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Analysis of Tensions and Deformations of Fixing Supports of Photovoltaic Panels Installed on Rooftops

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Abstract. This paper aim to analyze the exerted pressions by the wind on photovoltaic panels installed on rooftops as well as perform analysis of tensions and deformations of supporting aluminum structures for photovoltaic panels. Computational simulations are performed in order to save time and obtaining the best solution. The wind intensity and directions exert pressures on the photovoltaic installation and its support structure resulting on the concentration of tensions on the fixing points on both structural components and roof's attachment points.

Key words

Fastening Structures, Photovoltaic Panels, Tensions and Deformations, Wind Actions.

1. Introduction

At 2004 the Incentive Program for Renewable Eletric Power Source (PROINFA) was established with the aim of promoting the brazilian power matrix diversification [1]. In this sense the solar energy gains strength due its great production potential in Brazil which is a privileged country in terms of the high solar radiation index in most part of its territory.

The increase in energy tariffs and the development of researches justifies the greatest demand for renewable energy sources mainly for photovoltaic (PV) energy.

The photovoltaic plants may be designed to attend any tipe of costumer, as industry, houses or rural properties. The installation is versatile adapting to the building's characteristics fixed in roofs on the ground or on any possible place [2].

In the vast majority the PV plants are installed on bulding's rooftop and one of the main concerns of the design engineer is the actions due the wind which is preponderant factor in the design of the structure. However, in case of photovoltaic panels presence on roofs the wind actions analysis recieves particular importance in order to verify the structural response from fixing supports and photovoltaic panels.

The wind characteristics vary according to the geographic region having different basic valocities according to the brazilian standard ABNT NBR 6123 – Wind Forces in Buildings [3] and the european standard Eurocode 1 – Actions in Structures, section 1-4: Wind Actions [4] which have been used as reference to determine the natural wind action for building's design and construction work.

The ABNT NBR 6123 – Wind Forces in Buildings [3] in its section 5.1 defines as basic wind velocity as wind burst velocity during 3s exceeded in average once in 50 years 10 m above of the ground at an open flat field. The Fig. 1 shows the isopleths chart of the basic wind velocities in Brazil.

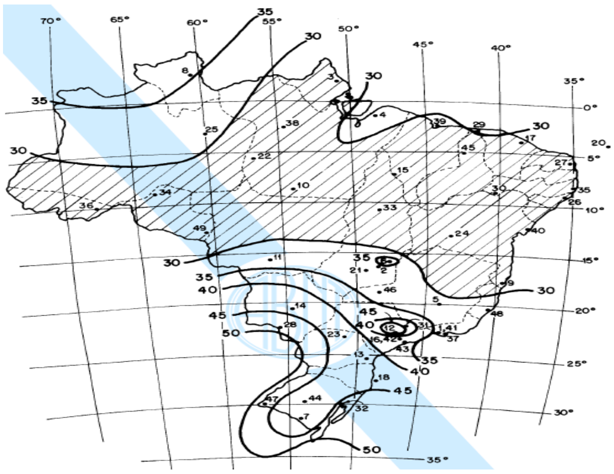

Fig. 1. Isopleths of the basic Wind velocity in Brazil (m/s).

The metioned standards consider flat roof those wich have an inclination (α) of $-5^{\circ} < \alpha < 5^{\circ}$ that should be divided in zones and the pressure coefficients should be define for each zone as suggested by Eurocode 1 – Actions in Structures, section 1-4: Wind Actions [5], Fig. 2.

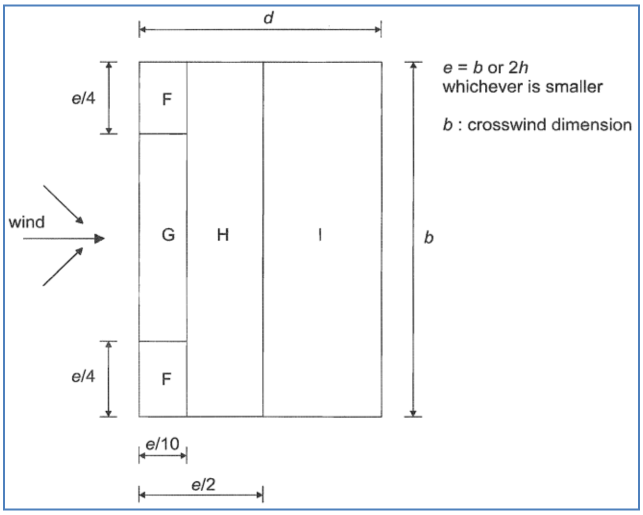

Fig. 2 Flat roof zones.

The flow analysis and wind pressures on the buiding's roof has great importance for the structure design and to decide the type of coverage to be used.

In case of flat roofs with photovoltaic panels usually they are mounted on metal supports made of aluminum in order to guarantee the inclination planned in Project. This conditions can be seen in the Fig. 3 and Fig. 4. By the mechanical characteristics of the support structures there is an indication that they can be easily demaged by wind action [5].


Fig. 3 Photovoltaic pannels on flat roof.


Fig. 4 Aluminum supports for photovoltaic panels.

In order to ensure greater safety for the photovoltaic system, avoid increased maintenance costs of the building and above all avoid accidents it is important to varify the structural behavior of the both supports and fixing points of the photovoltaic panels performing an analysis of tensions and deformations of the supports's structural elements.

2. Methotology

The methodology consists in performing a 3D computational simulation of a building that has on its roof two photovoltaic panels with inclination of 20°.

The standards ABNT NBR 6123 – Wind Forces in Buildings [3] and Eurocode 1 – Actions in Structures, section 1-4: Wind Actions [4] recommends calculating procedures of this nature but such standards may be insufficient due the specific character of this study.

Houever it is indispensable the use of cumputational numerical analysis resources as axample the Computational Fluid Dynamics and structural analysis of tension and deformation using the Finit Element Method (FEM).

In this sense wind flow simulations are performed in the rooftop and photovoltaic panels to verify the exerted pressures by the wind on the panels. For that it is used the software COMSOL Multiphysics in its module CFD turbulent flow with *k-Ɛ interface* which is modeled by equations of the turbulent kinetic energy transport (*k*) and its dissipation rate (Ɛ) [6].

It is consider the basic wind velocity of 35 m/s in two directions: 0° and 180° according to the Fig. 5.

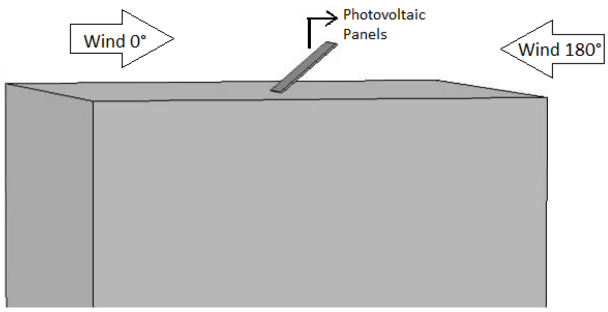

Fig. 5. Wind directions.

Therefore they are performed first two simulation situations, the first one being considering the wind at 35 m/s and direction of 0° and the second one considering the wind at a velocity of 35 m/s and direction of 180°.

After the wind flow analysis and exerted pressures on the photovoltaic panels the worst situation is chosen for performing simulation of the support structural behavior.

The support structure of the panels is modeled with the aid of software Solidworks which is composed of three aluminum angle bracket with cross-section of 5 cm x 5 cm x 0,5 cm. This support structure consists of base angle bracket of 200 cm, other of 50 cm and a support diagonal of 175 cm forming a triangle rectangle, all conected by screws.

The mentioned structure is fized in a corrugated tile of galvanized steel with thickness of 5 mm with only the angle bracket having contact with the tile having three attachment points, Fig. 4.

The applied materials characteristics for each componente are described on Table I.

Table I. Suppoprt components material

Component	Material	Yield Strenght [N/m²]	Tensile Strenght [N/m²]	Shear Modulus [N/m²]
Angle brackets	Aluminum alloy 6063-T6	$2.15x10^8$	$2.4x10^8$	$2.58x10^{10}$
Screw	Stainless steel	$2.92x10^8$	$6.85x10^8$	-
Tile	Galvanized steel	$2.04x10^8$	$3.57x10^8$	-

They are performed other two situations, the first one consists in applying the pressure previously chosen directly to the diagonal component support. The second one situation consists in applying the same pressure on the base angle bracket which is fixed to the tile in order to analyze the tensions and deformations both for angle bracket and tile.

3. Results

The wind flow computational analysis shows that there is a speed gain of the wind afther it get in touch to the building's edge causing the panels to be reached at a faster speed then the predetermined one (35 m/s).

In the first situation it is possible to observe a velocity gradient over the panel with high values, being 35 m/s on its base going approximately up to 60 m/s in its highest edge, according to Fig. 6.

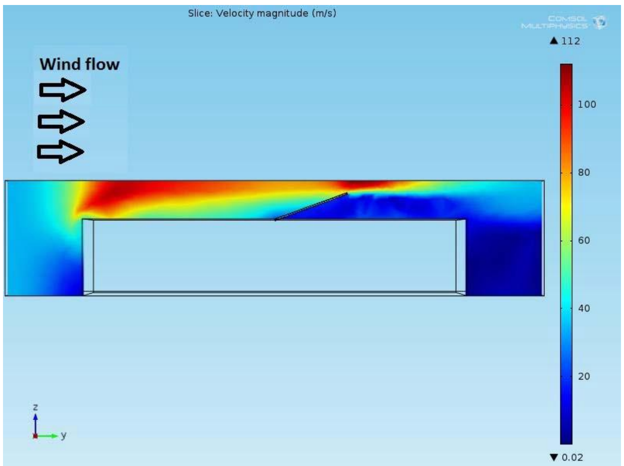

Fig. 6 Wind 0°, reference velocity 35 m/s.

Just as occurs a velocity gradientes over the panel the same occurs with de pressures exerted by the wind, as observed in the Fig. 7.

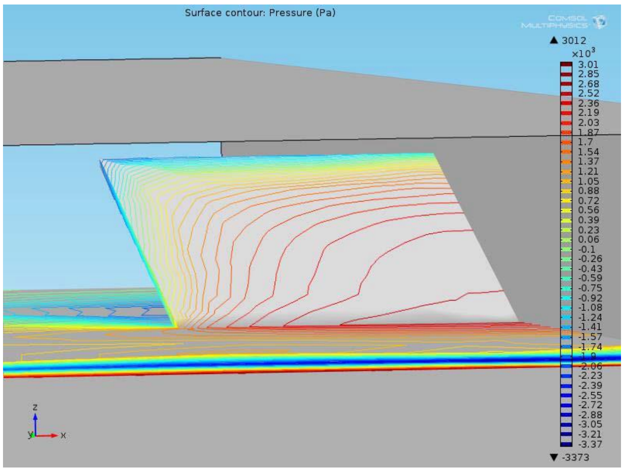

Fig. 7. Pressure over the panels for wind 0° and velocity 35 m/s

In the second situation that consists in the wind at 180° and velocity of 35 m/s occurs similar situation, the wind hits the back of the panel which is considered a risk factor, because the wind forces act in order to pull the panel from its attachment point in the structure, as can be observed in the Fig. 8.

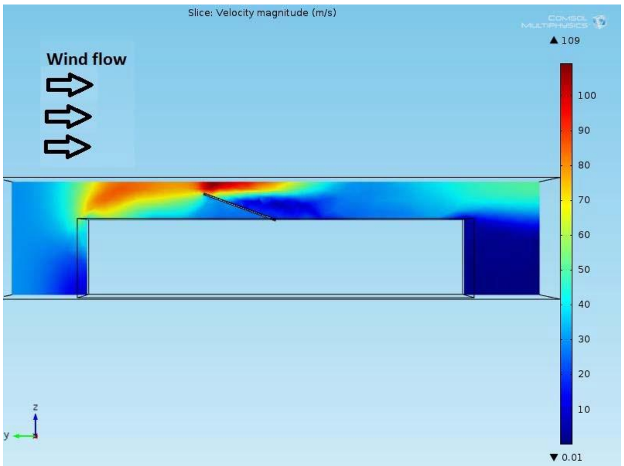

Fig. 8. Wind 180°, reference velocity 35m/s

Wind pressures also concentrate in the panel's back acting in order to pull it out of its attachment point, as observed in Fig. 9.

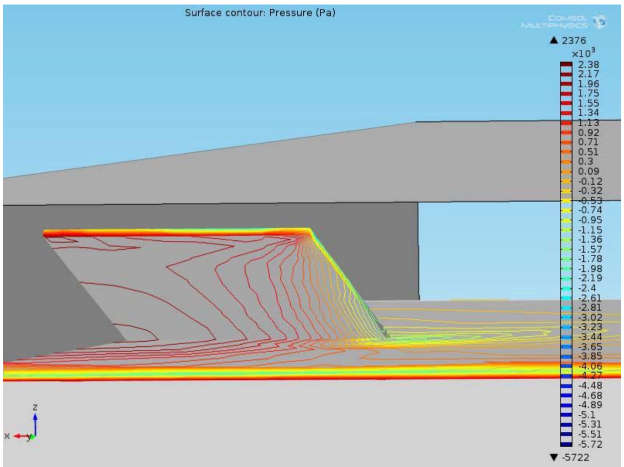

Fig. 9. Pressure over the panel for Wind 180° and velocity 35m/s.

It is importante to observe that the exerted pressures on the panels are of the greatness of 10^3 Pa, which is considered relatively high.

The Table II demonstrates the higher pressure values for the two analyzed situations.

Table II. Greater pressures on the panels

Situations	**Wind direction**	**Wind velocity [m/s]**	**Greater pressure [Pa]**
1	0°	35	2,03x10^3
2	180°	35	1,96x10^3

Even having a lower pressure value the second situation (wind at 180°) is the one chosen as the worst situation since the wind pressures act in order to pull the panel out of its attachment point that represents greater potential to cause major accidents.

So the pressure of 1,96x10^3 Pascal (Pa) will be applied in the support structure of the panels firstly in the diagonal which is in direct contact with the panels, as demonstrated in the Fig. 10.

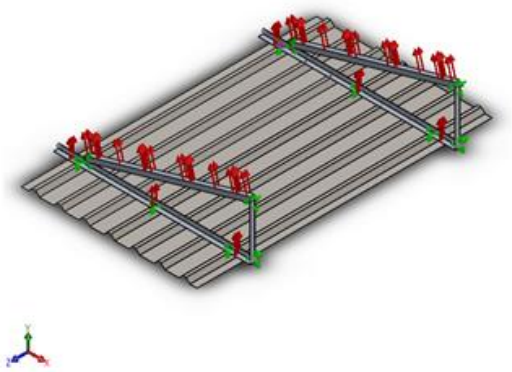
Fig. 10. Characterization of pressure application.

The results from this simulation shows that the higher stresses are concentrated near the bolted connections and the higher displacements are in the central span of the structural elements.

Initially considering the stresses the Table III demonstrates the maximum and minimum tensions along the model which are represented by von Mises strain.

Tabela III. Maximum and Minimum Tensions

Stress	**Minimum [N/m²]**	**Maximum [N/m²]**
von Mises	1.759*10^2	6.708*10^6

The Fig. 11 and Fig. 12 demonstrates the close detail of the stress concentrated in the screw connection of the diagonal angle bracket.

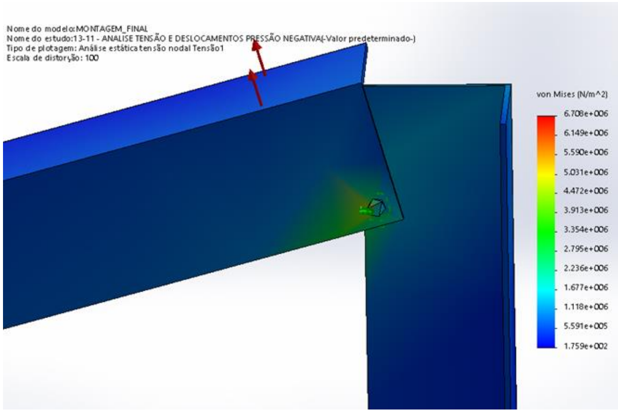
Fig. 11. Detail 1: Stress in screw connection.

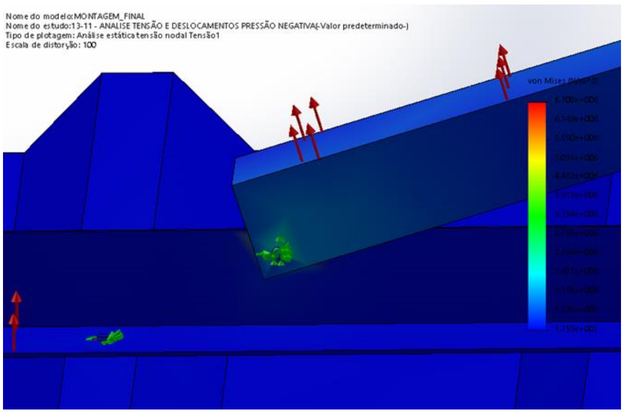
Fig. 12. Detail 2: Stress in screw connection.

In relation to the displacements did not occur great values as it is shown on Table IV

Table IV. Maximum and minimum displacements

Displacements	**Minimum [mm]**	**Maximum [mm]**
	1.475*10^{-10}	8.084*10^{-2}

The Fig. 13 demonstrates how the structure deforms on larger scale for better visualization.

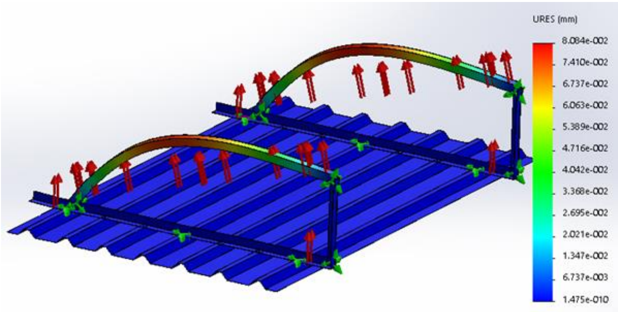

Fig. 13. Displacements of the fixing supports of photovoltaic panels.

The Fig. 14 demonstrates the vertical angle bracket behavior which undergoes displacement in its upper part.

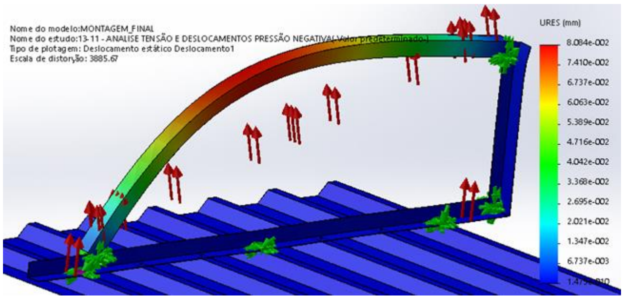

Fig. 14. Detail of the displacement of fixing angle brackets of the photovoltaic panel.

As to resulting deformations also did not presente great values according to the Table V

Tabela V. Minimum and maximum deformations

Deformations	Minimum	Maximum
	$5.560*10^{-10}$	$1.386*10^{-4}$

In the Fig. 15 it is possible to note the points of bigger deformations.

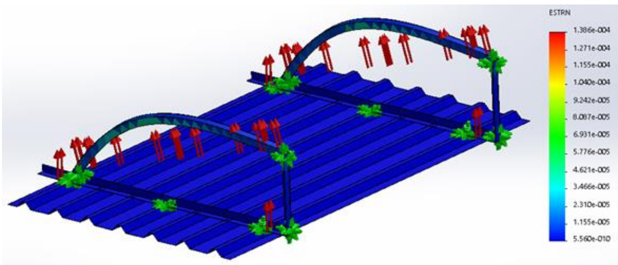

Fig. 15. Structure deformation.

In relation to the second structural analysis which consists of analysis of the connection between the base angle bracket and the roof it is also possible to observe the stress concentration in the attachment points, according to the Fig. 16. The Table VI demonstrates the minimum and maximum stresses.

Tabela VI. Stress in the roof and base angle bracket

Stress	Minimum [N/m²]	Maximum [N/m²]
von Mises	$4.146*10^{1}$	$6.223*10^{6}$

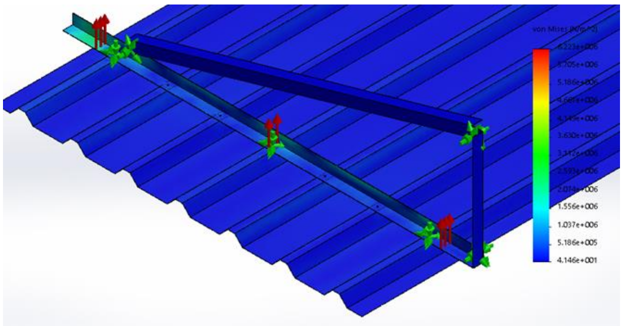

Fig. 16. Stress concentration in the attachment points of the structure on the roof.

The connection in the center of the angle bracket was the point of higher concentration of stresses in the structural component as can be observe in the Fig. 17.

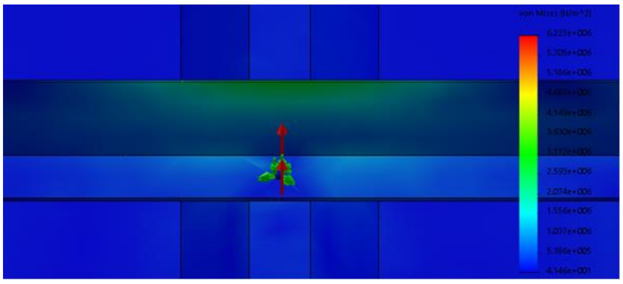

Fig. 17. Detail: central connection point between angle bracket and roof.

It is importante to observe the stress concentration in the back of the roof which are higher then the roof's top, according to the Fig. 18.

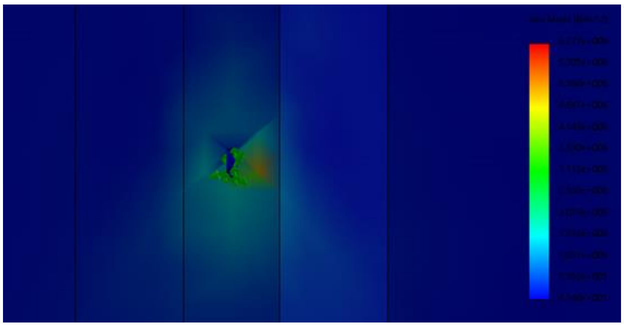

Fig. 18. Stress concentration in the roof's back.

About the displacements it is observed on Table VII the maximum and minimum displacements for this case and the Fig. 19 demosntrates the structural behavior of both angle bracket and roof.

Tabela VII. Minimum and maximum displacements

Displacements	Minimum [mm]	Maximum [mm]
	$3.787*10^{-9}$	$1.884*10^{-1}$

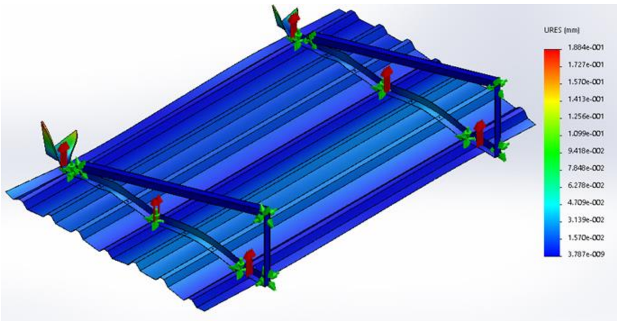

Fig. 19. Roof’s behavior.

About the deformations the Table VIII demonstrates the minimum and maximum values and the Fig. 20 the componentes behavior.

Tabela VIII. Minimum and maximum deformations

	Minimum	Maximum
Deformation	$3.472*10^{-10}$	$3.019*10^{-4}$

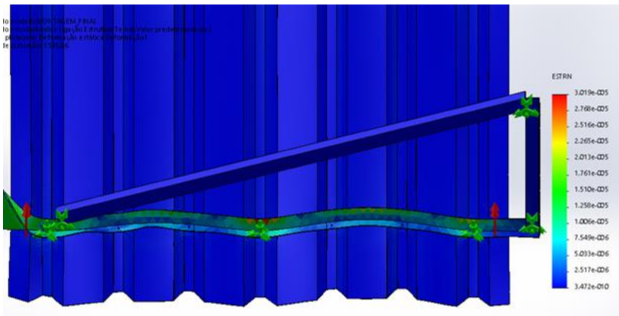

Fig. 20. Deformation of strcutural components.

4. Conclusion

According to the computational simulations performed it is possible to note the great importance of analyzing the wind actions on the photovoltaic panels installed on rooftops as well as the structural behavior of the supports and its attachment points.

There were no major stresses, deformations or displacements of the support structural elements since the mechanical characteristics of the materials are sufficient in relation to the actions applied in this study.

Even with small values of stress and deformations observe that on the diagonal angle bracket occured higher stresses then on the angle bracket fixed on the roof but in the angle bracket-roof analysis occured higher displacements.

It is worth noting the structural behavior which demonstrates higher stress concentrations around the attachment points for both angle bracket and roof, besides realizing thar the higher displacements occur in the larger spans of the componentes that may indicate the need for more attachment points to support more demanding load situations.

It is prudente to be careful when desingning screwed connections between supports and roofs, that should be done directly to the roof structure and not only on the tiles.

Future studies will go in the sense to perform new simulations considering higher wind velocities and form of attachment of the photovoltaic systems in order to observe the structural behavior in situations which are more demanding from a structural point of view willing to ensure greater safety for the system and take preventive decisions against possible accidents and losses.

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