Reflections on 30 years of full-scale experiments and what's next.

Roger Hoxey
Silsoe Research Institute

Summary

Silsoe Research Institute has a programme of full-scale measurements on structures that started 30 years ago; a programme that I have been involved with for the past 28 of those years. This paper takes a look at some of the lessons we have learnt, effects we can explain and those we cannot. The lessons are based on making comparisons with other published work in particular comparisons are made with wind-tunnel and computational modelling. We also take a look forward to where the work is likely to lead us in the next decade or so.

Review

The early part of the programme of work at Silsoe was based on, and funded by, customer driven demand for pressure distributions for a range of low-rise agricultural buildings. The results of this work have been used in specific designs and also in codes; there is ongoing application of this work to British and European codes. The approach used was to select buildings of the required geometry, sited in exposed positions, and to install tapping points for surface pressure measurement. Measurements were made when the approach flow was from the required direction and above a minimum threshold speed, usually 8 m/s. The detailed experimental approach was similar to that used in a wind-tunnel. It is only possible to make full-scale measurements when buildings of the required geometry already exist, as is the case for mass produced buildings.

Example pressure distributions are shown in Fig. 1 for two buildings with geometrically similar cross-sections but with a 3:1 difference in size, and, as can readily be seen, the pressure distributions are not similar. The fetch was similar in both cases with a roughness length $z_o \sim 0.05$. We have never satisfactorily explained the difference and feel it cannot be solely attributed to a mismatch of Jensen number (h/z_o) nor to differences in fetch or to building surface detail. The increase in building size appears to increase the extent of separation at the windward eaves; this affects the subsequent pressure field although the extent of roof slope may also contribute.

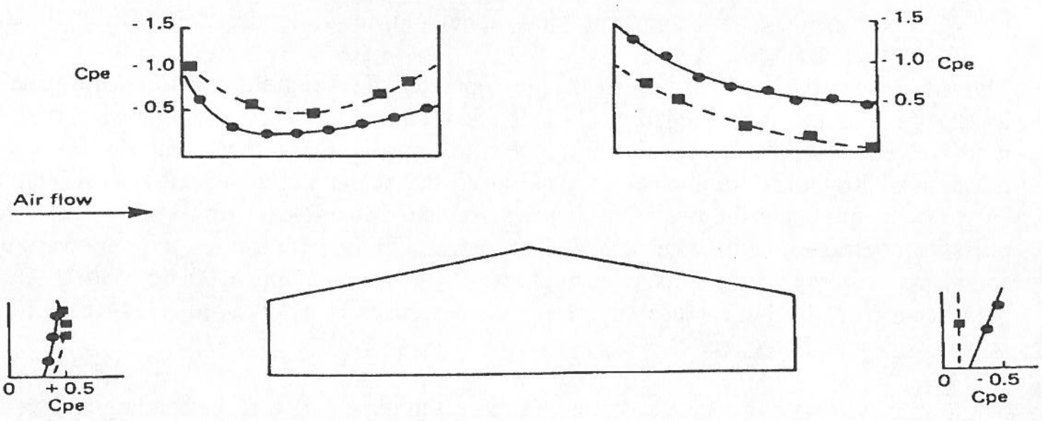

Fig. 1. Comparison of measured loads on a 7.4 m span building (——●——) and a geometrically similar building with a 21.5 m span (---■---)

There is often a problem of providing a reference pressure in full-scale work and like others, we used a ground level tapping in our early work; however when the ground is saturated this tap becomes blocked. For this and other reasons we developed a static pressure probe based on a design by Marshall, NBS, USA. This probe is insensitive to the horizontal flow direction and once set, it has a moveable shroud, is robust, unaffected by rain and reliable. This is the one sensor, more than any other, that has made our full-scale measurements more reliable although there is still more to be understood about the variation of static pressure in the atmospheric boundary layer (ABL): we will come back to this later.

The question that follows the definition of pressure is how to apply the information to produce design structural loads and stresses. To provide some answers a strain-gauged building was erected at Silsoe, the Silsoe Structures Building, where simultaneous surface pressure and strain measurements were recorded. The results of this work have been widely reported and show how mean value coefficients can be used to compute mean strains and that some relaxation can be applied to predict peak strains based on the non-simultaneous action of gust effects. Appropriate factors can be found in the UK code, BS6399 (C_a factor). Following this, measurements were made on a free-standing wall where again overall loads were compared to surface pressure and similar reduction factors were found. Recently both these data sets have been used to assess the application of proper orthogonal decomposition (POD) methods.

In the late 1980's and early 90's there was an opportunity to make measurements on some scale models of our full-scale buildings in a number of different wind tunnels including the boundary layer wind tunnel at the University of Western Ontario. An example of the comparison is shown in Fig. 2 for the roof of the Silsoe Structures Building at mid-length.

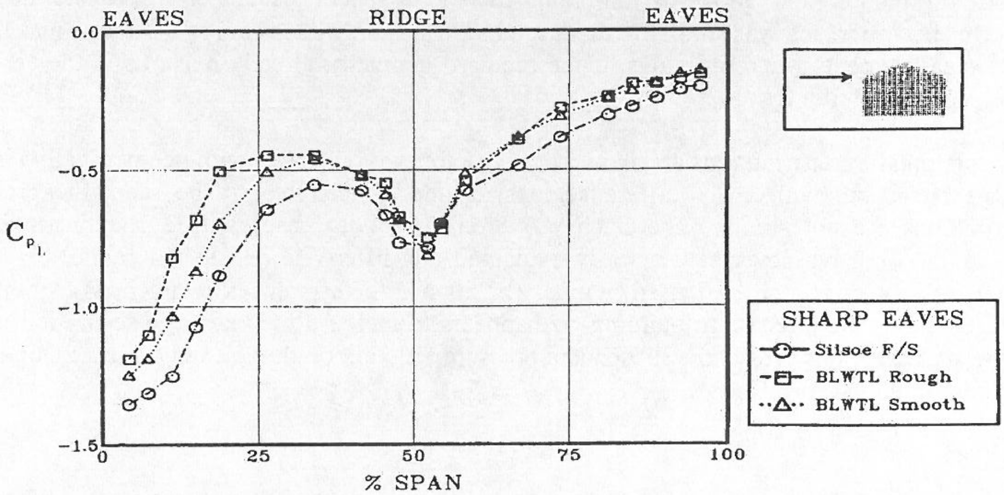

Fig. 2. Example of wind-tunnel and full-scale measurements.

The differences were consistent, in that in separated flow regions the full-scale usually gave lower pressure i.e. more negative Cp's as illustrated in Fig. 2. Attempts to correct this by modifying the boundary layer did not appear to improve the comparisons. In this context the question of Reynolds Number effect was raised but so far not answered in wind-tunnel tests. However at full-scale the available data was revisited to look for any systematic variation of pressure coefficient with wind speed. For many tapping points no significant variation was found but for tapping points near regions of flow reattachment there was a statistically significant ($p < 0.01$) decrease in pressure coefficient with wind speed. This was confirmed in recent work on a 6 m cube.

The 6 m cube was constructed to conduct more fundamental work on loading and ventilation. One objective is to determine the validity of the quasi-steady method that relates fluctuations in surface pressure to approach-flow turbulence. To achieve this the aerodynamic derivatives of pressure coefficient are required with respect to the horizontal and vertical flow direction: hence the cube could be rotated and to a limited extent pitched. Early results from the cube are encouraging supporting the quasi-steady approach. The mean pressure distribution for the cube central section is shown in Fig. 3 and compared to a number of published wind-tunnel measurements. Again, at full-scale, the region of flow separation and reattachment show lower pressure than in the wind tunnel although this is less noticeable than on 'longer' more two-dimensional buildings (high aspect ratio). An example of Reynolds number effect is shown in Fig. 4 for a roof tap near reattachment. Ten-minute mean pressure coefficients for a mean wind direction within 2 degrees of normal to the cube are plotted against a Reynolds number based on cube height and free-stream velocity at cube height.

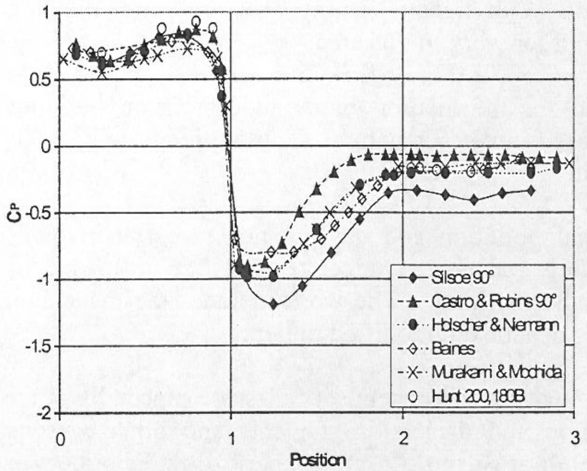

Fig. 3 Pressure distribution for the vertical central section of a cube.

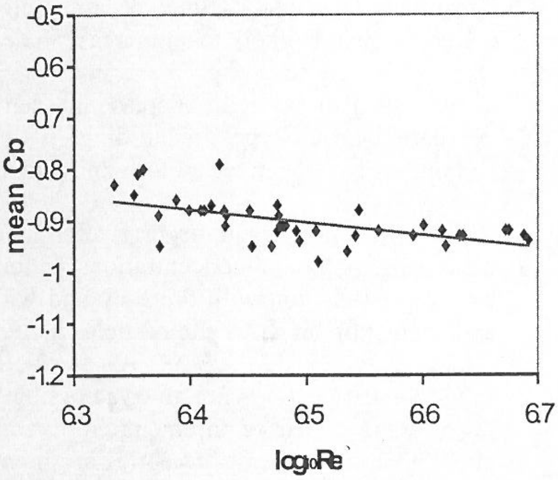

Fig. 4 Mean pressure coefficient variation with Reynolds number for a roof tap near the centre of the 6 m cube.

In recent years Computational Fluid Dynamics (CFD) has been used in wind engineering, sometimes in place of a wind tunnel study; this would appear premature without first validating the methods. We have made comparisons of CFD with our full-scale measurements as illustrated in Fig. 5; in this case comparison with full-scale is reasonable and comparable with the wind-tunnel but this is not the case for some other buildings.

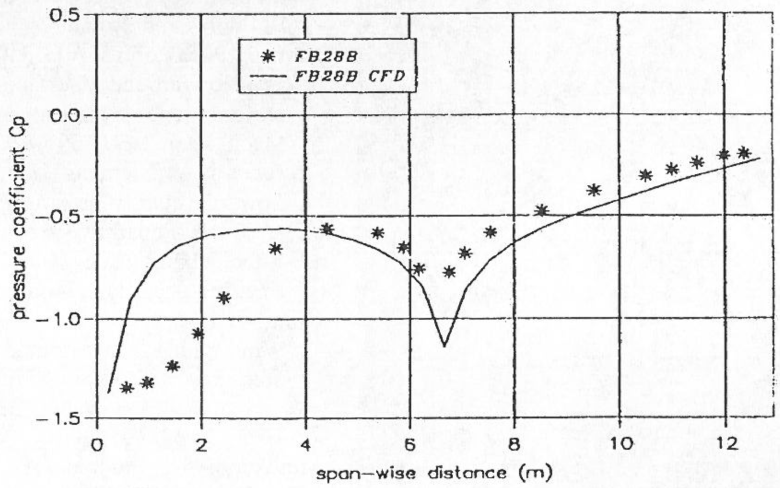

Fig. 5 Comparison of a k-ϵ CFD calculation with full-scale measurements.

Thoughts on meeting industry needs in the future

Omitted from the review is the work on wind structure in the lower part of the ABL. We have made measurements of wind structure and proposed spectral models but more multi-point simultaneous measurements are required for correlation statistics for determining loadings. This information is also needed for pollution dispersion, a topic that is now occupying more of our time. The sensing of static pressure was mentioned earlier but its variation both temporally and spatially has not been studied; experiments are planned to explore this at the same time as measuring the three-components of wind velocity.

Until recently our work had addressed static loading but with work on lighting columns, dynamic effects and fatigue became relevant. With lighter weight structures and cladding materials there is likely to an increase in demand for work in this area.

There has also been an increase in demand for information on wind effects on building ventilation for all types of buildings with forced, mixed or natural ventilation systems. Inlets and outlets have been tested for wind effect and more work is planned.

Wind is the primary transport factor in aerial pollution and our planned research involves measuring pollutant concentrations in building wakes and understanding the influence of building interaction with the flow and with other buildings. The work includes the dispersion and deposition on gases and particles including genetically modified pollen.

In the longer term it is not always possible to conduct experiments at full-scale especially at the lower wind speed requirements for ventilation and dispersion; for this and other reasons alternative experimental facilities are being built at Silsoe. An atmospheric flow laboratory is being constructed to reproduce a low speed ABL at scales up to full-scale. The flow is created by an array of 8x7 fans speed controlled in pairs by 28 independent controllers. The fans are shown in Fig. 6 following the preliminary phase of construction. The working section has a 6x5 m cross-section with a length of over 20 m. Preliminary measurements have shown that shear and turbulence can be generated similar to a full-scale ABL.

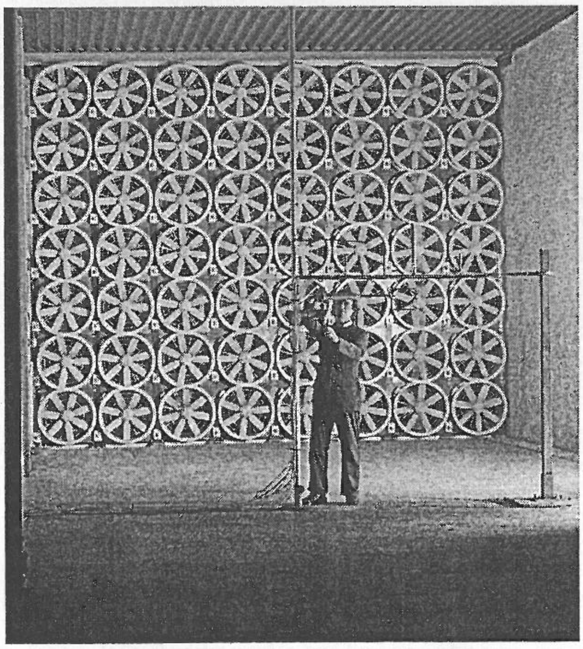

Fig. 6 The Silsoe Atmospheric Flow Laboratory

REFERENCES

Baines, W.D., 1963
Effects of velocity distribution on wind loads and flow patterns on buildings, Proceedings Symp. No. 16 Wind Effects on Buildings and Structures, NPL, UK, 1963.

Castro, I.P. & Robins, A.G. 1977
The flow around a surface-mounted cube in uniform and turbulent streams, J. Fluid Mech. 79 pt 2, 307-335, 1977.

Hölscher, N. & Niemann, H-J., 1998
Towards quality assurance for wind tunnel tests: A comparative testing program of the Windtechnologische Gesellschaft, J. Wind. Eng. Ind. Aerodyn. 74-76, 599-608, 1998.

Hunt, A., 1982
Wind-tunnel measurements of surface pressures on cubic building models at several scales, J. Wind. Eng. Ind. Aerodyn. 10, 137-163, 1982.

Murakami, S. & Mochida, A., 1990
3-D numerical simulation of airflow around a cubic model by means of the k-ε model, J. Wind Eng. Ind. Aerodyn. 31, 283-303, 198