been proposed for wind applications (Zhou and Kareem 2001, Zhou, Kijewski, and Kareem 2002):

$$f_{n1} = 150/H \text{ (ft)} \quad \text{(C26.9-8)}$$

This frequency expression is based on older buildings and overestimates the frequency common in U.S. construction for smaller buildings less than 400 ft in height, but becomes more accurate for tall buildings greater than 400 ft in height. The Australian and New Zealand Standard AS/NZS 1170.2, Eurocode ENV1991-2-4, Hong Kong Code of Practice on Wind Effects (2004), and others have adopted Eq. C26.9-8 for all building types and all heights.

Recent studies in Japan involving a suite of buildings under low-amplitude excitations have led to the following expressions for natural frequencies of buildings (Sataka et al. 2003):

$$n_1 = 220/H \text{ (ft) (concrete buildings)} \quad \text{(C26.9-9)}$$

$$n_1 = 164/H \text{ (ft) (steel buildings)} \quad \text{(C26.9-10)}$$

The expressions based on Japanese buildings result in higher frequency estimates than those obtained from the general expression given in Eqs. C26.9-6 through C26.9-8, particularly since the Japanese data set has limited observations for the more flexible buildings sensitive to wind effects and Japanese construction tends to be stiffer.

For cantilevered masts or poles of uniform cross-section (in which bending action dominates):

$$n_1 = (0.56/h^2)\sqrt{(EI/m)} \quad \text{(C26.9-11)}$$

where EI is the bending stiffness of the section and m is the mass/unit height. (This formula may be used for masts with a slight taper, using average value of EI and m) (ECCS 1978).

An approximate formula for cantilevered, *tapered*, circular poles (ECCS 1978) is

$$n_1 \approx [\lambda/(2\pi h^2)]\sqrt{(EI/m)} \quad \text{(C26.9-12)}$$

where h is the height, and E, I, and m are calculated for the cross-section at the base. λ depends on the wall thicknesses at the tip and base, e_t and e_b, and external diameter at the tip and base, d_t and d_b, according to the following formula:

$$\lambda = \left[1.9\exp\left(\frac{-4d_t}{d_b}\right)\right] + \left[\frac{6.65}{0.9 + \left(\frac{e_t}{e_b}\right)^{0.666}}\right] \quad \text{(C26.9-13)}$$

Equation C26.9-12 reduces to Eq. C26.9-11 for uniform masts. For free-standing lattice towers (without added ancillaries such as antennas or lighting frames) (Standards Australia 1994):

$$n_1 \approx 1500w_a/h^2 \quad \text{(C26.9-14)}$$

where w_a is the average width of the structure in m and h is tower height. An alternative formula for lattice towers (with added ancillaries) (Wyatt 1984) is

$$n_1 = \left(\frac{L_N}{H}\right)^{2/3}\left(\frac{w_b}{H}\right)^{1/2} \quad \text{(C26.9-15)}$$

where w_b = tower base width and L_N = 270 m for square base towers, or 230 m for triangular base towers.

Structural Damping. Structural damping is a measure of energy dissipation in a vibrating structure that results in bringing the structure to a quiescent state. The damping is defined as the ratio of the energy dissipated in one oscillation cycle to the maximum amount of energy in the structure in that cycle. There are as many structural damping mechanisms as there are modes of converting mechanical energy into heat. The most important mechanisms are material damping and interfacial damping.

In engineering practice, the damping mechanism is often approximated as viscous damping because it leads to a linear equation of motion. This damping measure, in terms of the damping ratio, is usually assigned based on the construction material, for example, steel or concrete. The calculation of dynamic load effects requires damping ratio as an input. In wind applications, damping ratios of 1 percent and 2 percent are typically used in the United States for steel and concrete buildings at serviceability levels, respectively, while ISO (1997) suggests 1 percent and 1.5 percent for steel and concrete, respectively. Damping values for steel support structures for signs, chimneys, and towers may be much lower than buildings and may fall in the range of 0.15 percent to 0.5 percent. Damping values of special structures like steel stacks can be as low as 0.2 percent to 0.6 percent and 0.3 percent to 1.0 percent for unlined and lined steel chimneys, respectively (ASME 1992 and CICIND 1999). These values may provide some guidance for design. Damping levels used in wind load applications are smaller than the 5 percent damping ratios common in seismic applications because buildings subjected to wind loads respond essentially elastically whereas buildings subjected to design level earthquakes respond inelastically at higher damping levels.

Because the level of structural response in the serviceability and survivability states is different, the