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DYNAMICAL ANALYSIS OF THE CROSS-WIND RESPONSE OF A VIBRATING TALL INDUSTRIAL CHIMNEY DUE TO TURBULENT WIND FLOW

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Abstract: *The paper is concerned with the numerical analysis of the cross-wind response of a tall industrial chimney due to lateral turbulence component and vortex excitation with taking into account motion-induced wind forces. The lateral turbulence component response has been estimated by means of the random vibration approach. The vortex excitation response has been estimated by means of the Vickery and Basu's model. Motion-induced wind forces acting on a vibrating chimney have been taken into account as a nonlinear aerodynamic damping force. Computer program have been developed to obtain the response of a six-flue, 250m-tall chimney. The numerical results of a complete cross-wind response are presented.*

1 INTRODUCTION

In case of a turbulent wind flow a complete analysis of the dynamic cross-wind response of a tall industrial chimney requires that the lateral turbulence component response, vortex excitation response and motion-induced response are evaluated.

Models existing in literature have been applied to obtain the cross-wind response of a tall chimney. Three power spectral density functions for the evaluation of the lateral response are taken into account. Influence of all cross-wind forces on the total response have been compared and conclusions have been formulated.

2 TURBULENCE MODELING

The calculation of the wind excited response of slender structures requires a modeling of the wind field.

Let x, y, z be a Cartesian reference system with origin in O on the ground; z is vertical and directed upwards. The wind field is decomposed into its average component vector and the fluctuating vector around the mean, Ref. [1]. In this case the wind velocity at point x, y, z may be written as, see Fig. (1)

$$\mathbf{V}(x,y,z,t) = \bar{\mathbf{V}}(x,y,z) + \mathbf{V}'(x,y,z,t) \tag{1}$$

where t is the time, $\bar{\mathbf{V}}$ is the mean wind velocity vector and $\mathbf{V}'$ is the turbulent fluctuation vector (zero mean). Considering a flat homogeneous terrain and the internal boundary layer, they are given by

$$\bar{\mathbf{V}}(x,y,z)=\vec{\mathrm{i}}\bar{u}(z) \tag{2}$$

$$\mathbf{V}'(x,y,z,t)=\vec{\mathrm{i}}u'(x,y,z,t)+\vec{\mathrm{j}}v'(x,y,z,t)+\vec{\mathrm{k}}w'(x,y,z,t) \tag{3}$$

where $\vec{\mathrm{i}}, \vec{\mathrm{j}}, \vec{\mathrm{k}}$ are the unit vectors in the directions x, y, z; $\bar{u}(z)$ is the mean wind velocity along with x; u', v', w' are the longitudinal (x), lateral (y) and vertical (z) turbulence components.

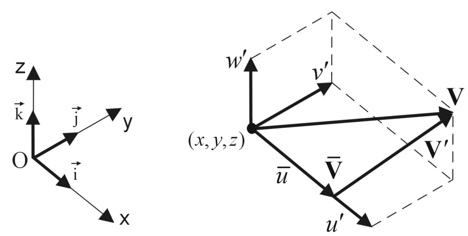

Figure 1: Average component vector and the fluctuating vector of the wind velocity field.

3 DESCRIPTION OF THE CHIMNEY, ITS CALCULATION MODEL AND FREE VIBRATIONS OF THIS CHIMNEY

The analyzed six-flue, 250 m-tall industrial chimney which is placed on the circular foundation slab – 50 m in diameter (lying directly on the soil) has been described in Ref. [2] in detail. In the paper the calculation model of the chimney and numerical results for the first four natural vibration periods and mode shapes are also given.

4 CROSS-WIND FORCES CAUSED BY STRUCTURAL MOTION

The chimney is a typical line-like structure, with a single spatial coordinate z. Let assume that the chimney is moving. For small vibration amplitudes a relative velocity generates an aerodynamic force proportional to the velocity of the structure. Let $W_m(z,t)$ be the force per a unit length along the chimney as the motion-induced wind force in the form (Ref. [3])

$$W_m(z,t)=4\pi f_i\rho\, d^2(z)K_{ao}\left(z\right)\left[1-\left(\frac{\sigma_y\left(z\right)}{\alpha\, d\ \left(z\right)}\right)^2\right]\dot{q}_y(z,t) \tag{4}$$

where f_i is the ith natural frequency, ρ is the air density, $d(z)$ is the diameter of the chimney, $K_{ao}\left(z\right)$ is the aerodynamic damping parameter, $\sigma_y\left(z\right)$ is the rms of the cross-wind displacement, $\alpha\, d\left(z\right)$ is the limiting displacement ($\alpha \cong 0.4$, Ref. [3]) and $\dot{q}_y\left(z,t\right)$ is the velocity of the chimney in the cross-wind direction.

The critical wind velocity of the vibrating chimney u^*_{cr} is greater than the critical wind velocity of the stationary chimney u_{cr} and is equal to (Ref. [4])

$$u^*_{cr}\left(z_{ref}\right)=\frac{f_i\cdot d_{ef}\left(z_{ref}\right)}{St} \tag{5}$$

where *St* is the Strouhal number and $d_{ef}\left(z_{ref}\right)=d\left(z_{ref}\right)+\alpha_c\, q_y\left(z_{ref}\right)$ is the effective reference diameter of the vibrating chimney, α_c is the experimental parameter.

5 CROSS-WIND RESPONSE OF THE CHIMNEY

The lateral wind response of the chimney due to the lateral turbulence component has been computed by means of the random vibration approach and presented in Ref. [5]. Three power spectral density functions for the evaluation of the lateral response have been taken into account. The vortex shedding response has been estimated by means of the Vickery and Basu's model and presented in Ref. [6]. The motion-induced wind force acting on the vibrating chimney have been taken into account as a nonlinear aerodynamic damping force. Computer program were developed to obtain the response of a six-flue, 250m-tall chimney.

The comparison of the lateral wind displacements of the top of the chimney due to the lateral turbulence component for the different reference wind velocity $\overline{u}_{10}$ are shown in Fig. (2). Fig. (3) depicts the comparison of the complete cross-wind response of the top of the stationary and vibrating chimney for the different reference wind velocity $\overline{u}_{10}$.

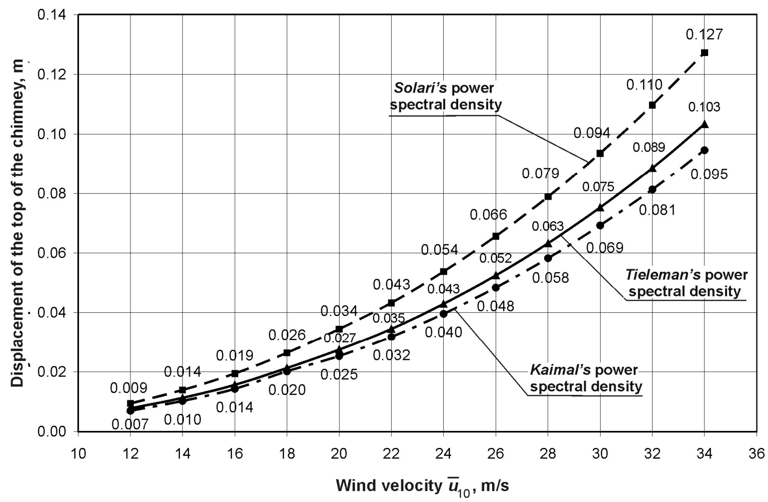

Figure 2: Comparison of lateral displacements of the top of the chimney due to the lateral turbulence component for different values of $\overline{u}_{10}$.

6 CONCLUSIONS

- The response of the chimney due to the lateral turbulence component depends on its power spectral density. The response computed according to the Solari's power spectral density is greater about 25% than for the Tieleman's power spectral density and about 35% than for the Kaimal's power spectral density.
- The vortex shedding excitation has relevant influence on the cross-wind response of the chimney in the range of the wind velocities $\overline{u}_{10}$=16÷22 m/s. The highest vortex shedding response appears for $\overline{u}_{10}$=19 m/s.
- The vortex shedding response is about 6 times greater than the lateral turbulence component response for $\overline{u}_{10}$=19 m/s. However, the second response component should be taken into account because its influence on the total cross-wind response is about 14%.

- The motion-induced wind forces are insignificant on the cross-wind response of the tall chimney. The influence of the motion-induced response for $\overline{u}_{10}$ = 19 m/s is about 1%.

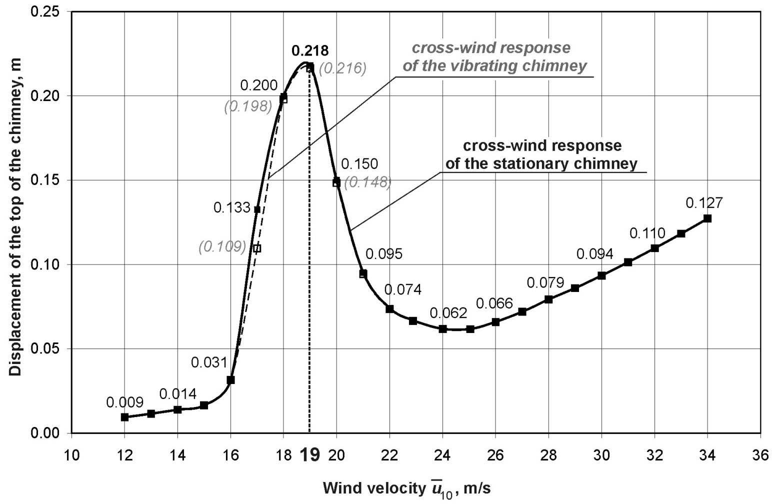

Figure 3: Comparison of cross-wind response of the stationary and vibrating chimney due to the vortex excitation (Vickery and Basu's model) and lateral turbulence component (Solari's power spectral density) for different values of $\overline{u}_{10}$.

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