Velocity/pressure cross-correlations on the Texas Tech Building

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Introduction

Wind loads on low rise buildings are usually determined by a quasi-steady approach which attributes all fluctuations in pressure to fluctuations in velocity. In such circumstances, the cross-correlation of velocity and pressure would be unity and the peak pressure or load occurs when the velocity has a maximum.

This approach fails where there is significant interference to the flow by the body, such as in separated flow regions where pressure fluctuations are now influenced by building generated turbulence. In the time domain, the cross-correlation of velocity and pressure is reduced from unity. While in the frequency domain, it has been observed that on the windward face the high frequency pressure fluctuations are attenuated faster than the high frequency velocity frequencies [1]. On separated flow faces, the frequency content of the pressures is markedly different to that of the approach velocity due to the building generated turbulence.

The purpose of this paper is to examine the performance of the quasi-steady theory as it applies to velocity/pressure cross-correlations on full scale measurements obtained from the Texas Tech Building.

Experimental details

The Texas Tech Wind Engineering Field Research Laboratory has been fully described elsewhere [2,3] and only brief details relevant to this experimental data are presented here. The Building is 9.1 × 13.7 × 4.0m high and surrounded by flat, generally featureless terrain for at least 900m. The unique feature of the facility is the ability to rotate the building to afford a measure of control over the angle of attack.

Pressure measurements were obtained using Validyne and Omega(Honeywell) pressure transducers, with system response greater than 20Hz. After low pass filtering at 10 and 8Hz respectively, the pressure signals were sampled at 40Hz. This is the MODE 15 data acquisition configuration.

Velocity measurements were obtained from a Gill 3-cup anemometer mounted at 4m height on a meteorological tower located 46m to the west (azimuth 280°) of the building centre. The anemometer has a distance constant of 2.7m. Wind directions were measured using a Gill microvane, delay constant of 1.1m, mounted beside the anemometer. Both wind speed and direction were sampled at 10Hz.

In order to obtain cross correlations of velocity and pressure it was necessary to identify data records with a wind azimuth passing through the meteorological tower and onto the building. Three such records in the MODE 15 data have been identified and the data summaries are presented in Table 1. Runs 24 and 25 have the wind blowing almost directly from the tower onto the building while run 86 is some 7° off.

TABLE 1. Data Summary

Run	Date	θ^a (deg)	V_4 (m/s)	G	α_4^b (deg)	I_u	I_v	^xL_u (m)
24	14/4/91	294	10.1	1.57	279	0.17	0.24	89
25	14/4/91	295	9.7	1.59	278	0.19	0.23	83
86	28/4/91	228	9.7	1.61	273	0.21	0.20	159

[a] angle of attack [b] wind azimuth at 4m height

In Table 1 above, the longitudinal length scales (^xL_u) at 4m height were estimated from the product of the integral time scale of the auto-correlation of fluctuating velocity and the mean velocity.

Standard IMSL FFT routines were employed to obtain, auto- and cross-correlations as well as auto- and cross-spectra of the velocity and pressure time histories. Decimation of the pressure time histories was required because they were sampled at four times the rate of the velocity signal. The greatest magnitude in cross-correlation coefficient (r_{vp}) occurred at time delays appropriate to the time taken for the flow to travel the 46m from the tower to the building at the mean velocity.

Results and discussion

Figure 1 shows the building and angle of attack geometry. In Figure 2, the mean, standard deviation and minimum pressure coefficients across the roof centreline for an angle of attack of 294° are plotted. The mean reattachment point occurs at approximately $x/H = 1$.

In Figure 3, mean and pseudo-static pressure coefficients are compared with the provisions of AS1170.2-1989 incorporating local pressure factors and area reduction factors. The pseudo-static pressure coefficients are defined as $C\check{p}/G^2$, ie. the minimum pressure coefficient divided by the gust factor (peak velocity/mean velocity) squared. If the quasi-steady theory applied in this region the pseudo-static pressure coefficients would be equal to the mean pressure coefficients. It is noted that the AS1170.2-1989 values are in reasonable agreement with the mean pressure distribution, however, the pseudo-static pressure coefficients are always greater in magnitude. As the pseudo-static pressure coefficients better estimate the peak pressure distribution using the quasi-steady approach, they are to be preferred for codification purposes.

Figure 4 shows the cross-correlation (r_{vp}) between upstream velocity and roof pressures. Both point and area-averaged roof pressures over the strip about the roof centreline have been used. The fluctuating area-averaged pressure has been obtained from the point pressures weighted according to their tributory area. The cross-correlation is weakest ($|r_{vp}| < 0.3$) around reattachment ($x/H=1$), with stronger correlation at the leading and trailing edges. This distribution is to be expected as the flow is highly disturbed around the fluctuating reattachment point, while the pressures adjacent to the leading edge separation line will relate quite well to the turbulence in the approach flow.

The pressure fluctuations under the separation bubble are much more significant than those over the remainder of the roof (refer to Cprms in Figure 2). They thus dominate the area-averaged pressure producing a relatively high cross-correlation with velocity of $|r_{vp}| > 0.6$ for both runs 24 and 25.

Run 86 has a quatering wind approaching the heavily instrumented corner region of the building. The conical vortices formed along the leading edges cause highly disturbed flow and yet similar observations to those for runs 24 and 25 can be made. This is particularly so for the area-averaged pressures at the corner where $|r_{vp}| > 0.7$.

Conclusions

Although the quasi-steady theory is invalidated in flow separation regions, significantly high cross-correlations have been observed between upstream velocity fluctuations and,

(a) point pressures adjacent to the separation line,
(b) area-averaged pressures over substantial areas of the roof.

References

1. H. Kawai, Pressure fluctuations on square prisms - applicability of strip and quasi-steady theories, J. Wind Eng. Ind. Aerodyn. 13(1983) 197-208.

2. M.L. Levitan and K.C. Mehta, Texas Tech field experiments for wind loads part 1: building and pressure measuring system, 8th ICWE, London, Canada, July 1991.

3. M.L. Levitan and K.C. Mehta, Texas Tech field experiments for wind loads part 2: meteorological instrumentation and terrain parameters, 8th ICWE, London, Canada, July 1991.

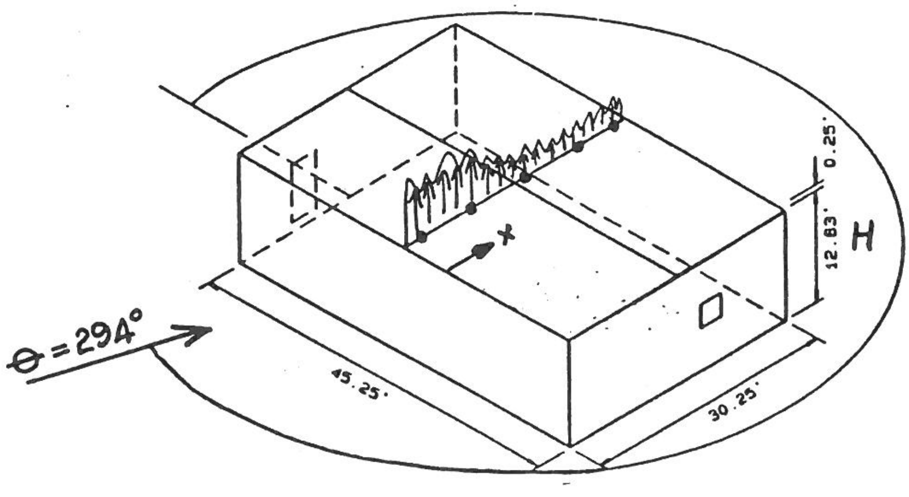

Figure 1. Building and angle of attack geometry.

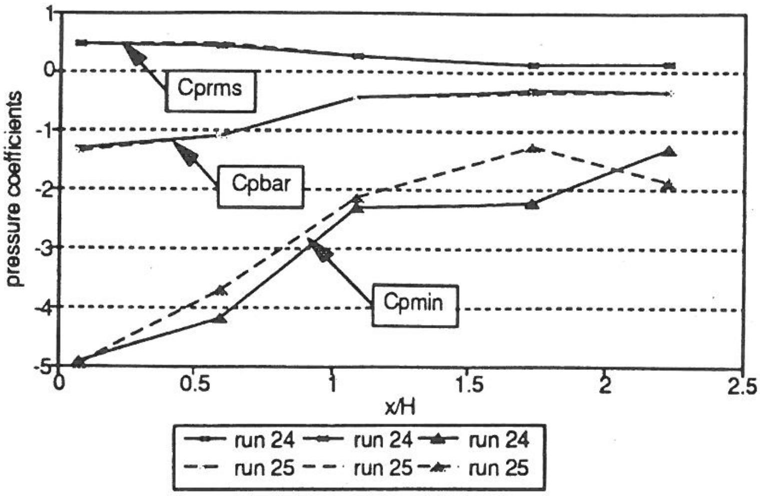

Figure 2. Pressure coefficients for $\theta = 294^\circ$

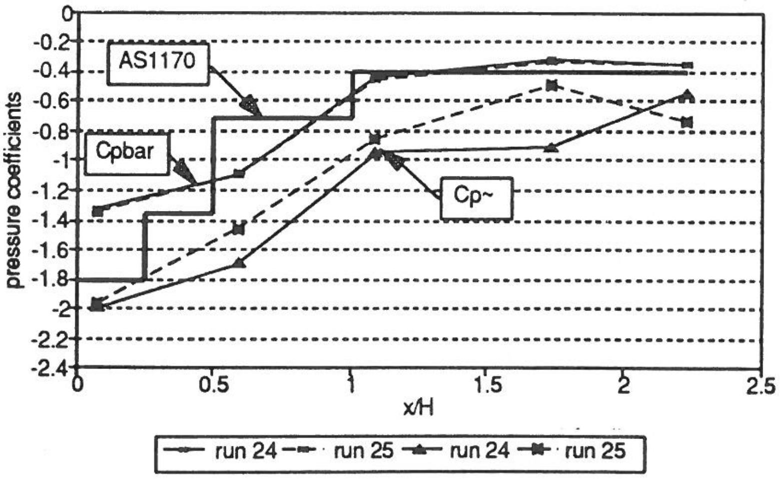

Figure 3. Comparison of mean and pseudo-static pressure coefficients with AS1170.2-1989.

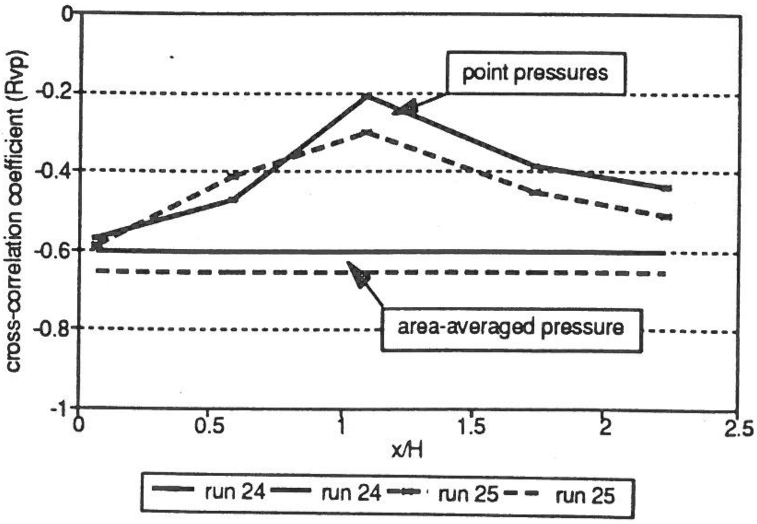

Figure 4. Velocity/pressure cross-correlations for $\theta = 294^\circ$.