XIX International Conference on Building Pathology and Constructions Repair
8th to 10th, june 2023 - Sobral, Brazil

USG Method in the assessment of construction defects in foundations of wind turbines

Kércia da Silva NOGUEIRA[1], Laura Cristiane da Silveira ANDRADE[2], **Paulo Henrique Araújo BEZERRA**[3]

[1] UFERSA, Pau dos Ferros, Brazil, kercia.nogueira@alunos.ufersa.edu.br
[2] UFERSA, Pau dos Ferros, Brazil, paulo.bezerra@ufersa.edu.br
[3] TRACTEBEL, Bahia, Brazil, laurac_s@hotmail.com

Abstract: This paper proposes the use of the Urgency, Seriousness and Growth (USG) Method in the assessment of construction defects in foundations for wind turbines. To present how the method can be applied in the evaluation of defects in foundations for wind turbines, we critically analyzed filed data from the construction and inspection of foundations at an onshore wind farm in Brazil using the USG Method. Results demonstrate the importance of using the USG Method.

Keywords: Construction defects, Wind farms, Foundations

1. Introduction

Wind energy has increasingly become one of the main sources of clean and renewable power generation, augmenting the demand for wind farm construction. In 2021, 72.5 GW of new onshore wind capacity was recorded globally, causing cumulative onshore wind capacity to attain 780 GW, corresponding to the installation of tens of thousands of new wind turbines [Mathern et al. (2022); Global Wind Energy Council (2022)].

The construction of wind farms involves the assembly and installation of large wind turbine towers, a key component in its infrastructure. Such elements demand an appropriate structural detailing and a careful building procedure; thus, many works have approached the design and construction of wind turbines. Paredes et al. (2011) performed numerical simulations of wind turbine towers, Wymore et al. (2015) surveyed commercial and research turbine health monitoring systems - providing an analysis of their current state and associated challenges – and Msigwa et al. (2022) reviews the impacts of wind energy generation on environmental, economic, and social aspects of sustainability and mitigation strategies.

The foundation of the turbine towers is one of the most critical components in the wind farm construction and particular concerns include the potential problems in concrete used in the foundations - which can lead to structural failures, environmental degradation, and safety risks. In that context, studies have highlighted issues in foundation's concrete, including the ones related to strength, durability, and cracking. For example, a study by Cunha et al. (2015) found that the use of recycled aggregates in concrete mixtures can lead to a reduction in strength and durability, potentially compromising the safety and longevity of wind turbine foundations. Another study by Wang et al. (2017) identified issues related to the cracking of concrete used in wind turbine foundations, which can compromise structural integrity and increase the risk of failure. Additionally, the use of certain types of cement in wind turbine foundations, such as high-alumina cement,

https://doi.org/10.4322/CINPAR.2023.012

has been linked to environmental issues such as the release of heavy metals into surrounding ecosystems (Cazacliu et al., 2014). Other studies have highlighted issues related to the potential for groundwater contamination during the construction and operation of wind turbine foundations (Khalil et al., 2018).

However, as mentioned in Braga et al. (2019), the Urgency, Seriousness and Growth (USG) Method, presented in Kepner et al., 1981, is a very useful and important tool handle that process. By applying the USG Method, we can form an order of solving problems.

This work then proposes the use of the USG on the assessment of defects in the construction of foundations of wind turbines. To present how the method can be applied, filed data from the construction of 9 towers at an onshore wind farm in Brazil were compiled and critically analyzed.

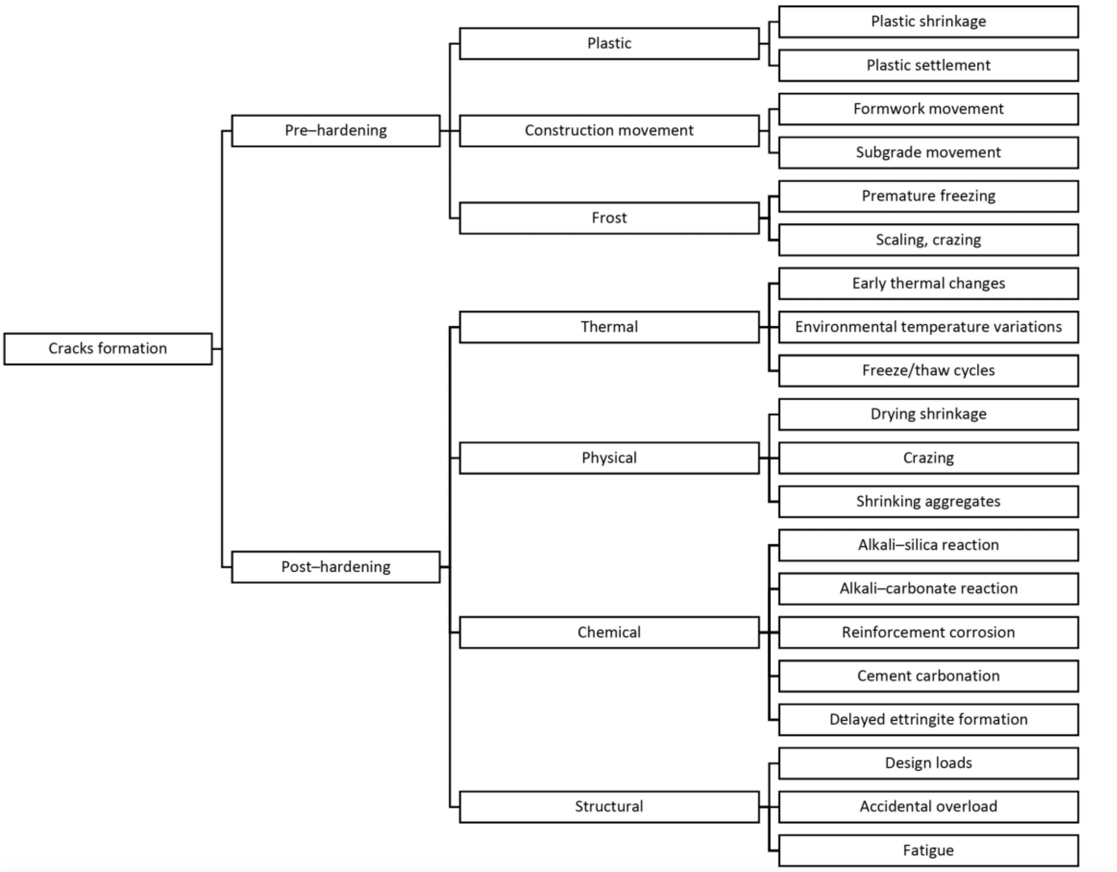
2. Methods

2.1 Introduction

In this work, we use the term defect as a general concept, that may refer to anomalies or nonconformities and be associated to durability and functionality of the foundations. Defects can be related to design errors, construction failures or material deficiencies.

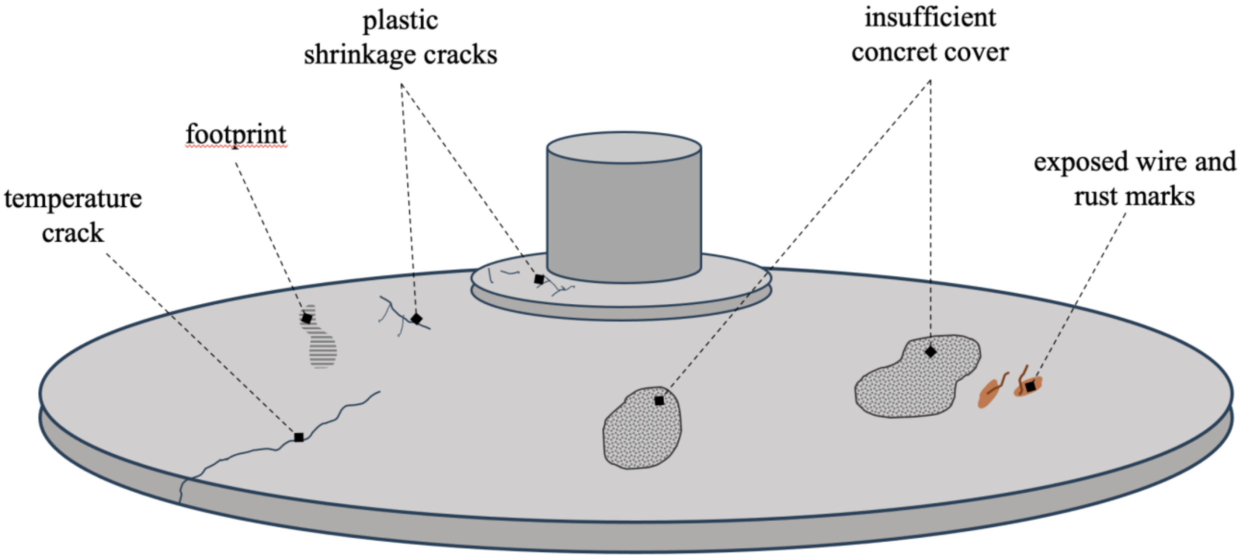
Among the construction defects catalogued in this work, cracking was the most abundant type. As mentioned in Mathern et al. (2022), most concrete structures present any kind of cracking, which may be often classified in two main categories, depending on whether they occur before or after hardening of the concrete. Figure 1 illustrates crack formation mechanisms.

Figure 1 – Types of cracks and underlying causes. Elaborated from Mathern et al. (2022).



In this work, we analyzed nine wind turbine foundations, which presented nonconformities after execution phase. The most recurring types of defects found, therefore the ones studied in this work were cracks, footprints, exposed wire, segregation of concrete, and concrete honeycombs. Figure 2 illustrates a scheme with the main types and the respective occurrence locations of concrete defects found in the wind turbine foundations.

Figure 2 – Scheme of main types of concrete defects found on the analyzed wind turbine foundations and their respective locations.



2.2 Urgency, Seriousness and Growth (USG) Method

We catalogued all the nonconformities, classified the defects into different the categories and characterized them quantitatively according to the USG Method. In order to identify nonconformities in wind turbine foundations, we analyzed the photographs of defects as well as data from quality control inspection forms – which contain information about the anomalies and indicate or propose a procedure to be followed to repair the problem.

Defects repair priority order was established by applying the Urgency, Seriousness and Growth (USG) Method, which contributes to an efficient planning as well as facilitates solution programming, focusing on quality control. When evaluating urgency, the definition of each degree was based on the defect's magnitude and repair time, as presented in Table 1.

Table 1 – Urgency evaluation in USG Method

Degree	Score
Extremely urgent	5
Very urgent	4
Urgent	3
Less urgent	2
Non-urgent	1

Seriousness assessment considers possible risks and extent of damages, as presented in Table 2.

Table 2 – Seriousness evaluation in USG Method

Degree	Score
Extremely serious	5
Very serious	4
Serious	3
Less serious	2
Non-serious	1

Growth evaluation considers how quickly defect magnitude can increase. Table 3 shows the classification.

Table 3 – Growth evaluation in USG Method

Degree	Score
Quick growth	5
Short-term growth	4
Medium-term growth	3
Long-term growth	2
No growth trend	1

After evaluating the specific USG scores, the total score T_s is obtained by using Equation 1, in which U_s, S_s, and G_s represent the urgency, seriousness and growth scores respectively.

$$T_s = U_s \times S_s \times G_s \quad (1)$$

One example of wind turbine foundation score computing is presented in Table 4. Data for foundation 1 includes nonconformity description and location of the defect; from such information, we assigned scores for urgency, seriousness and growth of each defect and then computed the respective total score T_s.

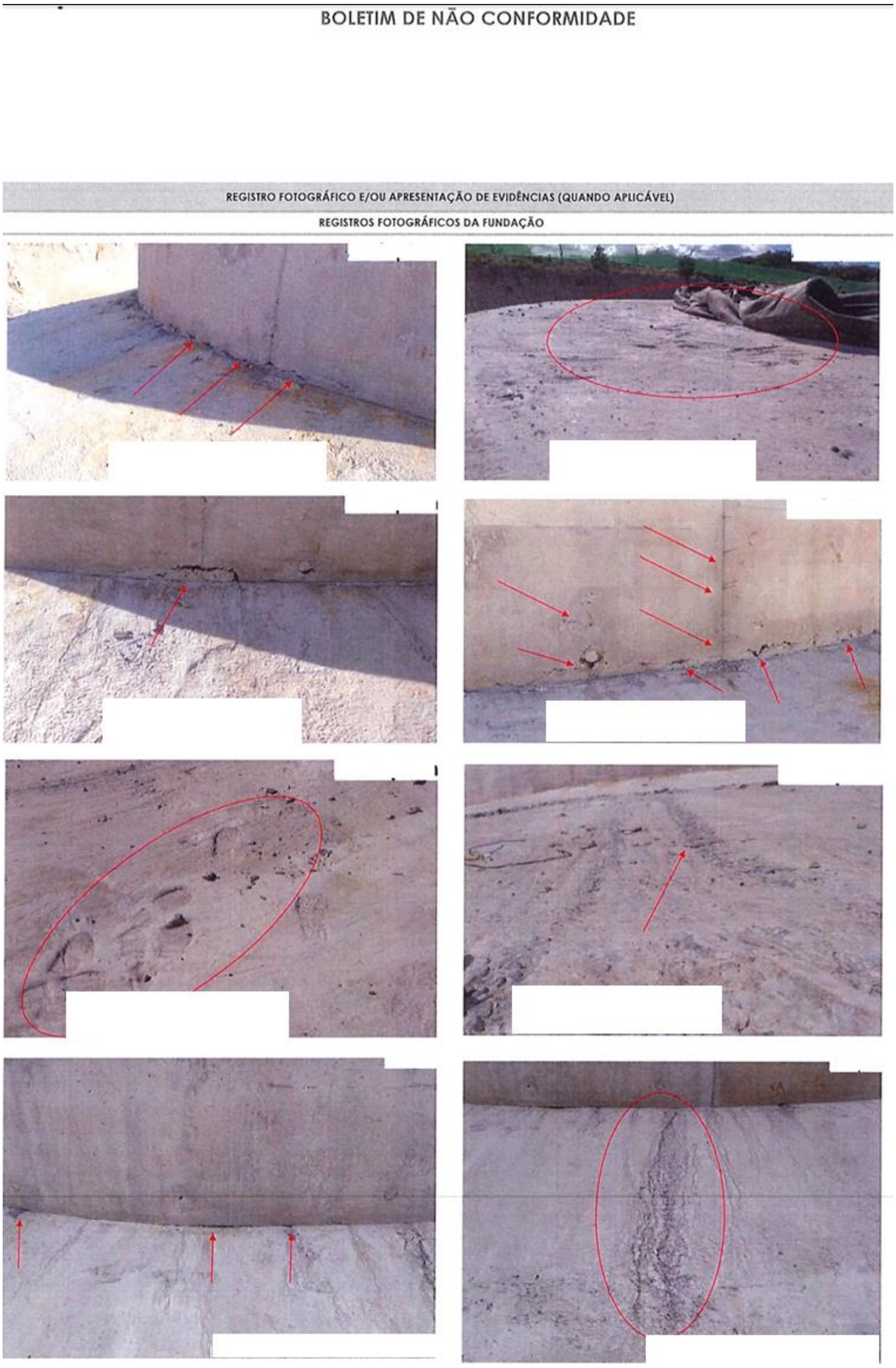
Table 4 – Score computing for wind turbine foundation 1.

Number	Nonconformitie description	Defect location	USG METHOD			
			Urgency	Seriouness	Growth	U x S x G
1	Exposed wire	Top	1	2	2	4
	Concrete segregation	Base	4	3	4	48
	Cracks	Base	3	3	3	27
	Concrete honeycombs	Top	4	3	3	36
	Footprints	Base	1	1	1	1

2.3 Quality control inspection forms and defects examples

Defects had been catalogued previously in quality control inspection forms by construction company's workers. An example of inspection form defect presentation is shown in Figure 3.

Figure 3 – Example of quality control inspection form.



BOLETIM DE NÃO CONFORMIDADE

REGISTRO FOTOGRÁFICO E/OU APRESENTAÇÃO DE EVIDÊNCIAS (QUANDO APLICÁVEL)

REGISTROS FOTOGRÁFICOS DA FUNDAÇÃO

Photographs of all defects have also been analyzed in order to help classifying them according to the USG Method. Figure 4 presents an example of a crack at the base of one foundation.

Figure 4 – Example of a crack at the base of a wind turbine foundation.

Figure 5 illustrates a honeycomb in a wind turbine foundation.

Figure 5 – Example of honeycomb in a wind turbine foundation.

An example of footprint is shown in Figure 6.

Figure 6 – Example of footprints at the base of a wind turbine foundation.

Figure 7 – Example of concrete segregation in a wind turbine foundation.

Figure 8 – Repair action reported inspection form.

3. Results and Discussion

According to the quantitative analysis carried out in this study, presented in Figure 9, honeycombs were the most frequent construction defect in the analyzed wind turbine foundations, followed by segregation and cracking. Footprints and exposed presented a lower frequency.

Figure 9 – Construction defects occurrence

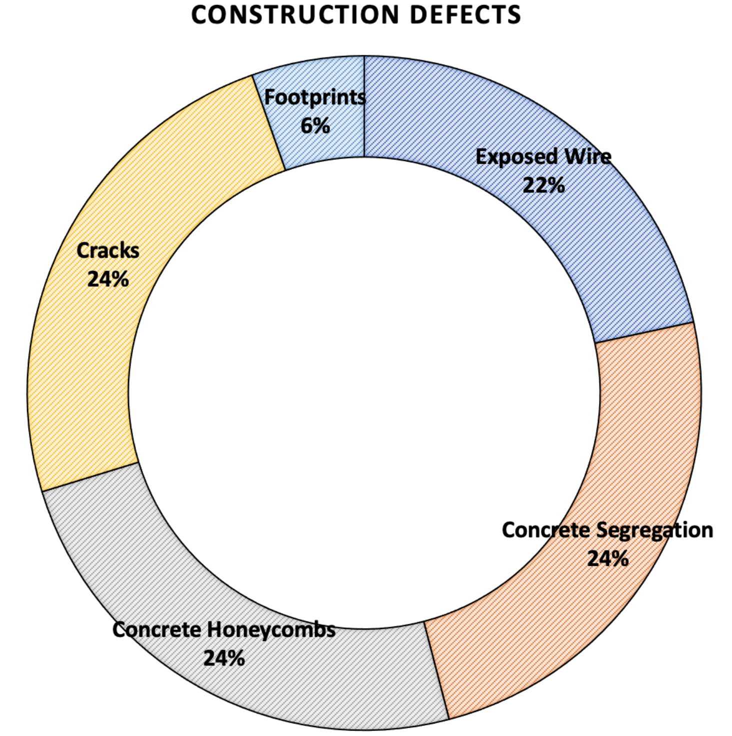
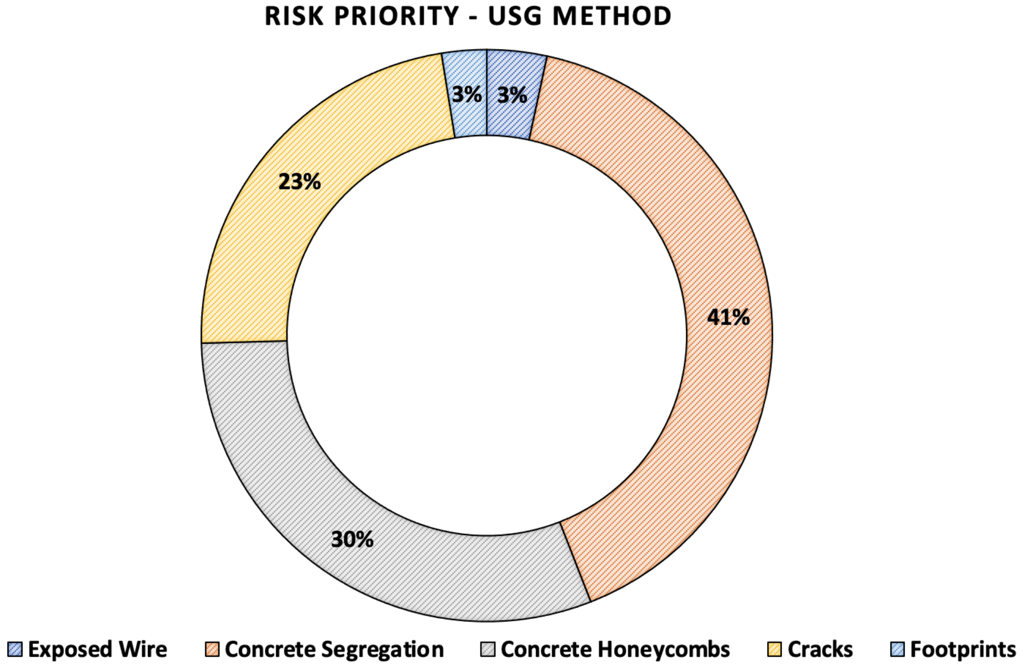


Figure 10 illustrates the results, in percentage, of the prioritization order obtained by applying the USG Method.

Figure 10 – Priority risk percentage from USG Method



According to those scores, the concrete segregation presents 48 points, leading the priority ranking. Concrete honeycombs was placed second because it attained 36 points, followed by cracks (27 points), then exposed wire (4 points) and footprints (3 points).

Exposed wire and footprints presented a lower score since urgency, as well as seriousness and growth are very low compared to the other defect types. Such anomalies do not represent a risk for the wind turbine foundations.

4. Conclusions

In this work we presented the most frequent construction defects in wind turbine foundations of a specific wind farm in Brazil. After cataloguing the main types of defects, we established a priority order by applying the USG Method, a tool used prioritize which problem should be solved first by considering their urgency, seriousness and potential growth.

By analyzing the USG scores, we found that concrete honeycombs, concrete segregation and cracks are the most frequent defects in wind turbine foundations and the ones that can cause the greatest damages, affecting structural performance and lifespan. Therefore, immediate correction action must be taken in order to restore the foundations' affected areas.

Consequently, in order to minimize construction defects occurrence, we can notice the necessity for adequate planning, with a view to attaining an effective quality control - regarding materials and execution management – and even to proposing new construction methods.

Future works can propose new technical recommendations to repair construction defects, as well as new construction techniques capable of minimizing common anomalies and its consequences.

References

Braga, I. C.; Brandão, F. S.; Ribeiro, F. R. C.; Diógenes, A. G.(2019) Application of GUT Matrix in the assessment of pathological manifestations in heritage constructions. Revista Alconpat, [S.L.], v. 9, n. 3, p. 320-335, Alconpat Internacional.

Cazacliu, B.G., Muntean, M., Patrascu, A., & Sandu, I. (2014). Environmental impact of high-alumina cement use in wind turbine foundations. Environmental Engineering and Management Journal, 13(9), 2231-2238.

Cunha, R., Ferreira, P., De Brito, J., & Evangelista, L. (2015). Use of recycled aggregates in a dry-stack concrete wind turbine tower. Journal of Cleaner Production, 96, 365-374.

Global Wind Energy Council. Global Wind Report 2022; Global Wind Energy Council: Brussels, Belgium, 2022.

Kepner, C. H., Tregoe, B. B. (1981) The New Rational Manager. New Jersey: Princeton Research Press, 1981.

Khalil, H.A., Essam, T.M., & El-Metwally, A.E. (2018). Environmental impact assessment for wind farm projects: A case study in Egypt. Renewable Energy, 129, 721-733.

Mathern, A. Magnusson, J.(2022) Lessons Learned from the Construction, Inspection, and Defect Assessment of Reinforced Concrete Foundations for Wind Turbines. Applied Sciences, [S.L.], v. 12, n. 3, p. 1443, MDPI AG.

Msigwa, G.; Ighalo, J. O.; Yap, P. (2022). Considerations on environmental, economic, and energy impacts of wind energy generation: projections towards sustainability initiatives. Science Of The Total Environment, [S.L.], v. 849, p. 157755, Elsevier BV.

Paredes, J. A., Barbat, A. H., Oller, S. (2011). A compression–tension concrete damage model, applied to a wind turbine reinforced concrete tower. Engineering Structures, [S.L.], v. 33, n. 12, p. 3559-3569, Elsevier BV.

Wang, J., Zhang, Y., & Shi, Y. (2017). Crack propagation and fatigue analysis of concrete wind turbine tower based on ANSYS. Materials Research Express, 4(8), 086304.

Wymore, M. L., Van Dam, J. E., Ceylan, H., Qiao, D. (2015) A survey of health monitoring systems for wind turbines. Renewable And Sustainable Energy Reviews, [S.L.], v. 52, p. 976-990, Elsevier BV.