Comparison of Wind Tunnel Prediction Techniques for Pedestrian Level Winds with Full-scale Measurements

C. Chiappini[1] and R.G.J. Flay[2]

[1] Former Postgraduate Student, The University of Auckland, New Zealand
[2] Professor of Mechanical Engineering, The University of Auckland, New Zealand

Abstract

This paper details the analysis and validation of the wind tunnel testing techniques used at the University of Auckland for investigating the pedestrian level wind environment. The first stage of the research focused on analysing, comparing and improving the two testing techniques: erosion method and hot wire measurement. The second stage of the research focused on the acquisition of full-scale wind data at street level in Auckland City and their comparison with wind tunnel results at the equivalent locations. It was found that the hot-wire and erosion test techniques presently used in the de Bray Wind Tunnel in the Aerodynamics Laboratory of the Department of Mechanical Engineering at the University of Auckland gave good agreement. It was also found that full-scale velocity ratios agreed well with wind tunnel velocity ratios measured with a vertical hot-wire located at the corresponding height positions in the wind tunnel.

Introduction

Wind conditions resulting from configurations of buildings can adversely affect the comfort and safety of pedestrians in urban areas. The construction of tall buildings significantly alters the street level wind environment deflecting high-speed winds towards the ground producing unpleasant and sometimes unsafe conditions for pedestrians. Many city authorities (including Auckland City Council) now require wind tunnel testing of proposed new developments to assess their impact on the local wind environment (Peterka and Ratcliff, 1989), (Livesey 1992).

The following tasks were hence undertaken as part of this investigation.

- Measurements and comparison of pedestrian level winds above the 1:400 Auckland wind tunnel model using hot wire anemometer and erosion methods.
- Full-scale measurements of pedestrian level wind environment using cup anemometers mounted on traffic light arms above the street, paying particular attention to areas which have heavy pedestrian traffic, or which are known to be rather windy.
- Comparison of wind tunnel and full-scale measurements, and validation of wind tunnel testing techniques.

Wind comfort categories

Pedestrian level winds in Auckland City are regulated by the District Plan (Auckland City Council 1997). Wind categories are specified in terms of the probability of exceeding certain hourly mean speeds and are shown in Fig. 1. The curves delineating the boundaries between the acceptable categories (A – D) and unacceptable (E) categories of wind performance are described by the Weibull expression

$$P(>V) = e^{-\left(\frac{V}{C}\right)^{k}} \qquad (1)$$

where V is the mean velocity in m/s, P is the probability that the wind speed is greater than V, k = 1.5 and c is a variable depending on the boundary being defined: c(A/B) = 1.548, c(B/C) = 2.322, c(C/D) = 3.017, c(D/E) = 3.715. Wind comfort categories A, B, C and D correspond approximately to locations suitable for the following respectively: sitting for a long time, sitting for a short time, walking slowly, and walking fast.

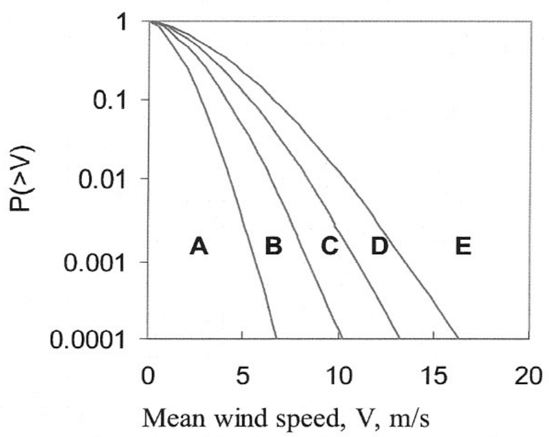

Fig. 1 Auckland wind environmental categories

In pedestrian level wind investigations, the wind tunnel is used simply to obtain velocity ratios, $R_{i,\theta} = \frac{V_{i,\theta}}{V_{ref}}$ between a local position *"i"* for a wind direction *"θ"*, and the reference location, which is usually at an elevated location unaffected by model buildings. At the University of Auckland, the number of hours that certain wind speeds are exceeded is determined by integration, according to the following equation.

$$P(>V) = \sum_{\substack{\theta=0,30,60,90,\\210,240,270,300}}^{300} A_\theta e^{-\left(\frac{V_{i,\theta}}{C_\theta R_{i,\theta}}\right)^{K_\theta}} \qquad (2)$$

A_θ, k_θ, and c_θ are the Weibull coefficients for the reference location for each direction. The number of hours a certain wind velocity is exceeded is usually calculated for three mean velocities: 4, 8 and 12 m/s, and comfort categories assigned to each one. Ideally, it should not make any difference to the calculated comfort category which wind speed is selected for the calculation, providing that the delineations between the categories are correct. However, the boundaries using a Weibull curve with k = 1.5 are only an approximation to the real variation – which varies from site to site - and so in practice real data do not always follow the boundaries shown in Fig. 1 exactly. A more complete account of methods used at the University of Auckland can be found in (Eaddy, 1999).

Wind Tunnel Investigations

A model of Auckland built at 1/400th of full-scale was used for all the wind tunnel investigations. Four sites were chosen for investigation at exposed locations where there is known to be heavy pedestrian traffic. The sites were also chosen where cup anemometers could be attached to traffic light arms above the street. Hot-wire measurements were made at each of these locations for the 8 most common wind directions: 0, 30, 60, 90, 210, 240, 270, 300 degrees, at heights of 4 and 14 mm above local ground level corresponding to full scale heights of 1.5m (chest height) and 5.6m (anemometer on traffic light arm).

Table 1. Hot wire and calculated erosion comfort categories comparison

	Hobson/Quay St			*Albert/Quay*			*Queen/Custom*			*Ferry Building*		
V local (m/s)	4	8	12	4	8	12	4	8	12	4	8	12
Hot wire CATEGORIES	B	B	B	B	B	B	B	B	B	C	C	C
Erosion CATEGORIES C eroding speed)	C	B	B	C	B	B	C	B	B	C	C	C

Comparison of hot-wire and erosion results

Table 1 compares the wind comfort categories determined from the hot-wire and the erosion method. It is evident that the comparison is good, but that the wind comfort category does differ when the comparison is made at a local mean wind speed of 4 m/s. This indicates that the wind comfort is close to the boundary between categories.

Comparison of Wind tunnel and Full-scale results

Cup anemometers were mounted on traffic light arms (Figs. 2, 4) at the locations on Queen, Quay and Hobson Streets shown in Fig. 3. A data acquisition system (Fig. 5) was designed and built to save the accumulated pulses (2 per revolution) for periods of 3 seconds, and then from the 100 values saved every five minutes record the mean, standard deviation, maximum and minimum, and discard the raw data. The data could be downloaded by phoning the cellular phone located inside the data acquisition system box from a phone connected to the data acquisition computer and instructing the remote phone to communicate in data mode, and to transmit the data to the data acquisition computer. The data for 3 weeks could be downloaded in less than 1 minute. The remote cell phones never need to phone out, which has kept the communication costs to a minimum. The unit is powered by 240v provided by one of the cables from the traffic light where the unit is fixed. A set of batteries is included in the box in order to cope with any power cuts.

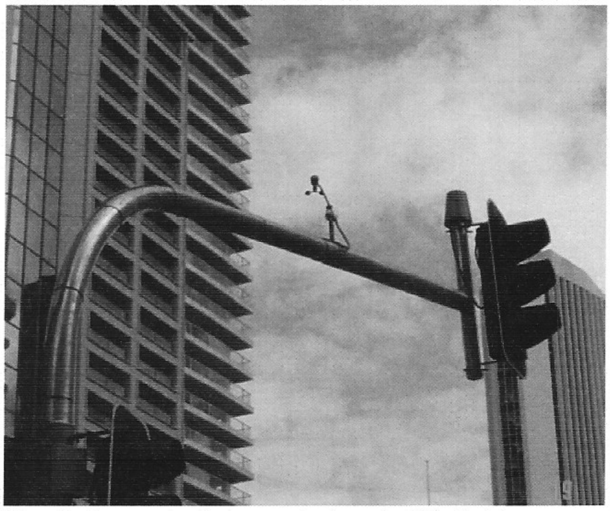

Fig. 2 Anemometer mounted on traffic light arm

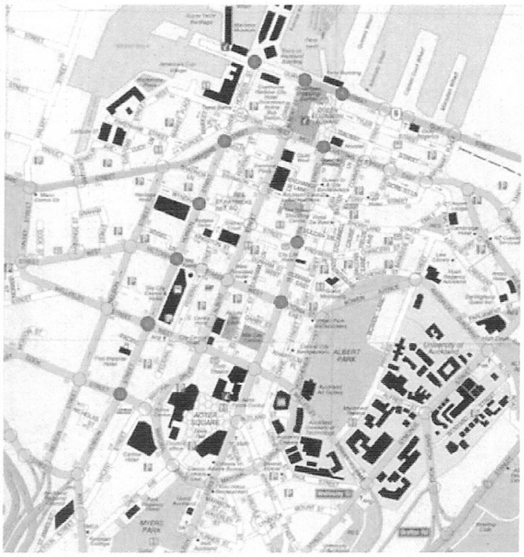

Fig. 3 Locations of measurements shown in red.

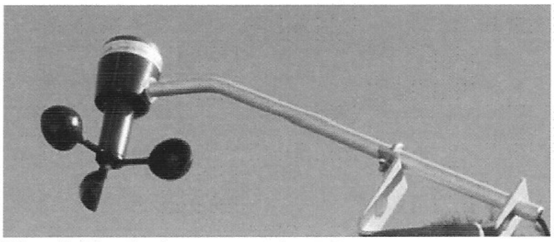

Fig. 4 Typical cup anemometer.

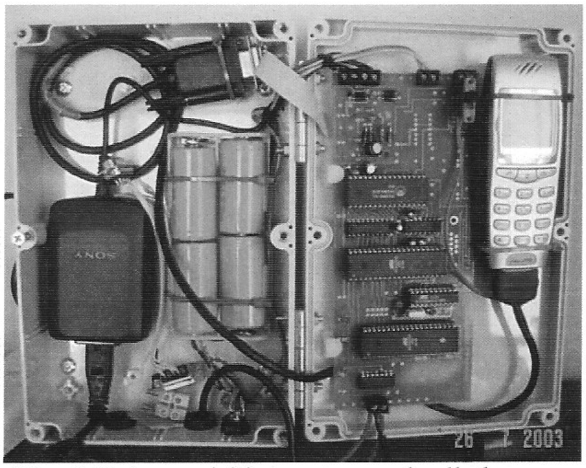

Fig. 5 Data acquisition system and cell phone.

The full scale and wind tunnel data were compared by forming speed ratios between reference and traffic light locations. In order to calculate full-scale velocity ratios, data from the Sky Tower anemometers were used. SkyTower has two anemometers on 3.1 m long arms orientated at 122° and 295° from true north installed on the top section 318 m above sea level and 297 m above ground at the tower base. Wind speeds and directions are recorded every 3 seconds and then wind statistics determined for periods of 15 minutes. Fig. 6 shows typical results from the site at the intersection of Queen and Quay Streets. It can be seen that the agreement is poor when the wind speed at the SkyTower is low, but is otherwise very good.

Comparison between velocity ratios at 1.5 m and 5.6 m height

An anemometer mounted at 1.5m on a portable tripod was used to determine wind speeds at chest height on the footpath in the vicinity of the traffic light arm anemometers at heights of 5.6 m. Results from measurements at the intersection of Queen and Quay Streets are shown in Fig. 7. These measurements were not very complete, and on the day that the full-scale data were recorded the wind was blowing from about 300° at only about 2 m/s.

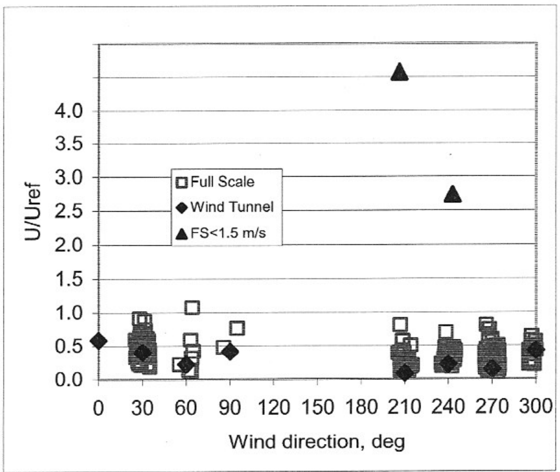

Fig. 6 Comparison of wind tunnel and full scale velocity ratios.

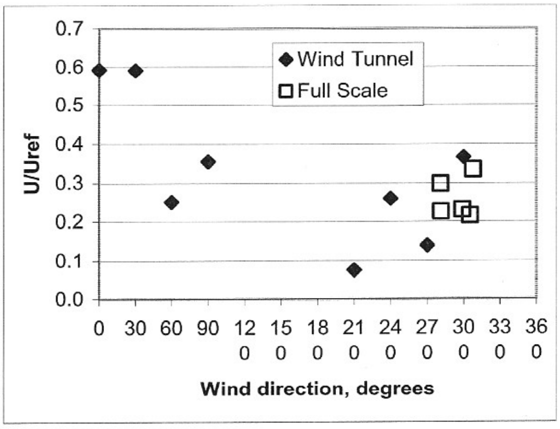

Fig. 7 Comparison of wind tunnel and full-scale velocity ratios at 1.5 m height.

Conclusions

- Wind comfort categories determined from hot-wire and the erosion method showed good agreement for the four sites investigated.
- A remote wind speed data acquisition system has been developed, tested and proven.
- Full-scale velocity ratios have been calculated and compared to wind tunnel velocity ratios and found to show good agreement except when the wind speed is low.
- Measurements at two sites using a portable anemometer at 1.5 m height showed generally good agreement between full-scale velocity ratios and corresponding wind tunnel velocity ratios.

References

Auckland City Council (1997). Auckland City proposed district plan 1997: central area section. Auckland, Auckland City Council.

Eaddy, M. J. (1999). Pedestrian level wind measurement using computer image processing. Mechanical Engineering. Auckland, University of Auckland.

Livesey, F. (1992). "Enhanced scour tests to evaluate pedestrian level winds." Journal of Wind Engineering and Industrial Aerodynamics 44(pt 4): 2265-2276.

Peterka, J. A. and M. A. Ratcliff (1989). Comparison of Pedestrian Wind Acceptability Criteria. The Sixth U.S. National Conference on Wind engineering, Houston TX.