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Authorial models of buffeting wind actions on slender rigid structures considering similarity principles of mechanic phenomena

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SUMMARY:
Basing on similarity principles of mechanic phenomena, authorial models of buffeting phenomenon have been formulated and analysed. The following four issues have been considered: 1. Model of buffeting where angle of wind attack is not taken into account explicitly; 2. Model of buffeting in which angle of wind attack and static component of wind action are explicitly taken into account; 3. Quasi-steady theory and quasi-steady analogy of the issue of buffeting. 4. Problem of validation of model parameters in model tests in the wind tunnel. In the buffeting wind action models, filtered turbulent components of wind velocity appeared using time averaging, spatial averaging and classic filtration of convolution type. Using time averaging in measurements is much easier than using spatial averaging. The first of them seems to be more rational with respect to structures whose cross-sections are prolonged in direction of wind. The latter seems to be more suitable in the case of compact cross-sections of the structure. Classical filtration is very convenient from mathematical point of view, especially when measurements and calculations are made in frequency domain.

Keywords: atmospheric turbulence, buffeting wind actions, similarity principles

1. SETS OF QUANTITIES CHARACTERISING PHENOMENON OF BUFFETING FROM DIMENSIONAL ANALYSIS AND THEORY OF MODEL SIMILARITY POINT OF VIEW

Basing on current experiences and observations of buffeting, the following sets of dimensional and dimensionless quantities (independent variables, dependent variables, parameters), which are important for this phenomenon, can be adopted (comp. e. g. Flaga (1994, 1995a, 1995b, 1996) and see Fig. 1):

1. $\{X, Y, Z\ ;\ x_e, y_e, z_e\ ;\ x, y, z\ ;\ n, b, s\ ;\ t\}$ – set of spatial-temporal coordinates, other dependent quantities can be dependent on them;
2. $\{W\}$ – set of quantities which are independent on time t, characterising onflowing air in vertical plane, perpendicular to planes yz and bs, situated in length $x_o = n_o$ in front of the structure, adopting that $x_o = n_o = D_w = \varkappa D$, where D – transverse dimension of cross-section in direction of binormal b; D_w – width of aerodynamic wake; $\varkappa$ – number of order 3;

3. $\{G\}$ – set of geometrical quantities which are independent on time t, characterising geometry of the object (longitudinal axis, contour curve of cross-section, roughness of external surface of the object, etc.);
4. $\{v'_x, v'_y, v'_z\}$ or $\{v'_n, v'_b\}$ - sets of turbulent components of wind velocity in the surface as above, dependent on time t;
5. $\{w_n^{ta}, w_b^{ta}, w_m^{ta}\}$ – set of components of wind action caused by atmospheric turbulence, wherein:

$$w_k^{ta} = w_k^{ta}(s, t\ ;\ \{P_{wk}^{ta}\});\ k = n, b, m \qquad (1)$$

where $\{P_{wk}^{ta}\}$ – set of parameters of this action.

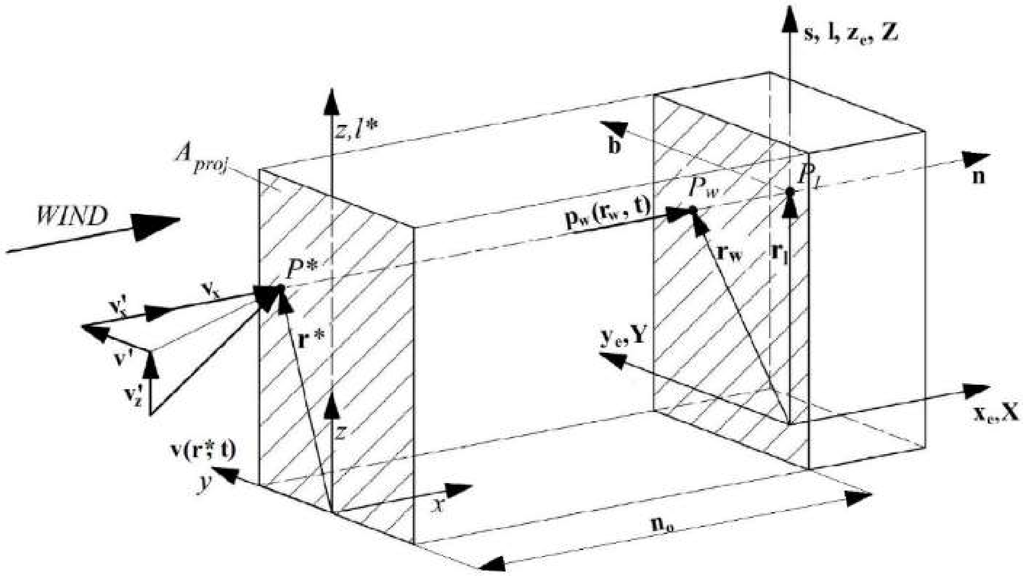

Figure 1. Graphical relationships of different geometrical quantities.

When defining more accurate functional relationships for wind action w_k^{ta}, the following phenomena, which are crucial for analysed issue, should be taken into account:

1. Wind action w_k^{ta} is shifted in time by certain time period T_{on}, T_{ob}, T_{om} with respect to turbulent components v'_n, v'_b, where: $T_{on} \cong T_{ob} \cong T_{om} \cong T_o = \frac{n_o}{\bar{v}(-n_o, 0, s)}$.
2. Each integration of wind pressure over contour curve of object cross-section is similar to filter operation (in this case spatial filter) resulting in reduction or elimination of amplitude-frequency components of higher and higher frequencies in the resultant processes (i.e. components of w_k^{ta}). Thus, components of w_k^{ta} should rather be related to quantities v'_n and v'_p which are also filtered using different filters. Postulating the following two types of averaging and filtration in practical applications seems to be rational Flaga (1995a, 1995b, 1996):

- Time averaging:

$$v_{kT}(-n_o, 0, s\ ;\ t) = \frac{1}{T}\int_{t-\frac{T}{2}}^{t+\frac{T}{2}} v'_k(-n_o, 0, s\ ;\ t)\,\mathrm{d}t;\ k = n, b \qquad (2)$$

It is recommended to adopt: $T \cong T_o$;

- Spatial averaging:

$$v_{k\Delta}(-n_o, 0, s\,;\, t) = \frac{1}{\Delta}\int v'_k(-n_o, b, s\,;\, t)\, \mathrm{d}\Delta; k = n, b \tag{3}$$

It is recommended to adopt: $\Delta \cong n_o = D_w = \varkappa D$ (i.e. equal to the width of aerodynamic wake);

- Classic filtration of convolution type:

$$v_{kh}(-n_o, 0, s\,;\, t) = \int v'_k(-n_o, 0, s\,;\, \tau) h_{v'_k}(t - \tau)\, \mathrm{d}\tau;\ k = n, b \tag{4}$$

where: $h_{v'_k}(t)$ – impulse response of the system (filter) $F_{v'_k}$ on Dirac impulse $\delta(t)$.

Each of described integration operations defining quantities v_{kT} , $v_{k\Delta}$ and v_{kh} has its advantages and disadvantages. Using time averaging in measurements is much easier than using spatial averaging. The first of them seems to be more rational with respect to structures whose cross-sections are prolonged in direction of wind. The latter seems to be more suitable in the case of compact cross-sections of the structure. Classical filtration is very convenient from mathematical point of view, especially when measurements and calculations are made in frequency domain. In this situation algebraic relationships for respective complex functions of real variable f are considered. To simplify designations – if it is not necessary to distinguish which quantity is considered – one symbol v_{kf} will be used to denote quantities v_{kT}, $v_{k\Delta}$, v_{kh}.

2. POSTULATED FORM OF FUNCTIONAL RELATIONSHIPS IN PHYSICAL/MATHEMATICAL MODEL OF BUFFETING WHERE ANGLE OF WIND ATTACK IS NOT TAKEN INTO ACCOUNT EXPLICITLY

Taking into account considerations from section 1 it is postulated to adopt the following functional relationships for components of wind action w_n^{ta}, w_b^{ta}, w_m^{ta}:

$$w_k^{ta} = w_k^{ta}(\{W\}, \{G\}\,;\, s\,;\, v'_{nf}, v'_{bf}); k = n, b, m \tag{5}$$

$$v'_{nf} = v'_{nf}(-n_o, 0, s\,;\, t - T_o);\ v'_{bf} = v'_{bf}(-n_o, 0, s\,;\, t - T_o) \tag{6}$$

Dimensional base of the issue was adopted as: $\{\rho_o, D_o, v_o\}$, where: $\rho_o = \rho$ – atmospheric air density; $D_o = D(s_o)$ – characteristic transverse dimension of object cross-section; $v_o = \bar{v}(-n_b, s_o)$ – reference velocity in front of the object. Using generalised theorem π of dimensional analysis and theory of model similarity of analysed issue (Flaga, 2015), it must be possible to present above mathematical model of buffeting in dimensionless form, as below:

$$\breve{w}_k^{ta} = \breve{w}_k^{ta}(\{\breve{W}\}, \{\breve{G}\}\,;\, \breve{s}\,;\, \breve{v}'_{nf}, \breve{v}'_{bf}); k = n, b, m \tag{7}$$

$$\breve{v}'_{nf} = \breve{v}'_{nf}(-\breve{n}_o, 0, \breve{s}\,;\, \breve{t} - \breve{T}_o);\ \breve{v}'_{bf} = \breve{v}'_{bf}(-\breve{n}_o, 0, \breve{s}\,;\, \breve{t} - \breve{T}_o) \tag{8}$$

3. LINEARIZATION OF THE ISSUE

Since quantities $\breve{v}'_{nf}$ and $\breve{v}'_{bf}$ are small, function (7) can be expanded into Taylor series, keeping only linear elements (of first degree) as it follows:

$$\breve{w}_k^{ta} \cong \left.\frac{\partial \breve{w}_k^{ta}}{\partial \breve{v}'_{nf}}\right|_{\breve{v}'_{nf}=0} \cdot \breve{v}'_{nf} + \left.\frac{\partial \breve{w}_k^{ta}}{\partial \breve{v}'_{bf}}\right|_{\breve{v}'_{nf}=0} \cdot \breve{v}'_{bf} = C_{kno}^{ta} \cdot \breve{v}'_{nf} + C_{kbo}^{ta} \cdot \breve{v}'_{bf} \tag{9}$$

where:

$$C_{kno}^{ta} = C_{kno}^{ta}\left(\{\breve{W}\},\{\breve{G}\}\,;\,\breve{s}\right); C_{kbo}^{ta} = C_{kbo}^{ta}\left(\{\breve{W}\},\{\breve{G}\}\,;\,\breve{s}\right) \tag{10}$$

are aerodynamic coefficients at buffeting. Dimensionless quantities appearing in above functional relationships constitute similarity criteria of the analysed issue. The dimensional components of linearised turbulent (buffeting) wind action w_k^{ta} can then be written as:

$$w_n^{ta} = \frac{1}{2}\rho v_o^2 D_o\left(C_{nno}^{ta}\breve{v}'_{nf} + C_{nbo}^{ta}\breve{v}'_{bf}\right) = \frac{1}{2}\rho \bar{v}_s^2 D_s\left(C_{nn}^{ta}\breve{v}'^{*}_{nf} + C_{nb}^{ta}\breve{v}'^{*}_{bf}\right) \tag{11}$$

$$w_b^{ta} = \frac{1}{2}\rho v_o^2 D_o\left(C_{bno}^{ta}\breve{v}'_{nf} + C_{bbo}^{ta}\breve{v}'_{bf}\right) = \frac{1}{2}\rho \bar{v}_s^2 D_s\left(C_{bn}^{ta}\breve{v}'^{*}_{nf} + C_{bb}^{ta}v'^{*}_{bf}\right) \tag{12}$$

$$w_m^{ta} = \frac{1}{2}\rho v_o^2 D_o\left(C_{mno}^{ta}\breve{v}'_{nf} + C_{mbo}\breve{v}'_{bf}\right) = \frac{1}{2}\rho \bar{v}_s^2 D_s^2\left(C_{mn}^{ta}\breve{v}'^{*}_{nf} + C_{mb}\breve{v}'^{*}_{bf}\right) \tag{13}$$

where: $\bar{v}_s = \bar{v}(-n_o, 0, s)$; $D_s = D(s)$.

Dimensional components of mean wind action at buffeting conditions will take the following form:

$$\bar{w}_n = \frac{1}{2}\rho \bar{v}_s^2 D_s C_n; \qquad \bar{w}_b = \frac{1}{2}\rho \bar{v}_s^2 D_s C_b; \qquad \bar{w}_m = \frac{1}{2}\rho \bar{v}_s^2 D_s^2 C_m \tag{14}$$

Summing up, there are 9 aerodynamic coefficients which are the most commonly determined in model tests in wind tunnels.

4. FINAL REMARKS

Basing on dimensional analysis and similarity principles of mechanical phenomena, authorial models of buffeting wind action were formulated and analysed. In this abstract, only basic issues of the problem were presented.

In the full paper, three additional important problems will be presented and analysed:

- The postulated form of functional relationships in physical/mathematical model of buffeting in which angle of wind attack and static components of wind action are explicitly taken into account;
- Quasi - steady theory and quasi - steady analogy of the issue of buffeting;
- Problem of validation of model parameters in model tests in wind tunnel.

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