Eighth Australasian Fluid Mechanics
Conference, University of Newcastle,
N.S.W., 28 November/2 December 1983.

COMPARATIVE STUDIES OF WIND PRESSURES ON A LOW-RISE BUILDING

J.D. HOLMES

DIVISION OF BUILDING RESEARCH

CSIRO, HIGHETT, VIC. 3190 AUSTRALIA

SUMMARY The Aylesbury house was a full-scale experimental building, of variable pitch roof, on which wind pressure measurements were obtained by the Building Research Establishment (UK) between 1972 and 1974. Recently an international experiment was set up in which several identical models of the prototype building, at a scale of 1/100, are being circulated to participating laboratories for wind tunnel testing. Some measurements, carried out at CSIRO, from one of the circulating models are presented and compared with the full scale data.

1. INTRODUCTION

During the early period of development of the boundary layer wind tunnel (the late 1960s and early 1970s), great emphasis was placed on their use for the determination of the wind induced response of major structures such as long span bridges, tall buildings and flexible towers. The more mundane low-rise building received only cursory attention until the mid-1970s. Since that time there has been a resurgence of interest in the more accurate determination of wind loads on low-rise buildings, both by full scale measurement and by use of the boundary layer wind tunnel. This has been stimulated partly by the occurrence of some notable windstorms causing large scale damage to low-rise structures (e.g. Cyclones Althea and Tracy in Australia), and partly by the desire of structural loading code committees to improve the specification of wind loads for such structures.

The validation of wind tunnel measurements with full scale studies is important for both low-rise and larger structures. In the case of low-rise buildings, the Aylesbury building operated by the Building Research Establishment (UK) between 1972 and 1974 (Eaton and Mayne 1975, Eaton et al. 1975), has become a test case for wind tunnel comparisons (Figure 1).

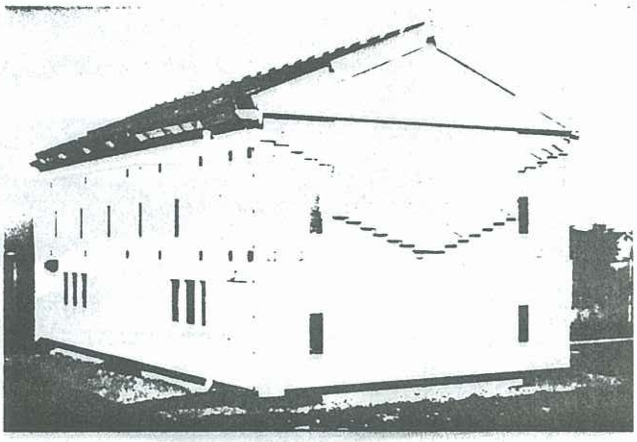


Figure 1 The Aylesbury house (roof pitch 22 1/2°)

At the 6th Conference in this series, some initial mean (time averaged) pressure measurements on models of the Aylesbury building, carried out at James Cook University were described by Holmes and Best (1977). Further measurements at James Cook, including fluctuating pressures, were later described by the same authors (Holmes and Best 1978). Concurrently with these tests, wind tunnel tests on the Aylesbury building were in progress at the University of Western Ontario (Apperley et al. 1978) and at Oxford University (Greenway and Wood 1977-8). Later studies were made at Virginia Polytechnic and State University (Tieleman et al. 1981a,b).

These tests, which covered a range of geometric scaling ratios from 1/500 to 1/25, were carried out in boundary layer wind models of varying quality, of the site. Also, information on the detailed geometry of the prototype building was not available to these laboratories at the time. The pressure measuring systems used by the laboratories varied in their frequency response characteristics, thus affecting their ability to measure fluctuating and peak pressures. Despite the above differences, reasonable agreement was achieved between the mean pressure measurements on the walls of the Aylesbury models and the full scale building, for various wind directions, when the differences in mean velocity profile and static pressure reference were taken into account. Not surprisingly, poorer agreement was found for the fluctuating pressures on the walls, and for the mean and fluctuating roof pressures, which are more sensitive to geometrical details and to the upwind turbulence conditions.

A review of the Aylesbury house tests up to 1981 has been given by Holmes (1982).

In an attempt to explain some of the differences previously described and also to provide benchmark data for newcomers to the field of wind tunnel testing of low-rise buildings, an International Aylesbury Collaborative Experiment (IACE) was set up in late 1981 and early 1982. The Experiment 'seeks to improve the assessment of wind-induced loads on low-rise buildings through model scale tests by resolving any differences between the various experimental techniques in current use, and to assess the uncertainties inherent in measurement and modelling. The use of the BRE Aylesbury experimental building as a prototype enables this experiment to be calibrated against full-scale data.' Identical models of the Aylesbury building (at a geometric scale of 1/100) are being circulated to participating laboratories. Participants are required to make their own models of the surrounding site at the scale of 1/100. An extensive program of wind flow and pressure measurements has been specified.

This paper describes some of the measurements on the Aylesbury model carried out at CSIRO in late 1982. Space requirements limit the discussion to the main features of the results only (full details of the results are available in a CSIRO internal report).

2. EXPERIMENTAL

2.1 The Wind Tunnel and Site Simulation

The large low speed wind tunnel at the CSIRO, Highett, site is jointly operated by the Divisions of Energy Technology and Building Research. The boundary layer section, used for the present study, has cross-section dimensions of 2 m (width) x 1 m (height) and a usable length of about 10 m.

The turntable in the boundary layer section is 1.8 m in diameter, and a site model of the surroundings of the Aylesbury building was manufactured on a circular base of the same diameter. The site model was made from 'grass' sheeting and from hedges and trees used for model railways (HO scale). The hedges and trees were located in equivalent positions to those at the full scale location when the tests were carried out. The static pressure 'manhole' used in the full scale tests was represented by a pressure tapping on the model, and the position of the reference mast, from which wind speed measurements were obtained at the full scale Aylesbury site, was also located on the model. Figure 2 shows the building and site models, and the upwind terrain for one of the wind directions tested.

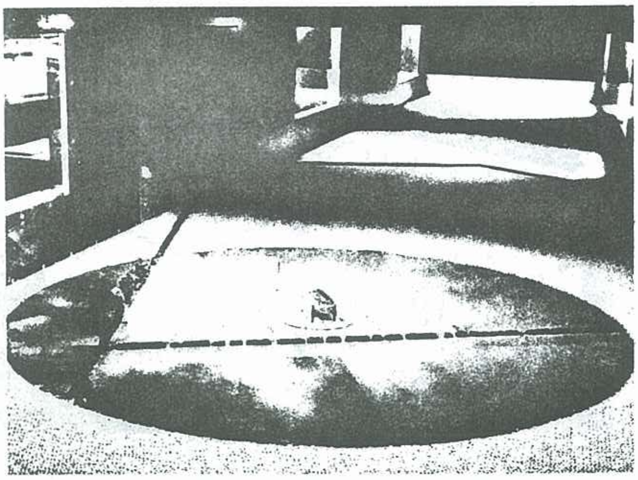


Figure 2 CSIRO wind tunnel and Aylesbury model (θ = 208°)

2.2 Atmospheric Boundary Layer Simulation

The basic elements in the simulation of the lower part of neutral atmospheric boundary layer, used at CSIRO, are a plain fence or barrier at the start of the 10 m long test section, followed by surface roughness appropriate to the terrain being simulated (in this case, carpet was used). This technique is described in another paper presented at this Conference (Holmes and Osonphasop 1983).

The velocity characteristics at the full scale Aylesbury site were found to be a function of the wind direction (Holmes 1982). For the westerly wind directions, the upwind terrain is found to be more aerodynamically rough than the southerly directions. This was taken account of in the model simulations in two ways - firstly by reproducing the upwind hedges and trees upwind of the site model using an expanded foam material, and secondly by increasing the height of the barrier for the westerly directions.

Figure 3 shows the mean velocity and turbulence intensity profiles for one of the four wind directions tested (wind direction θ is measured from the north-south axis of the building). The profiles were obtained at the position of the anemometer mast near the building in both full scale and in the wind tunnel. In the wind tunnel, the measurements were obtained by means of a linearised hot wire anemometer, with the sensor mounted vertically, thus responding to the instantaneous wind speed independent of direction in a similar way to the cup anemometers in full scale. Reasonable agreement of the profiles with the limited full scale data is seen, although there is a large dispersion in the range of measured full scale turbulence intensities. The full scale mean speed profiles are slightly steeper near the ground than in the wind tunnel.

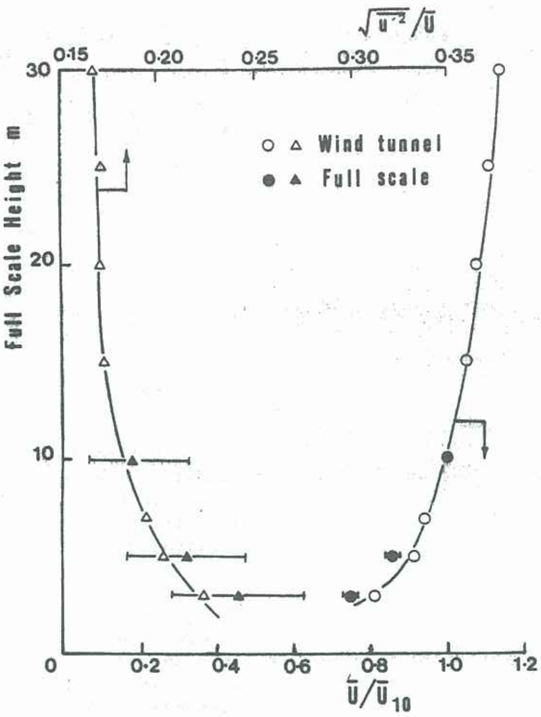


Figure 3 Mean speed and turbulence intensity profiles (θ = 208°)

3. PRESSURE MEASUREMENTS

The 1/100 scale model of the Aylesbury house was mounted at the centre of the wind tunnel turntable and site model. One of four different roofs with pitches of 5°, 10°, 15° or 22.5° was attached to the model for each test. The pressure taps on the model were connected by 400 mm long lengths of vinyl tubing, supplied with the model, to a 'Scanivalve' pressure scanner containing a Setra 237 pressure transducer. The lengths of tubing contained a small diameter brass 'restrictor' inserted halfway along, to attenuate the resonant peak in the frequency response curve. The frequency response of the tube-restrictor-Scanivalve-transducer system was measured at CSIRO using a sinusoidal pressure generator. The amplitude response was found to be within 10% of unity up to about 150 Hz; the phase response was close to linear up to the same frequency. These frequency response characteristics are adequate for measuring the mean and r.m.s. fluctuating pressures carried out in the present series of tests.

Tests at ten different combinations of wind direction and roof pitch were made. The space limitations restrict the discussion in this paper to the 22.5° pitch roof tests for the major directions.

Mean and root-mean-square fluctuating (r.m.s.) pressure coefficients were derived using the mean speed at a height of 10 m in full scale (100 mm in the wind tunnel), to determine the reference dynamic pressure. The reference static pressure was the static pressure from a pitot-static probe mounted in the relatively low turbulence region near the top of the test section. The mean pressure at the ground pressure tap on the site model was also recorded, enabling conversion of the mean pressure coefficients to that reference pressure, for comparison with the full scale data.

4. RESULTS AND DISCUSSION

The wind tunnel pressure coefficients were compared statistically with the corresponding full scale values using linear regression techniques. An example of one comparison graph showing the regression line is given in Figure 4. The wind direction for the data in Figure 4 was nearly normal to the ridge of the building (θ = 263°). Apart from two points on the leeward roof, the agreement achieved for this direction was very good, with a regression line slope near unity and intercept near zero; the correlation coefficient was also high. The good agreement for the mean pressures on the walls, for this case, is also shown in Figure 5(a). Note that the model pressure coefficients were corrected to the ground reference tap; the pressure coefficient at the ground with respect to the wind tunnel static pressure was +0.30. This large correction was essential to achieve agreement with full scale.

Unfortunately the agreement for the other three wind directions, and for the r.m.s. pressures was not so good. This can partly be explained by some anomalies in the full scale data such as those shown in Figure 5(b). Here, the full scale data from two different runs differ markedly. Except on the windward wall, the wind tunnel data agrees well with one of the full scale runs. In many cases, the r.m.s. pressures from the wind tunnel were consistently higher than in full scale; this has yet to be explained.

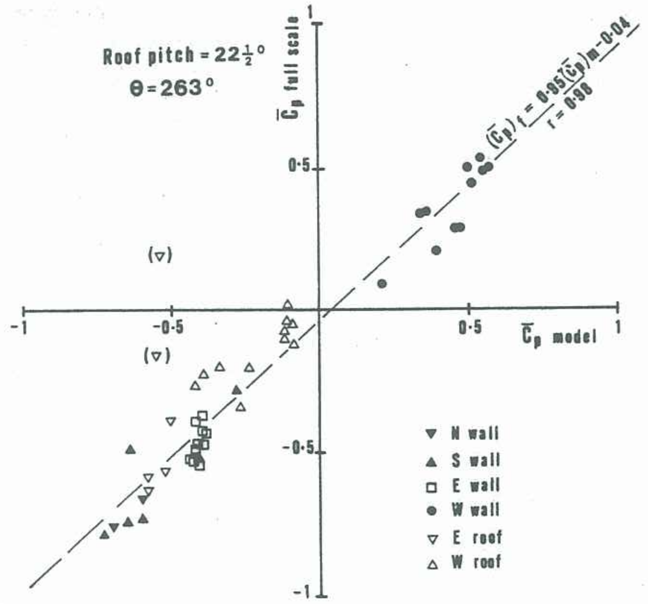


Figure 4 Model/full scale comparison of mean pressure coefficients

Figure 6 shows the importance of modelling details such as the guttering at the eaves of the roof. A simplified model, of the same scale, but without the guttering, and with a sharp ridge line instead of the hinge details as on the accurate model, was also used to measure roof pressures (this model had previously been tested at James Cook University). The detailed modelling had a significant effect on the pressures on the windward half of the roof, and improved greatly the agreement with the full scale data.

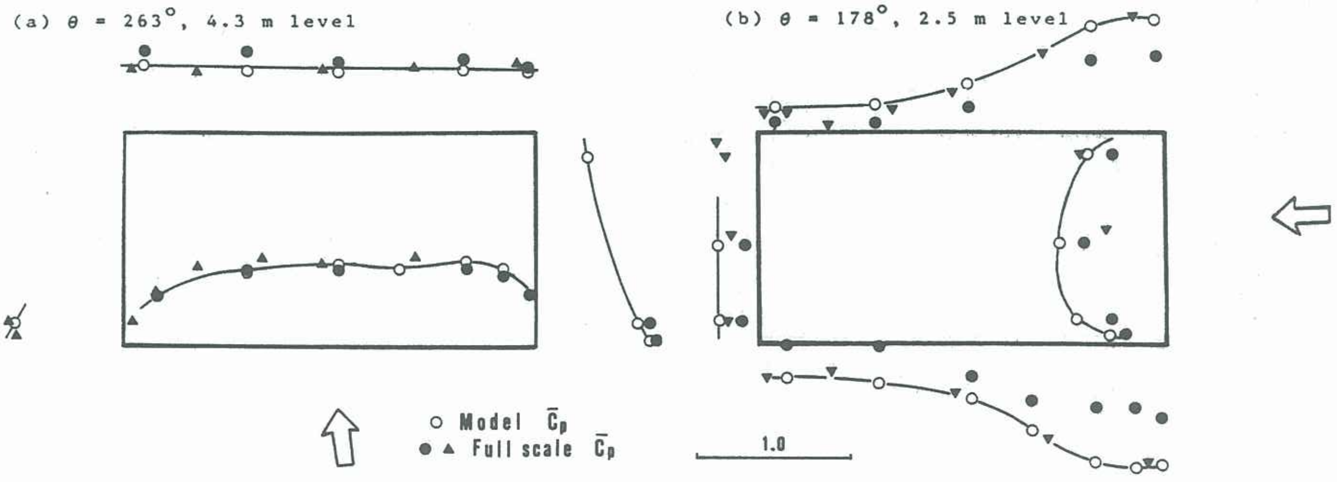
Figure 7 shows some examples of spectra of the pressure fluctuations on the accurate model. In Figure 7, the spectrum of the wind speed fluctuations obtained from the hot wire is also plotted. The reference curve is the standard Harris-von Karman spectral density curve with a peak wavelength appropriate to the rural terrain at Aylesbury (ESDU 1974). This curve falls about halfway between the two wind speed spectra measured at the Aylesbury site (Eaton and Mayne 1975). It has been included as a reference for all the other spectra. With respect to this curve, the wind tunnel spectrum is shifted slightly towards higher frequencies or lower wavelengths - an apparently unavoidable consequence of modelling at the relatively large scale of 1/100.

The pressure spectrum on the windward roof of the model is not dissimilar to the wind speed spectrum, although shifted towards higher frequencies. However, the spectra on the leeward roof and wall are quite different in shape. The double peak on the leeward end of the roof is to be noted; it is conjectured that this is associated with scales in the shear layer separating from the ridge and intermittently reattaching at the back of the leeward roof.

5. CONCLUSIONS

Excellent agreement between the model and full scale mean pressures was achieved for a wind direction nearly normal to the ridge of the building. Less good agreement was obtained for other directions, but this, at least partly, appears to be caused by anomalies in the full scale data.

The importance of modelling the detailed geometry near the separation points on the structure, and of using the same static reference pressure as in full scale, has been highlighted by the study.


(a) θ = 263°, 4.3 m level

(b) θ = 178°, 2.5 m level

Figure 5 Comparison of wall mean pressures

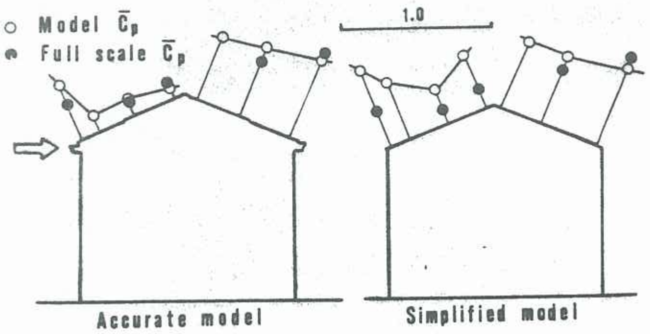


Figure 6 Effect of detailed modelling on roof pressures

The changing character and origin of the pressure fluctuations on different parts of a building such as this, are revealed by the spectra of the pressure fluctuations. There is considerable scope for a more detailed fundamental study of the phenomena involved.

6. REFERENCES

APPERLEY, L., SURRY, D., STATHOPOULOS, T. and DAVENPORT, A.G. (1979) Comparative Measurements of Wind Pressure on a Model of the Full-scale Experimental House at Aylesbury, England. J. Ind. Aerodyn., 4, 207-228.

EATON, K.J. and MAYNE, J.R. (1975) The Measurement of Wind Pressures on Two-Storey Houses at Aylesbury. J. Ind. Aerod., 1, 67-109.

EATON, K.J., MAYNE, J.R. and COOK, N.J. (1975) Wind Loads on Low-Rise Buildings - Effects of Roof Geometry. Proc. 4th Int. Conf. on Wind Effects on Buildings and Structures, London, Sep. 95-110. Cambridge Univ. Press.

ENGINEERING SCIENCES DATA UNIT (1974) Characteristics of Atmospheric Turbulence near the Ground - Part II: Single Point Data for Strong Winds (Neutral Atmosphere), Data Item 74031, October. Engineering Sciences Data Unit, London.

GREENWAY, M.E. and WOOD, C.J. (1977-8) Wind Pressure Measurements on the Aylesbury Low-Rise Housing Estate. Oxford University Engineering Laboratory. Reports OUEL 1213/77, 1271/78 and 1272/78.

HOLMES, J.D. (1982) Comparison of Model and Full Scale Tests of the Aylesbury House. Proc. Int. Workshop on Wind Tunnel Modelling for Civil Engineering Applications, Gaithersburg, April. 605-618. Cambridge University Press (ed. T.A. Reinhold).

HOLMES, J.D. and BEST, R.J. (1977) Wind Tunnel Measurements of Mean Pressures on House Models and Comparison with Full Scale Data. Proc. 6th Aust. Hyd. and Fluid Mech. Conf., Adelaide, December.

HOLMES, J.D. and BEST, R.J. (1978) Pressure Measurements on Wind Tunnel Models of the Aylesbury Experimental House. Wind. Eng., 2, 203-220.

HOLMES, J.D. and OSONPHASOP, C. (1983) Flow Behind Two-Dimensional Barriers on a Roughened Ground Plane, and Applications for Atmospheric Boundary Layer Modelling, Proc. 8th Aust. Fluid Mech., Conf., Newcastle, Nov.

TIELEMAN, H.W., AKINS, R.E. and SPARKS, P.R. (1981) A Comparison of Wind-Tunnel and Full-Scale Wind Pressure Measurements on Low-Rise Structures. J. Wind Eng. and Ind. Aerodyn., 8, 3-19.

TIELEMAN, H.W., AKINS, R.E. and SPARKS, P.R. (1981) Model/Model and Full-Scale/Model Comparison of Wind Pressures on Low-Rise Structures. Proc. Colloque, 'Construire avec le Vent', Nantes, June 1981.

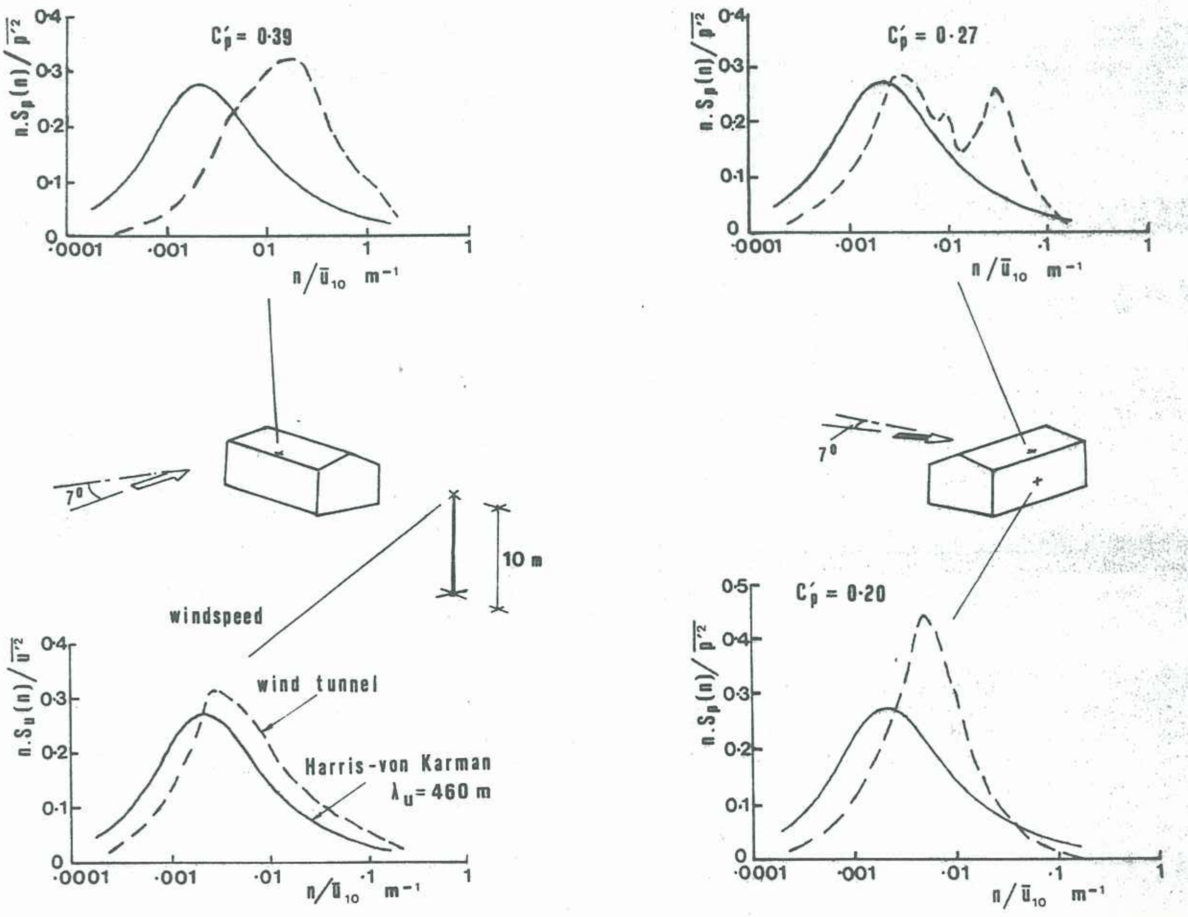


Figure 7 Wind speed and pressure spectra