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HIGH REYNOLDS NUMBER WIND TUNNEL MEASUREMENTS OF PRESSURES ON A CURVED ROOF BUILDING

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ABSTRACT

Mean and root-mean-square fluctuating pressure coefficients have been obtained from a large model of a curved roof building in a simulated atmospheric boundary-layer flow in a wind tunnel. The measurements were carried out at a relatively high Reynolds number (based on the model height) of 7 x 10^5.

A comparison with computations based on the k-ε model of turbulence shows reasonable agreement in regions where the pressures might have been expected to be Reynolds number-sensitive, but less good agreement near regions of separating-reattaching flow (i.e. at sharp leading edges), where the turbulence model has deficiencies.

INTRODUCTION

Wind pressures on buildings with curved or arched roofs are dependent on the mean position of separation of the flow over the roof, which, in turn, may depend on Reynolds number as well as the upwind turbulence and velocity profile characteristics of the atmospheric boundary layer. The possible Reynolds number dependency is a problem when carrying out wind-tunnel tests to determine wind pressures as, at the usual geometric scaling ratios and tunnel speeds, the model Reynolds number is typically three orders of magnitude below that for full scale.

In this paper, large-scale model studies of a shape representative of a typical curved roof industrial building are described. The paper will describe the flow characteristics, and the mean and fluctuating pressures on the model for five different wind directions. The main purpose of the work was to compare the measured mean pressure coefficients with values obtained by numerical solutions, based on solutions of the mean flow equations with a k-ε model of turbulence, described by Holmes and Paterson (1992).

EXPERIMENTAL METHODS

Atmospheric Boundary-layer Modelling

The tests were carried out in the new large boundary-layer wind tunnel at Monash University with a 5 m high by 6 m wide working section. A simulated strong wind atmospheric boundary layer, with a roughness length equal to about 1.2 mm, was generated using a system of spires, a 600 mm high barrier and floor roughness.

Model Building

The model building was 2.5 m x 2.5 m in plan dimensions, and 0.725 m high to the apex; the roof had a rise/span ratio of 0.20. The ratio of wall height to rise was 0.45. The Reynolds number based on the height to the top of the model was about 7 x 10^5. The Jensen number (Cook 1986), representing the ratio of building height to boundary-layer roughness length, was about 600; this value compares with the value of 500 used in the computations of Holmes and Paterson (1992).

Pressure Measurement Techniques

Pressure measurement was carried out by connecting measurement points on the roof and walls of the model by flexible PVC tubing to 'Scanivalve' pressure scanning devices containing Setra 237 pressure transducers. The tubing was 1.5 mm internal diameter, and had a total length of 2.3 m. A length of restrictor tubing of internal diameter 0.5 mm and length 35 mm was inserted in the line 0.2 m from the Scanivalve. The amplitude frequency response is within 15% of unity up to about 30 Hz, and the phase response is close to linear over this range. These response characteristics are adequate for measurement of mean and r.m.s. fluctuating pressures at the model scale and wind speed of these experiments but are inadequate for accurate measurement of peak pressures. Peak pressures on buildings are often 'spiky' and are significantly influenced by high frequencies which contribute little to the total variance of fluctuating pressures. Only mean and r.m.s. pressures are presented in this paper.

The measured pressure differences were adjusted to the static pressure in the flow at the position of the model, and were converted to pressure coefficients by dividing by the dynamic pressure at the top of the model. No corrections for wind tunnel blockage were made to the data.

RESULTS

Figures 1 and 2 show the recorded mean and r.m.s. pressure coefficients for two wind directions: perpendicular and parallel to the axis of the building. Data was also obtained for several oblique wind directions.

These distributions show the following characteristics:

(a) Maximum mean pressure coefficients occur near the top of the centre of the windward wall.

(b) Maximum negative mean pressures occur near the region of flow separation on the roof or side walls. In the case of Fig. 1, the highest negative values occur on the roof just upwind of the apex of the roof. However, mean flow separation probably occurs downwind of the apex, where there is a rapid pressure recovery to the value characteristic of the leeward part of the building. At sharp leading edges, i.e. on the side walls or on the roof in Fig. 2, the highest negative values are found immediately downwind of the edge.

(c) Mean pressure coefficients in the reattached flow regions and on the leeward wall have values that are in the range −0.05 to −0.20.

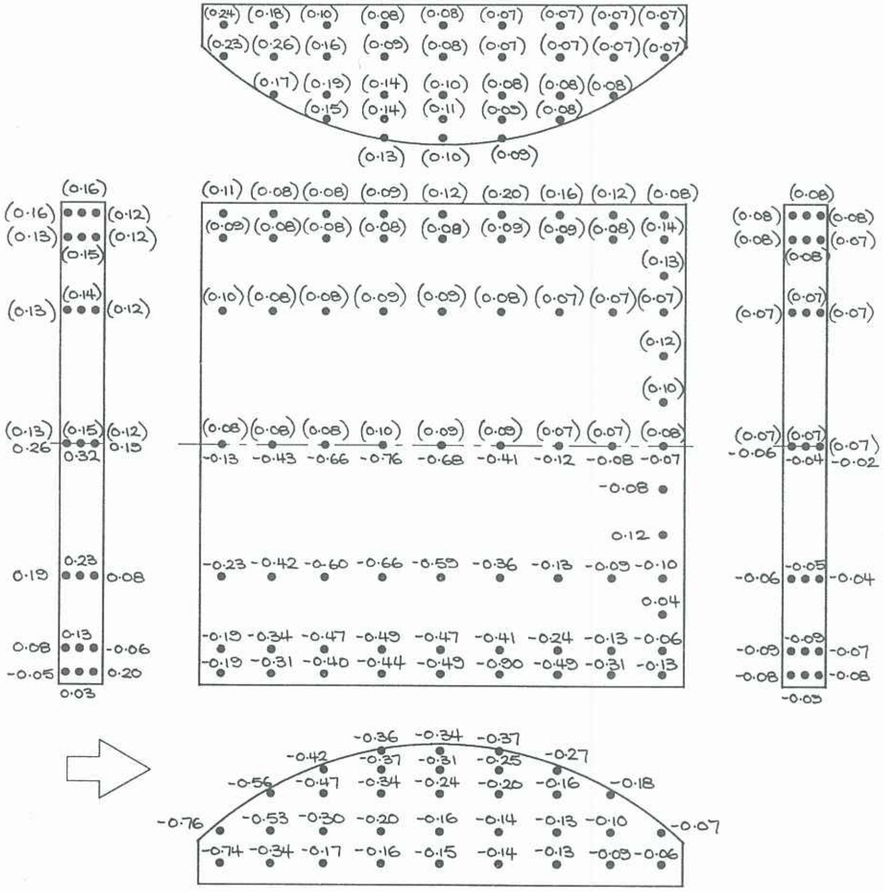

Figure 1. Mean and r.m.s. pressure coefficients for wind direction normal to the arch axis (values in parentheses are r.m.s. values).

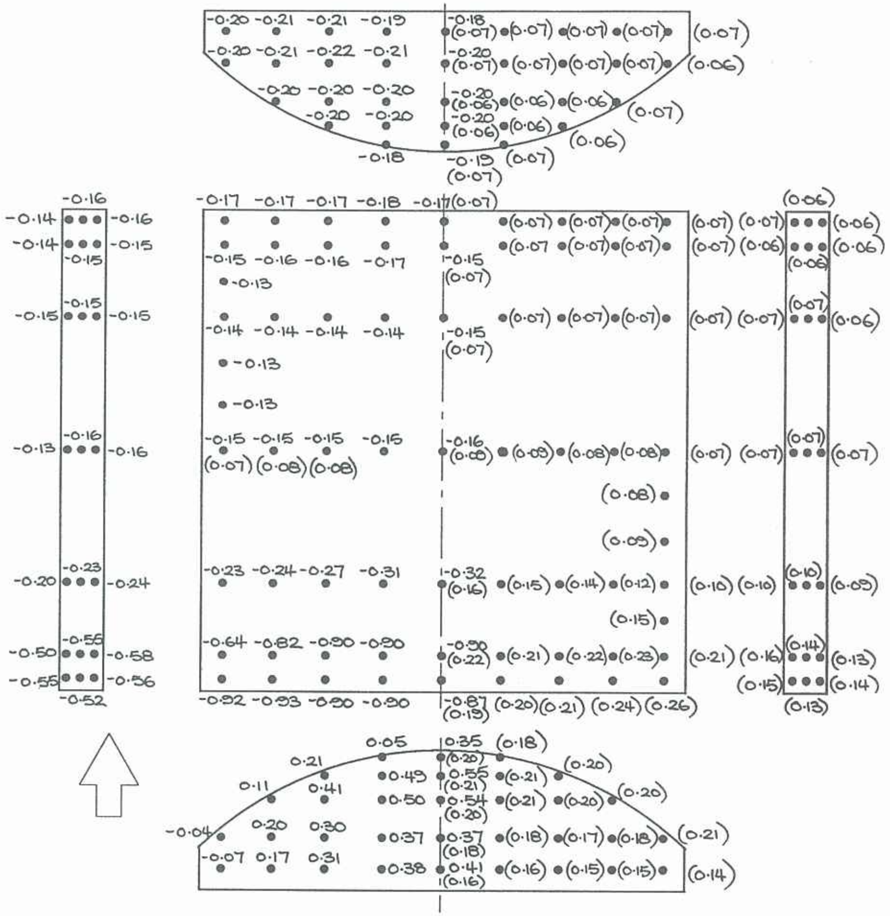

Figure 2. Mean and r.m.s. pressure coefficients for wind direction parallel to the arch axis (values in parentheses are r.m.s. values).

(d) The r.m.s. pressures in Fig. 1 are highest on the side walls, immediately behind the corner separation. For the wind direction parallel to the building axis (Fig. 2), high r.m.s. pressures also occur on the windward wall and on the leading edge of the roof. For the wind direction in Fig. 1, i.e. 'over the arch', it is interesting that high magnitude negative pressures near the apex of the roof are not associated with high r.m.s. pressures, i.e. the 'quasi-steady' assumption, which predicts proportionality between the magnitude of the mean pressure coefficient and the r.m.s. pressure coefficient, is not well satisfied in this region.

(e) For the mean pressures for the oblique wind directions, there is a zone of very high magnitude negative pressure at the centre of the windward end of the arch. However, due to the slope of the roof, the pressure is much higher (less negative) towards the windward end of the roof, and is positive near the windward corner. High r.m.s. pressures are associated with the high negative pressure zone.

COMPARISON WITH COMPUTATIONS

In this section, a comparison will be made with computed pressures for the same shape described by Holmes and Paterson (1992).

A general indication of the agreement between the computed and measured mean pressure coefficients can be obtained from Fig. 3. In this figure, values from equivalent points for three wind directions are plotted against each other, and a straight line of best fit obtained by linear regression added. The slope of this line is slightly greater than unity and the line passes close to the (0,0) point, indicating generally favourable agreement. However, the correlation coefficient of 0.89 is not as high as might be hoped. The differences between the measured and computed values are significant for certain areas of the building, for particular wind directions, as is apparent in Figs 4–6.

Figure 4 shows the comparison for the windward wall pressures. The computed values are generally slightly more positive. For the wind directions normal to the walls, the computed pressures appear to be more uniformly distributed, perhaps due to the inadequate modelling of large-scale lateral turbulence (wind direction changes) in the computer model.

In Fig. 5 measured and computed pressures are compared for the roof for the wind direction normal to the arch axis, i.e. the direction for which Reynolds number effects might be expected to be most noticeable. Agreement is generally favourable although the scatter above and below the line of equality is considerable.

In Fig. 6, the pressures are compared for the wind direction parallel to the building axis. At the leading edge of the roof, there are significant differences. The computed negative values are significantly higher in magnitude at the pressure taps immediately adjacent to the leading edge, but are lower in magnitude than the measured values in the next row of taps.

This is consistent with other applications of the k–ε turbulence model to bluff body flows, and is caused by the overestimation of turbulence energy in the windward corner region by this model, as discussed by Murakami (1992).

CONCLUSIONS

Mean and root-mean-square fluctuating pressure coefficients have been obtained from a large model of a curved roof building in a simulated atmospheric boundary layer flow in a wind tunnel. The measurements were carried out at a relatively high Reynolds number (based on the model height) of 7 x 10^5. The data is available as a reference for wind-tunnel tests at lower Reynolds numbers, and for computational studies.

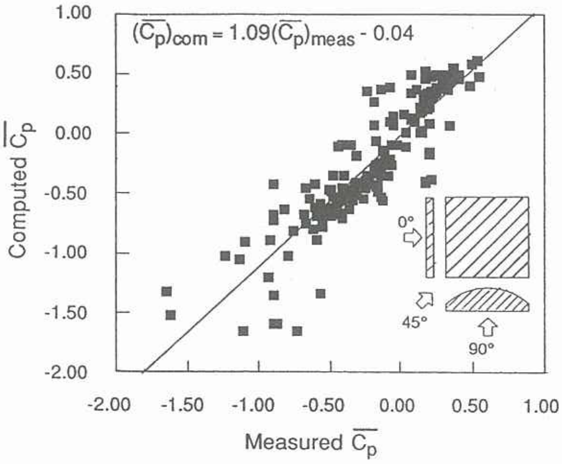

Figure 3. Comparison between all mean pressure coefficients for three wind directions.

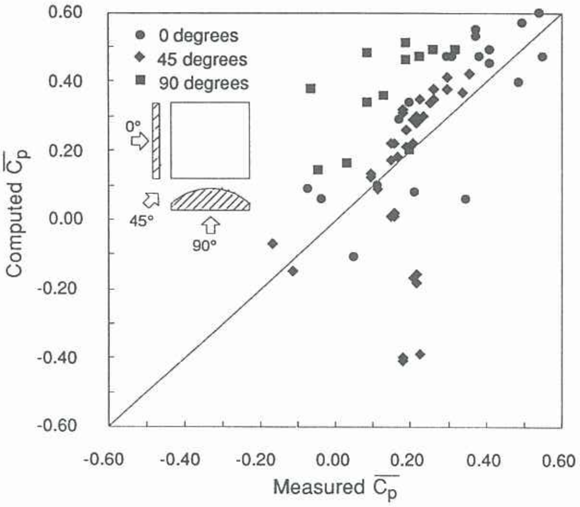

Figure 4. Comparison of windward wall pressures for three wind directions.

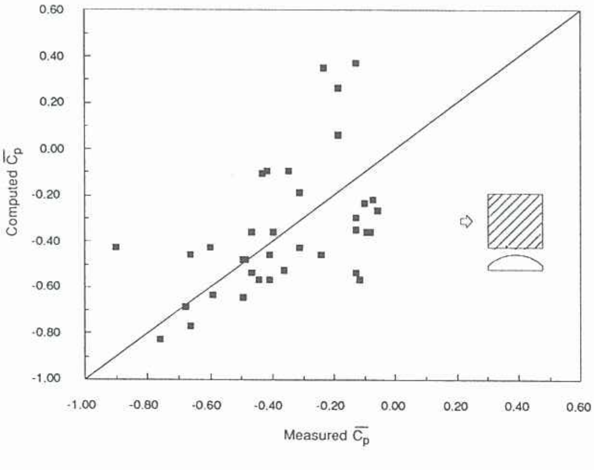

Figure 5. Comparison of roof pressures – wind normal to arch axis.

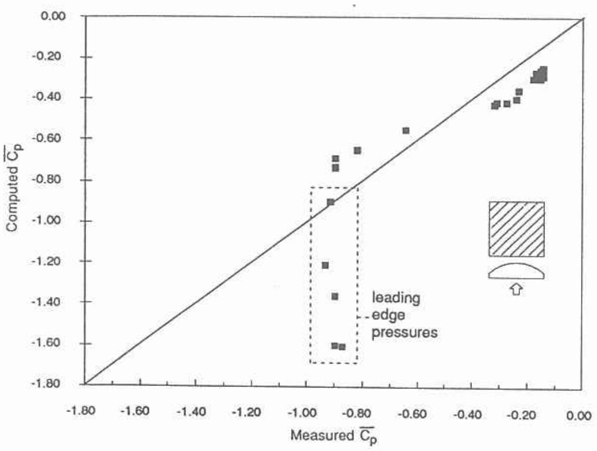

Figure 6. Comparison of roof pressures – wind parallel to arch axis.

A comparison with computations based on the k-ε model of turbulence shows reasonable agreement in regions where the pressures might have been expected to be Reynolds number-sensitive, but less good agreement near regions of separating-reattaching flow (i.e. at sharp leading edges), where the turbulence model has deficiencies.

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REFERENCES

COOK, NJ (1986) Jensen number – a proposal. Letter to the Editor, J. Wind Engg & Ind. Aerodyn., 22, 95–96.

HOLMES, JD and PATERSON, DA (1992) Mean wind pressures on arched-roof buildings by computation. 2nd Int. Colloq. on Bluff-body Aerodynamics and Applications, Melbourne. Proceedings to be published.

MURAKAMI, S (1992) Comparison of various turbulence models applied to a bluff body. 1st Int. Symp. on Computational Wind Engg, Tokyo. Proceedings to be published.