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The Reliability Analysis of Concrete Chimneys Due to Random Vortex Shedding

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Abstract : Chimneys are generally tall and slender structures with circular cross-sections, due to which they are highly prone to wind forces. Wind exerts pressure on the wall of the chimneys, which produces unwanted forces. Vortex-induced oscillation is one of such excitations which can lead to the failure of the chimneys. Therefore, vortex-induced oscillation of chimneys is of great concern to researchers and practitioners since many failures of chimneys due to vortex shedding have occurred in the past. As a consequence, extensive research has taken place on the subject over decades. Many laboratory experiments have been performed to verify the theoretical models proposed to predict vortex-induced forces, including aero-elastic effects. Comparatively, very few proto-type measurement data have been recorded to verify the proposed theoretical models. Because of this reason, the theoretical models developed with the help of experimental laboratory data are utilized for analyzing the chimneys for vortex-induced forces. This calls for reliability analysis of the predictions of the responses of the chimneys produced due to vortex shedding phenomena. Although several works of literature exist on the vortex-induced oscillation of chimneys, including code provisions, the reliability analysis of chimneys against failure caused due to vortex shedding is scanty. In the present study, the reliability analysis of chimneys against vortex shedding failure is presented, assuming the uncertainty in vortex shedding phenomena to be significantly more than other uncertainties, and hence, the latter is ignored. The vortex shedding is modeled as a stationary random process and is represented by a power spectral density function (PSDF). It is assumed that the vortex shedding forces are perfectly correlated and act over the top one-third height of the chimney. The PSDF of the tip displacement of the chimney is obtained by performing a frequency domain spectral analysis using a matrix approach. For this purpose, both chimney and random wind forces are discretized over a number of points along with the height of the chimney. The method of analysis duly accounts for the aero-elastic effects. The double barrier threshold crossing level, as proposed by Vanmarcke, is used for determining the probability of crossing different threshold levels of the tip displacement of the chimney. Assuming the annual distribution of the mean wind velocity to be a Gumbel type-I distribution, the fragility curve denoting the variation of the annual probability of threshold crossing against different threshold levels of the tip displacement of the chimney is determined. The reliability estimate is derived from the fragility curve. A 210m tall concrete chimney with a base diameter of 35m, top diameter as 21m, and thickness as 0.3m has been taken as an illustrative example. The terrain condition is assumed to be that corresponding to the city center. The expression for the PSDF of the vortex shedding force is taken to be used by Vickery and Basu. The results of the study show that the threshold crossing reliability of the tip displacement of the chimney is significantly influenced by the assumed structural damping and the Gumbel distribution parameters. Further, the aero-elastic effect influences the reliability estimate to a great extent for small structural damping.

Keywords : chimney, fragility curve, reliability analysis, vortex-induced vibration
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