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THE COMPUTATION OF THE INTERNAL FORCES IN THE STRUCTURE OF A WIND TURBINE

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Abstract: *The paper aim is to present the computation of the internal forces and the analysis of the distribution of these forces (N - axial force, T - shear force, Mi – bending moment) for the structure of a wind turbine with main components blades - nacelle - pillar. For this, the structure was simplified in a frame-type model (2D structure), where the main elements were reduced to their longitudinal axes and fixed to each other at an angle of 90 degrees. They were analyzed, calculated and represented the internal efforts for two cases from the point of view of the position of the blades related to the nacelle axis. The computation and the distribution of the internal forces of wind turbine structure have the advantage that it can be customized for any real dimensions of structure elements or load intensity.*

Keywords: *internal forces; axial forces, shear forces and bending moment distribution; wind turbine, computation*

1. INTRODUCTION

The way in which wind energy is converted into electrical energy is achieved through a rotor with blades, which are rotating with angular speed given by wind speed. A difference in disk pressure is created due to the aerodynamic profile of the blades, which is responsible for the loss of the axial impulse. This "loss of wind energy" is collected by an electric generator attached to the rotor shaft, the generator exerting an equal and opposite direction torque to the air flow that maintains the rotation speed constant. The mechanical work done by the aerodynamic torque on the generator is converted into electrical energy. The transmission of the rotation motion of the rotor influences the efficiency of the wind turbine, as well as its reliability over time.

The main components of a wind turbine with horizontal axis are presented in Fig. 1 [1, 2]: ***the blade*** which ensures the capture of the wind energy and the rotor drive; ***the nacelle*** which contain the main shaft, amplifying the rotation motion through a multiplier, which is captured as a mechanical energy of generator, transforming into electricity; ***the pillar (the tower)*** that provides the support structure and strength of the upper assembly; ***the foundation*** that provides the mechanical strength of the whole wind turbine assembly.

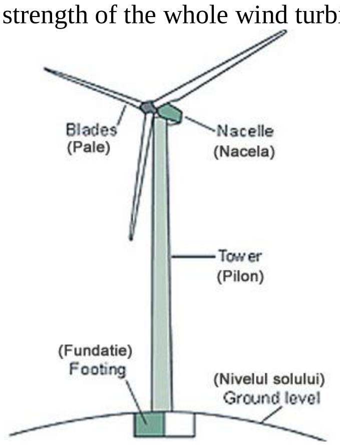


Figure 1: The structure components of a wind turbine with horizontal axis

The tower and the foundation dimensions of the wind turbine depends on the internal forces of the permanent (the own weight of the structural elements) and the temporary (wind action) loads, for which a calculation and distribution of these efforts are necessary, these being the objectives of the present study [3].

2. HYPOTHESES OF COMPUTATION

For the calculation of the strength, stiffness and stability of the bars from the mounting system structure of the wind turbine, the following simplifying assumptions were used:

- The action of the wind on the the pillar was neglected;
- The blade-nacelle-tower system is considered to be plane structure (frame) fixed at one end and free to the other (the blade area);
- Wind pressure is considered a linearly distributed load on the blade with maximum intensity in the rotor area;
- The own weight of the blade and the own weight of the pillar were included in the computation;
- Depending on the position of the blade, the axial forces, shearing forces and bending moments were plotted.

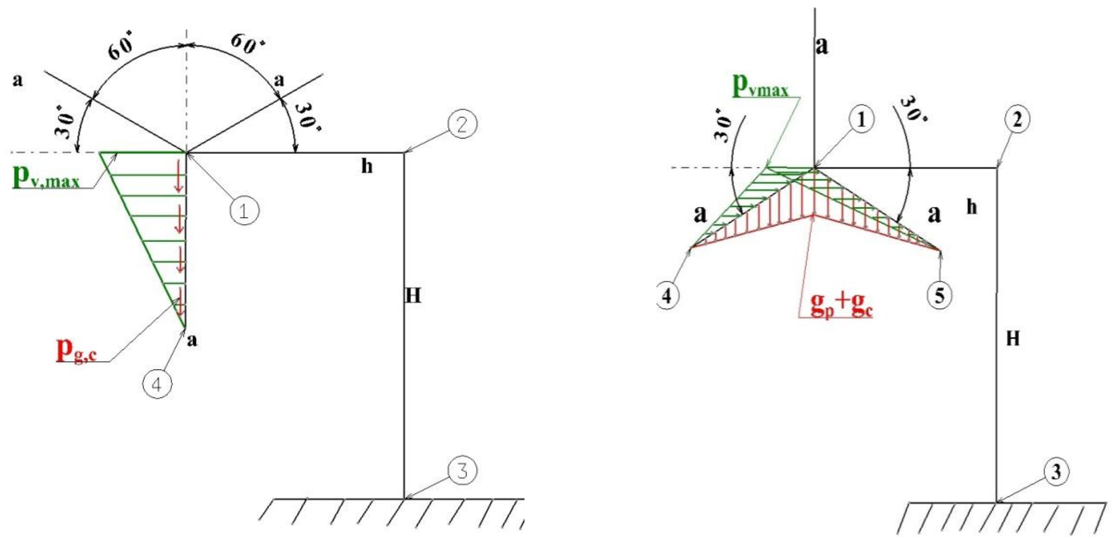
2.1. Case 1

Thus, in ***case 1*** in which a blade is downward, perpendicular to the nacelle axis *h* (Fig 2, a) and the following are known:

- p_{vmax} – the maximum wind pressure;
- $p_{g,c}$ – its own weight of blade and centrifugal force;
- *a*, *h*, *H* – the blade, the nacelle and the pillar length;
- Q_{st} – the pillar weight.

2.2. Case 2

Case 2 consist of a blade is pointing up, perpendicular to the nacelle axis *h* (Fig 2, b). In this case the loading of the structure is given by the wind pressure on two blades and the weight of the two blades disposed at 120 degrees to each other (g_p - own weight, g_c - centrifugal force, p_{vmax} - the maximum wind pressure).



a) b)

Figure 2: Distribution of the wind pressure and representation of the weight and centrifugal force on turbine blade: a) case 1; b) case 2

3. CALCULATION AND DISTRIBUTION OF INTERNAL EFFORTS

3.1. Case 1

As a fixed frame, the calculation of the internal forces and the drawing of the diagrams *(N, T, Mi)* was made from the free end noted 4 to the fixed end noted 3, through the inside of the frame with respect to reference line representing the axis of the beam (Fig. 3). Knowing the maximum values of the internal forces and using the calculation relations for the equivalent normal stresses, the stresses on each section can be determined using the following:

$$\sigma_{max}(x) = \frac{M_i(x)}{W_z(x)} \quad (1)$$

$$M_1 = -\frac{1}{6} p_{vmax} a^2 \quad (2)$$

$$M_2 = -p_{g,c} a h - \frac{1}{6} p_{vmax} a^2 \quad (3)$$

$$M_3 = \frac{1}{2} p_{vmax} a \left(H - \frac{a}{3}\right) - p_{g,c} a h \quad (4)$$

$$p_{g,c} = Q_{14} + \frac{1}{2} p_c a \quad (5)$$

As we can see in the above relations, the internal forces and the stresses have been expressed parameterized in order to be used indifferent of the size structure, the strength of the forces and the geometry of the main parts.

It can be seen in Fig. 3, a, that the axial force **N** varies linearly with the length of the blade, stressed the blade to tensile, the maximum axial force being in the blade holding area of the rotor. This effort is also transmitted to the pillar, producing the compression of them. The nacelle is subjected to compress as a result of the wind pressure on the blade and on the rotor axis. From the point of view of shear forces **T** on the blade, the shear curve is a parabola obtained as a second degree function. The maximum effort where obtained in the blade attachment area. The weight of the blade produces a constant internal shear forces on the length of the nacelle. In the pillar a constant shear force is developed as a result of the action of the wind on the blade (Fig. 3, b).

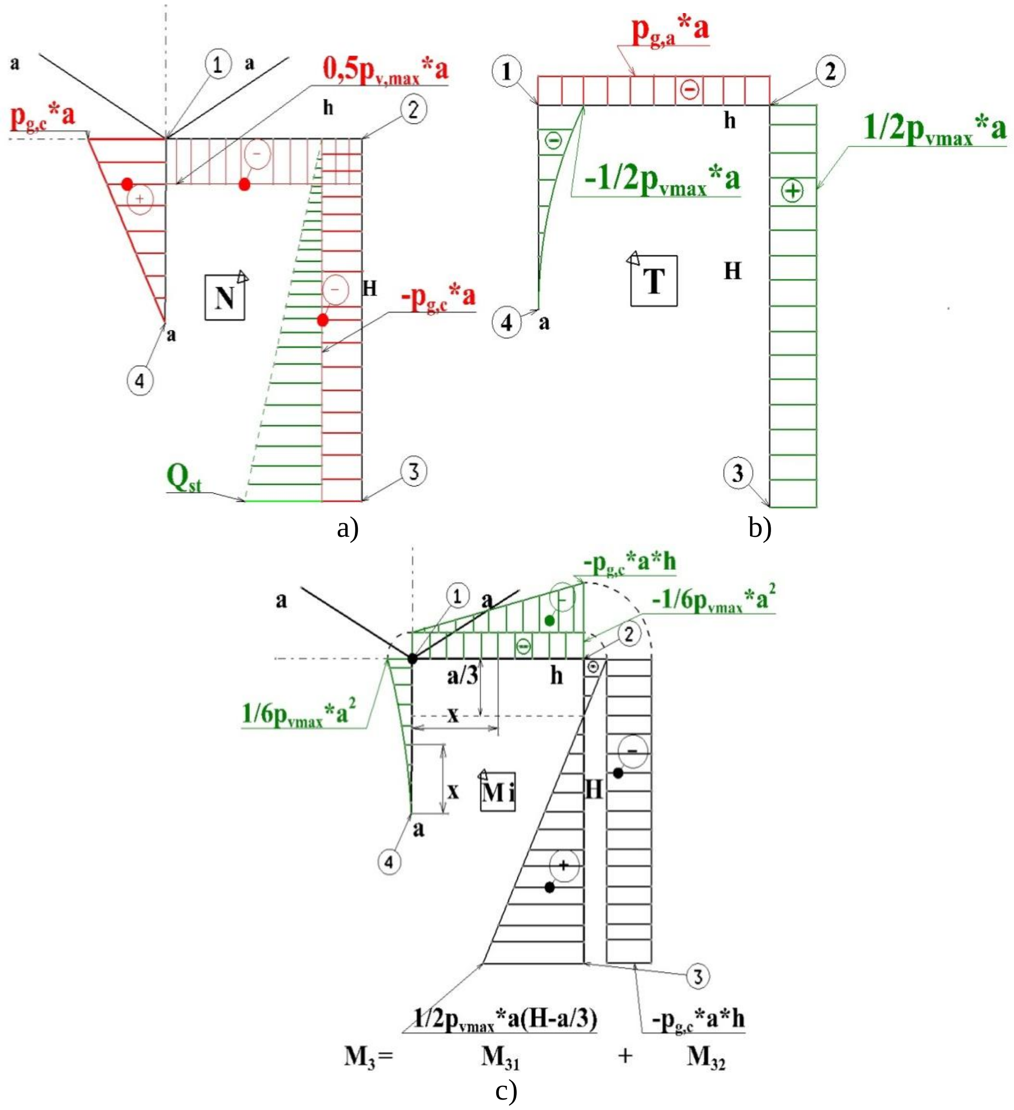


Figure 3: Internal forces diagrams in case 1: a) axial forces (N); b) shear forces (T); c) bending moment (Mi)

The bending moment varies parabolic on the blade after a third degree function, with the maximum value in the rotor blade attachment area, and then transmitted to the next sections (nacelle and pillar - with a constant distribution). The own weight of the blade produces a bending moments to the nacelle with a linearly distribution that is transmitted to the pillar. The pillar is also subjected to bending by the calculated wind pressure as a concentrated equivalent force applied on the top of the pillar (Fig. 3, c).

3.2. Case 2

Similar to the calculation steps in case 1, the internal forces diagrams were drawn, and their values could be replaced in previous calculation relations. The maximum value of the bending moment is given by mathematical expression (6).

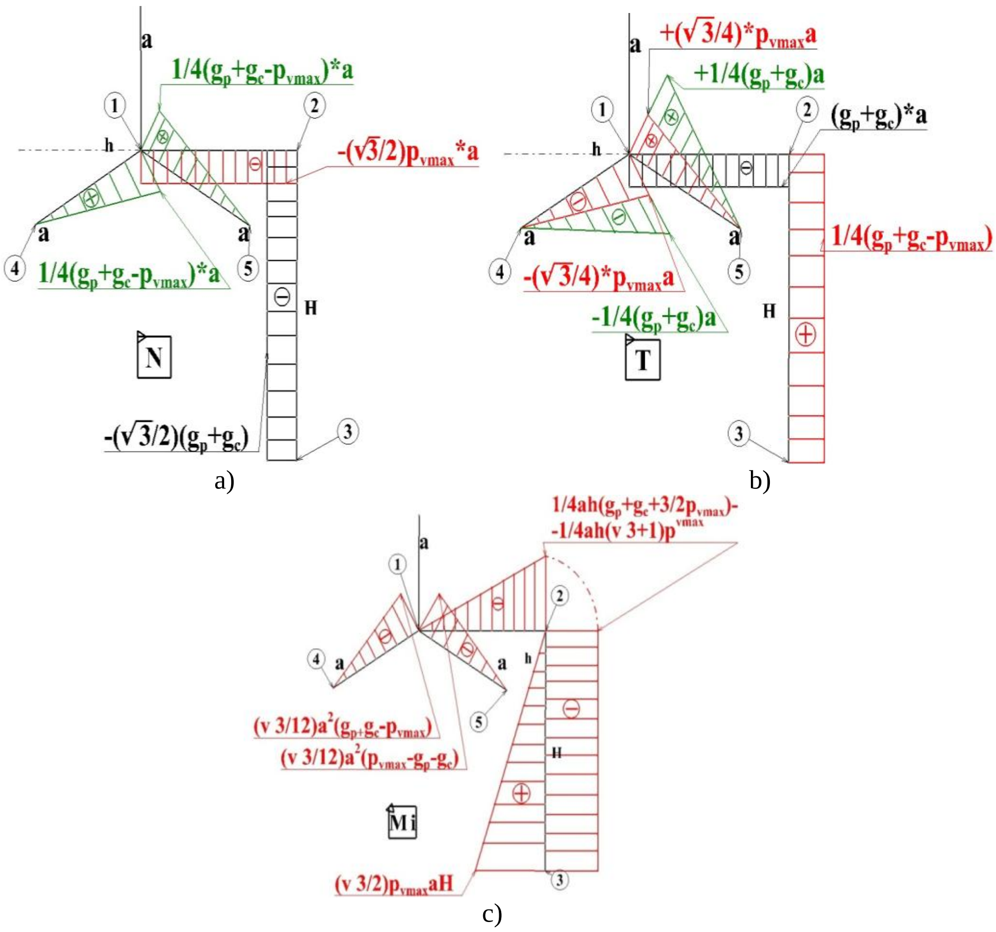


Figure 4: Internal forces diagrams in case 2: a) axial forces (N); b) shear forces (T); c) bending moments (Mi)

$$M_3 = \frac{\sqrt{3}}{2} p_{vmax} aH - \frac{1}{4} ah \left[p_{vmax} (\sqrt{3}+1) \frac{3}{2} \right] - \frac{1}{4} ah (g_p + g_c) \quad (6)$$

3. CONCLUSION

The internal forces computation and their distribution, on the three main components of the wind turbines are basic issues in identifying the dangerous areas/ sections of the assembly so that the equivalent stress can be determined either for the structure verification or for dimensioning it.

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