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Static analysis of a lamppost according to Eurocode EN-40

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Abstract

When people move around a town, at some point in their journey they need to cross the road using a dedicated crosswalk. However, crossing is not always done safely due to weather conditions, lack of visibility or distraction. The VALLPASS project, aims to install two lampposts in opposite positions to the direction of crossing, with various functionalities and technological innovations, creating a luminous tunnel for the safe passage of pedestrians. To verify the mechanical resistance of the lighting poles, numerical simulations were performed using the finite element method, where the boundary conditions considered the criteria defined by the European standard EN-40 "Lighting Columns". This standard specifies the loads acting on the column, namely the horizontal forces due to the action of wind according to standard NP EN 1991-1-4:2010 and the vertical forces due to the self-weight of the entire structure. Considering a lighting pole with a square lower section and a cylindrical upper section, with a total height of 7 meters and with a support structure for photovoltaic panels, according to the static analysis performed, a maximum combination of axial and bending stresses of 138.74MPa, was obtained in the connection zone between the square section and the pole shaft. The maximum displacement of 6.9cm, was obtained at the free ends of the photovoltaic panel support structure and a minimum factor of safety of 1.64 in the zone where the combination of axial and bending stresses is more severe.

Keywords: Ambient temperature; Batteries; Thermal analysis;

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1. Introduction

Considering the costs to society associated with the failure or collapse of a lamppost, namely the economic costs and safety risks associated with it (which are often much higher than the cost of the structure itself), it is essential to ensure the reliability and safety of these structures (Antunes, 2008; Carvalho and Silva, 2006; Ferrão, 2012). To evaluate the behavior of lampposts, several studies have been developed concerning their static and dynamic behavior (Barros et all, 2003; Pagnini and Solari, 2021; Peil and Behrens, 2002). In general, the studies developed consider the wind action as the most severe action (Antunes, 2008; Ferrão, 2012; Barros et all, 2003) and the structural sizing is done through an analytical method using European standards (Eurocodes) or through numerical simulations using the Finite Element Method (FEM), where the boundary conditions are defined through the Eurocodes (Carvalho and silva, 2006).

According to the legislation in use, lampposts are subject to specific dimensioning, according to the European standard EN-40 "Lighting columns", prepared by the Technical Committee CEN/TC 50 (Carvalho and silva, 2006). Thus, among the EN-40 series of standards, the following parts were considered for the lamppost sizing in this paper: Definitions and terms; General requirements and dimensions; Design and verification; Requirements for steel lighting columns.

An autonomous lamppost with integrated photovoltaic panels and which is subject to permanent and time-varying actions was considered (Dias, 2015). According to the standard EN-40, for the permanent actions whose values remain constant over time, the self-weight of the lighting pole, consisting of a lower square and an upper cylindrical section, and of a lattice structure for fixing the photovoltaic panels, located at the top of the column, were considered. The self-weight of all the integrated electronic components was also considered, namely the solar panels, batteries, and luminaire. Regarding the variable actions, whose values vary over time, the European standard EN-40 only specifies the quantification of the wind action, however, as snow may accumulate on the photovoltaic panels, the snow action was also considered, as defined by the Portuguese standard NP EN 1991-1-3:2009 and its National Annex. As a complement to standard EN-40, regarding the quantification of the wind action, the Portuguese standard NP EN 1991-1-4:2010 and its National Annex was also used.

Passive safety and the behavior of the column due to the impact of a motor vehicle, as well as seismic action, are requirements that are not included in EN-40 and were not considered in this paper (Barros, 2003; Carvalho and Silva, 2006).

The characterization of the forces applied to the lamppost was intended to obtain the boundary conditions for the sizing of the structure by the Finite Element Method.

1.1. Wind action

According to the standard BS EN 40-3-1:2013, the horizontal force resulting from the wind action in one direction, and acting at any part of the perpendicular column shaft, is given by the following formula:

$$F_{c\,(z)} = A_c \cdot c \cdot q(z) \tag{1}$$

where, $F_{c(z)}$ is the partial horizontal force, in N, due to wind pressure acting at the centre of the area of the section of the column shaft being considered; A_c is the projected area, in m^2, on vertical plane normal to the direction of the wind, of the section of column shaft being considered; c is the shape coefficient for the section of the column shaft being considered (according to standard NP EN 1991-1-4:2010, a shape coefficient c equal to 1 was considered), and, $q(z)$ is the design wind pressure, in N/m^2, at a height, z in metres above ground level. The values of z should be taken at the centre of the area of the section of the column shaft being considered.

1.1.1. Characteristic wind pressure q(z)

The characteristic wind pressure $q(z)$, in N/m^2, for any particular height above the ground, z, shall be obtained from the following formula:

$$q(z) = \delta \cdot \beta \cdot f \cdot c_e(z) \cdot q(10) \tag{2}$$

where $q(10)$ is the reference wind pressure, in N/m^2; δ is a factor related to the column size; β is a factor dependent on the dynamic behaviour of the column; f is a dimensionless factor related to topography The topographic factor f was taken as 1, since topography was not considered to be significant, and $c_e(z)$ is a dimensionless factor dependent on the terrain of the site and the height above the ground, z.

As a lamppost can be installed in different terrain categories and as the precise location of the installation is not known, according to the standard BS EN-40-3-1:2013 the calculations were made considering the terrain category II. Thus, according to Table 1 of that standard, considering a height above ground of 7 meters and terrain category II, was obtained an exposure coefficient $c_e(z)$ equal to 2.13.

1.1.2. Reference wind pressure q(10)

The value of $q(10)$ (in N/m^2), accounts for the geographical location of the lighting column. It is derived from the reference wind velocity V_{ref} using the following formula:

$$q(10) = 0{,}5 \cdot \rho \cdot (C_s)^2 \cdot {V_{ref}}^2 \tag{3}$$

where, V_{ref} corresponds to the 10-minute average wind speed at 10 m above ground level for Terrain Category II.

$$V_{ref} = C_{ALT} \cdot V_{ref,0} \tag{4}$$

$V_{ref,0}$ corresponds to the basic value of the reference wind velocity at 10 m above sea level obtained from the national annex of the Portuguese standard NP EN 1994-1-4:2010. Considering zone B, the value of the reference wind velocity corresponds to 30m/s; C_{ALT} is an altitude factor. According to BS EN 40-3-1:2013, the value 1.0 was adopted because the National Annex of the Portuguese standard NP EN 1991-1-4:2010 does not specify another value; ρ corresponds to the air density and this value should be taken as 1,25 kg/m^3; C_s is a factor to convert V_{ref} from an annual probability of exceedence of 0,02 to other probabilities. For lighting columns, the normal requirement is for a mean return period of 25 years, for which the factor C_s should be taken as $\sqrt{0{,}92}$.

1.1.3. Factor for column size δ

The greater the size of a surface subject to wind, the more unlikely it is that the maximum pressure, on which the calculation is based, acts over its full area. The resultant smaller wind load on a component is taken into account by the factor δ dependent on the size of the area. The ruling dimension for the size of the area subject to the wind is the greatest dimension in one direction. For a lighting column, this is the nominal height in meters and the value of the factor (δ) is obtained from the formula:

$$\delta = 1 - 0{,}01 \cdot h \tag{5}$$

where h, according to BS EN 40-2:2004 represents the nominal height, in meters, from ground level to the spigot, as shown in Figure 1.

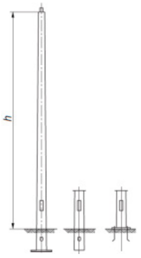

Figure 1 - Nominal height

The factor β is dependent upon the basic period of vibration T and the damping of the "column/luminaire" system and considers the increase in the load, resulting from the dynamic behavior of the lighting column, caused by wind gusts. The factor β was determined using the following formula:

$$\beta = 1{,}00240 - 0{,}00500 \cdot T^4 + 0{,}05144 \cdot T^3 - 0{,}22793 \cdot T^2 + 0{,}67262 \cdot T \tag{6}$$

where T is the basic period of vibration in seconds.

1.2. Snow action

To determining the value of the load due to snow according to the Portuguese standard NP EN 1991-1-3:2009, initially, the location of the lamppost was defined in the city of Bragança, Portugal. According to the National Annex of the referenced standard, this city is classified as Zone B of the national territory, where snowfall is not regular and should be considered as an accidental situation.
Assuming that the snow is undisplaced, the snow load, in kN/m2, is given by the formula:

$$s = \mu_i \cdot C_e \cdot C_t \cdot S_k \tag{7}$$

where, μ_i is the shape coefficient for snow load; C_e is an exposure coefficient; C_t is a thermal coefficient, and S_k is the characteristic value of the snow load at ground level at the considered site, in kN/m^2.
Considering that there is no impediment to snow sliding over the photovoltaic panels and assuming that the angle of inclination between the photovoltaic panels and the horizontal plane is 20º, according to the standard, $\mu_i = 0.8$.
As for the coefficient C_e, it varies according to the terrain topology and consequent wind exposure. Considering a terrain topology with normal exposure, it was considered $C_e = 1{,}0$.
Relatively to the surface thermal coefficient C_t, according to the Portuguese standard NP EN 1991-1-3:2009, and the International standard ISO 4355, $C_t = 1$ was considered.

1.2.1. Characteristic value of snow load at ground level at the considered location

The characteristic value of the snow load at ground level, in kN/m^2, was obtained through the expression:

$$S_k = C_z[1 + (H/500)^2] \tag{8}$$

where C_z is a zone-dependent coefficient and H is the altitude of the site in meters. Considering the city of Bragança, an altitude of 860 meters was considered and as this city located in the Z_2 zone of the Portuguese continental territory, a zone-dependent coefficient equal to 0.2 was taken.

1.3. Static analysis

For the structural analysis of the lamppost, the geometric 3D modeling software SOLIDWORKS was used, where the structure of the lamppost was modeled, consisting of a lower square tubular section and a upper circular section, as well as a latticed tubular structure to support and fix the solar panels. The characteristics of the materials used are summarized in Table 1.

Table 1. Geometric characteristics of light column

Section	Tubular geometry	Dimensions [mm]	Material
Lower lamppost section	square	300x300x5	S234JR
Upper lamppost section	circular	168.3x3	S234JR
Solar panel support structure	square	30x30x2	S234JR

Considering the wind action, the snow action, and the structure's self-weight, the boundary conditions presented in Table 2 where obtained.

Table 2. Boundary conditions

Load Type	Value	Unit
Self-weight of the two photovoltaic panels	491.00	N
Self-weight of a luminaire	196.00	N
Self-weight of two batteries	438.00	N
self-weight of the structure supporting the photovoltaic panels	370.00	N
self-weight of the cylindrical section of the column	498.00	N
self-weight of the square section of the column	1174.00	N
Snow load on photovoltaic panels	2034.00	N
Wind load on the cylindrical section of the column	798.00	N
Wind load on the square section of the column	1067.00	N
Wind load on photovoltaic panels	1809.00	N

The definition of the boundary conditions consisted in applying the vertical and horizontal forces at their respective application points, as well as defining the surface of the pole base as fixed, as shown in Figure 2.

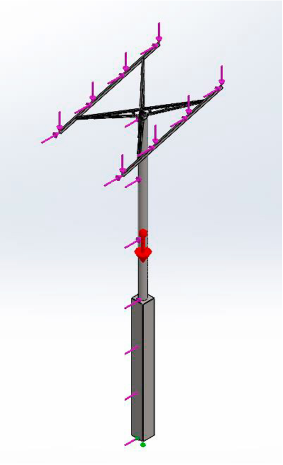

Fig. 2. Acting loads

2. Results and Discussion

2.1. Modal analysis

Through a modal analysis using SOLIDWORKS software, a frequency of 4.0145 H_Z was obtained for the first vibration mode, as presented in Figure 3.

Fig. 3. Modal analysis

After this analysis, using the formula for the vibration period of the lighting column $T = 1/f$, a vibration period of 0.25 seconds was obtained.

2.2. Static analysis

As a result, a combination of axial and bending stresses was obtained, with the highest value corresponding to 138.74 MPa. Figure 4 shows that the most requested area is in the central part of the lamppost, more precisely in the connection region between the square and cylindrical sections.

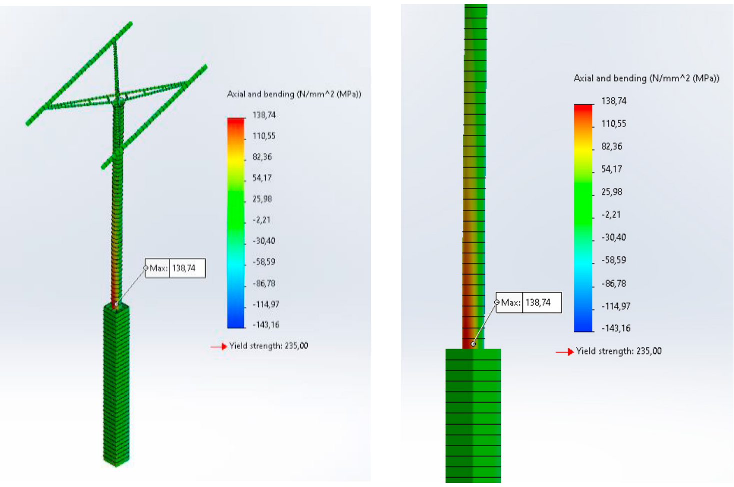

Fig. 4. Combination of axial and bending stresses

For the displacement, a maximum value of 6.9 cm was obtained at the free ends of the solar panel attachment support, such as shown in Figure 5. This value can be justified due to the considerable height of the column and consecutively due to wind gusts considered according to BS EN 40-3-1:2013. However, with the fixing of the solar panels, more rigidity will be conferred to the structure, and in reality, the displacement value will tend to be lower.

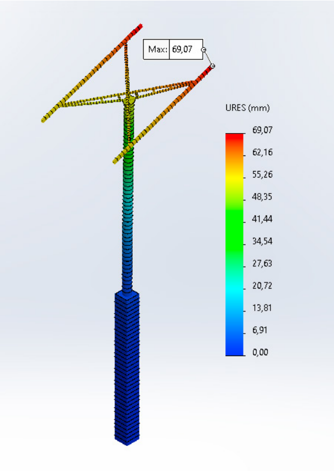

Fig. 5. Displacement

Under these circumstances, a minimum coefficient of safety of 1.64 was obtained at the location where the axial and bending stresses are most expressive, such as defined in Figure 6. This value can be considered satisfactory, since only approximately 59% of the elastic range of S235JR steel is used.

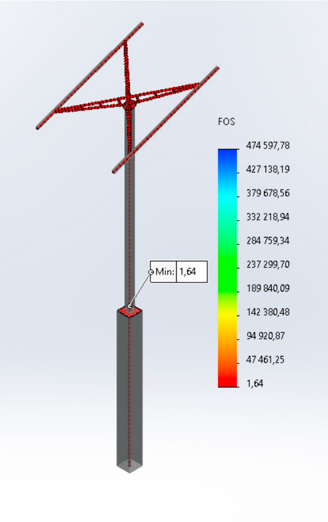

Fig. 6. Factor of safety

3. Conclusion

This work aims to predict the behavior of a lighting column through numerical simulation, using the finite element method. The application of the boundary conditions was based on the European standard EN-40 "Lighting columns", as well as the Portuguese standard NP EN 1991-1-3:2009 on snow loads on structures and the Portuguese standard NP EN 1991-1-4:2010 on wind loads on structures.

With the results obtained it was possible to verify that the most stressed area of the structure is located in the central part of the lamppost, more precisely in the connection region between the square and cylindrical sections. In this same area it was obtained a minimum safety factor of 1.64 values, which represents an acceptable result since it is only used approximately 59% of the elastic regime of the S235JR steel.

Regarding the displacement, a maximum value of 6.9 cm was obtained at the free ends of the solar panel fixing support, however with the fixing of the solar panels, more rigidity will be conferred to the structure, and in reality, the displacement value will tend to be lower. This result also means that the structure presents high flexibility, which contributes positively to the resistance to impacts.

Considering the height of the pole, the considerable area of the photovoltaic panels, and that the wind has a random nature and can only be subject to analysis in the statistical field, the correct quantification of this action was essential for the structural calculation and, consequently, for the reliability and safety of the structure.

In summary, this work allowed the design of the lamppost using numerical simulation, avoiding waste of material and time, when compared to destructive experimental tests.

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References

Adrián R. Wittwer, Juan M. Podestá, Hugo G. Castro, Javier L. Mroginski, Jorge O. Marighetti, Mario E. De Bortoli, Rodrigo R. Paz, Fernando Mateo. 2022. Solar Energy 240, 315-328. https://doi.org/10.1016/j.solener.2022.04.061

Aloy M. Aly. 2016. On the evaluation of wind loads on solar panels: The scale issue. Solar Energy 135, 423-434. https://doi.org/10.1016/j.solener.2016.06.018

António P. R. B. M. Antunes. 2008. Projeto de Postes e Mastros Tubulares. Faculdade de Engenharia. Universidade do Porto. https://hdl.handle.net/10216/58843

CEN/TC 50. 1992. BS EN 40-1: Lighting columns. Part 1: Definitions and terms.

CEN/TC 50. 2004. BS EN 40-2: Lighting columns. Part 2: General requirements and dimensions.

CEN/TC 50. 2013. BS EN 40-3-1: Lighting columns. Part 3-1: Design and verification - Specification for characteristic loads.

CEN/TC 50. 2002. BS EN 40-5: Lighting columns. Part 5: Requirements for steel lighting columns.

Instituto Português da Qualidade. 2009. NP EN 1991-1-3: Eurocódigo 1- Ações em estruturas. Parte 1-4: Ações gerais. Ações da neve.

Instituto Português da Qualidade. 2010. NP EN 1991-1-4: Eurocódigo 1 - Ações em estruturas. Parte1-4: Ações gerais. Ações do vento.

Jorge Miguel Nogueira Dias. 2015. Análise de estabilidade e fundações de equipamentos de sinalização vertical rodoviária. Instituto Superior de Engenharia do Porto. http://hdl.handle.net/10400.22/8077

Luisa Carlotta Pagnini, Giovanni Solari. 2001. Damping measurements of steel poles and tubular towers. Engineering Structures 23/9, 1085-1095. https://doi.org/10.1016/S0141-0296(01)00011-6

Marta Carvalho, Arlindo Silva. 2006. Estudo Experimental e Numérico de Colunas de Iluminação Conforme a Norma EN 40 “Lighting Columns. Mecânica Experimental 12, 139-145. http://www-ext.lnec.pt/APAET/pdf/Rev_12_A14.pdf

R. Carneiro de Barros, J. Mota Freitas, J. Campos e Matos e A. Costa Lopes4. 2003. Dimensionamento Estrutural de Postes Metálicos de Iluminação. 4º Congresso de Estruturas Metálicas e mistas (CMM IV). https://www.researchgate.net/publication/260942688

Sérgio Miguel Seara Ferrão. 2012. Dimensionamento de um mastro metálico. Faculdade de Ciências e Tecnologia. Universidade Nova de Lisboa. http://hdl.handle.net/10362/8864

Udo Peil, M. Behrens. 2002. Fatigue of tubular steel lighting columns under wind load. Wind and Structures An International Journal 5 (5). doi:10.12989/was.2002.5.5.463.