PRESSURE FLUCTUATIONS ON BUILDINGS

FLUCTUATIONS DU PRESSION SUR BÂTIMENTS

by
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SUMMARY

Wind loading, with emphasis on the local pressure fluctuations, on a small scale building model in a thick turbulent boundary-layer wind tunnel was investigated. A striking similarity between the oncoming turbulent energy spectra and surface pressure-fluctuation spectra was consistently observed. This similar behavior suggests that the upstream turbulence plays a dominant role in producing the pressure fluctuations on the upwind face of a bluff body.

INTRODUCTION

The study of wind loading on buildings produced by strong turbulent winds is an integral element of safe, functional and economical design. Lately, advances in architectural concepts and structural materials have spurred the design and construction of building with increasing slenderness and decreasing structural damping. Moreover, the use of thinner cladding and more extensive glass areas has increased in recent years. All of these factors yield structures vulnerable to damage by wind loading. Many failures of various exterior building elements clearly indicate the lack of an adequate evaluation of local wind loading.

The practical and reliable method for investigating the aerodynamic forces and moments on buildings induced by strong turbulent winds is through use of adequately scaled models in suitable large scale wind tunnels [1]. The wind-tunnel flow must be capable of simulating the atmospheric boundary layer over the surrounding topography and structures. The surrounding and upwind roughness, both natural and man-made, practically establish the fluctuating velocity field accompanying the mean wind. Consequently, a realistic study must include appropriate modeling of all these features. These requirements can be met by using a long wind-tunnel test section capable of developing a thick turbulent boundary layer. Furthermore, the wind-tunnel cross section should be large enough to accommodate models scaled from 1:200 to 1:500 which can be fully immersed in the boundary layer with a blockage effect smaller than 5%. In addition, a sectionally adjustable ceiling is desirable to control the downwind pressure gradient. Such facilities have been designed and constructed at the Fluid Dynamics and Diffusion Laboratory of Colorado State University. A closed-circuit meteorological wind tunnel [2] capable of simulating thermally stratified atmospheric boundary layers and another of open-circuit type are shown in Figs. 1 and 2, respectively.

Geometric, kinematic and dynamic similarity between the prototype and modeled flow are necessary [3,4]. The similarity requirements are usually represented in

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of an oscillogram and a frequency spectrum record of the fluctuating pressure are displayed in Fig. 4. Most of the pressure-fluctuation energy is concentrated at low frequencies. A dominant frequency at about 17 Hz is observed.

The one-dimensional total energy for any random fluctuating quantity (under the ergodic assumption) is

$$\overline{\beta'^2} = \overline{\beta'^2} \int_0^\infty F_{\beta'}(n)\, dn \quad , \tag{1}$$

where β' denotes the fluctuating quantity, i.e., fluctuating velocity u' or fluctuating pressure p'. The fraction of normalized energy within the frequency interval n to $n + dn$, i.e., the frequency density function, is designated by $F_{\beta'}(n)$. In terms of the mean-square output signal of a wave analyzer, the fraction of energy at each frequency is

$$F_{\beta'}(n) = \frac{1}{B_w} \overline{e^2(n,B_w)} \quad , \tag{2}$$

where $\overline{e^2(n,B_W)}$ is the square of the rms output at any selected frequency, B_W is the filter bandwidth and n is the central frequency within the bandwidth. The frequency spectra of both fluctuating velocity and pressure was monitored at 8 stations in the vertical direction over a distance of 14 in. They were recorded at stations located at the same height or within less than 20% difference. The turbulence spectra for the longitudinal velocity component was measured by means of a single hot-wire located 1 ft upstream of the model building.

The turbulence-energy and wall pressure-fluctuation-energy spectra are shown in Figs. 5 and 6. Generally, both power spectra exhibit a similar behavior. Most of the turbulence energy and pressure-fluctuation energy are concentrated, at all stations, within the same low-frequency range. The latter stretches up to about 15 to 20 Hz depending upon the particular spacial position. Furthermore, at relatively high frequencies both spectra reveal a - 5/3 power variation characteristic of the inertial subrange. It is important to remark that at $z = 0.145$, i.e., near the tower base at $z^* = 3.6$ in, this similarity breaks down. At this position the pressure-fluctuation spectrum differs drastically from the turbulence energy distribution. This discrepancy is caused by a wake from one of the upwind buildings sweeping across the station where the turbulence spectrum was measured but not impinging upon the model. Since the natural frequency of the structure is about 200 Hz the pressure spectra within the range 200 Hz ± 20% contains additional input from the model vibrational motion. No large shift of energy within the low frequencies was observed. The turbulence energy does decrease slightly with height but a definite trend was not observed. However, most of the energy is concentrated within the same frequency range. At high frequencies the slope does not change with height. In general, a similar variation is observed for the pressure spectrum. At low frequencies, where most of the pressure "energy" is concentrated, the intensity changes randomly with height. On the other hand, in the so-called inertial subrange it is practically the same and the - 5/3 power law is approximately satisfied at all heights except near the base.

The important aspect of these results is the general congruence between the turbulence-energy and the surface pressure-fluctuations spectra. It can be inferred that the latter are produced primarily by the boundary-layer turbulence. Furthermore, it is suspected that they do correlate directly since it appears that they do differ by some constant of proportionality. Systematic research to determine the relationship between the energy spectra for a variety of building shapes is needed.

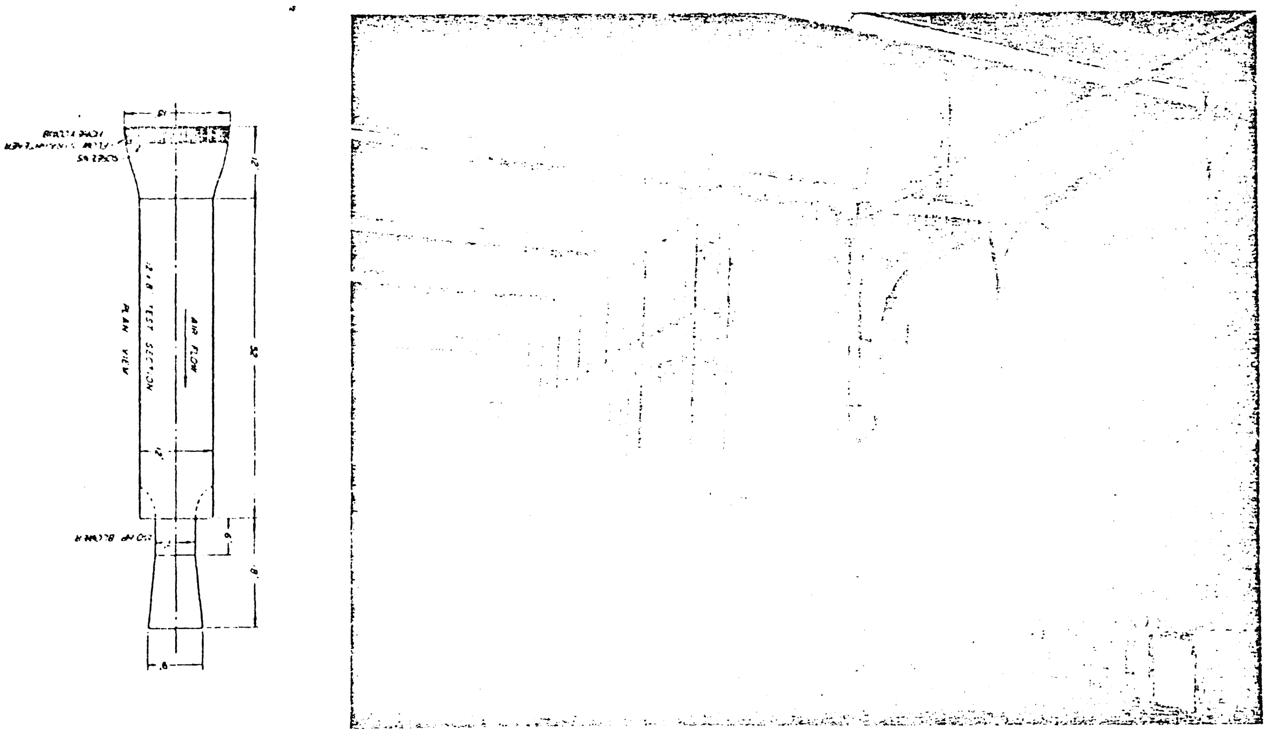

Fig. 2. Overall View of the Fluid Dynamics and Diffusion Laboratory Open-Circuit Environmental Wind Tunnel.

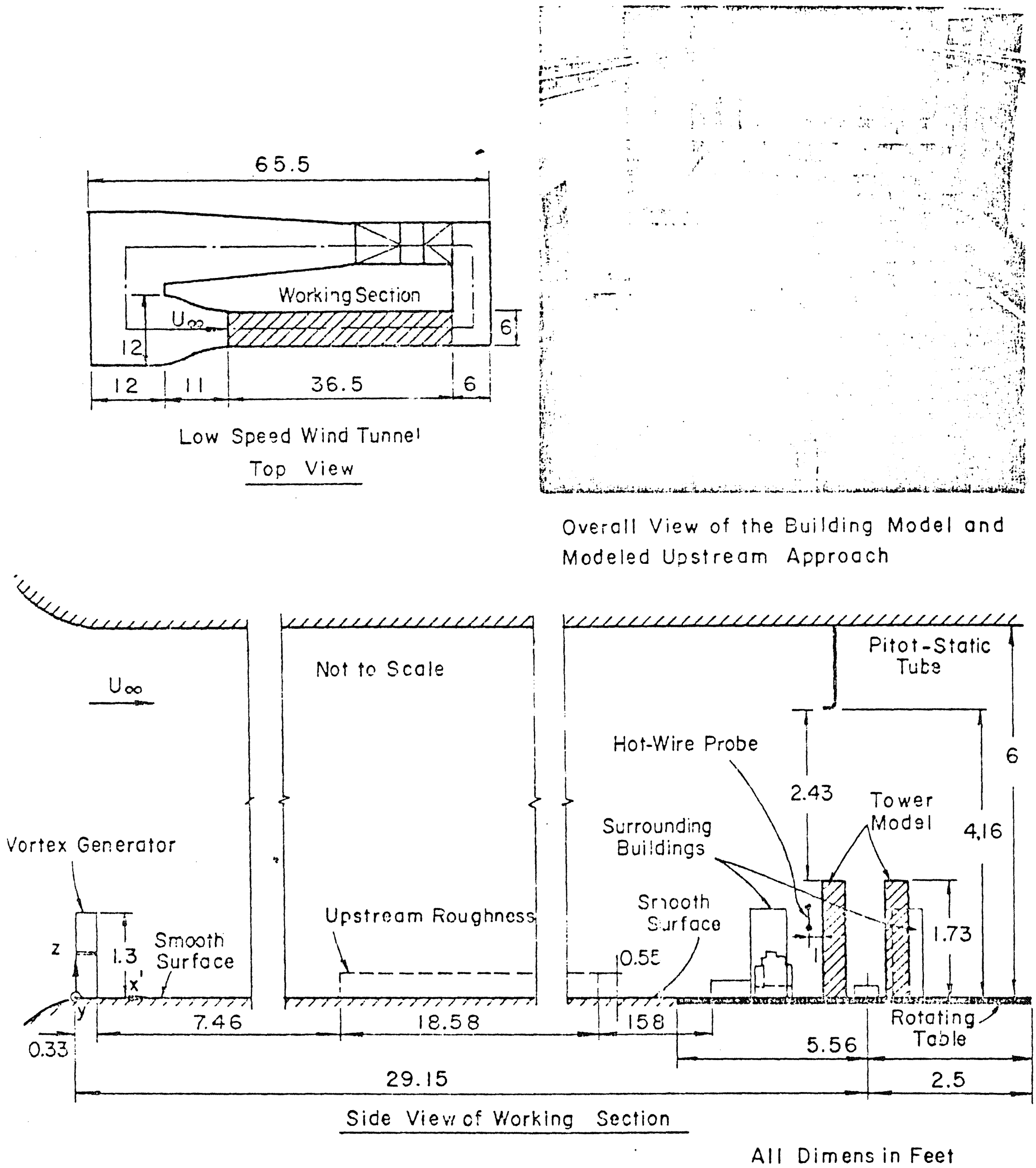

Fig. 3. Sketch and Overall View of the Building Model and Upstream Approach Experimental Arrangement, and of the Low-Speed Wind Tunnel.

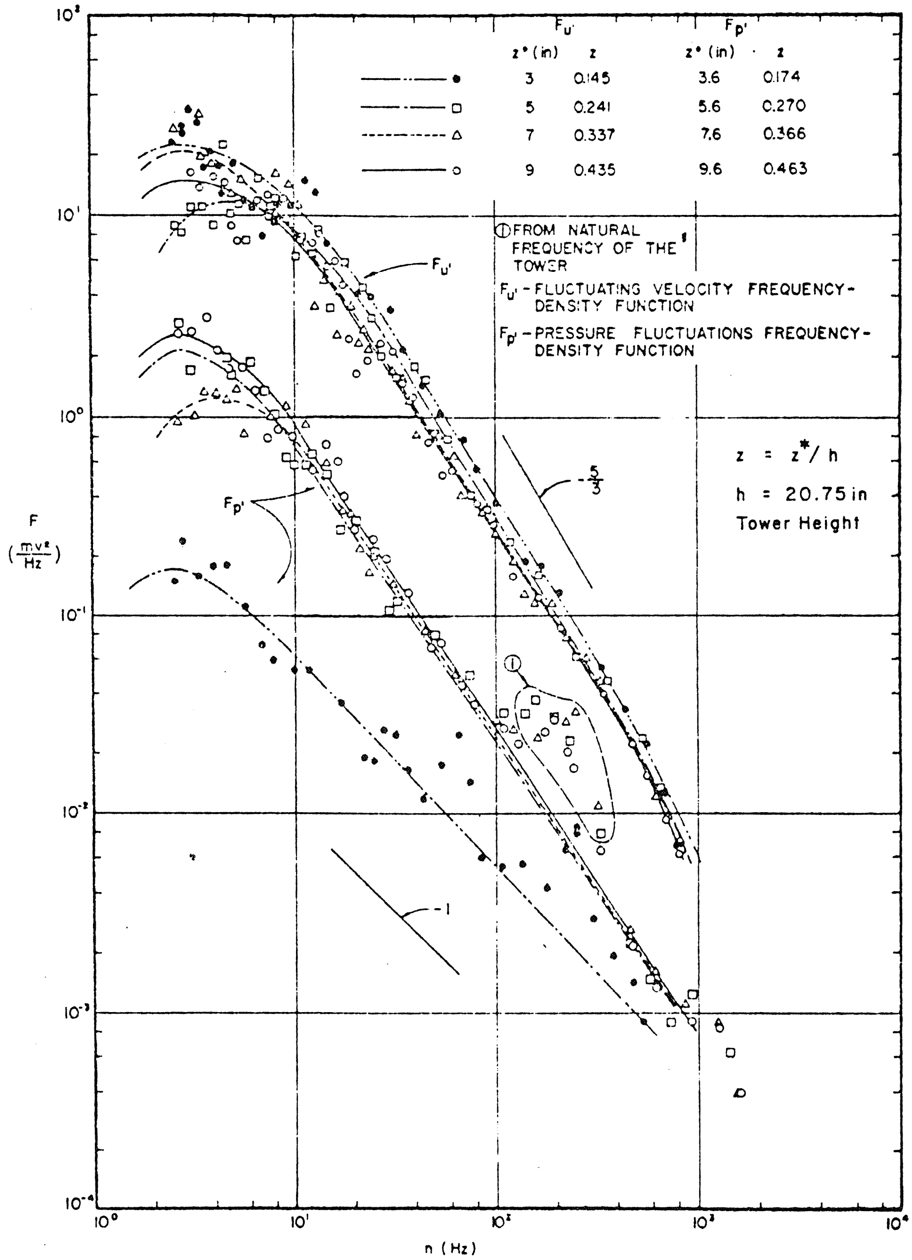

Fig. 5. Turbulent-Energy and Pressure-Fluctuation Spectra on the Upwind Face.