PARTICULARITIES OF THE AIRELASTIC INSTABILITY PHENOMENA GENERATED BY VORTICES ON THE GREENHOUSES LOCATED ON THE ROOFS OF THE BUILDINGS

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Abstract: *The paper analyzes the phenomena of airelastic instability that the wind, which manifests in the form of vortices, causes the greenhouses placed on the roofs to cause the buildings. The calculation of the stresses in which the greenhouses are exposed, recommended in the paper, is based on the hypothesis that the metallic structures of their resistance are manifested in the linear-elastic domain, and their dynamic properties will be evaluated on theoretical and / or experimental basis by the application of the dynamic methods structures. The dynamic properties of the structures (own frequencies, own vectors, equivalent masses, and logarithmic decay of damping) can be evaluated in a simplified way with the relationships that are specified in the paper.*
Keywords: *greenhouses on roofs of buildings, whirlpools, instability phenomena.*

1. INTRODUCTION

By varying the roofing of the greenhouse, changes in the slimness of the buildings may occur, which is why it is necessary to take into account the dynamic effect produced by the alternating wind-breaking in the form of whirlpools [1]. This process is manifested by a fluctuating action perpendicular to the direction of the wind, the frequency of which depends on the average wind speed and the shape and dimensions of the section of the greenhouse. If the velocity of the vortices is close to a new frequency of the new construction, the quasi-resonance conditions that produce considerable increases in the amplitude of the building oscillations can be met, the higher the damping and the mass of the structure of the building, namely of the greenhouse on the roof are smaller [2].

2. PARTICULARITIES OF THE AIRELASTIC INSTABILITY

The calculation of stresses in which the greenhouses are recommended is based on the hypothesis that their metallic resistance structures are manifested in the linear-elastic domain and their dynamic properties will be evaluated on theoretical and / or experimental basis by applying the methods of structure dynamics. The dynamic properties of the structures (own frequencies, own vectors, equivalent masses, and logarithmic decrement of depreciation) can be assessed in a simplified manner with the relationships that will be specified below[3].

In the case of greenhouses embedded on the building roofs, which can be considered attached to the free end, the relation [SR EN 1991-1-4: 2006 / NB: 2007] can be used to calculate the fundamental own frequency.

$$n_1 = \frac{1}{2 \cdot \rho}\sqrt{\tfrac{g}{x_1}}, \tag{1}$$

where: is the density of air; g-gravitational acceleration, in m / s2; x1 - maximum displacement produced by the weight of the greenhouse applied in the vibration direction in m.

If, by placing a greenhouse on the roof, the building exposed to the wind is considered multi-layered, the fundamental own frequency can be estimated with the relation:

$$n_1 = \frac{55}{h}[Hz], \tag{2}$$

where h is the height of the building.

If the building-green building assembly is considered a metal structure, the fundamental own frequency can be estimated with the relation:

$$n_1 = \frac{40}{h}\left[Hz\right]. \qquad (3)$$

Depending on the concrete situation in which the greenhouse is located, the designer will choose the most appropriate case for determining the basic frequency of the greenhouse.
The basic vertical bending vector F1 (z) for simple, rectangular and rectangular structures and structural elements where frames can be framed on roofs has F1 (s) = 0,6 ... 2,5, [SR EN 1991-1-4: 2006 / NB: 2007]: Depending on the ratio z / h, where z is the height of the greenhouse and h - the total height of the assembly.
For roof-type greenhouse structures with variable mass distribution, the equivalent mass per unit of length me can be approximated by its average value in the upper third of the structure.
The logarithm of the damping for the fundamental mode of vibration can be appreciated by the relationship [SR EN 1991-1-4: 2006 / NB: 2007]:

$$d = d_s + d_a + d_d, \qquad (4)$$

where: d_s is the logarithmic decrement of structural damping; the logarithmic decay of aerodynamic damping for the fundamental mode; d_d- logarithmic decay of damping by special devices (masses granted, liquid dampers, etc.), if applicable.
For roofed greenhouses, the value of d_s = 0.10 is recommended for the logarithmic decay of structural damping.
The logarithmic decrement of aerodynamic damping for the fundamental bending mode produced by vibrations in the wind direction can be estimated with the relation:

$$d_a = \frac{c_f \cdot \rho \cdot b \cdot v_m(z_s)}{2 \cdot n_1 \cdot m_e}, \qquad (5)$$

where: c_f is the aerodynamic force coefficient for the wind action in the longitudinal direction; ρ - air density equal to 1,225 kg / m^3; b - the width of the structure; v_m (zs) - mean wind speed for z = zs, where zs is the reference height; n_1 - the fundamental vibrational frequency of the structure in the direction of the wind; m_s- equivalent mass per unit length of structure.
The resonance condition is met when the wind speed is theoretically equal to the critical speed at which the whirling occurs. The critical wind speed for the vibration mode is defined as the wind velocity for which the winding frequency of the vortices is equal to the actual vibration frequency of the structure in the transverse direction of the wind and is given by the relation:

$$v_{crt,i} = \frac{b \cdot n_i}{St}, \qquad (6)$$

where: b is the width of the transversal section in which the resonance of the vortices is produced;n_i- the actual frequency of the vibration mode in the wind direction; Strouhal's St (the dimensional parameter which depends on the shape of the section, the turbulence characteristics, the number of Reynolds calculated for v_{crit}, and the roughness of the surface). **In the case of sharp edges / corners, as is the case with most roof greenhouses, the Strouhal's number can be estimated simply according to the shape of the section, having values St = .0.07 ... 0.18 depending on the shape of the greenhouse**.
Another parameter to be taken into account when analyzing the influence of whirlpools on roofed greenhouses is **the Scruton number**, which is a dimensionless parameter that depends on the equivalent mass, the critical damping fraction and the section reference dimension. The vibration sensitivity depends on the structure's damping and the ratio between the mass of the structure and the mass of the air.
Scruton's number is given by the relationship:

$$Sc = \frac{2 \cdot m_e \cdot d_s}{\rho \cdot b^2}, \qquad (7)$$

where: me is the equivalent mass per unit length for the vibration module in the transverse direction; ds - logarithmic deformation of structural damping; - air density, the value of which depends on the amplitude of the site, temperature, etc .; b - the width of the cross section, evaluated in the section where the critical phenomenon of resonant vortices ejection occurs.
The action of separating the whirlpools from a rooftop, which is close to a cylinder, also depends on the Reynolds number, corresponding to the critical wind speed. Reynolds's number corresponding to this wind speed is given by the relationship:

$$\mathrm{Re}(v_{crt,i}) = \frac{b \cdot v_{crt,i}}{\upsilon}, \tag{8}$$

where: b is the outer diameter of the shape of a greenhouse close to a cylinder; υ - kinematic air viscosity (15.10-6 m2 / s); $v_{crt,\,i}$ - the critical speed of the wind.
The effect of the vibrations produced on the rooftop verticals by the deviations of these vortices shall be evaluated using the inertia force on the unit of length F_w (s) acting perpendicularly to the wind direction at the z-dimension of the structure (measured at its base)[4].
The magnitude of the maximum displacement y_{vmax} of the greenhouse placed on the roof in the wind direction can be estimated with the relation:

$$\frac{y_{F\max}}{b} = \frac{1}{St^2} \cdot \frac{1}{Sc} \cdot K \cdot K_w \cdot c_{lat}, \tag{9}$$

where: y_{Fmax} is the amplitude of the maximum displacement of the greenhouse; b - the width of the cross section of the greenhouse, evaluated in the section where the critical phenomenon of resonant vortices is produced; St- is the number of Strouhal; Sc- is Scruton's number; K_w- is the factor of correlation length lj; K- factor of the modal vibration form; clat - is the aerodynamic force coefficient in the wind direction.
The aerodynamic force coefficient in the transverse direction of the clutch wind depends on the Reynolds number and for the values of the ratio $\frac{v_{crt,j}}{v_{m,Lj}} \leq 0{,}83$ **has values ranging from 0.2 ... 0.7, and for other values of this ratio the yaw coefficient can take values between 0.8 ... 2.4.**
The factor of the correlation length Kw is calculated with specific relations (SR EN 1991-1-4: 2006 / NB: 2007) p.98], and the modality of vibration K is recommended for **K = 0.1 ... 0.13**.
The action of air whirlpools that are formed near the rooftop is dangerous not only for the greenhouse but also for other constructions in their area of influence. When approving the greenhouse project, the urban architect must be informed about the action of these whirlpools and make the corresponding decision.
It should also be borne in mind that if, by placing the greenhouse on the roof, the building becomes twice as high as the average height of the neighboring buildings, the peak values of the wind speed and dynamic pressure for any adjacent structure are will consider the height of the building higher.

3. CONCLUSION

1. Structures of greenhouse grids, studs for fixing them to the roof structure resistance of roofs, transparent roofing materials and greenhouse walls, connecting elements between the structure and the transparent materials, etc. should be appropriately sized, both in terms of resistance to environmental stresses and in order to best satisfy the growing requirements of the plants grown inside them.
2. Practice has shown that among the factors in the external environment, the greatest demand for objects like the type of greenhouses placed on roofs of buildings is exerted by the wind, the influences of other factors being added to the influence of the wind in the form of coefficients validated by their exploitation. In this paper we also analyze the influence of snow deposits on the roofs of greenhouses, which are considered by construction specialists to be only a static request, unlike the action of wind, which is a dynamic demand.
3. In Romania it is used for the design of buildings with different forms of roofs, but also of other structures with different uses The design and assessment code for wind action on constructions, CR 1-1-4 / 2012, resulting from SR EN 1991-1- 4: 2006, but also other norms specified in the work. This normative act is, in turn, consistently in line with European legislation and other standards that designers and builders of roof greenhouses must follow. The same is true of other countries where building regulations are constantly updated so as to make buildings safer at the action of environmental factors, especially the wind.
4. Monitoring the effect of wind and weather on special constructions such as high buildings, bridges, dams, etc. is a basic concern for designers, builders and staff who oversee those structures. The buildings on whose roofs are placed greenhouses for vegetables and flowers can be classified as special constructions because the destruction of greenhouses under the influence of wind could have particularly serious consequences. The paper presents in detail and demonstrates the usefulness of two proposals for monitoring and verifying the status of greenhouses on the roofs: using accelerometers, using the RTK-GPS system; based on accurate monitoring of maintenance work

REFERENCES

[1] Badiu E.C., Brătucu Gh,**:** Research on the Construction on the Greenhouses Located on the Roofs of Buildings , in The 5th International Conference COMAT 2014, Brasov, România, 2014, Vol. 2, p. 237-242, ISBN 978-606-19-0411-2.

[2] Bodolan, C., Costiuc, L., Brătucu, Gh.: *Greenhouse Energy Management Simulation Model,* in. Bulletin of the *Transilvania* University of Braşov • Series II • Vol. 9 (58) No. 1, 2016, p. 51-58 ISSN 2065-2135 (Print), ISSN 2065-2143 (CD-ROM).

[3] Castelano, S.: *Loads Interaction Domains Methodology for the Design Of Steel Greenhouse Structures*, Journal of Agricultural Engineering, 2007, nr. 1, p. 21-29.

[4] Kijewski-Correa, T., Kochly, M.: *Monitoring the wind-induced response of tall buildings: GPS performance and the issue of multipath effects*. Journal of Wind Engineering and Industrial Aerodynamics, 95.9 (2007): 1176-1198.