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NUMERICAL EXPERIMENTAL ANALYSIS OF A WIND BLADE FROM VERNE 555 WIND TURBINE MODEL

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Abstract. *The studies carried out in the field of wind turbines have led to a structural design of horizontal axis wind turbines composed of a set of three blades of composite material. The blades are subjected to dynamic loads which assume variable intensities over time. These dynamic influences, for a long time, by the difficulty of numerical reproduction, are estimated by a static load. Thus, the parameters of resistance were evaluated in order to improve the numerical modeling, since the manufacturer does not provide all the data characteristic of the blade. However, in the field of evaluation of the strength of the structural element, the numerical-experimental analysis was proposed here under a static approach on a blade of a small Verne 555 wind turbine. The characteristics of the blade were not provided by the manufacturer as being industrial property. Thus, the blade was subjected to reading metrology to obtain the external geometry, as well as the composite materials used in its manufacture were estimated, using physical parameters based on the literature. The results extracted in both models were compared based on the observation of the deflection at four points of the blade and were satisfactory, since this is still a preliminary investigation.*

Keywords: *Numerical analysis, static test, wind turbine blade, composites materials.*

1. INTRODUCTION

The understanding of the structural behavior is of fundamental importance in the evolution of new design conceptions. Over the years there has been great progress in this area. The technology and its developed tools have facilitated the analysis of more complex structures without having to resort to simplified models. The result of this technological era are leaner, more economical and attractive structures.

However, the problems of overloads that lead the structure to collapse must be observed more carefully. According Chazly (1993), the majority of structural failure in wind turbine blades occurs at the root, with the urgent need to evaluate deflections and tensions resulting from drag and lift forces under constant wind conditions. According to IEC 61400:23 (2001), the blade must be subjected to static load tests of standard design load distribution, producing a margin between this load and the blade breaking strength at its weakest position.

This work, therefore, proposes a numerical-experimental study of small wind turbine blades, model VERNE 555. It will be presented the numerical modeling of the blade, in finite elements, by Araújo *et al*. (2016). The extracted data will reveal if the numerical modeling corresponds with the original model, since it was not provided geometric details and relative the properties of the materials that compose it. Although the blade is a structure conditioned to dynamic behavior, numerical and experimental tests will be limited to the field of static analysis only.

2. WIND TURBINE DESCRIPTION

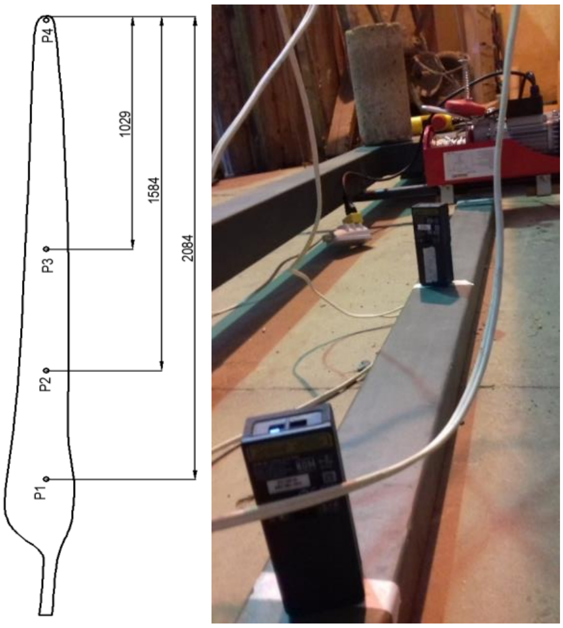
The sample used in this work is the wind turbine Verne 555, developed by Enersud - Energy Solutions Ltda, headquartered in Maricá, Rio de Janeiro, Brazil. With an extension of 5.5 m in diameter and a rotational speed of approximately 240 rpm at 12 m/s wind speed, the wind turbine is designed to capture energy in low wind conditions with a capacity of up to 6 kW. Figure 1 show the model of the wind turbine.

Figure 1: Horizontal axis turbine model Verne 555 (Source: Enersud, 2016).

3. METODOLOGY

From the QBlade software the aerodynamic parameters were obtained, such as the wind load applied to the blade. This load can be represented by a triangular profile, however, the load applied in the computational model and in the experimental test was punctual, at a distance of 2/3 of the blade root, thus representing an approximation of the resultant of the wind load. The load was manipulated by an electric hoist through a steel cable fixed in this position, where it was measured by means of a load cell of the manufacturer HBM with a sensitivity of 2 mV/V, as seen in Figure 2. The deflection amplitude monitoring was done with four lasers, positioned at four strategic points along the blade to capture the curvature. Of course, as the blade is flexed, it is necessary to move the tracks in order to follow the points previously marked on the blade. Figures 3 (a) and (b) show the locations and layout of the tracks with ± 3 mm accuracy.

Figure 2: Test bench configuration.



(a) (b)

Figure 3: Locations of deflection measurement and positioning of the laser beam (in millimeters).

In the calculation of turbine blade design, three additional load coefficients are taken into account. The management of the uncertainties - through the coefficients - at several stages of the project is fundamental, the coefficients that quantify the design loads in the static regime were used as a basis to establish the test loads and evaluate the blade resistance. In this way, it aims to evaluate the behavior of the blade in the imposed demands. IEC 61400 (2014) describes the coefficients used to calculate the static test load, as shown in Table 1.

Table 1. Partial safety coefficients for ELU analysis.

Partial Safety Factor	IEC 61400/1:2014	IEC 61400/23:2001 (minimum values)
Load test (γf)	1,35	1,25
Consequence of failure (γn)	1,0	
Static test (γs)	1,1	1,1

Therefore, to calculate the load designed for the static test we use, according to IEC 61400:1 (2014), we use Equation (1):

$$F_p = Fd.\gamma_n.\gamma_s \tag{1}$$

where F_d is the value of the design load and F_k is the characteristic value of the load (obtained from numerical simulation results by QBlade software). Table 2 shows the load values based on Equation (1).

Table 2. Load values for numerical and experimental tests.

Limit State	Value for test load (N)
Service	850.11
Ultimate	935.11

This, we attribute to the elements the mechanical properties of each material based on the values mentioned in Callister Jr (2007), as shown in Table 3.

Table 3. Mechanical properties of the materials used in the analysis.

Materials	Young Modulus (GPa)	Poisson Coefficient
Aluminum	69.0	0.33
Epoxy	2.4	0,40
Fiberglass	72.5	0,22

4. COMPUTATIONAL AND EXPERIMENTAL PRODUCE

4.1 Numerical model

To obtain a corresponding numerical model, it is necessary to obtain geometric information of the blade. As it is industrial property, some information was not provided by the manufacturer, such as the internal and external dimensions along the blade and the properties of the materials that make up the blade. Thus, the external dimensions of the blade were obtained through digitized blade readings using coordinate measurement technology, at the Metrology Laboratory of the Department of Mechanical Engineering of the University of Brasília. However, according to the manual of the wind turbine Verne 555 (Enersud, 2016), the blade is composed of a composite material with an outer layer of glass fiber and internal reinforcement of aluminum. We estimate that the internal reinforcement in aluminum begins at the root until supposedly in one of its sections - forming a kind of "racket" giving rigidity to the structure - and the rest of the thermoplastic internal polymer area in appearance of foam. The measurements were reproduced on the CAD platform and then exported to ANSYS, resulting in the model shown in Figure 4.

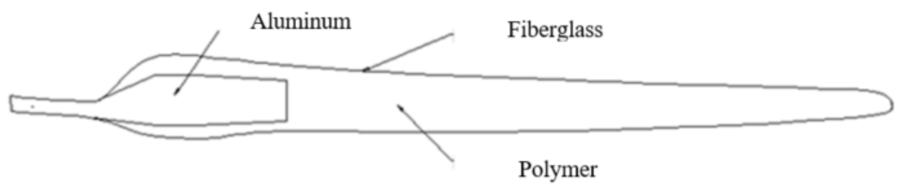


Figure 4: Representation of the numerical model of the VERNE 555 wind blade in ANSYS.

ANSYS is a commercial software that uses finite element method (FEM) as the basis for simulations of engineering problems, allowing resolution of complex structures in various scenarios. In the present work, beam element was used, with two nodes, each one with 6 degrees of freedom, considering just linearity geometric.

4.2 Experimental program

Experimental tests are used to determine different parameters of a project, complementing and attesting a set of analyzes conducted to guarantee the safety and functionality of the part. The tests can reproduce dynamic or static behaviors. It aims to evaluate the reliability of the design, the behavior of the structural element in front of predetermined influences, extract properties of the material as well as attest a numerical model.

It was reproduced a bench model similar to that adopted by Alé *et al*. (2011) for the static tests, made here of carbon steel tube of square cross-section, with principal dimensions of 275 x 960 cm in length and width, respectively. The base of the sword was made with ½ inch steel sheets forming a "cradle" type to better fit the blade root. The blade will be subjected to static loads in order to reach the ultimate limit state (ULS). The methodology adopted is based on the International Electrotechnical Commission (IEC) standard and the results obtained will be used in the calibration of the computational model. Figures 5 show the blade holder detail.

Figure 5: Blade holder detail.

The blade sample was fixed at one of its ends on the test bench and flexed in the free part by a steel cable coming from an electric hoist integrated to the bench – capable of holding up to 600 kg – at a distance of 1.83 m, where this location has a greater concentration of aerodynamic force. The value of the applied load, the deformation and the deflection of the blade were measured at each loading step.

During the test, in addition to the monitoring of the points mentioned, the site designated for blade setting was supervised in order to follow a possible angular displacement. A hand laser was positioned in this region and pointed to a support artifact at 6.85 m distance. As the blade was deflected, therefore, at each increment of charge, the laser sight was tracked, manually recording the sight of the object in that object. Thus, by evaluating the position of the initial laser sight with the final laser sight, the angle of rotation of that point.

In this test the load reached 154.7% of the expected design load. A load history was elaborated and organized in Table 4 with the purpose of reproducing them in the test and observing them in those points the reached deformation. These target loads were obtained through the aerodynamic results by QBlade software in conjunction with Equation (1).

Table 4. Load values for limits states.

Load percentage	**Value of the load to ULS (kgf)**
25%	23,83
50%	47,66
75%	71,49
100%	93,52

During the test, an unplanned slippage of the connection of the steel cable of the electric hoist with the blade was identified after the 10 s of load bearing the standard load. This displacement caused dynamic blade effects, however, with no apparent damage. However, in this loading step the maximum load provided for in the ULS seen in Table 3 was exceeded. Subsequent loads also suffered this incident. At that time, the test was suspended to stabilize the attachment assembly with silver tape and clamps on the blade surface, as shown in Figure 6. The wind blade remained intact during the static charging test. However, approximately 20% more than the ULS, crack sounds were then detected and identified on the surface drawn the comprised between 0.71 m and 1.58 m distant from the blade root – in the transverse direction, located in the region of the leading edge. Although there were cracks, the blade held the static positive load.

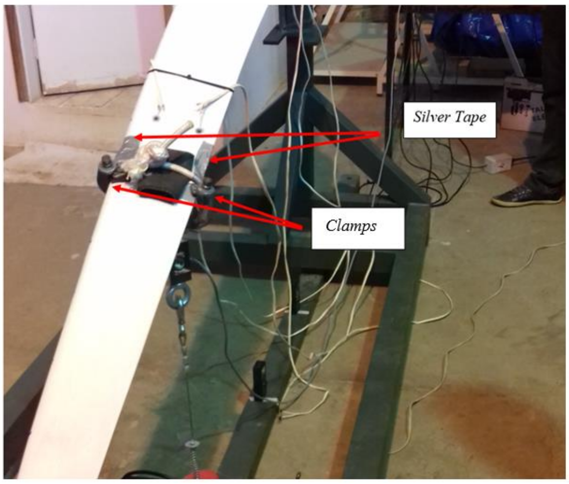


Figure 6: Detail of the settings at the blade loading location.

The test was again interrupted in the loading step 48 due to the limitation of the hoist which was prepared to reach a load of 150 kg. With the load at 54.7% more than the maximum load on the ULS, the hoist motor was not able to generate more force. In the meantime, it was decided to close the test, since, according to IEC 61400-23 (2001), most of the wind turbine materials exhibit a certain reduction of resistance according to the duration of the load, and may introduce undesirable uncertainties in the interpretation of results.

5. RESULTS

In the course of the test, that is, 25% of applied load - a certain inclination of the steel cable was observed, as noted in Figure 7, causing the emergence of perpendicular force vectors. It is considered, therefore, that from that moment, all the forces applied in the blade were decomposed, so that Graph 1 shows only the force in the Y direction. The angle of inclination was measured with the aid of Meazure software, where it presented variations between 0.1º and 6.2º degrees.

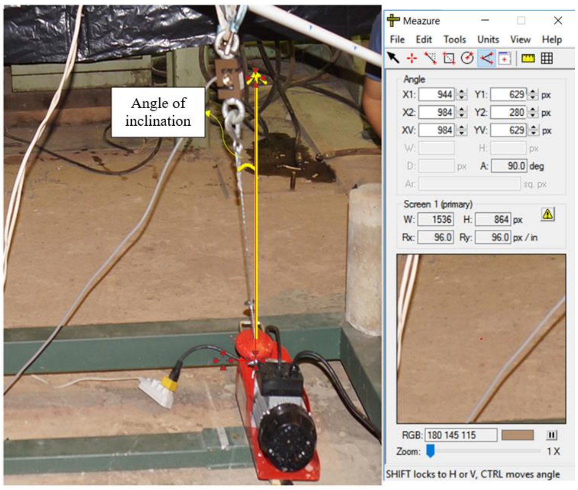
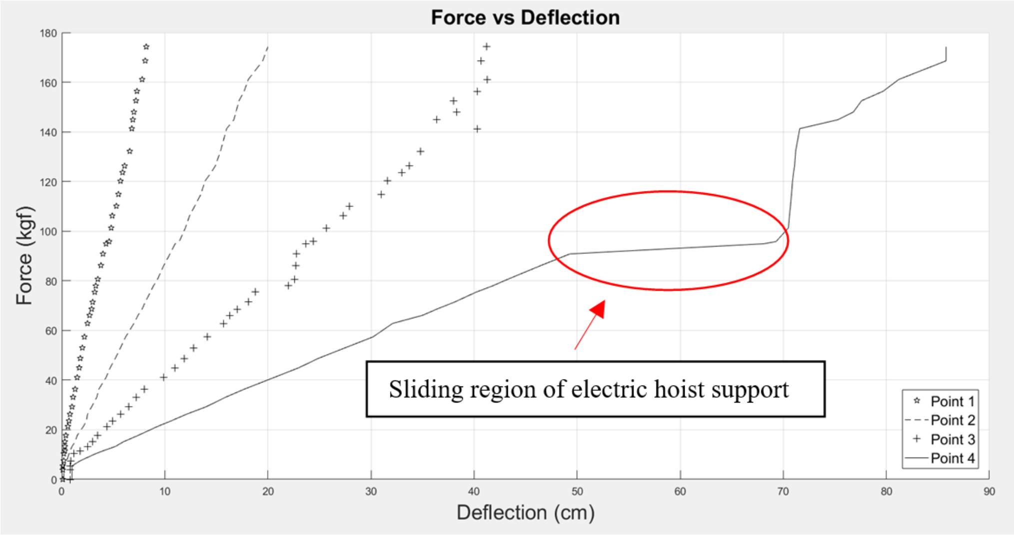


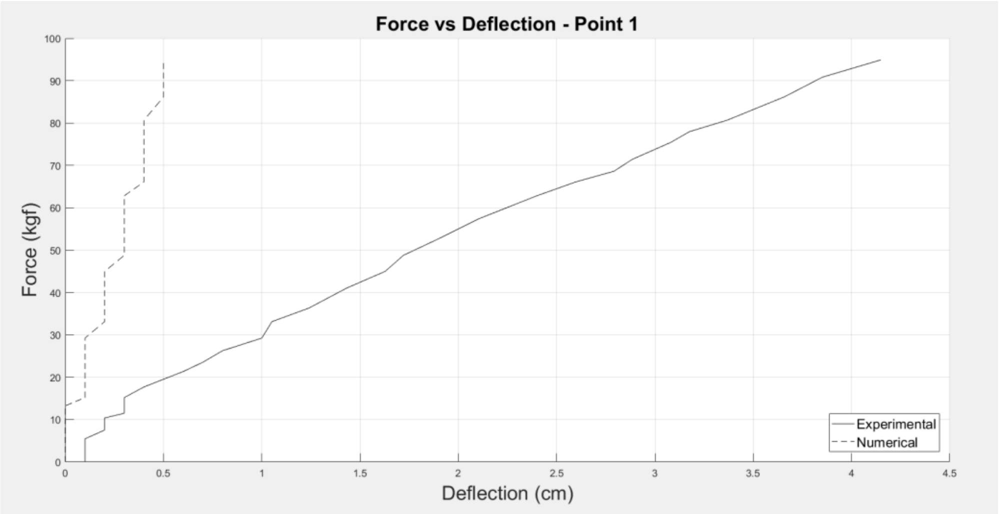
Figure 7: Angle of inclination produced during the static test.



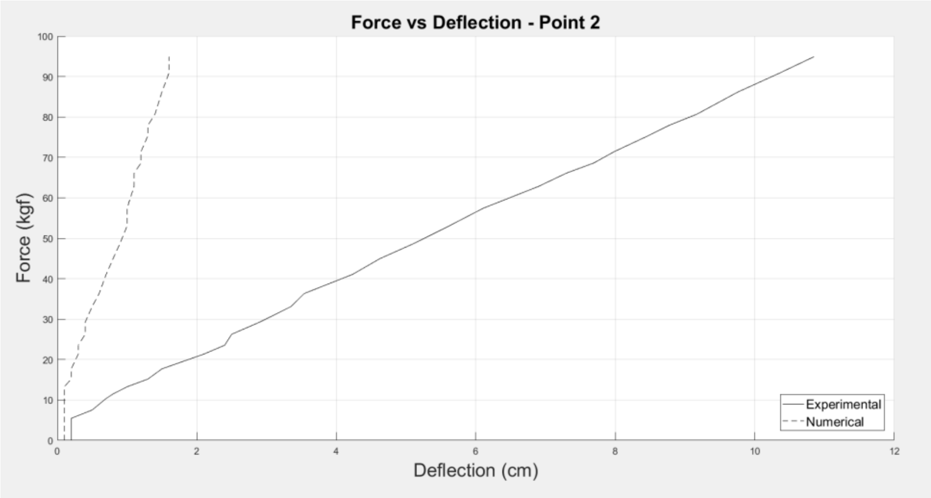
Graphic 1: Force vs. Deflection graph of the decomposed test.

With the application of the loads during the test, the upper plate of the blade holder was showing some displacement due to observation in the juxtaposed artifact, interfering with the measured results. It was noticed that the base of the support has not suffered any type of damage that it can configure in rotational displacement. The reason, however, for the yield of the upper plate was only in the loosening of some screws. However, after blade deflection measurements for each load, the data were corrected taking into account this event, but there was no significant change in the results that compromised them. During the test, an unplanned slippage of the connection of the steel cable of the electric hoist with the blade was identified after the 10 s of load bearing the standard load. This displacement caused dynamic blade effects, however, with no apparent damage. However, in this loading step the maximum load foreseen in the ULS. This occurrence is identified in Graphic 1.

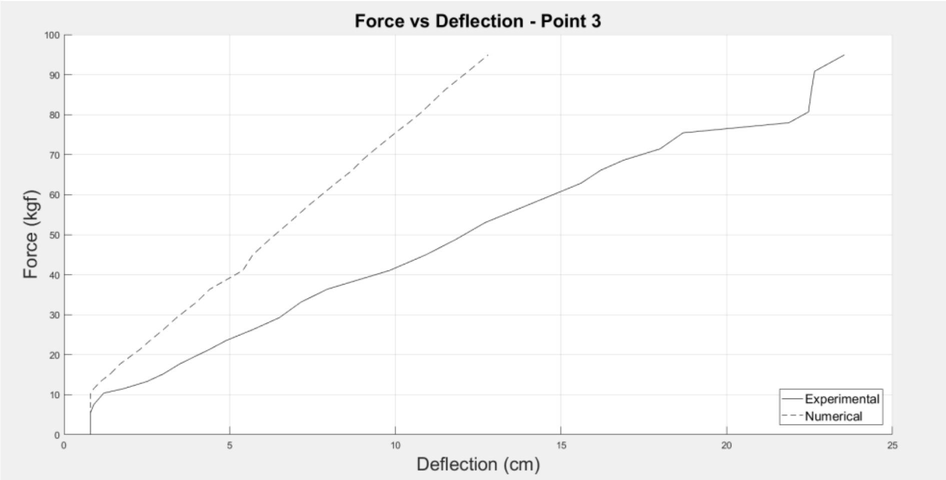
Next, graphs 2 to 5 show a comparison between the numerical and experimental model results at the four deflection points analyzed. The results of the numerical analysis were conducted based on geometric linearity. This simplified model presented a closer curve in the region where the target load was applied. Point 4, however, did not have much importance, since the deformation occurs from the point of the target load to the root.



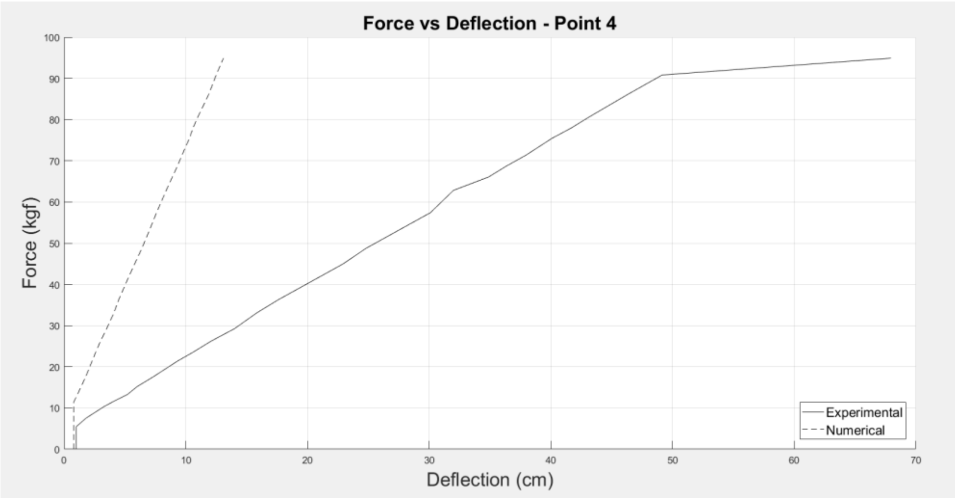
Graphic 2: Force vs. Deflection in the point 1.



Graphic 3: Force vs. Deflection in the point 2.



Graphic 4: Force vs. Deflection in the point 3.



Graphic 5: Force vs. Deflection in the point 4.

6. CONCLUSION

The future intention in the experimental field is to adjust the faults that have certainly influenced the results, such as the electric hoist pulley inversion, the adjustment of the blade setting in order to reduce or eliminate the rotation in this place as well as to modify the fit in the location of the target load. In the numerical field, improve modeling by conducting analysis compatible with the actual behavior of the blade, validating the numerical design.

The results of this trial are considered satisfactory, since this research is still preliminary. Despite some setbacks and due to the lack of information from the wind turbine blade by the supplier, an initial numerical model could be reproduced and can be used for comparative purposes with the experimental results. Like any experimental study, it is necessary to repeat the procedure in order to evaluate the external influences and to overcome the instabilities of the methodology adopted. The instability of the procedure is portrayed in the graphs generated at the moment that one perceives a sudden change in the evolution of the deformation trajectory.

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8. RESPONSIBILITY NOTICE

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