Analysis of the wind effect on the mechanical structures in the case of the four-side sunshade

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Abstract. This paper presents the analysis of the wind effect of four-side sunshade construction. The aim of the paper is to demonstrate the possibility of applying analogy in research, with examples from civil constructions, in order to simplify and reduce the analysis. The paper presents the analytical calculation of the pressure on the sides of the four-sided sunshade, analogously to the calculation of pressure on the four-sided roofs of civil construction objects.

1. Introduction
Sunshade are used in different places and in different weather conditions, from high mountain areas with large amounts of snowfall, to sea beaches where tempest and storm can often do damage if the parasols are not adequately closed. As the sunshade has burdened by the wind (most cases), this paper presents the method of calculating the wind pressure on the sunshades, analogous to the method of calculating the influence of the wind on the roofs of building structures.

The wind load belongs to the climate effects of the environment. The wind force depends primarily on the actual characteristics of this natural phenomenon, from the speed and direction of the air movement, the mode of action (constant, variable or both). The effect of the wind on a particular construction depends on the dimension of the structure and its position in the area. Although the dynamic nature of the wind is, in most cases, an equivalent static load can replace it. The effect of wind on the stability of structures has defined by norms. The description of the wind action is based on the adoption of the reference wind velocity (vref) defined based on meteorological measurements [1]. The influence of wind on the structures has investigated considerably in the construction industry, and special attention has paid to the study of the effects of the wind on bridges to European norms [2, 3].

2. Analytical determination of wind pressure affecting the sunshade
Under special conditions - during weather conditions, the sunbathing is exposed to the wind effect and therefore the pressure of the wind (Wi) is operating on the surface of the dome, and the stated load is further transferred to the other elements of the sunshades, where they can break if they are not adequately designed. In order to ensure the carrying capacity of the sunshades at the time of strong winds, it is necessary to carry out the calculation of all of its elements; therefore, it is necessary to know the load, wind pressure on the sunshade. Figure 1 shows broken Collage 8x8 sunshade from the wind in Dubrovnik on August 13, 2017. In this paper, it has shown the calculation of wind pressure on the sunshade, just on the example given in the figure.
On First place, the published metrological data for Dubrovnik from the State Hydro meteorological Institute DHMZ has published in the year, for the day on August 13, 2017., and these data are given in Table 1.

| Location  | Date       | min daily temperature | max daily temperature | average wind speed | max hit the wind |
|-----------|------------|-----------------------|-----------------------|--------------------|------------------|
| Dubrovnik | 13.8.2017. | 21°C                  | 30°C                  | 54 km/h            | 84 km/h          |

The pressure of the wind on the outer surfaces $w_e$, as well as the wind pressure on the inner surfaces $w_i$, is calculated by the terms:

\[
W_e = q_{ref} \cdot c_e(Z_e) \cdot c_{pe}
\]

\[
W_i = q_{ref} \cdot c_e(Z_i) \cdot c_{pi}
\]

where are:
- $q_{ref}$ - Medium pressure caused by an average wind speed
- $c_e(Z_e), c_e(Z_i)$ - Coefficient of exposure
- $c_{pe}, c_{pi}$ - Coefficient of external and internal pressure

2.1. Determination of the mean pressure caused by the average wind speed
Net pressure on the wall, roof or element is equal to the difference in pressure on the opposite surfaces, taking into account their signs. Pressure, directed at the surface has taken as positive. Negative pressure has considered as a pressure that is direct from the surface. Examples has shown in Figure 2.
Figure 2. Surface pressure [4].

The average pressure caused by the average wind speed is calculated using the following form:

$$q_{\text{ref}} = \frac{1}{2} \cdot \rho \cdot v_{\text{ref}}^2$$

(3)

where $\rho$ is the air density, which is read from the diagram shown in Figure 3. at an average temperature of 25 °C and is $\rho=1.18$ kg/m$^3$.

Figure 3. Diagram of air density and temperature relationship.

By adding known values to equality (3), wind pressure is obtained:

$$q_{\text{ref}} = \frac{1}{2} \cdot \rho \cdot v_{\text{ref}}^2 = \frac{1}{2} \cdot 1.184 \text{ kg/m}^3 \cdot \left(\frac{15}{s}\right)^2 = 133 \text{ N/m}^2 = 0.133 \text{ kN/m}^2$$

(4)

2.2. Determination of the coefficient of external and internal pressure

The dome is at a height of $h=3.5$ m, which is smaller than the width of the dome 3.88 m on which the wind blows and on this basis the reference height is $z_e=h=3.5$ m. The dome of sunshade has viewed as a four-conductor roof and, according to Figure 4; a division has made into eight surfaces in which the coefficients of the external pressure were determined $c_{pe}$. 
Figure 4. Division of quadruple roofs to surfaces [4].

Based on the known dimensions of the sunshade, the dimensions from figure 5 are adopted, $e=3.88$ m, $b=3.88$ m; $2h=7$ m. According to Figure 4 for the direction of wind 0, the four-stream roof of the dome of the sunshade is 19° and it has divided into eight surfaces, as shown in Figure 5.

Figure 5. Division of the dome of sunshade to surfaces

The coefficients of the external pressure $c_{pe}$, depends on the dimensions of the loaded surfaces. The coefficient $c_{pe1}$ is suitable for calculating small elements, with an area of up to 1m$^2$ or less, while the coefficient $c_{pe10}$ is suitable for calculating areas larger than 10 m$^2$. These codes are readable from Table 2.
Table 2. External pressure coefficients for four-conductor roofs [4].

| a₀ | θ = 0° | θ = 90° |
|----|--------|--------|
| 5° | -1,7   | -1,2   |
| 15°| -0,9   | -0,8   |
| 30°| -0,5   | -0,5   |
| 45°| +0,7   | +0,7   |
| 60°| +0,7   | +0,7   |
| 75°| +0,8   | +0,8   |

| θ = 0° | θ = 90° |
|--------|--------|
| 5°     | -0,6   |
| 15°    | -1,2   |
| 30°    | -0,5   |
| 45°    | -0,3   |
| 60°    | -0,3   |
| 75°    | -0,3   |

For the calculation of the coefficient of external pressure, the area between 1 m² and 10 m² was used:

\[
c_{pe} = c_{pe,1} - (c_{pe,1} - c_{pe,10}) \cdot \log_{10} A
\]

A is the corresponding surface for which the coefficient is calculated.

Since in Table 2, value cannot be read for angle 19°, it is necessary to use linear interpolation, and finally it is obtained:

- F = 0,376 m² → \( c_{pe} = -1,866 \)
- G = 0,752 m² → \( c_{pe} = -1,50 \)
- H = 2,500 m² → \( c_{pe} = -0,273 \)
- L = 0,620 m² → \( c_{pe} = -2 \)
- K = 0,055 m² → \( c_{pe} = -1,6 \)
- M = 2,970 m² → \( c_{pe} = -0,728 \)
- \( 15° \rightarrow c_{p1} = -1,2; \ c_{p10} = -0,6; \rightarrow c_{pe} = -1,2 - (-1,2 + 0,6) \cdot \log_{10} 2,97 = -0,669 \)
- \( 30° \rightarrow c_{p1} = -1,2; \ c_{p10} = -0,8; \rightarrow c_{pe} = -1,2 - (-1,2 + 0,8) \cdot \log_{10} 2,97 = -0,892 \)
- J = 0,665 m² → \( c_{pe} = -1,42 \)
- I = 2,471 m² → \( c_{pe} = -0,47 \)

The internal pressure coefficient can be readed from Figure 6 and is \( c_{pi} = -0,5 \), since it is clearly seen that this is an hole with a opening coefficient \( \mu = 1 \).
Figure 6. Diagram of the ratio of the coefficient of the opening and the coefficient of internal pressure [4].

The sunshade is located on the ground level III category, and for a height of \( z = 3.5 \) m above the ground, the exposure coefficient can be read from Figure 7 and it will be \( c_e(z) = 1.6 \).

Figure 7. Exposure coefficient [4].

3. Results and discussion
Wind pressure on the external surface is:
\[
\begin{align*}
    w_e(F) & = 0.133 \cdot 1.6 \cdot (-1.868) = -0.3975 \text{ kN/m}^2 \\
    w_e(G) & = 0.133 \cdot 1.6 \cdot (-1.50) = -0.3192 \text{ kN/m}^2 \\
    w_e(H) & = 0.133 \cdot 1.6 \cdot (-0.273) = -0.0581 \text{ kN/m}^2 \\
    w_e(L) & = 0.133 \cdot 1.6 \cdot (-2) = -0.4256 \text{ kN/m}^2 \\
    w_e(K) & = 0.133 \cdot 1.6 \cdot (-1.6) = -0.3404 \text{ kN/m}^2 \\
    w_e(M) & = 0.133 \cdot 1.6 \cdot (-0.7282) = -0.1549 \text{ kN/m}^2 \\
    w_e(J) & = 0.133 \cdot 1.6 \cdot (-1.42) = -0.3021 \text{ kN/m}^2 \\
    w_e(I) & = 0.133 \cdot 1.6 \cdot (-0.4736) = -0.1007 \text{ kN/m}^2 \\
\end{align*}
\]

Wind pressure on the inner surfaces is:
\[
    w_i = 0.133 \cdot 1.6 \cdot (-0.5) = -0.1064 \text{ kN/m}^2
\]
The wind load has determined by algebraic addition of external and internal pressure:

\[
\begin{align*}
    w_1(F) &= (-0.3975 + | -0.1064 |) = -0.2911 \frac{kN}{m^2} = -0.000291 \frac{N}{mm^2} \\
    w_1(G) &= (-0.3192 + | -0.1064 |) = -0.2128 \frac{kN}{m^2} = -0.000212 \frac{N}{mm^2} \\
    w_1(H) &= (-0.0581 + | -0.1064 |) = 0.0483 \frac{kN}{m^2} = 0.0000483 \frac{N}{mm^2} \\
    w_1(L) &= (-0.4256 + | -0.1064 |) = -0.3192 \frac{kN}{m^2} = -0.000319 \frac{N}{mm^2} \\
    w_1(K) &= (-0.34048 + | -0.1064 |) = -0.23408 \frac{kN}{m^2} = -0.000234 \frac{N}{mm^2} \\
    w_1(M) &= (-0.1549 + | -0.1064 |) = -0.0485 \frac{kN}{m^2} = -0.0000485 \frac{N}{mm^2} \\
    w_1(J) &= (-0.3021 + | -0.1064 |) = -0.1957 \frac{kN}{m^2} = -0.000195 \frac{N}{mm^2} \\
    w_1(I) &= (-0.1007 + | -0.1064 |) = 0.0057 \frac{kN}{m^2} = 0.000057 \frac{N}{mm^2}
\end{align*}
\]

4. Conclusion

The method of researching the influence of wind on mechanical constructions based on the example of wind impact studies on construction structures, by the method of analogy, is shown in this paper. An example of wind pressure arrangement on structures that are not controlling the wind effect has presented. Also, an example of sunshades construction analysis has used in specific climatic conditions (temperature and air density) is, in fact, based on an example of four-leaf roofs, using known patterns for calculating the external and internal wind pressure in order to determine the load from the wind. The purpose of this research is simplification, because experimental research, besides being expensive, is often very time-consuming and technologically demanding. Therefore, it has been shown here that using the symmetric model simplified the construction analysis procedure, the time period of production is shortened, and the obtained results are reliable and can be used in the next research in the field of wind impact on machine constructions. In addition, the obtained analytical consistency of the wind pressure allows mechanical constructions to be calculated both analytically and numerically.

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