linha de transmissão submetida a ventos do tipo EPS. 2018.
- JOHNSON, Gabriel A.; FRENCH, Jesse J. Evaluation of infill effect on mechanical properties of consumer 3D printing materials. *Advances in Technology Innovation*, v. 3, n. 4, p. 179, 2018.

8. **RESPONSIBILITY NOTICE**

The author(s) is (are) the only responsible for the printed material included in this paper.