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A Comparison between the Particle Erosion Technique and Omnidirectional Irwin Probe for an Auckland Wind Environment Study

Y. F. Li[1], B. E. Goodwin[1] and R. G. J. Flay[1]

[1]Department of Mechanical Engineering
University of Auckland, Auckland 1142, New Zealand

Abstract

The pedestrian wind environment of a tall building development in Auckland has been wind tunnel tested using the particle erosion technique and the "Irwin Probe". Wind speed ratios between the two testing technique were compared and agreement between the two tests are generally good. The measured speed ratios from these two experimental methods have been combined with Auckland's wind climate data and then put into comfort categories using the rules in the district plan. The comfort categories obtained using the particle erosion and the Irwin probe techniques gave good agreement at the locations of the Irwin probes.

Introduction

The particle erosion, or scour technique is a method of studying the pedestrian level wind (PLW) environment around buildings by mean of wind tunnel testing of scaled models. It has been the de-facto technique for PLW investigation in the Department of Mechanical Engineering at the University of Auckland, and it has been streamlined through many years of development [1-5]. Recently the Department built a set of 140 Irwin probes [6,7] in order to align with the practice of the wider wind engineering community in terms of the approach to PLW investigations. The probes were built according to the geometry given in [6] with a central tube height of 3.75 mm corresponding to 1.5 m and chest height in full-scale at a model scale of 1:400. The current paper presents the comparison of the application of the two techniques on a PLW study of a proposed tall building development in Auckland, New Zealand.

Auckland Wind Comfort Categories

Richard Flay helped Auckland City Council set up wind comfort criteria in 1989 when they were included in the city ordinances. The comfort categories consist of 5 categories, A, B, C, D and E corresponding to sitting for a long time, sitting for a short time, walking slowly, walking fast and dangerous. The demarcation between categories was done on the basis of Weibull curves, with k=1.5, which was shown to be appropriate in [1] for the overall pedestrian level wind speed in regions around buildings where the upper level winds are sheltered for some directions and enhanced in other directions by buildings. The 1989 criteria were developed with reference to criteria in [8,9] and use mean wind speeds. However, the 1989 Auckland wind comfort criteria were later judged to be too lenient based on further wind tunnel testing experience and the review in [10] and were updated in 1994 to be stricter and to give good agreement with [11,12]. They have remained unchanged since 1994, and are shown in figure 1 where they are compared with criteria from [11,12]. Further details are available on the Auckland City website [13] and in [14].

The practice at The University of Auckland is to determine the probability of exceedance for speeds of 4, 8 and 12 m/s and to determine which comfort zone areas lie in. It has been found that the comfort categories determined are relatively insensitive to the wind speed used from hundreds of tests we have done. Boundaries with k=2 are not so robust, as can be seen in [15] for stations C and M, where the comfort category is dependent on the speed used to determine the probability.

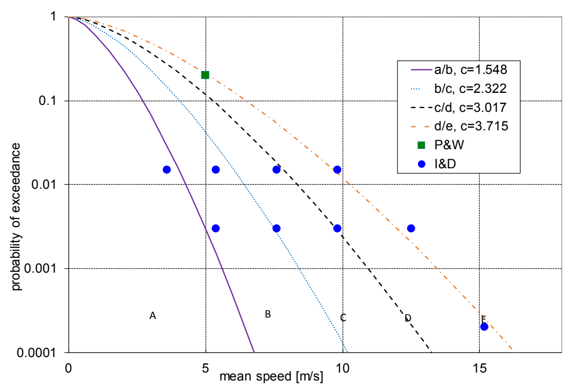

Figure 1. Comparison of Auckland wind comfort categories with Penwarden and Wise [11], and Isyumov and Davenport [12]. A: sitting long; B: sitting short; C: walking slowly, D: walking fast; E: dangerous.

Testing Methods

Particle Erosion Method for Pedestrian Comfort Determination

As stated above, the wind category statistics are specified in terms of the probability of exceedance of certain hourly mean wind speeds, but erosion techniques are more indicative of gust wind speeds. By knowing the gust wind speed when erosion occurs, and the speed at a reference height (usually 200 m full-scale) a speed ratio can be found and combined with wind climate data for the 200 m height to enable wind comfort categories to be found.

The erosion technique [3,4,5] uses a bed of erodible material (bran flakes) which are sprinkled over the area to be tested and the wind speed is increased until the bran flakes move to form an eroded pattern. Erosion images corresponding to different wind speeds are recorded by a 5 Mega-pixel high resolution camera. At each stage the wind speed is held constant for about 90 s, equivalent to about one hour in full-scale, so that the erosion pattern is fully developed before an image is acquired. Measurements have been made using a hot-wire anemometer to establish the wind speed, at model scale height equivalent to 1.5 m in full scale, at which the bran flakes erode from under the wire. Having established this wind seed, the ratio between wind speed at 1.5 m and the reference level may be deduced by noting the velocity at 200 m when erosion in a particular region occurs. It is then assumed that this ratio holds for all wind speeds from the particular direction.

Once the full set of erosion images has been obtained for a particular direction, a computer image processing system is used to combine them together, and then the process is repeated for the next direction. The areas that erode first are of course the windiest regions. When combined with the meteorological data, a pixel by pixel calculation of the wind statistics can be carried out, and a wind comfort category assigned as a particular colour to each pixel, resulting in a very simple image which shows up any areas of concern.

Irwin Sensors and Data Processing

The Irwin sensor, first proposed by Irwin [6,7] consists of an annular hole at ground level and a tube, slightly smaller than the hole, protruding above the ground level with a flat top as shown in figure 2. When the probe is submerged in log-law dominated part of the boundary layer, the wind speed at the top of the tube can be calculated from the differential pressure between the hole at ground level and the top of the tube. The practice at The University of Auckland is to use an electronically scanned pressure system to record the pressures from each of the openings using separate pressure sensors, to then determine the pressure difference, and then determine the speed at the top of the probe (equivalent to 1.5 m at full-scale) by using a prior calibration. Typically data are recorded at 400 Hz for 60 s for each probe. The time histories of wind speeds are then analysed to determine the mean speed, standard deviation and peak speeds.

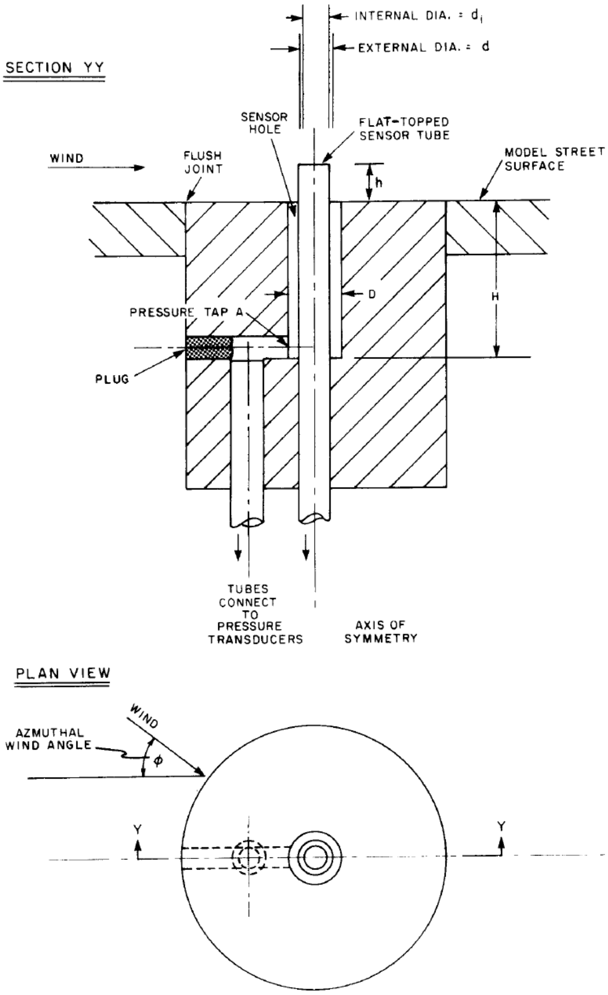

Figure 2. Irwin probe design [6].

Wind Tunnel Studies

The wind tunnel tests were conducted in the boundary layer wind tunnel of the Department of Mechanical Engineering, the University of Auckland. The working section of the wind tunnel is 3.6 m wide x 2.5 m high x 20 m long, with a top speed of 20 m/s.

In order to correctly model the characteristics of the approaching wind, such as turbulence intensity and velocity profiles, in the wind tunnel, a combination of roughness blocks, square posts, tripping fence and spires were placed in the upwind section of the wind tunnel. The target wind structure was Terrain Category 3 as specified in the wind loading standard AS/NZS1170.2 [16]. The resulting flow can be seen in figure 3, which shows the comparison between the measured wind profiles and the full-scale target profiles. It can be seen that the wind tunnel flow matches the target profiles very well.

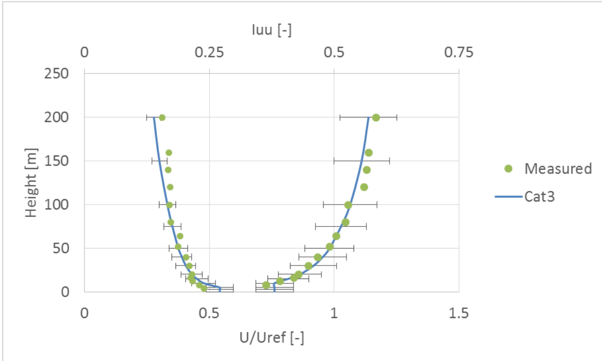

Figure 3 Comparison of measured mean velocity and turbulence intensity profiles for the wind tunnel test with target profiles from [16]

The development under investigation for this comparison is shown in figure 4 and consists of two 75 m high residential buildings, and two 5-storey townhouse blocks encircling a recreational courtyard area on the roof of a two-storey podium, which the four buildings sit atop. The two tall buildings have a trapezoidal footprint of 40 m x 15 m. The surrounding buildings within a radius of 500 m from the target development were included in the model as shown in figure 5. The reference wind speed was taken as the mean wind speed at 200 m height in full-scale. The central portion of the wind tunnel model was painted black to enhance the contrast of the erosion patterns for the imaging system.

For the particle erosion test, bran flakes were the erosion material and the erosion time was set at 90 s. Ten different reference wind speeds, from 2.0 m/s to 8.2 m/s at approximately uniform increments were chosen to ensure a reasonable resolution of wind speed ratios.

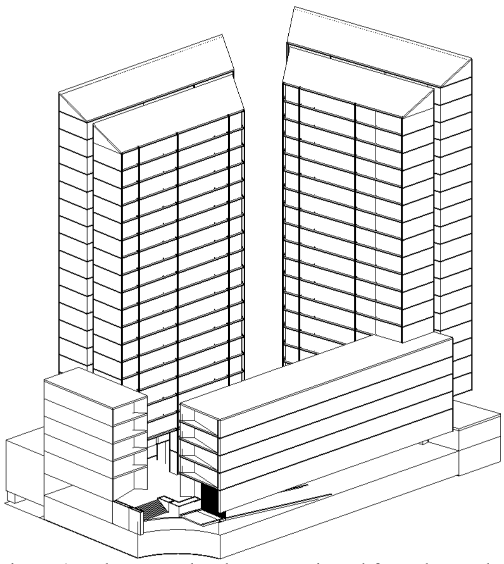

Figure 4. The target development, viewed from the southeast

Figure 5. The wind tunnel model

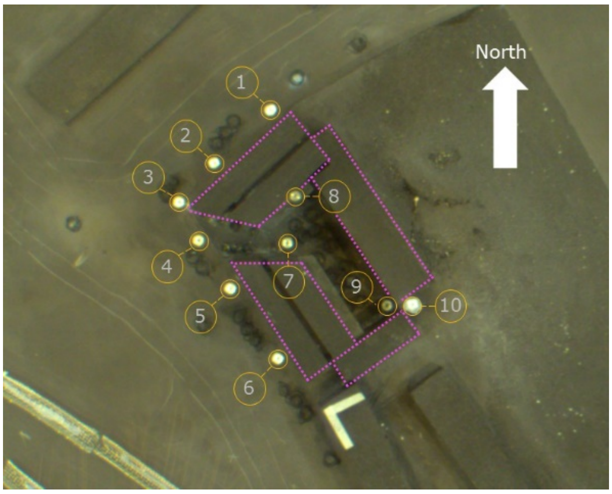

Figure 6: Locations of Irwin sensors, dotted lines denote building footprints

Ten Irwin sensors were installed in the wind tunnel model as shown in figure 6. Locations 1-6 and 10 are on footpaths at street level, whilst locations 7-9 are inside the elevated courtyard surrounded by the target buildings. Pressures from the sensors were measured at 400 Hz using the University of Auckland 512 channel pressure scanning system. The raw pressure data were corrected for tubing response using digital filtering technique detailed in [17] before the differential pressures of each Irwin probe were obtained by subtraction of relevant pairs of channels.

Results and Discussion

Figure 7 shows the comparison of mean wind speed ratios measured using Irwin probes and the corresponding speed ratios at the probe locations using erosion technique at 0 deg. The results show that the two techniques do pick up the same trends, i.e., locations 4-6 are calm and locations 1-3 and 9-10 are generally windier. The measurements between the 2 techniques do show discrepancies of up to +/- 50% at some of the worst locations.

Since the erosion technique is more indicative of a gust wind speed, a comparison between gust measurements from the Irwin probe with the erosion results is of interest.

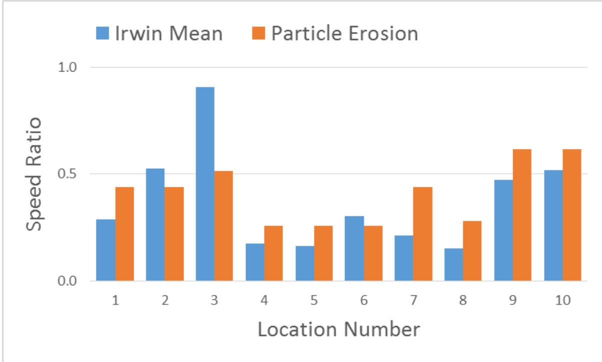

Figure 7: Comparison of mean wind speed ratios

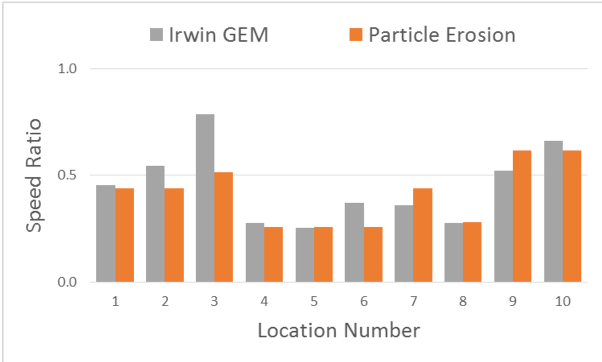

Figure 8: Comparison of gust equivalent mean wind speed ratios

Figure 8 shows the gust equivalent mean wind speed ratios from the Irwin probes compared to their erosion technique counterparts. The gust equivalent mean embodies the speed caused by both the mean and fluctuating winds via a gust factor as described in [18,19]. A gust factor of 1.85 is adopted for this study. The result shows a substantial improvement in terms of agreement, which reinforces the argument that the bran erosion technique, or any other particle erosion technique, is more sensitive to gust speed than mean speed.

Figure 9 shows the comfort category in accordance with the Auckland City Council's criteria[13] derived from the erosion technique, Figure 10 shows the same criteria derived from mean Irwin measurements for the 10 probe locations. The comfort category is essentially a weighted combination of "windiness" caused by all tested wind directions.

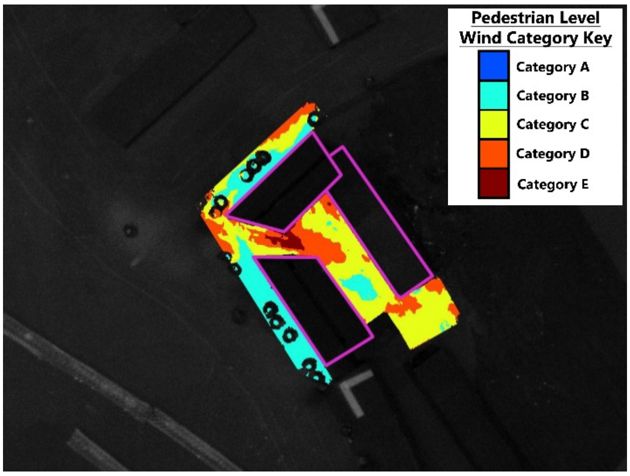

Figure 9: Comfort category derived from erosion technique

The agreement between the 2 techniques is generally good. The wind tunnel data has shown that locations 4 and 6 are "borderline" and can "switch" in final category if a different threshold wind speed is considered. The test data also shows that the measurements from the Irwin probes consistently measured higher mean wind speeds than using the erosion technique across the majority of the tested directions. This is perhaps because bran physically responds to gusts while the comfort criteria of Auckland City are specified in terms of mean wind speeds, whereas they are often determined from a gust equivalent mean wind speed.

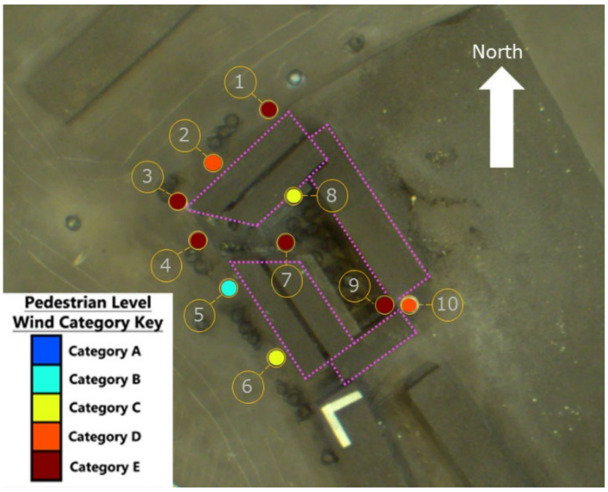

Figure 10: Comfort category derived from Irwin probes

Conclusions

In this paper a brief history of the derivation of the wind comfort criteria for Auckland City has been presented. Wind speed measurements from the erosion technique and Irwin probes have been compared. Agreement between the two techniques is generally good despite some locations showing differences in their predictions. It was found that there was better agreement between the bran erosion results and a gust equivalent mean speed from the Irwin probes than with mean speeds from the Irwin probes. This was as-expected since the bran is eroded by gusts to form an eroded pattern.

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