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ASSESSMENT OF THE EFFECT OF THE FLUCTUATING COMPONENT OF WIND PRESSURE ON A LATTICE TELECOMMUNICATION TOWER

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This paper presents a computational methodology for accounting for the fluctuating component of wind loading in the analysis of a spatial lattice telecommunication tower 50 m high, designed according to a modular concept (2.0 m vertical module) with plan-dimension changes along the height. Unlike the standard approach, in which the dynamic coefficient is taken as an input multiplier, a peak-response-based methodology is proposed. In this methodology, the equivalent dynamic coefficient Cd_{eq} is determined by the criterion of the structure's peak response (top displacement, base bending moment, or critical axial force), and the distribution of equivalent nodal forces is formed so as to ensure equality of the generalized modal force in the first vibration mode. The matrix form of the equations of motion is given in full as $M\ddot{u} + C\dot{u} + Ku = F(t)$, including the derivation of the element stiffness and mass matrices of a spatial truss element and the rules for assembling the global matrices. An algorithm is proposed for piecewise formation of the equivalent wind load over the height intervals 0–32, 32–34, 34–44, 44–46, and 46–50 m, converting pressure to forces through the effective projected area of the lattice. The methodology provides a physically justified consideration of the fluctuating component without direct time-history simulation of the wind process and improves the reproducibility of calculation results.

Keywords: wind load, fluctuating pressure, steel structures, equivalent load, dynamic coefficient, modal analysis, stiffness matrix, mass matrix, finite element method.

Introduction. Lattice telecommunication towers are tall, flexible spatial structures for which wind is one of the principal governing actions. In engineering practice, wind loading is often represented as an equivalent static load; however, real wind is stochastic in nature: wind velocity and pressure contain turbulent fluctuations that can excite structural vibrations and produce peak values of displacements and internal forces.

The instantaneous wind speed at height z is expressed as the sum of a mean component and a fluctuating component:

$$V(z,t) = V(z) + v'(z,t). \tag{1}$$

Then, the dynamic (velocity) pressure of the flow is:

$$q(z,t) = \frac{1}{2}\rho_{\text{air}} V^2(z,t), \tag{2}$$

Substituting (1) into (2) yields the following expansion:

$$q = 0.5\rho_{\text{air}}(V^2 + 2Vv' + (v')^2), \tag{3}$$

which implies that the fluctuating component of pressure is determined, in particular, by the product $V(z)v'(z,t)$. Therefore, it increases with increasing mean wind speed and height, which is critical specifically for slender structures.

The code-based specification of the design wind pressure is typically given in terms of the basic (characteristic) value $W0$ and a generalized multiplier:

$$w(z) = W0\,C(z), \tag{4}$$

where

$$C(z) = Caer(z)Ch(z)Calt\,Crel\,Cdir\,Cd(z). \quad (5)$$

This form makes it possible to separate the quasi-static components (through *Caer* and *Ch*) and the dynamic component (through *Cd*). However, for lattice towers, treating *Cd* solely as an «input» multiplier may be insufficiently justified, since the dynamic increment depends on the natural frequencies, damping, and vibration mode shapes.

The dynamic response of the tower to fluctuating loading is described by the matrix equation of motion:

$$M\ddot{u}(t) + C\dot{u}(t) + Ku(t) = F(t), \quad (6)$$

where the dominant contribution to the along-wind response is typically provided by the first bending vibration mode, characterized by the circular natural frequency ω_1 and the frequency:

$$f_1 = \omega_1/(2\pi). \quad (7)$$

In this regard, it is relevant to apply an approach that preserves the code-based structure (4)–(5) but determines the dynamic increment on the basis of the structural response, taking into account ω_1, damping, and the modal distribution, which constitutes the subject of this study.

Analysis of recent research and publications. Approaches to accounting for the pulsation (turbulent) component of wind loading have evolved from simple gustiness factors to modal–spectral methods and equivalent static wind load (ESWL) procedures. The classical basis for an engineering transition from a random wind action to a design peak effect is the gust loading factor (GLF) concept formulated by A.G. Davenport [1], in which the extreme effect (or response) is related to the mean value through a multiplier that summarizes turbulence and dynamic sensitivity.

Subsequently, the ESWL direction was advanced by E. Simiu, who proposed procedures for constructing equivalent static loads for tall structures based on the characteristics of the along-wind response [2]. In the spectral framework, a significant contribution was made by G. Solari: in work on closed-form evaluation of along-wind response it was shown how to obtain design response parameters relying on the structure's dynamic properties [3], and a consistent approach to peak velocity and equivalent pressure was developed (Gust buffeting. I) [4]. Particularly important for unifying terminology and procedures is Solari's work on a generalized definition of the «gust factor» [5], where the heterogeneity of approaches for different «gust factors» (velocity, pressure, displacement, etc.) is critically analyzed.

For lattice towers (including telecommunication towers), it is essential that the structure is «permeable»: the aerodynamic action is formed as the sum of contributions from individual members and their mutual shielding, while the dynamic response is often governed by the dominance of the first bending mode. In this context, the series of works by J.D. Holmes on the along-wind dynamic response of lattice towers is key: Part I derives expressions for gust response factors [6], Part II accounts for aerodynamic damping and deflections [7], and Part III provides effective static load distributions reproducing the background and resonant components [8]. Further development of ESWL and their generalization for various combinations of mean/background/resonant components is presented in Holmes (2002) [9].

A modern interpretation of GLF as a «load factor» versus a «response factor» is given in the work of Kareem & Zhou, where more consistent procedures for determining design loads are proposed, in particular by focusing on the base moment as a representative effect [10]. Design codes reflect a similar logic through structural factors (generalization of background + resonance, correlation effects, etc.). For practical calculations, provisions of Eurocode EN 1991-1-4 [11] are widely used, as well as the international standard ISO 4354, which covers methods for determining wind actions for buildings, towers, chimneys, and other structures [12].

A foundation for describing turbulence in spectral approaches is provided by model spectra of longitudinal turbulence (e.g., Kaimal-type), which are based on experimental data from the atmospheric surface layer [13]. The comprehensive monographs by Simiu & Scanlan [14] and Holmes [15] systematize the links between meteorology, aerodynamics, and structural dynamics and serve as a basis for engineering implementation of spectral and ESWL procedures.

For applied engineering practice, general-purpose standards for minimum design loads are important (ASCE/SEI 7-22) [16], as well as experimental and applied studies that provide data on aerodynamic coefficients specifically for lattice towers—for example, Bayar's work on drag coefficients for latticed towers [17] and the experimental study by Carril Jr. et al. for lattice communication towers made of angle sections [18].

More recent studies show that «tower–antenna» interaction and wind direction can significantly influence aerodynamic coefficients and design internal forces; in particular, a computational protocol has been proposed for assessing wind load coefficients for telecommunication towers and antennas based on numerical simulation [19]. In parallel, multi-target ESWL methods are being developed, allowing several target responses (displacements/moments/forces) to be reproduced using a small number of load distributions—useful as an ideological basis for «response-consistent» calibration [20].

Problem statement. It is necessary to ensure a methodically correct consideration of the pulsation component of wind loading for a 50 m high spatial lattice tower, which has segments with changes in plan dimensions and a non-uniform distribution of stiffness/mass along the height. Typical challenges include:

- the need to transform pressure into forces for a permeable lattice (absence of a continuous windward area);
- dependence of the dynamic amplification on the first natural frequency ω_1 and damping ratio ζ_1;
- correct formation of the equivalent load distribution along the height that reproduces the peak response.

The aim of the article. To develop a response-consistent methodology for forming an equivalent wind load for a modular lattice tower, which:

- enables determination of an equivalent dynamic factor Cd_{eq} based on the criterion of the peak response R;
- generates a segment-wise distribution of nodal forces consistent with the first mode shape φ_1;
- pis implemented within a matrix finite-element (FEM) formulation.

Presentation of the main research material. The analysis is performed for a spatial bar-type lattice system (truss idealization), in which members work predominantly in axial force, and joints are assumed pinned or quasi-pinned. Wind acts in a fixed direction (conventionally along the *X*-axis), and the response is controlled in the same direction (along-wind formulation).

The pulsation component is treated as a stochastic process but is ultimately replaced by an equivalent static peak load, calibrated to match the response. The key principle is not to simulate a time history of wind, but to reproduce the peak effect (displacement/moment/force) through:

1. identification of the dynamic sensitivity parameters (ω_1, ζ_1, φ_1);
2. construction of an equivalent load distribution consistent with the first mode;
3. determination of Cd_{eq} from the response.

The mean and pulsation components of pressure (derivation and interpretation): from (1)–(3) it follows that for engineering linearization (first-order approximation) the following expansion is introduced:

$$q(z) \approx 0.5\rho_{air} V^2(z), \;\; q'(z,t) \approx \rho_{air} V(z) v'(z,t). \tag{8}$$

Physical meaning of (8): even for the same turbulence intensity, the pulsation action increases with height due to the increase of $V(z)$.

From the code-based (normative) pressure structure and the decomposition into components in (4)–(5), it is convenient to isolate the «static» part of the coefficient:

$$C_{st}(z) = Caer(z)Ch(z)Calt\,Crel\,Cdir. \tag{9}$$

Then:

$$w_{st}(z) = W0\,C_{st}(z), \tag{10}$$

$$w_{eq}(z) = w_{st}(z)Cd(z), \tag{11}$$

$$\Delta w(z) = w_{st}(z)[Cd(z) - 1]. \tag{12}$$

In engineering practice, (10)–(12) are conveniently implemented through two load cases: «mean wind» w_{st} and «pulsation increment» Δw, while the full equivalent peak is specified w_{eq}.

FEM equation of motion and physical meaning of the terms.

Let us rewrite the equation of motion (6) in the form:

$$M\ddot{u}(t) + C\dot{u}(t) + Ku(t) = F(t). \tag{13}$$

Here: $M\ddot{u}$ - inertial forces defining the dynamic nature of the problem; $C\dot{u}$ - dissipation (damping) limiting resonant amplitudes; Ku - elastic restoring forces; $F(t)$ - external wind forces (mean + pulsation) or equivalent peak forces.

Free vibrations (without damping and external forces):

$$M\ddot{u}+Ku=0. \tag{14}$$

A harmonic solution $u(t)=\varphi\sin(\omega t)$ leads to:

$$(K-\omega^2 M)\varphi=0, \tag{15}$$

$$\det(K-\omega^2 M)=0. \tag{16}$$

First circular frequency and first (cyclic) frequency:

$$\omega_1=\sqrt{\lambda_1},\ f_1=\frac{\omega_1}{2\pi}. \tag{17}$$

Modal expansion:

$$u(t)=\Phi q(t),\ \ \Phi=[\varphi_1,\varphi_2,\ldots,\varphi_m]. \tag{18}$$

For the r-th mode:

$$\ddot{q}_r+2\zeta_r\omega_r\dot{q}_r+\omega_r^2 q_r=\frac{Q_r(t)}{M_r}, \tag{19}$$

Where

$$M_r=\varphi_r^T \mathrm{M}\varphi_r,\ Q_r(t)=\varphi_r^T F(t). \tag{20}$$

Practically, it is important to ensure consistent normalization of the mode shapes φ_r, since the scalar $\varphi_r^T F$ is used later.

Local stiffness matrix of an axial member

$$k_e^{(loc)}=\frac{E_e A_e}{L_e}\begin{bmatrix}1 & -1\\ -1 & 1\end{bmatrix}. \tag{21}$$

Direction cosines

$$l_e=\frac{\Delta x}{L_e},\ m_e=\frac{\Delta y}{L_e},\ n_e=\frac{\Delta z}{L_e}. \tag{22}$$

Global stiffness matrix of a spatial truss element (6×6)

$$k_e^{(glob)}=\frac{E_e A_e}{L_e}\begin{bmatrix}l_e^2 & l_e m_e & l_e n_e & -l_e^2 & -l_e m_e & -l_e n_e\\ l_e m_e & m_e^2 & m_e n_e & -l_e m_e & -m_e^2 & -m_e n_e\\ l_e n_e & m_e n_e & n_e^2 & -l_e n_e & -m_e n_e & -n_e^2\\ -l_e^2 & -l_e m_e & -l_e n_e & l_e^2 & l_e m_e & l_e n_e\\ -l_e m_e & -m_e^2 & -m_e n_e & l_e m_e & m_e^2 & m_e n_e\\ -l_e n_e & -m_e n_e & -n_e^2 & l_e n_e & m_e n_e & n_e^2\end{bmatrix}. \tag{23}$$

Consistent local mass matrix

$$m_e^{(loc)}=\frac{\rho_{mat}A_e L_e}{6}\begin{bmatrix}2 & 1\\ 1 & 2\end{bmatrix}. \tag{24}$$

After transformation (analogous to stiffness), one obtains $m_e^{(glob)}$ of size 6×6.

Assembly of global matrices

$$\mathrm{K}=\sum_{e=1}^{n_e}\mathrm{A}_e^T k_e^{(glob)}\mathrm{A}_e,\ \ \mathrm{M}=\sum_{e=1}^{n_e}\mathrm{A}_e^T m_e^{(glob)}\mathrm{A}_e. \tag{25}$$

Rayleigh damping and selection of parameters

$$\mathrm{C}=\alpha\mathrm{M}+\beta\mathrm{K}. \tag{26}$$

Modal damping ratio:

$$\zeta_r = \frac{1}{2}\left(\frac{\alpha}{\omega_r} + \beta\omega_r\right). \tag{27}$$

given ζ_a, ζ_b at ω_a, ω_b :

$$\beta = \frac{2(\zeta_b\omega_b - \zeta_a\omega_a)}{\omega_b^2 - \omega_a^2}, \quad \alpha = 2\zeta_a\omega_a - \beta\omega_a^2. \tag{28}$$

It is practically advisable to «tie» damping to the lower modes (the 1st and the 2nd/3rd), since these modes govern the along-wind response.

Unlike the approach where «Cd is used as an input multiplier», the methodology works as follows:

1. the mean-wind load vector F_{st} is formed;
2. the peak response R_{peak} is specified/estimated;
3. Cd_{eq} is determined as a response-consistent coefficient;
4. the equivalent load vector F_{eq}, consistent with the first mode shape φ_1 is constructed.

In this logic, Cd_{eq} is an output quantity rather than a prescribed coefficient.

Segment-wise scheme along the height.

The height $H = 50$ m is divided into 5 segments:

- $i = 1:[0;32], \ h_1 = 32, \ z_1 = 16;$
- $i = 2:[32;34], \ h_2 = 2, \ z_2 = 33;$
- $i = 3:[34;44], \ h_3 = 10, \ z_3 = 39;$
- $i = 4:[44;46], \ h_4 = 2, \ z_4 = 45;$
- $i = 5:[46;50], \ h_5 = 4, \ z_5 = 48.$

Such segmentation reproduces structural transitions (changes in dimensions/stiffness/area) and prevents their influence from being «smeared» over the entire height.

Effective projected area of a segment. For a permeable lattice, the effective «sail area» is defined as the sum of projections of the members:

$$A_{ef,i} = \sum_{e \in i} d_e L_e \sqrt{1 - l_e^2}. \tag{29}$$

Here, $\sqrt{1 - l_e^2}$ represents the projection of a member onto the plane perpendicular to the wind direction: members nearly parallel to the wind contribute little to the frontal area.

Mean pressure, segment forces, and conversion to nodal forces.

Mean (quasi-static) pressure at the reference height z_i:

$$w_{st,i} = W0\,Caer_i\,Ch(z_i)\,Calt\,Crel\,Cdir. \tag{30}$$

Resultant force on the segment:

$$F_{st,i} = w_{st,i}\,A_{ef,i}. \tag{31}$$

Equivalent distributed line load:

$$p_{st,i} = \frac{F_{st,i}}{h_i}. \tag{32}$$

Decomposition to the lower/upper levels of the segment:

$$F_{st,i}^{bot} = F_{st,i}^{top} = \frac{F_{st,i}}{2}. \tag{33}$$

Decomposition to the nodes of a level:

$$F_{st,node} = \frac{F_{st,i}^{lev}}{n_{lev}}. \tag{34}$$

Thus, the global vector F_{st} is formed.

A control effect R is selected (e.g., $u_{top}, M_{base}, N_{\max}$). The mean response is:

$$R_{mean} = R(F_{st}). \tag{35}$$

Peak response (Gaussian approximation):

$$R_{peak} \approx R_{mean} + g\,\sigma_R. \tag{36}$$

Equivalent dynamic factor:

$$Cd_{eq} = \frac{R_{peak}}{R_{mean}} \approx 1 + g\frac{\sigma_R}{R_{mean}}. \tag{37}$$

Here g is the peak factor and σ_R is the RMS of the response. The method of evaluating σ_R may be spectral or engineering-estimated; the methodology only requires consistency of the adopted model.

Generalized (modal) force in the first mode from the mean wind:

$$Q_{1,st} = \varphi_1^T F_{st}. \tag{38}$$

Target peak value:

$$Q_{1,peak} = Cd_{eq}\, Q_{1,st}. \tag{39}$$

«Mode-consistent» condition:

$$\varphi_1^T F_{eq} = Q_{1,peak}. \tag{40}$$

Construction of the pulsation force template ΔF_0 and segment weights

Segment weight:

$$g_i = w_{st,i}\, A_{ef,i}\, \eta_i, \tag{41}$$

where η_i is the «influence» of segment i in the first mode (the average value of the mode-shape component in the wind direction at the nodes of the segment):

$$\eta_i = \frac{1}{N_i}\sum_{k\in i}\varphi_{1x,k}, \tag{42}$$

Next, ΔF_0 is formed proportional to the weights g_i, using the same decomposition rules into levels and nodes as for F_{st}.

Scaling of the pulsation part and obtaining F_{eq}.

Equivalent force vector:

$$F_{eq} = F_{st} + s\,\Delta F_0. \tag{43}$$

The scale factor **s** is determined from condition (40):

$$s = \frac{(Cd_{eq} - 1)\varphi_1^T F_{st}}{\varphi_1^T \Delta F_0}. \tag{44}$$

Equation (44) is key: it guarantees that F_{eq} reproduces the peak generalized action in the dominant first mode.

Estimation of ω_1 and f_1: main approach and verification.

Main approach: perform a modal analysis according to (14)–(17) to obtain ω_1, f_1, and the mode shape φ_1. In practical interpretation, it is important to describe:

1. the character of the 1st mode (bending in the wind direction);
2. maximum displacements (typically in the upper segments);
3. if available, the participation factor of the first mode in the wind direction.

For a verification estimate, it is convenient to use the Rayleigh estimate:

$$\omega_1^2 \approx \frac{\psi^T \mathrm{K}\psi}{\psi^T \mathrm{M}\psi},\ f_1 \approx \frac{1}{2\pi}\sqrt{\frac{\psi^T \mathrm{K}\psi}{\psi^T \mathrm{M}\psi}}. \tag{45}$$

The vector ψ can be taken as:

1. either linear along the height, $\psi(z) \sim z/H$;
2. or as the static deflection shape under a unit horizontal force applied at the top (a better engineering option).

If (45) differs significantly from the modal result, typical reasons include incorrect mass, «mechanisms» in the model, or support/fixity errors.

Specific segment-wise distribution of the equivalent load (0–32, 32–34, 34–44, 44–46, 46–50 m). Formation of F_{eq} is carried out using a single procedure for all five segments:

Step 1. Compute $A_{ef,i}$ using (29) for each segment.

Step 2. Determine $w_{st,i}$ using (30) (coefficients *Chi,* and, if required, other multipliers are taken from code charts/tables; $Caer_i$ is taken from reference/experimental data or a conservative estimate).

Step 3. Compute $F_{st,i}$ using (31) and form F_{st} using (33)–(34).

Step 4. Perform modal analysis to obtain ω_1, f_1, φ_1.

Step 5. Select the control effect *R* and determine Cd_{eq} using (35)–(37).

Step 6. Compute the weights g_1 using (41)–(42) and build ΔF_0.

Step 7. Compute s using (44) and obtain F_{eq} using (43).

Numerical values *Ch*(*z*) and *Cd*(*z*) are adopted from code charts/tables and depend on terrain category, height, and effective geometric parameters (width/diameter; for lattice structures also on porosity/shielding). Since the aim of the article is to present the methodological algorithm (response- and mode-consistent calibration), in the demonstration it is sufficient to provide the structure and sequence (29)–(44), while the specific numbers can be moved to an illustrative calculation or an appendix.

Modal check: after forming F_{eq}, compliance with the condition is verified:

$$\varphi_1^T F_{eq} = Cd_{eq}\, \varphi_1^T F_{st}. \tag{46}$$

Response check: compare the target peak response with the response produced by F_{eq}:

$$R(F_{eq}) \approx R_{peak}. \tag{47}$$

Sensitivity to damping: Increasing ζ_1 (via (27)) reduces the resonant contribution and therefore typically reduces σ_R and Cd_{eq}.

Sensitivity to the choice of *R*: if $R = u_{top}$, Cd_{eq} is oriented to serviceability; if $R = M_{base}$, to foundation design; if $R = N_{\max}$, to member forces. This is an advantage of the methodology, as it allows the equivalent wind load to be tailored to a specific design objective.

Conclusions. A response-consistent methodology has been developed for forming an equivalent wind load for a 50 m high modular lattice tower, in which Cd_{eq} is determined based on the criterion of the peak response *R*, and the equivalent nodal force vector F_{eq} is made consistent with the first vibration mode. It is shown that the matrix FEM formulation $M\ddot{u} + C\dot{u} + Ku = F(t)$ with element stiffness (6×6) and mass matrices provides a sufficient basis for modal analysis and subsequent quasi-dynamic equivalencing of the pulsation action. A segment-wise load distribution scheme along the height (0–32, 32–34, 34–44, 44–46, 46–50 m) is proposed, corresponding to structural transitions and enabling correct consideration of variations in *Ch*(*z*), $Caer_i$ and A_{ef} with height. A geometrically defined computation of the effective projected area $A_{ef,i}$ through the sum of member projections is introduced, reducing subjectivity in assessing the «sail area» of a lattice system. Relations (37) and (44) provide a transparent transition from the mean wind action to an equivalent peak load without direct time-history simulation, with the possibility of selecting the control effect depending on the design objective (strength, stability, serviceability).

REFERENCES

1. *Davenport A.G.* Gust Loading Factors. - Journal of the Structural Division (ASCE). 1967. DOI: 10.1061/JSDEAG.0001692.
2. *Simiu E.* Equivalent Static Wind Loads for Tall Building Design. - Journal of the Structural Division (ASCE). 1976. DOI: 10.1061/JSDEAG.0004313.

3. *Solari G.* Alongwind Response Estimation: Closed Form Solution. - Journal of the Structural Division (ASCE). 1982. DOI: 10.1061/JSDEAG.0005861.
4. *Solari G.* Gust Buffeting. I: Peak Wind Velocity and Equivalent Pressure. - Journal of Structural Engineering (ASCE). 1993. DOI: 10.1061/(ASCE)0733-9445(1993)119:2(365).
5. *Solari G.* A generalized definition of gust factor. - Journal of Wind Engineering and Industrial Aerodynamics. 1990. DOI: 10.1016/0167-6105(90)90336-B.
6. *Holmes J.D.* Along-wind response of lattice towers: Part I – derivation of expressions for gust response factors. Engineering Structures. 1994. DOI: 10.1016/0141-0296(94)90069-8.
7. *Holmes J.D.* Along-wind response of lattice towers—II. Aerodynamic damping and deflections. Engineering Structures. 1996. DOI: 10.1016/0141-0296(95)00131-X.
8. *Holmes J.D.* Along wind response of lattice towers—III. Effective load distributions. Engineering Structures. 1996. DOI: 10.1016/0141-0296(95)00166-2.
9. *Holmes J.D.* Effective static load distributions in wind engineering. Journal of Wind Engineering and Industrial Aerodynamics. 2002. DOI: 10.1016/S0167-6105(01)00164-7.
10. *Kareem A., Zhou Y.* Gust loading factor—past, present and future. Journal of Wind Engineering and Industrial Aerodynamics. 2003. DOI: 10.1016/j.jweia.2003.09.003.
11. CEN. EN 1991-1-4: Eurocode 1: Actions on structures — Part 1-4: General actions — Wind actions. 2005.
12. ISO. ISO 4354:2009. Wind actions on structures.
13. *Kaimal J.C., Wyngaard J.C., Izumi Y., Coté O.R.* Spectral characteristics of surface-layer turbulence. Quarterly Journal of the Royal Meteorological Society. 1972. DOI: 10.1002/qj.49709841707.
14. *Simiu E., Scanlan R.H.* Wind Effects on Structures: Fundamentals and Applications to Design. 3rd ed. John Wiley & Sons. 1996.
15. *Holmes J.D.* Wind Loading of Structures. (3rd ed., CRC Press / Taylor & Francis).
16. ASCE/SEI. ASCE/SEI 7-22: Minimum Design Loads and Associated Criteria for Buildings and Other Structures. 2022. DOI: 10.1061/9780784415788.
17. *Bayar D.C.* Drag Coefficients of Latticed Towers. Journal of Structural Engineering (ASCE). 1986. DOI: 10.1061/(ASCE)0733-9445(1986)112:2(417).
18. *Carril C.F. Jr.* et al. Experimental study of the wind forces on rectangular latticed communication towers with antennas. Journal of Wind Engineering and Industrial Aerodynamics. 2003. DOI: 10.1016/S0167-6105(03)00049-7.
19. *Khazaali M., Ma L., Rokneddin K., Mazzotti M., Bocchini P.* A robust protocol to compute wind load coefficients of telecommunication towers and antennas using numerical simulation for risk and resilience assessment. (Resilient Cities and Structures). 2024. DOI: 10.1016/j.rcns.2024.02.001.
20. *Huang M.H., Lo Y.L.* A refined method of multi-target equivalent static wind loads: A bridge case. Journal of Wind Engineering and Industrial Aerodynamics. 2021. DOI: 10.1016/j.jweia.2021.104609.

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ОЦІНКА ВПЛИВУ ПУЛЬСАЦІЙНОЇ СКЛАДОВОЇ ВІТРОВОГО ТИСКУ НА ҐРАТЧАСТУ ТЕЛЕКОМУНІКАЦІЙНУ ВЕЖУ

Анотація. Наведено розрахункову методику врахування пульсаційної складової вітрового навантаження під час аналізу просторової ґратчастої телекомунікаційної вежі висотою 50 м, виконаної за модульним принципом (крок за висотою 2 м) із ділянками зміни габаритів у плані. На відміну від стандартного підходу, де коефіцієнт динамічності приймається як вхідний множник, запропоновано методику за параметром пікової реакції, у якій еквівалентний коефіцієнт динамічності Cd_{eq} визначається за критерієм пікової реакції конструкції (переміщення вершини, базовий момент або критична осьова сила), а розподіл еквівалентних вузлових сил формується так, щоб забезпечити рівність узагальненої модальної сили у першій формі коливань. Матричну постановку рівнянь руху наведено в повному вигляді $M\ddot{u} + C\dot{u} + Ku = F(t)$ з виведенням елементних матриць жорсткості та мас просторового фермового елемента і правилами складання глобальних матриць. Запропоновано алгоритм ділянкового формування еквівалентного вітрового навантаження для інтервалів 0–32, 32–34, 34–44, 44–46, 46–50 м з переходом від тиску до сил через ефективну проєкційну площу ґратки. Методика забезпечує фізично обґрунтоване врахування пульсаційної складової без прямого часово-історичного моделювання вітрового процесу та підвищує відтворюваність розрахункових рішень. Додатково обґрунтовано вибір першої форми як домінуючої для along-wind відгуку та наведено процедурні перевірки узгодженості навантаження через рівність модальної узагальненої сили. Показано, що ділянкова дискретизація дозволяє коректно врахувати конструктивні переходи та відмінності «парусності» по висоті, а застосування ефективної проєкційної площі зменшує суб'єктивність при моделюванні проникних ґратчастих систем. Запропоновано критерій контролю: $R(F_{eq}) \approx R_{peak}$ та $\varphi_1^T F_{eq} = Cd_{eq} \cdot \varphi_1^T F_{st}$, що гарантує збіжність за обраним ефектом.

Ключові слова: вітрове навантаження, пульсаційний тиск, сталеві конструкції, еквівалентне навантаження, коефіцієнт динамічності, модальний аналіз, матриця жорсткості, матриця мас, метод скінченних елементів.

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ASSESSMENT OF THE EFFECT OF THE FLUCTUATING COMPONENT OF WIND PRESSURE ON A LATTICE TELECOMMUNICATION TOWER

Abstract. The paper presents a calculation methodology for accounting for the fluctuating component of wind loading in the analysis of a spatial lattice telecommunication tower 50 m high, designed according to a modular concept (2 m vertical module) with plan-dimension changes along the height. Unlike the standard approach, where the dynamic coefficient is taken as an input multiplier, a methodology based on the peak response parameter is proposed. In this methodology, the equivalent dynamic coefficient Cd_{eq} is determined by the criterion of the structure's peak response (top displacement, base bending moment, or critical axial force), and the distribution of equivalent nodal forces is formed so as to ensure equality of the generalized modal force in the first vibration mode. The matrix form of the equations of motion is given in full as $M\ddot{u}+C\dot{u}+Ku=F(t)$, with derivation of the element stiffness and mass matrices of a spatial truss element and rules for assembling the global matrices. An algorithm is proposed for piecewise formation of the equivalent wind load over the height intervals 0–32, 32–34, 34–44, 44–46, and 46–50 m, converting pressure to forces through the effective projected area of the lattice. The methodology provides a physically justified consideration of the fluctuating component without direct time-history simulation of the wind process and improves the reproducibility of calculation results. In addition, the choice of the first mode as dominant for the along-wind response is substantiated, and procedural checks of load consistency are provided through equality of the generalized modal force. It is shown that the piecewise discretization enables correct consideration of structural transitions and differences in «wind-exposed area» along the height, while the use of the effective projected area reduces subjectivity when modeling permeable lattice systems. A control criterion is proposed: $R(F_{eq})\approx R_{peak}$ and $\varphi_1^T F_{eq}=Cd_{eq}\cdot\varphi_1^T F_{st}$, which guarantees convergence with respect to the selected response quantity.

Keywords: wind load, fluctuating pressure, steel structures, equivalent load, dynamic coefficient, modal analysis, stiffness matrix, mass matrix, finite element method.

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