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MODELING WIND ACTION ON SOLAR TRACKING PV PLATFORMS

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Abstract: *During the embodiment design stage of a tracking system for PV platforms, an important step is to determine loads as inputs for dimensioning the mechanical transmission and the entire structure. This paper presents a comparative analysis of different models of wind action, stated in standards or reports from important companies.*

Key words: *wind loads, PV platform, pressure coefficient, force coefficient.*

1. Introduction

The need for reducing the fossil fuels in the energy production by using renewable energy systems is legally defined by the EC 20/20/20 directive. The photovoltaic systems represent a significant part of this document because they have feasible technological and economical implementation possibilities. For large scale applications, the recommendable systems are the PV platforms.

To maximize the amount of solar radiation received by the platform surface, biaxial solar tracking systems are used, an energetic increase up to 40% being achieved [3].

These systems have specific functional positions, with tilt angles between 0° (horizontal platform) and 90° (vertical platform).

The two specific movements of the biaxial systems are insured by different mechanical transmissions. Dimensioning these transmissions represents an important step in the design stage of the PV platform. The dimensioning results are influencing the reliability and the cost of the system, and are dependent on the platform loads.

From all loads (wind, rain, snow, seism and own weight), wind represents a major concern [2], [4].

2. Models for Wind Action

Wind action is evaluated by the pressures or by the forces; its effect on structures is depending on wind properties (like mean velocity, turbulence characteristics, dynamic factor), structure characteristics (shape, size, orientation), structure dynamic properties and location [7], [8].

Standards like EN 1991-1-4 [7] and ASCE/ SEI 7-05 [6] present calculus procedures related to the wind loads determinations. There is also a specific Romanian standard [9], based on EN 1991-1-4. All these standards can be used to determine wind load on tracked PV platforms.

Following, there are presented the most relevant aspects of [7] and [9] for determining

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wind loading on solar tracking PV platforms.

According to [7], wind actions on structures and structural elements shall be determined considering both, external and internal wind pressures.

The wind pressure acting on the external (*e*) or internal (*i*) surfaces is obtained from the following expression:

$$w_{pe,i} = q_p \cdot c_{pe,i}\,, \tag{1}$$

where q_p is the velocity pressure; $c_{pe,i}$ is the pressure coefficient for the external (*e*) or internal (*i*) pressure.

Without considering the influence of height, the velocity pressure is:

$$q_p = \frac{1}{2} \cdot \rho \cdot v_p^2\,, \tag{2}$$

where v_p is the peak wind velocity and ρ is the air density, which depends on the altitude, temperature and barometric pressure to be expected in the region during wind storms. The recommended value for ρ is 1.25 kg/m^3.

The wind force, F_w, acting on a structure or a structural component can be directly calculated, for a height less than 15 m, by:

$$F_w = c_f \cdot q_p \cdot A_{ref}\,, \tag{3}$$

where A_{ref} is the reference area of the structure or structural element.

2.1. Eurocode and Romanian Standard

A. One situation presented by [7] is referring to monopitch roofs. This situation is far from the case of solar tracking platforms because the pressure coefficients are given only for the external surface of the roof, for tilt angles towards wind direction up to 75°.

The pressure coefficients c_{pe}, depend on the exposed area of the roof A. There are sectors with different pressure on a building roof, as seen in Figure 5. For an exposed area larger than 10 m^2, the values of the external pressure coefficients [7], for the main sector of roof surface *H* (see Figure 1), are presented in Table 1.

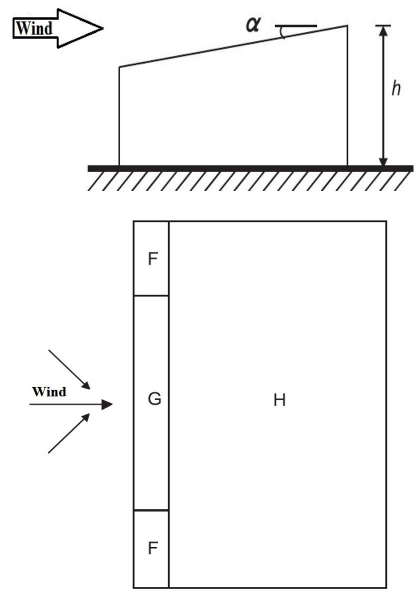


Fig. 1. *Diagram for monopitch roofs*

The values of the external pressure coefficients c_{pe}, presented in Table 1, are the highest from a range θ = ±45° of the angle between the wind direction and the orthogonal direction.

c_{pe} *for monopitch roofs* Table 1

α	5°	15°	30°	45°	60°	75°
c_{pe}	–0.6	–0.3	–0.2	0.0	0.7	0.8
	0.0	0.2	0.4	0.6		

Table 1 contains a maximum and a minimum value for the pressure coefficient, for each tilt angle, because, for θ = 0°, the values of the pressure coefficients change rapidly the sign for tilt angles α = 15°...30°.

The values of the internal pressure coefficients c_{pi} are not given in [7], for monopitch roofs.

B. Another case of structures similar to PV trackers is the case of monopitch canopies.

Force coefficients are presented in [7] instead of pressure coefficients in [9], based on the diagram presented in Figure 2.

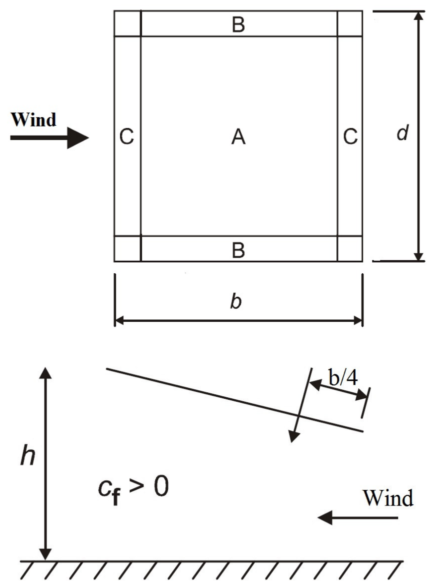


Fig. 2. *Force coefficients for monopitch canopies*

Even if this model is very similar with the case of the tracking PV platforms, limitation is given by the range of the tilt angle of the surface α = 0°... 30°. Table 2 presents maximal values of the force coefficients, for the given range of tilt angles.

c_p values for monopitch canopies Table 2

	Tilt angles α			
	0°	**10°**	**20°**	**30°**
$c_{f,\max}$	0.5	1.2	1.7	2.2
$c_{f,\min}$	–0.6	–1.5	–2.2	–3.0

C. A specific functional position of a solar tracking system for a PV platform is the vertical or close to vertical position, case of sunrise or sunset. This position is similar with the case of signboards [7].

For signboards separated from the ground by a height z_e larger than $h/4$ (see Figure 3), the force coefficients are c_f = 1.80.

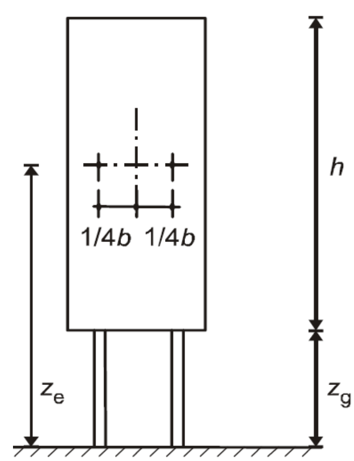


Fig. 3. *Signboards notations*

2.2. Russian Standard

Russian standard [8] of wind actions on buildings presents distribution of pressure coefficients on the surface of sheds roofs, similar to canopies [7] (see Figure 4). As in the previous cases, this case is not covering the whole range of tilt angles needed for the wind action model on tracking PV platforms.

Values of the pressure coefficients are presented in Table 3. See: [8].

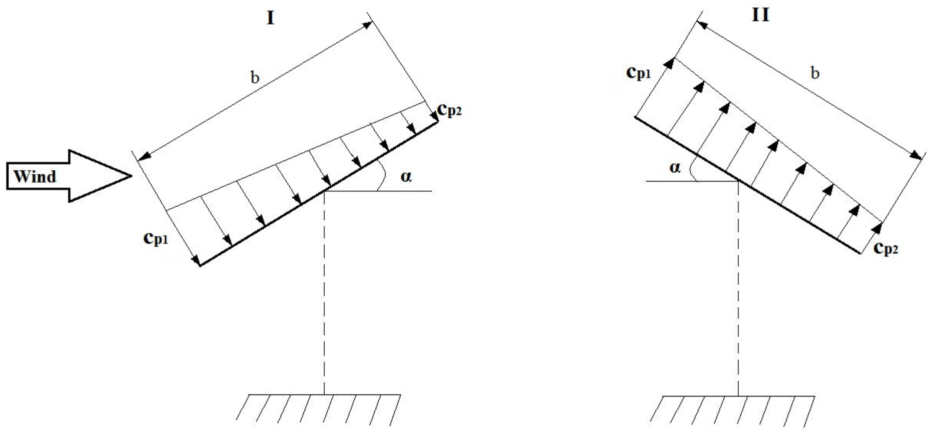


Fig. 4. *Pressure distribution on sheds roofs* [8]

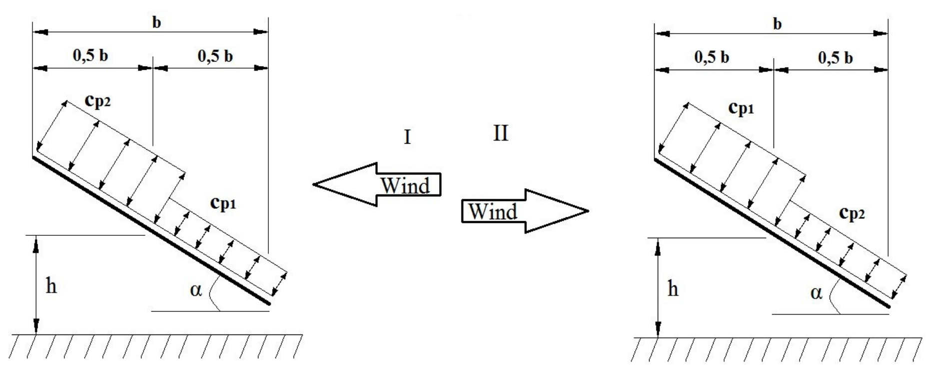


Fig. 5. *Pressure distribution on monoslope free roofs* [6]

c_p values for sheds roofs Table 3

α	Wind case	c_{p1}	c_{p2}
10°	I	1.4	0.4
	II	1.3	0.2
20°	I	1.8	0.5
	II	1.4	0.3
30°	I	2.2	0.6
	II	1.6	0.4

2.3. American Standard

The American Standard ASCE/SEI 7-05 presents a different model of load determination considering wind actions on buildings and different other structures [6].

One case analyzed by ASCE/SEI 7-05 is referring to monoslope free roofs (Figure 5), similar with the case of monopitch canopies [7] or sheds roofs [8]. Values of pressure coefficients are given for tilt angle of the surface towards wind direction up to 45° and presented in Table 4. See: [6]. Positive (+) values indicate a net downward acting wind action and negative (–) values represent a net upward acting wind action.

c_p values for monoslope free roofs Table 4

α	Load case	**Wind case I**		**Wind case II**	
		c_{p1}	**c_{p2}**	**c_{p1}**	**c_{p2}**
0°	max	1.2	0.3	1.2	0.3
	min	–1.1	–0.1	–1.1	–0.1
15°	max	1.3	1.6	–0.9	–1.3
	min	1.8	0.6	–1.9	0
30°	max	2.1	2.1	–1.8	–1.8
	min	2.6	1	–2.5	–0.5
45°	max	2.2	2.5	–1.6	–1.8
	min	2.6	1.4	–2.3	–0.7

Table 4 presents the maximum and the minimum values for the pressure coefficient (load cases), for each tilt angle, considering deviations of wind direction in vertical plane.

2.4. NBE-AE 88 Spanish Standard

The Spanish Standard NBE-AE 88 presents a model of wind action on inclined open surfaces very similar with the tracking systems for PV platforms, with values of the pressure coefficients covering the functional range of tilt angles 0°... 90°. Table 5 presents the values of the limit pressure coefficients c_{p1} and c_{p2} (according to a loading diagram similar to the one presented in Figure 4) [1].

c_p values for sheds roofs Table 5

	Tilt angle, α						
	0°	10°	20°	30°	40°	50°	60°-90°
c_{p1}	0	0.8	1.2	1.6	1.6	1.4	1.2
c_{p2}	0	0	0.4	0.8	0.8	1.0	1.2

The values of pressure coefficients c_p presented in Table 5 are the highest values given for the load case I (see Figure 5), for wind acting with a ±10° deviation in vertical plane.

2.5. NASA Technical Report

A NASA report [5] describes the effect of wind on the structure of a PV platform and presents values of pressure coefficients for tilt angles between 30° and 70°. The diagram from Figure 6, presents the limit pressure coefficients, according to the pressure distribution from Figure 6b. It considers an open field location with no wind barriers.

3. Comparison between the Models for Wind Action

For a unitary approach, all the data presented above will be reduced to force coefficients.

In the case of constant pressure on surface, the force coefficient has the same value with the pressure coefficient: $c_f = c_p$. In the case of trapezoidal distribution of pressure, the force coefficient can be calculated based on the limit pressure coefficients c_{p1} and c_{p2} (see Figures 4 and 6b) with relation:

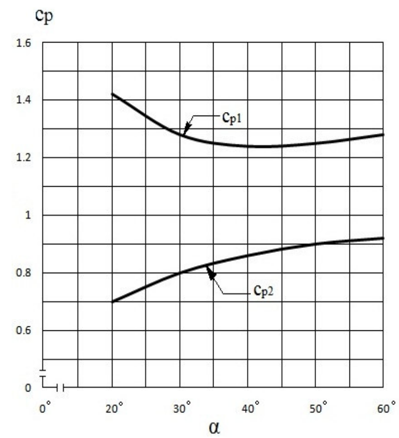
$$c_f = \frac{(c_{p1} + c_{p2})}{2}. \quad (4)$$

Same relation can be used for the case of pressure distribution presented in Figure 5.

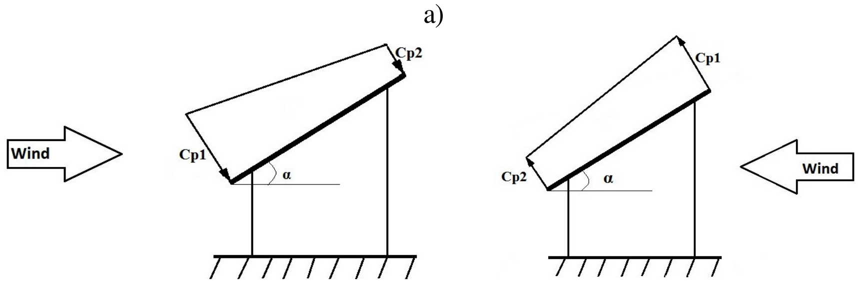
In Figure 7 a comparative analysis of the resulted force coefficients is presented, considering the previous presented models for wind action on structures similar to the solar tracking PV platforms.

In the diagram from Figure 7 the following notation are used:

- c_{f1} - the force coefficient acting on a signboard according to [7];



a)



b)

Fig. 6. *Pressure coefficients and load distribution diagram on the PV platforms*

- c_{f2} - the maximum values of the force coefficient acting on the roofs of open area buildings with one slope [6];
- c_{f3} - the minimum values of the force coefficient acting on the roofs of open area buildings with one slope [6];
- c_{f4} - the maximum values of the force coefficient acting on monopitch canopies [7];
- c_{f5} - the minimum values of the force coefficient acting on monopitch canopies [7];
- c_{f6} - the force coefficient acting on the open sheds roofs according to the Russian wind loads standard. Force coefficient values are given to shed's surface inclination angles in the range of 10°...30° [8];
- c_{f7} - the force coefficient acting on the sheds roofs structures according to Spanish wind loads standard NBE-AE 88. Force coefficient values are given for platform inclination angles in the range of 0°...90° [1];
- c_{f8} - the values of the force coefficient acting on buildings roof according to EN 04/01/1991. Pressure coefficient values are given for the situation when the pressure is

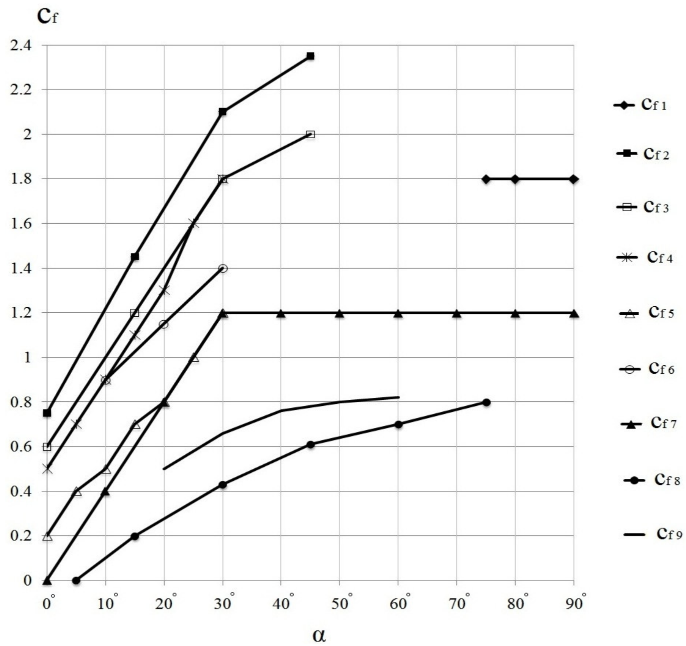


Fig. 7. *Diagram for comparison between force coefficients modeling wind action on structures for different standards or reports*

considered to be on the outer surface of the roof for inclination angles to wind up to 75° [7];

- c_{f9} - the force coefficient acting on the photovoltaic platform [5]. Pressure coefficients are given for surface inclination angles between 20°...60°.

4. Conclusions

From all the analysed standards, the legally applicable in Romania are the European standard (Eurocode) [7] and the Romanian standard [9]. Even considering different similar models (canopy - for tilt angle up to 30°, and signboards - for positions around vertical axis) both standards are not covering all the wind load cases for solar tracking platforms. The model given for the buildings roofs is not valid due to the closed shape of the structure.

The American standard [6] provides a model for tilt angles between 0° and 45°, with values significantly higher than those presented in Eurocode.

Smaller values are presented in the model of NASA report [8], for tilt angular range of 20°…60°.

The Spanish Standard NBE-AE 88 presents a model for the whole range of tilt angles 0°...90°, with values close to those from Eurocode, for canopies with tilt angles up to 30°.

Concluding, given the large range of the values resulting from wind action standards or other studies it is necessary an experimental approach in order to obtain a model closer to the reality.

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