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COMPUTATIONAL MODELLING AND FLOW VISUALISATION OF WIND FLOW OVER DOWNTOWN AUCKLAND

Peter J. RICHARDS and Gordon D. MALLINSON

Department of Mechanical Engineering, University of Auckland,
Private Bag 92019, Auckland, New Zealand.

ABSTRACT

Queen Elizabeth II Square in Downtown Auckland is notorious for being one of the windiest places in central Auckland. In the past No. 1 Queen Street, which is one of the oldest high rise buildings in Auckland, has been blamed for causing these wind problems. Computational modelling of the Downtown area using the finite volume code PHOENICS and graphical post processing using the locally written package SeeFD has enabled examination of the source of these wind problems. Although No. 1 Queen Street has a dominant effect on the wind environment in Queen Elizabeth II Square it is shown that it is the interaction of this building with the others around it that magnifies the problems.

INTRODUCTION

In 1968 three young architects mounted a campaign of opposition to what was described as "the biggest and costliest urban renewal project in New Zealand, the $36 - million Auckland Harbour Board downtown development scheme." In particular they objected to the siting of one of Auckland's first high rise buildings at No. 1 Queen Street, see Figure 1. They said that it "obstructed the view of the historic, elegant Ferry Building, and that its design, as well as its position, would deflect wind into Queen Elizabeth II Square and block the sun." In order to support their case they even built their own wind tunnel in a disused factory and used smoke visualisation to produce a film which, although shown on TVNZ, failed to convince the council.

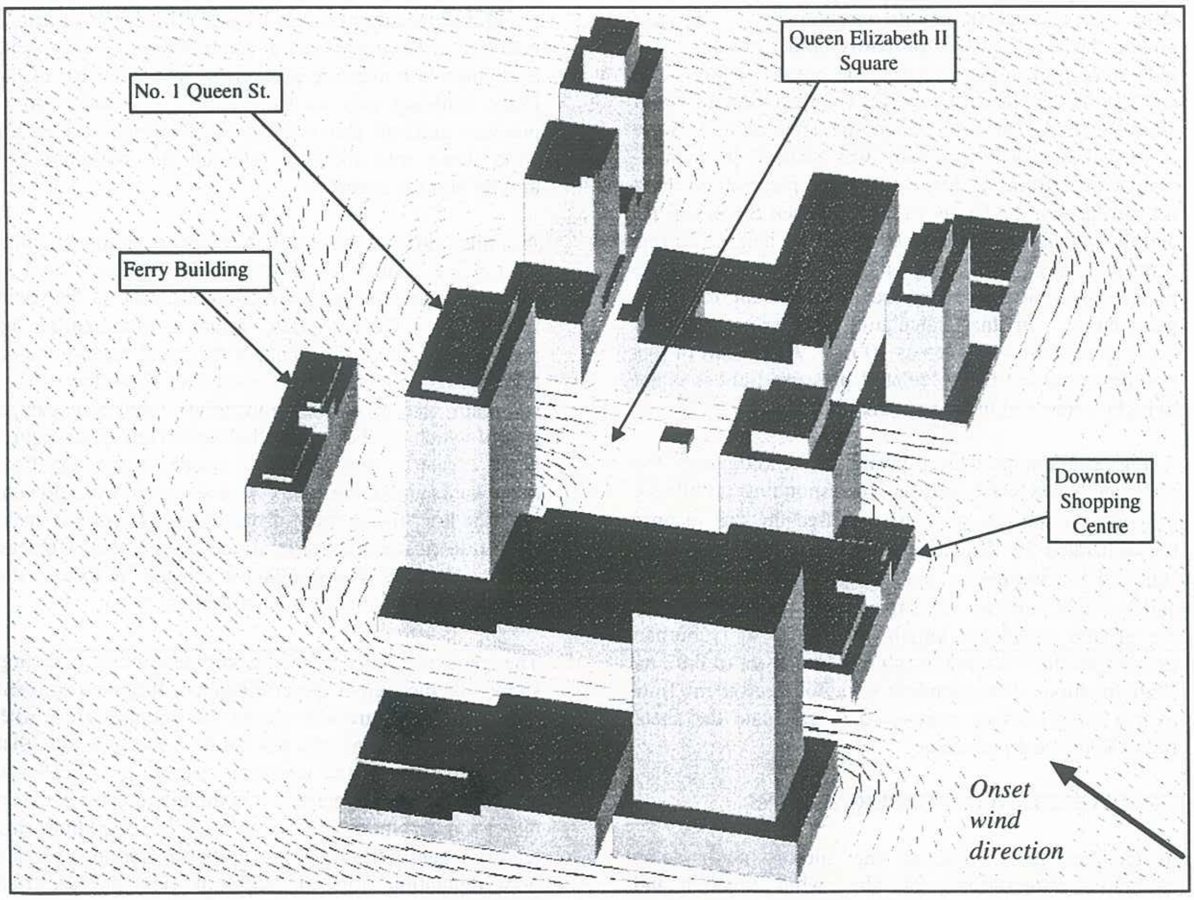

Figure 1. Near ground wind vectors around Downtown Auckland with a south-west wind.

30 years later Queen Elizabeth II Square, and in particular the area around No. 1 Queen Street, has the reputation of being one of the windiest areas in central Auckland. Recent wind-tunnel modelling of this area supports the general findings of those early tests. In particular, cork grain erosion tests of the wind environment show that the area around No.1 Queen Street is very gusty for many wind directions.

With wind tunnel tests certain features of the situation can be identified or measured but it is difficult to obtain an overall picture of the flow field or the interactions between the pressure and velocity fields. Although finite volume methods are limited to modelling the mean wind flow, it is possible to obtain details of the full 3-dimensional velocity and pressure fields and then use computational flow visualisation techniques to investigate the flow.

COMPUTATIONAL TECHNIQUES

Computational modelling of the flow over the Downtown shopping centre and surrounding buildings was undertaken using the PHOENICS (version 2.1) finite volume code. A rectangular grid, with domain boundaries extending the equivalent of 496 m above and around the block of buildings modelled, was used. The block of buildings extended 220 m in the south-north direction, 340 m in the west-east direction and was 80 m high. The grid contained 95 x 121 x 40 cells in the S-N, W-E and vertical directions respectively. The grid around the buildings was primarily built from 4m cubes with some grid refinement near the ground (lower 40m) and around the NE corner of No. 1 Queen Street (within 40 m S-N and 32m W-E) where the smallest cells were 2 m cubes. The problem was solved in a non-dimensional form, with the reference parameters being the air density, the height of No. 1 Queen Street (80 m) and the velocity in the inlet flow at that height. In this form the laminar kinematic viscosity is set equal to the inverse of the Reynolds number based on the reference parameters. In this calculation the reference inlet velocity at 80 m was taken as 10 m/s. As a result of this non-dimensioning the calculated pressure field is equal to half of the usual mean pressure coefficient.

A log-law boundary layer profile extending over the total depth was used with the corresponding turbulence property (k and ε) profiles specified in the manner recommended by Richards and Hoxey (1992). The standard k-ε turbulence model was used. The ground and building surfaces were treated as rough walls with the ground roughness length set to 0.2 m (suburban terrain) and the building roughness length set to 0.02 m. Wall functions corresponding to a fully-turbulent flow over a rough surface were used to calculate the shear forces in the near wall cells.

COMPARISON WITH OBSERVATIONS

In October 1995 one of the authors made some qualitative observations of the wind direction and relative strength at various points around Queen Elizabeth II Square and No. 1 Queen Street while the wind was blowing almost perpendicular to the north face of No. 1 Queen Street (Wind direction 20°). The results from these observations are reproduced in Figure 2 where the length of the vectors approximates the strength of the wind at that point. Figure 3 shows the pattern of vectors obtained from the computational modelling.

Both figures show similar flow patterns with flows away from the centre of the north face of No. 1 Queen Street across Quay Street and around the corner into Queen Elizabeth II Square. The strongest flow occurs through the gap into the square. Behind No. 1 Queen Street a circulating flow exists which could be clearly seen in the real flow due to the circling motion of dry leaves and litter in this area.

INTERACTIONS BETWEEN BUILDINGS

Further analysis of the computational results for the northerly wind shows that the interaction between the Ferry Building and No.1 Queen Street has a significant effect in deflecting flow into the square. Figure 4 shows the streamlines which originate upstream at a height of 25 m. It can be seen that those passing over the Ferry Building are strongly deflected downwards and then around the corner into the square. Also shown in this figure are the C_p= 0.4 iso-surfaces which help to illustrate the structure of the pressure field. It may be observed that with the buildings towards the eastern end of Quay Street the pressure iso-surface extends down to the ground whereas on No. 1 Queen Street the surface is confined to the upper part of the building. At the same time there is a negative pressure zone at the rear of the Ferry Building and so there exists a strong vertical pressure gradient above Quay Street which drives the wind down into the gap between the buildings and around into the square.

A similar situation occurs with the more common south-west winds which are illustrated in Figures 1 and 5. Figure 5 shows the pressure contours close to the south face of No. 1 Queen Street, where as noted earlier the pressure is equivalent to half of the usual mean pressure coefficient. It may be observed that the effect of the upstream section of the Downtown shopping centre, part of which can be seen in the bottom left of the figure, is to create a pressure field which drives the flow downwards and to the right. As a result the wind flowing over the low rise section of the shopping centre is again driven downwards and around the edge of No. 1 Queen Street. Hence a windy region is created in exactly the same area as affected by the northerlies.

The general results from the computational modelling show that the area of Queen Elizabeth II Square adjacent to No.1 Queen Street is one of the windiest areas with northerly, north-easterly and south-westerly winds (that is almost all of the common winds in Auckland). However it does appear that it is the interactions between No. 1 Queen Street and the surrounding buildings that tend to magnify the situation and hence lead to the area's poor reputation from the point of view of pedestrian comfort.

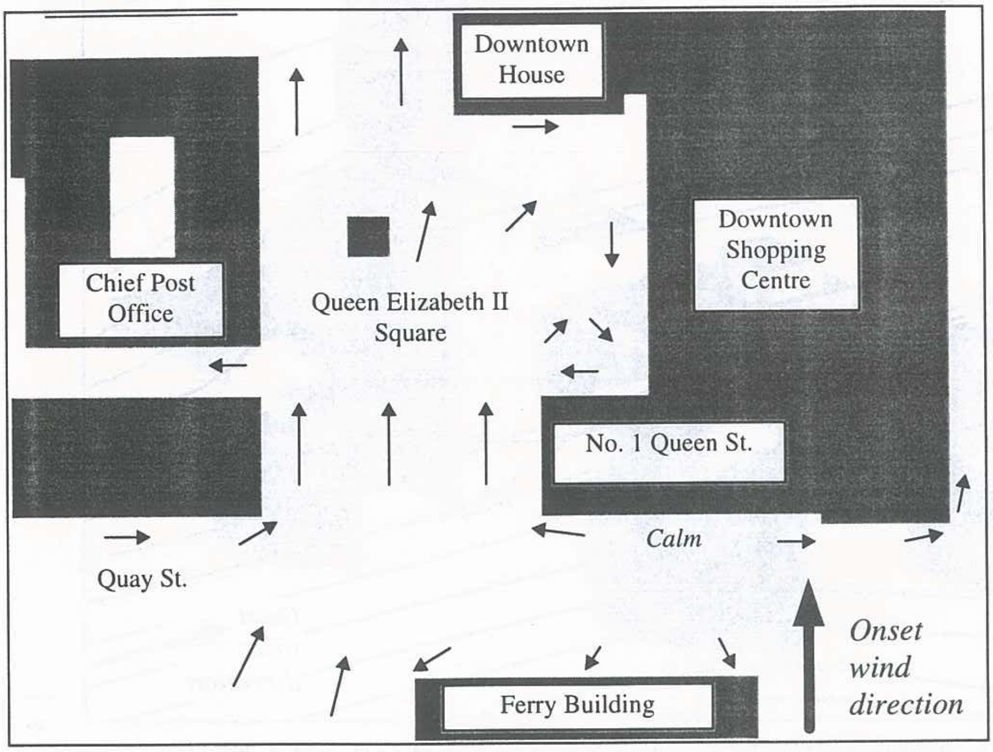

Figure 2. Observed local wind directions (Wind direction 20°)

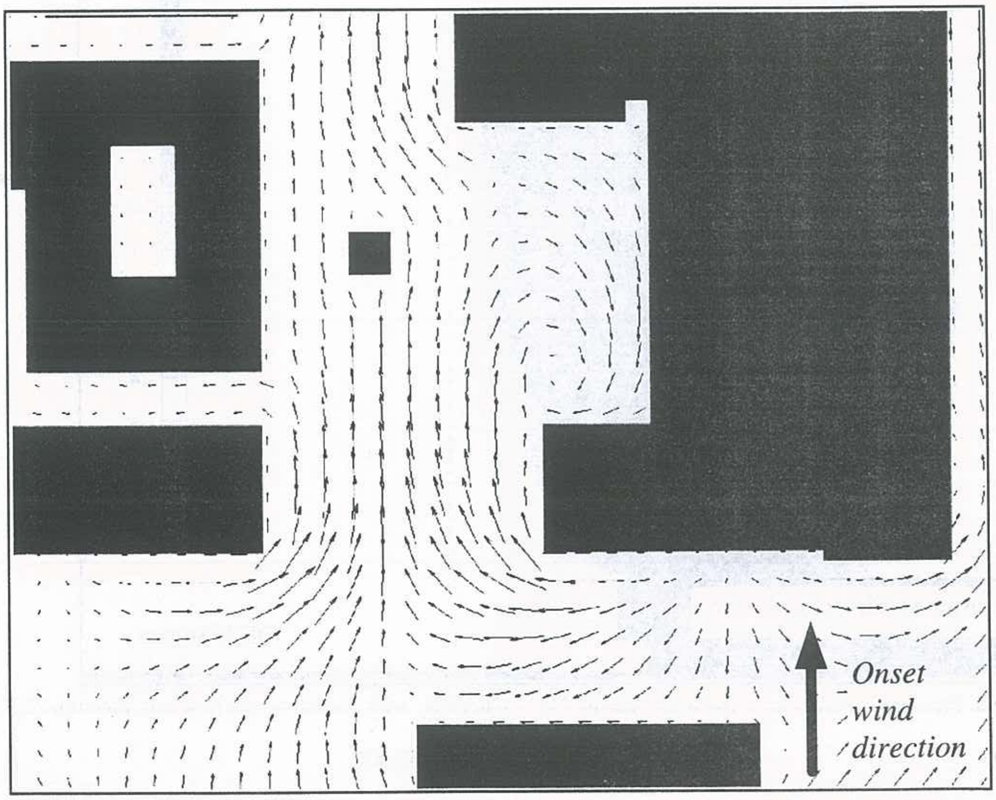

Figure 3. Computed near ground local wind vectors (Wind direction 20°)

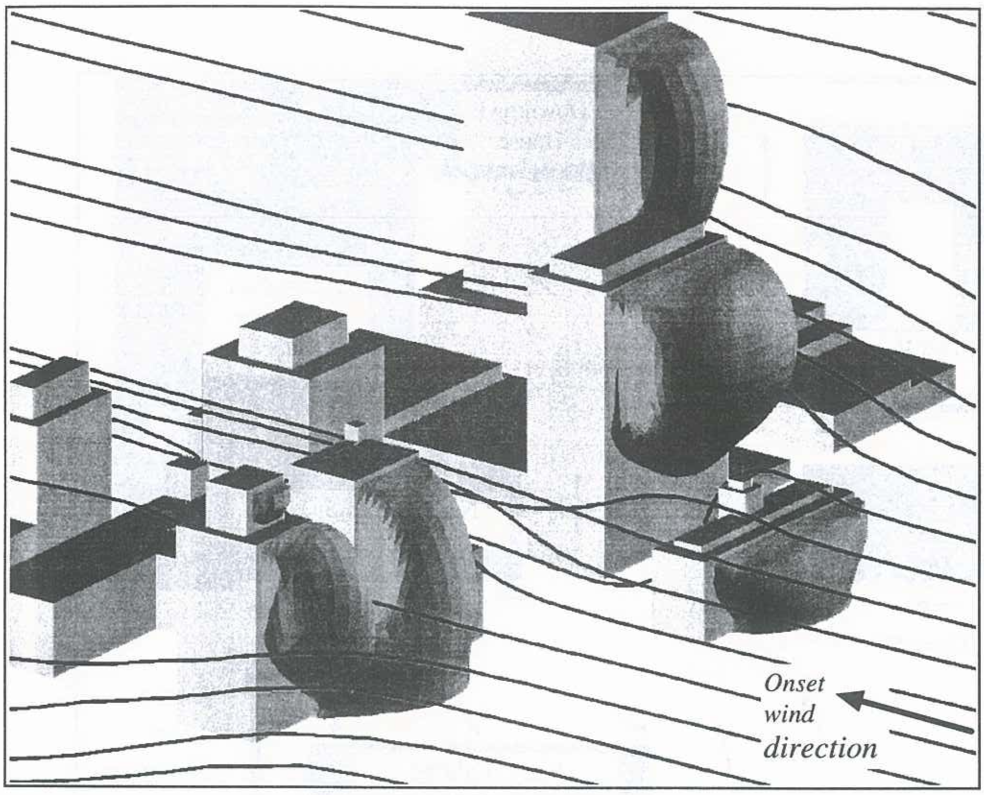

Figure 4. Streamlines and C_p= 0.4 iso-surfaces for a northerly wind (wind direction 20°)

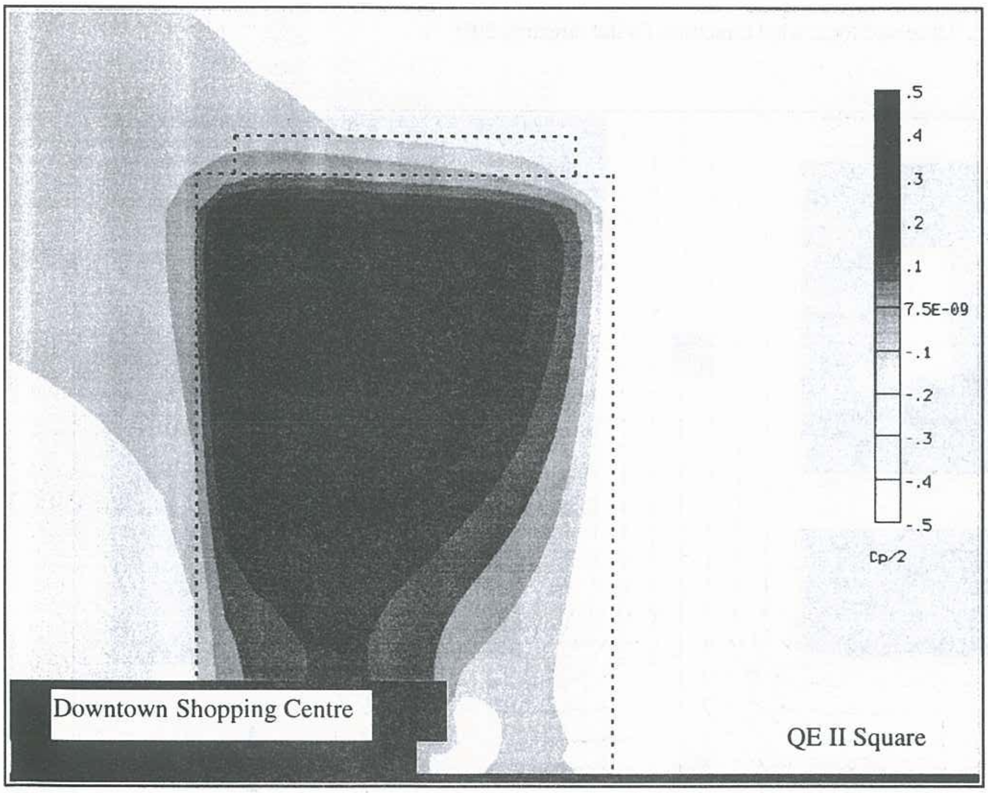

Figure 5. Pressure contours near the south face of No. 1 Queen St. with a south-westerly wind (direction 225°)

CONCLUSION

Computational modelling of the wind flow around Downtown Auckland has been used to illustrate the way that the buildings interact and create the particularly windy areas observed in reality.

REFERENCE

RICHARDS, P.J. and HOXEY, R.P., "Appropriate boundary conditions for computational wind engineering models using the k-ε turbulence model", J. Wind Eng. Ind. Aerodyn. **46&47**, 145-153, 1993.