ABSTRACT

Tall slender structures such as chimneys are subjected to significant wind forces. In the present work, various aspects related to the design of such structures have been studied using experimental, numerical and analytical techniques. The phenomena studied include, vortex induced vibration, aerodynamic interference between geometrically similar structures and the effect of strakes. In addition, reliability assessment was carried out using fatigue and probability analysis.

The phenomenon of aerodynamic interference was studied across three cases: between two straight circular cylinders; a pair of 1:50 tapered cylinders; and a pair of 1:40 tapered cylinders—all in the staggered arrangement. Experiments were conducted in the 1.6m × 1.6m wind tunnel at IIT Delhi. The focus was on the enhanced across-wind response of the downstream cylinder near the first critical wind speed (at which the vortex shedding frequency matches the natural frequency of the structure). It is shown that the magnification in the response (with respect to that of the isolated cylinder) is a strong function of both the pitch and the orientation and extends to distances much larger than that reported in literature. It is evident from the current investigation that the magnification factors recommended in IS 4998 (Part 1: 1992, see Figure 1 therein/2015) and Eurocode 1 (Actions on structures- General actions- Part 1-4: Wind actions, see Equation E. 11 therein) need to be revised upwards. Further, the rule of thumb, used in the design of tall structures, that beyond 15 to 20 diameters interference is negligible is not tenable, especially for structures of identical geometry.

To study the effect of strakes on structures vibrating in second mode, a straight cylinder of aspect ratio 12 was chosen. Wind forces were applied in along wind and across wind

directions. To simulate periodic vortex shedding at lock-in, the across-wind force was modelled as sinusoidally varying with time at the second mode frequency. Its amplitude was allowed to vary with height in a manner consistent with a boundary-layer profile with a power-law exponent. Three cases have been compared— without strakes, strakes over the top one third, and strakes over the top half. It was found that the use of strakes has an adverse effect if the structure vibrates in the second mode. The effect is more severe if strakes are used over the top one-third in comparison to the top-half.

An alternate method for fluid-structure interaction (FSI) studies has been developed. The method is useful for 2-D problems and involves solving the governing equations in the frame of the oscillating structure. It is computationally more efficient and robust than the standard ALE (Arbitrary Lagrangian Eulerian) methods. In conjunction with an appropriate turbulence model (the SST k-ω model in this case) this method was able to numerically capture the lock-in phenomenon which is computationally very challenging.

A numerical model of a typical chimney was validated against experiments with a scaled down model. A comparative study of its response using different international codes for design of concrete chimneys showed that IS 4998 and CICIND are conservative while ACI 307-08 yields a more realistic response. The fatigue life of the chimney was estimated using wind loading based on the Emil Simiu spectra. The rainflow cycle counting method clubbed with the Palmgren-Miner rule was used in the analysis. To take into account the uncertainties in the system (like wind velocity, drag coefficient and material strength) probabilistic analysis was also done using the stochastic finite element method. It was found that the system is most sensitive to variations in wind speed.