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STAYED BRIDGE: COMPUTATIONAL MODELING AND ANALYSIS OF THE SIMULATION OF WIND EFFECTS

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Abstract. Cable-stayed bridges can present damage to their components because they are constantly subjected to the action of the winds. This type of structure was a great advance in engineering, making it possible to build more economical bridges, as they were able to overcome large spans without the need for several supports or a large structure in arches. At the same time, it made the problem of wind forces more important, because it is a light and slender structure, it ends up suffering serious aerodynamic effects, which in more extreme cases can lead to collapse. Using finite element software, a model bridge located in the municipality of Foz do Iguaçu-PR, subjected to the effects of the natural action of the winds of this region, was analyzed to verify the behavior of the stays and the vibrations transmitted by them to the decks, verifying possible ruptures caused by fatigue and the possibility of the occurrence of rupture caused by the resonance of the components, thus obtaining expected results in terms of their resistance capacity to a stress situation.

Keywords: Aerodynamics; cable-stayed bridge; Finite elements

1 Introduced

One of the greatest difficulties faced by engineering throughout history has been the need to overcome large spans. Among the works of art that have stood out over the years, cable-stayed bridges are one of the most effective alternatives to span large spans.

Cable-stayed bridges are a large structure supported by stays (steel cables subjected to traction), which guarantee the safety and stability of the superstructures, thus enabling the bridge deck to be increasingly slender, so that the entire superstructure relieves the load. of the supports (masts or pylons), thus allowing large free spans. On the other hand, their supports become taller and, therefore, more susceptible to stability problems generated by aerodynamic effects from the action of the winds (LOPES BASTOS *et al.* [1]).

According to Beneduzi [2], the winds acting on superstructures can be studied by the fluid mechanics method, where the winds are analyzed according to their pressure and flow characteristics. The author also emphasizes that the linear motion of fluids, that is, laminar flow, can be neglected, since it presents little damage compared to turbulent flow. Complementing, Carvalho [3] mentions that the flow causes the collision between the particles, thus generating vortices, and sudden changes of direction, inducing vibrations in the stays

One way to determine the effects caused by the action of the wind on the stays is to know the history of gusts in the region, based on the wind chart. In this way, it will be possible to create an estimate by identifying the aerodynamic and aeroelastic characteristics of the section, using aerodynamic coefficients, such as: Drag coefficients, Lift coefficient, Torsion and pressure coefficients. Based on these parameters, it is possible to determine the forces acting, in static terms, on the structure, on the other hand, as a consequence of the strong interaction between the aerodynamic forces and the vibrations presented by the structure, problems of aeroelastic instability, such as draping, may arise. This phenomenon consists of the oscillation of the structure, but this oscillation presents an increasing amplitude until it reaches the critical speed, and enters into resonance until its rupture. According to Awruch *et al*. [4], Draping is the cause of most wind-induced accidents on bridges with long spans.

Based on studies by Leonhardt (1974) *apud* Torneri [5], in aerodynamics and its applications in cable-stayed bridges, the shape of the structure is fundamental to guarantee stability against the action of the winds, it also complements, that from the 1920s onwards, the cable-stayed bridges started to avoid the use of factors that cause dangerous oscillations, mainly the sharp corners that cause the Von Kárman effect.

The shape of the cross section is crucial in determining the design parameters and therefore the study of wind action and its interaction with the bridge must be taken into account during the design phase (LOREDO SOUZA *et al.* [6]).

With the advancement of computational models, the analysis of structures has ensured the design and more efficient ways of verifying parameters for the construction of superstructures. Based on the use of new calculation methods and more sophisticated tools, it is possible to carry out more complex processes of non-linear stress analysis. Elements such as towers and decks will be subjected to high compression forces and deformations that will cause second-order effects. With the use of software, the analysis of the real dynamic behavior of the bridge becomes viable, which capture the vibrations acting on the structure, all these generated analyzes allow the creation of a virtual model of the superstructure (LOPES BASTOS *et al*. [1]).

When analyzing the structure through software, most of them start from the approach by the Finite Element Method (FEM). The FEM aims to determine the state of stress and deformation of a solid of arbitrary geometry subject to external actions, among which, the dynamic actions of the wind that act on a work of art (AZEVEDO [7]).

This work will use analysis through computer software from finite element methods. Thus, it will be possible to verify the vibrations of the decks caused by the actions of the winds on the superstructure and transmitted to the stays.

2 Methodology

In this project it was proposed the analysis of a model cable-stayed bridge, submitted to the action of the winds acting in the region of Foz do Iguaçu.

This model bridge was defined between the authors, and dimensioned with the main purpose of overcoming a span of 280m, and having 2 lanes of 4.30m, with a shoulder of 3m and a sidewalk of 1.20m, in addition to a New Jersey barrier separating the lanes, this lane configuration allows the traffic of heavy trucks according to DNIT.

One of the 3D modeling was performed using Sketchup software, due to its low complexity of use and modeling agility, thus allowing a better visualization of the environment around the place of its implementation, as shown in figures 1, 2 and 3 below.

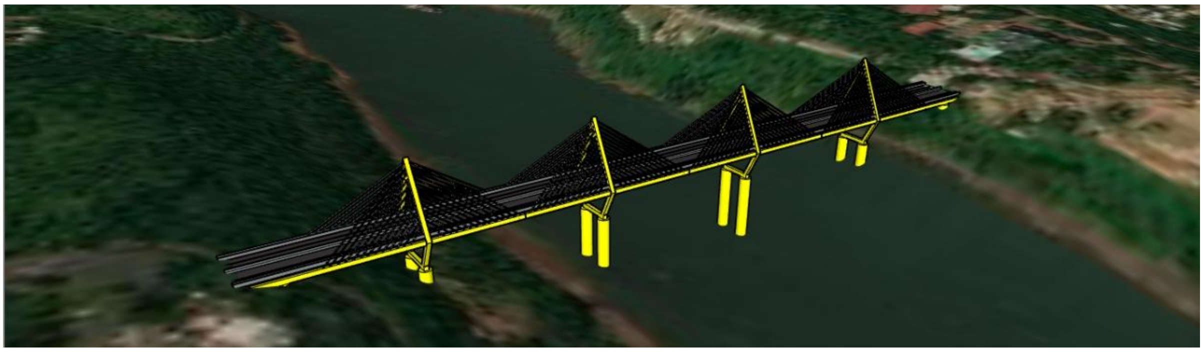

Figure 1 - Simulated 3D project in the possible location.

Figure 2 - View of the carriageway.

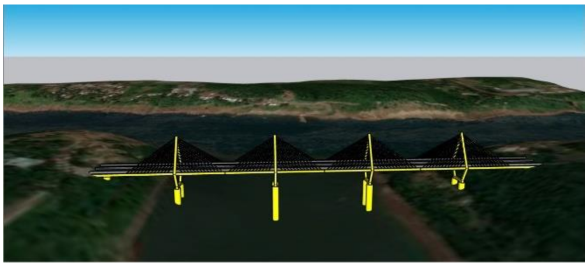

Figure 3 - view of the bridge on the wind side.

During the elaboration phase of the 3D project, some adjustments were made to the dimensions so that the structure adapts to the characteristics of the geographical location.

With the 3D project completed, the structural launches in Robot structural software from autodesk were carried out, with the entire structure being configured according to the materials used, with the pylons, decks and beams in reinforced concrete, while the stays are steel cables, after the release of the materials, the dimensions defined in the 3D project were released as shown in figure 4.

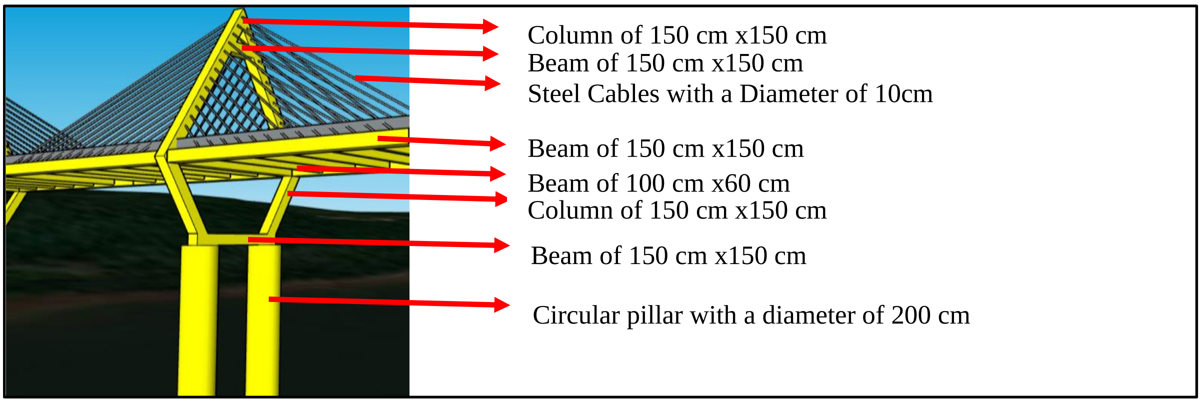

Figure 4 - Dimensions of structural parts.

With the launches of the entire structure carried out, as well as all the materials registered, we carried out the calculation process by the MEF, following the established parameters, initially analyzing only the effects of the structure's own weight.

After verifying the requesting efforts, and their respective reactions, the verification of the wind chart of the region of Foz do Iguaçu - PR began, based on the isopleths of NBR 6123.

By checking the wind charts, the basic wind speed in the region of Foz do Iguaçu was obtained, so we have that $V0 = 50\ m/s$.

After obtaining the wind speed, the pressure calculation begins, based on the particularity of the building, we have the factors:

- Topographic factor ($S1$= 1): considering the action of the winds parallel to the banks of the river, this can be categorized as flat or slightly uneven terrain;

- Factor Roughness of the terrain, dimensions of the building and height above the terrain ($S2$ = 1.27): Category I -: Large smooth surfaces, with more than 5 km in length, measured in the direction and direction of the incident wind; Class C, because the pylons have a vertical dimension greater than 50m, which are on the front surface of the wind action.- Statistical factor ($S3$ = 1.10): Buildings whose total or partial collapse can affect the safety or possibility of helping people after 1 a destructive storm (hospitals, fire stations and security forces, communication centers, etc.)

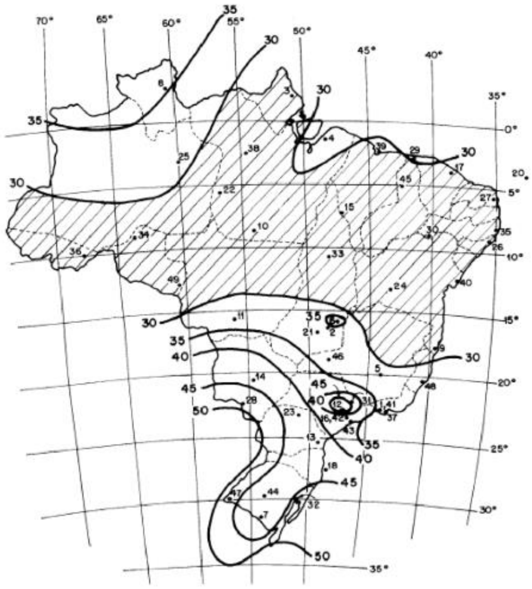

Figure 7 - Basic wind speed isopleth
Source: ABNT NBR 6123 (1988)

Thus, with the determined factors, we can calculate the characteristic wind speed:

$Vk = V0.\ S1.\ S2.\ S3$

Vk = 50 m/s . 1.0 . 1.27. 1.10 = 69.85 m/s

Then we calculate the dynamic wind pressure:

$q = 0.613\ .\ Vk2 = 2990.85\ N/m$

With these characteristics obtained for the region of Foz do Iguaçu, and for the location of the cable-stayed bridge, it can be applied in the CFD (Computational Fluid Dynamics) software from autoesk and thus generate a computational model of the action of the winds acting on the structure.

After the insertion of these data in the CFD, it generates interactions of the winds with the structure, demonstrating the areas of pressure and the forces exerted by the wind on the structure.

After obtaining these results, the effects caused in the structure can be analyzed.

3 Results

In the images below, the analyzes obtained by Autodesk's Robot structural software are presented for requesting efforts and in the CFD of the wind action, it is possible to observe the behavior of the structure against these parameters.

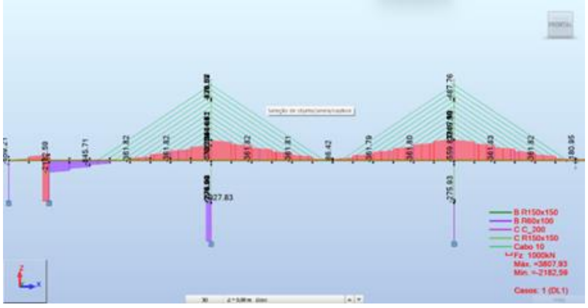

Figure 6 - Longitudinal shear stress

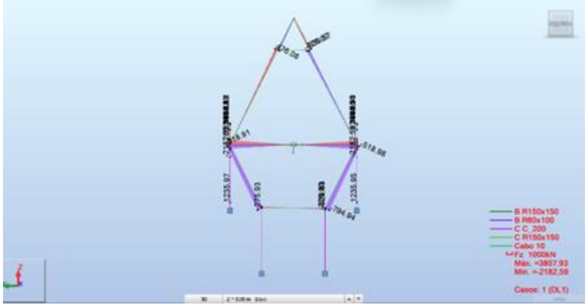

Figure 7 - Transverse shear stress

In figures 6 and 7 presented above, the shear stress presented by the structure can be verified, as expected the peaks of moments in the decks are at the meeting with the pillars for the longitudinal profile and on the sides of the track for the transverse profile, region where the steel cables are fixed to the deck.

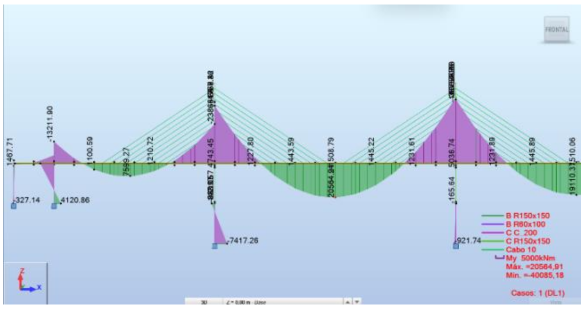

Figure 8 - Y-moment for the longitudinal profile

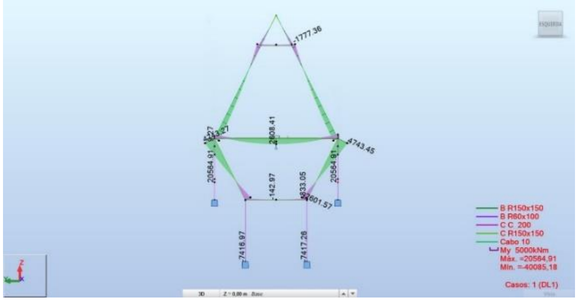

Figure 9 - Y-moment for the transverse profile

In figures 8 and 9 the bending moments of the structure are shown in the graphs, with the highest positive moment obtained for the longitudinal profile between the first and second pylons and equally between the third and fourth a value of 20564.91 kNm. In the transversal profile maximum positive moment obtained was 4743.45 kN.m. The maximum negative moment was 1777.39 kN.m in the second and third pylons for the longitudinal profile and 2601.27 kN.m between the pylons of the pylons and the support structure of the decks.

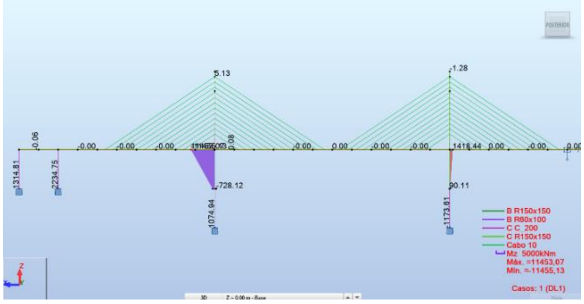

Figure 10 - Z-moment for the longitudinal profile

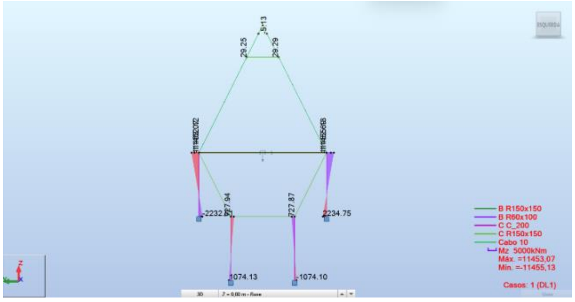

Figure 11 - Z-moment for the transverse profile

Figures 10 and 11 show the Z moments generated by the actions of the winds on the pillars. The highest moments in the transverse profile occurred in the pillars of the bridgeheads with a value of 11455.13 kN.m. In the longitudinal profile, the maximum moment was located in the support structure of the deck in the first and fourth pylons.

After the 3D remodeling and the proper registration of the types of structures and their characteristics, necessary to obtain the previous data, the model was exported to Autodesk's CFD software, in which it was possible to obtain graphics of the behavior of the winds in a wind simulator. structure virtual.

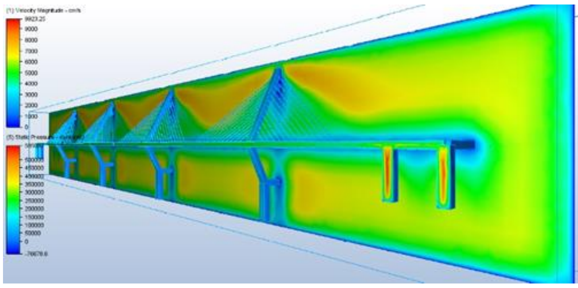

Figure 12 - Pressure caused by wind action on the front face of wind action

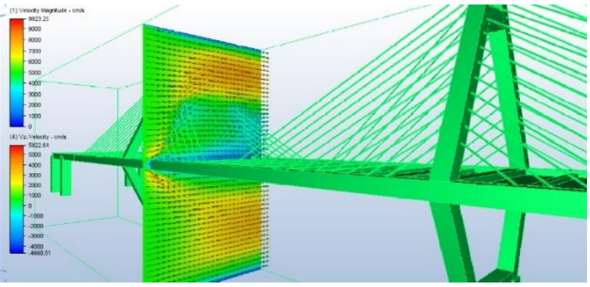

Figure 13 - Wind Flow Lines in the stays

In figure 12 it is observed that the highest positive pressures generated by the winds (identified by the red areas) are at the highest points of the pylons after they generated high turbulence when the wind deviates to the sides of the same. Likewise, turbulence can be noticed after the wind mass has to move to both sides of the deck and stays as seen in figure 13.

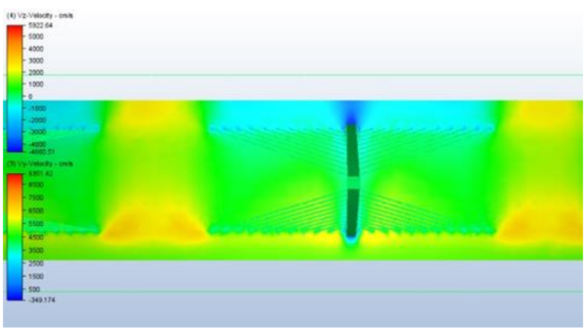

Figure 14 – Top view wind speed.

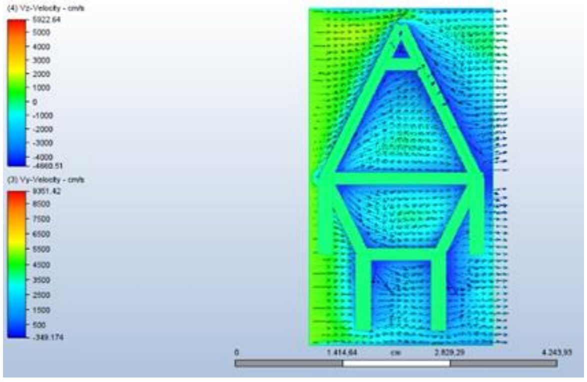

Figure 15 - Flow Lines in the Pylons

With figures 14 and 15 it is possible to perfectly identify the negative pressures (shown by the blue colors) generated after the division of the wind mass on the faces posterior to the face on which the wind hits. In these areas of turbulence, wind vortices are generated due to the vacuum generated. After dividing the air mass by the structure, the vacuum generated forces part of this mass to abruptly fill this space.

4 Conclusions

When analyzing the data provided by the software, we can observe and deduce that the model bridge, with the dimensions defined in this project, supports the proposed loads, being then considered stable within the parameters of use, being located in Foz do Iguaçu, it is subject to wind action of 69.85 m/s, and pressure of 2990.85 N/m would present pressure efforts on the circular pillars located at the ends of the bridge, we can also observe that the stays allow the passage of the winds, however they cause a deceleration in this, while the pylon structure presents the generation of small vortices which drastically reduce the speed of the wind acting on the structure, we can then deduce that the structure presents the reducing function of the speed of the acting winds, so we can deduce from the law of conservation of energy that this energy dissipated by the structure is actually only transferred to the supports, in contrast to the generated analyzes, oh It was not yet possible to quantify this energy transferred to the structure and whether it is capable of causing draping in the model bridge studied, so more studies and analyzes still need to be carried out in the course of the next studies.

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