TENTH AUSTRALASIAN FLUID MECHANICS
CONFERENCE - UNIVERSITY OF MELBOURNE
11-15 DECEMBER 1989

15B-2

WIND ENVIRONMENT MEASUREMENTS AND ACCEPTANCE CRITERIA DEVELOPED AT THE UNIVERSITY OF AUCKLAND

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ABSTRACT

Wind acceptance criteria developed for Auckland City based on the results of recent wind-tunnel investigations into pedestrian-level winds, and on the work by other investigators are presented. The criteria are framed around Weibull distributions with an exponent k=1.5, as this shape was found to fit the measured results much better than the more accepted value of 2.0. The curves expressing the criteria have also been matched to the percentage of time that the wind speed is non-zero. These criteria have been developed with the objective of making them insensitive to the wind speed which is selected to determine the percentage of time that the specified speed is exceeded.

INTRODUCTION

During the past few years, and particularly in 1986-88, a large number of investigations into pedestrian-level winds have been carried out at the University of Auckland in the Boundary-layer Wind-tunnel at the Mechanical Engineering Department. Such investigations have generally been required of developers by the Auckland City Council (ACC) to meet City Ordinances, although occasionally developers have also requested testing in order to improve the wind environment of public spaces to attract increased numbers of shoppers. Until recently ACC required that only buildings exceeding 55 m in height be tested, however, a new City Ordinance covering wind control now allows ACC to have any proposed development subjected to an environmental wind-tunnel test.

The proposed buildings are becoming increasingly large (often exceeding 100 m and in one case exceeding 200 m in height), and consequently such buildings are having a more severe effect on the pedestrian-level wind environment than the earlier smaller buildings had. In essence, whereas previously most buildings 'passed' without requiring any remedial attention, presently the reverse is true.

This situation has caused the laboratory to look much more carefully at the way Wind Environment Categories are specified. The large amount of experimental data which have been accumulated from all the tests and are now available on computer file have allowed wind environment categories to be studied quite thoroughly. This is because the data can easily be processed many times. For example, supposedly identical category criteria can be specified in different ways, and then applied to measured wind-tunnel results in order to compare the resulting category distribution obtained by the areas in question.

It was felt that it would be instructive to investigate the effect of specifying wind environment categories at different speeds, and at the same time altering the percentage of time the speeds were exceeded in an appropriate manner. Davenport, Lawson, and others have framed wind environment criteria in this way (Isyumov et al 1975, Lawson et al 1975). One might initially assume that it wouldn't matter a great deal because the climate of wind speeds is generally governed by a Weibull distribution with an exponent k of around 2; this is the basis of Melbourne's comparison of wind speed criteria (Melbourne,1978). However, as pointed out by Lawson(1980), supposedly identical wind speed criteria when specified at different speeds can give different results if the actual probability distribution of the wind is different from the one assumed. Ohba et al (1988) also show how criteria framed in different ways give different results. The paper examines this point and recommends suitable criteria for Auckland.

TESTING TECHNIQUE

Wind-tunnel investigations into pedestrian-level winds have generally been carried out by the author using two main techniques - hot-wire anemometry and the erosion of a bed of material sprinkled in the vicinity of the building under investigation. Hot-wire measurements provide detailed wind statistics at the locations selected for study. However, it is time consuming to do large numbers of points and frustrating recalibrating the wire when it inevitably gets broken. Because of this, in most cases the investigations are carried out using the erosion technique. Architects and developers observing the tests also like this method.

In the erosion technique, irregularly shaped cork grains, about 2 mm in diameter are sprinkled uniformly at a fairly low density of about 1 grain/50 mm**2 around the building. The experimental procedure is to then increase the wind speed gradually through a range of steps, running for about 30 seconds at each step in speed. The grains are watched closely by at least two operators and, in addition, all tests are videoed for later playback and analysis, especially to observe areas which are difficult or impossible to see from outside the test section. The operators look for the first grain movements and sketch these areas onto maps, noting the reference speed at which the movement occurred. By so sketching the erosion areas for all the test speeds, a kind of 'contour map' is built up as shown in Fig 1.

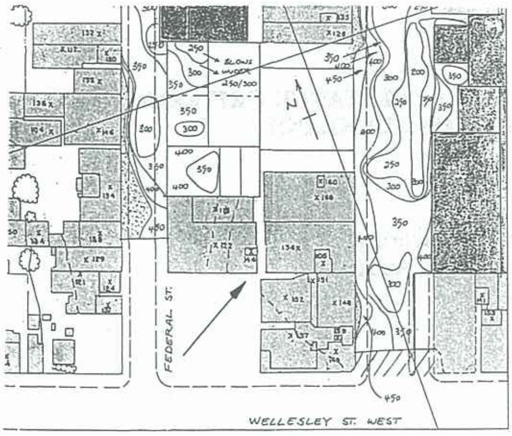

Fig 1 Typical contour map

Regions where the wind is accelerated erode early, corresponding to a low reference air speed, and conversely, sheltered areas erode last. This procedure is repeated for the predominant wind directions (usually about 8, spaced at 30 degree intervals), and in practice is quite fast. A more time consuming aspect is the enhancement of the original contour maps during video playback, when areas of special concern are looked at carefully, and obscured areas are filled in. Thus one ends up with about 8 contour maps of reference wind speeds for each test.

The aerodynamic characteristics of the grains have been studied to see what speed causes them to move. This has been done for about 100 grains by placing them on a suitable surface and mounting a hot-wire probe vertically with its centre at an equivalent height of 1.5 m full-scale, as close as possible to each grain. The mean and gust speeds when the grains moved were measured by the probe and a suitable average obtained. Hence from this calibration, the contours can be considered as speed ratios, R=Vl/Vr, where Vl is the local speed, (the mean speed at which it is known that the cork erodes) and Vr is the mean reference speed when the erosion occurred.

The next step is to combine these speed-up ratios with the climate data for each test wind direction. This is done by dividing the region of study into small areas and assigning R numbers to each area for each wind direction. These numbers are entered into a computer file, and then a program is run which combines the speed-up ratios with the long term Auckland climate data for each direction. The wind statistics for each area are then summed to give results for all directions combined, and then these results are used to assign a comfort category to each area. It has been found that colour plots of the results are the most informative method of presentation. The Auckland City Council has grown used to seeing them, and the advent of colour photocopying has made it feasible. Often the desired categories for each area are subtracted from the actual categories and colours used to highlight those areas which are possibly unsatisfactory leaving satisfactory areas uncoloured.

AUCKLAND'S WIND CLIMATE

Auckland is located at a latitude of about 37 degrees south, and its climate is subtropical. The predominant wind directions are NE and SW. It is sometimes visited by storms of tropical origin, e.g. Cyclone Bola on 5-12 March 1988, and it is vulnerable to strong gusty westerlies which may be accompanied by thunderstorms and rarely by tornadoes (Hessell,1988).

Wind speed frequency data have been recorded at a variety of sites since 1853 around Auckland. The Auckland City data used in the present pedestrian-level wind analysis were obtained from an anemometer mounted on a 10 m tower above a 21 m tall building in downtown Auckland.

The wind data used herein were for the period September 1962 to December 1983. Weibull distributions were fitted to each 30 degree sector and the agreement was found to be good. The coefficients are shown in Table 1. It can be seen that in most cases, k is a little over 2, and c is about 6. When the data from all directions are added together they are also fitted by a Weibull distribution with c=6.19 and k=2.08 quite well. Note that it is calm 12.4% of the time.

Table 1 Coefficients in Weibull Expression for 30 degree intervals - Auckland City.

direction	A	c	k
0	3.90	5.18	1.88
30	11.05	6.82	2.22
60	7.23	7.03	2.38
90	6.02	6.33	2.24
120	2.69	4.50	2.16
150	2.25	4.40	2.34
180	4.12	5.07	2.10
210	14.04	6.31	2.17
240	19.31	6.24	2.06
270	10.12	6.37	2.09
300	4.77	6.26	2.05
330	2.12	4.89	1.70
all combined	87.6	6.19	2.08

ANALYSIS PROCEDURE

The Weibull expression can be written in the following way

$$p(>V,\theta) = A(\theta)\exp\left\{-\left(\frac{V}{c(\theta)}\right)^{k(\theta)}\right\}$$

where $A(\theta)$ is the proportion of time that the wind blows from direction θ ,and $c(\theta)$ and $k(\theta)$ are the fitted mode and exponent respectively for the particular climate data.

The wind-tunnel test allows $R(n,\theta)$ to be determined, where R is the ratio of the wind speed at point or area n and direction θ to the reference wind speed.

Hence the wind speed at point n for wind direction can be written as

$$p(>V,n,\theta) = A(\theta)\exp\left\{-\left(\frac{V}{R(n,\theta)c(\theta)}\right)^{k(\theta)}\right\}$$

To determine the total time that speed V is exceeded at point n, the summation below is determined

$$p(>V,n) = \sum_{\theta=0,30...}^{330} A(\theta)\exp\left\{-\left(\frac{V}{R(n,\theta)c(\theta)}\right)^{k(\theta)}\right\}$$

This summation is carried out by the software. P(>V,n) is normally expressed as a percentage of total time, and results are available at all values of V so that suitable combinations of P(>V,n) and V can be extracted for the application of category criteria.

SAMPLE RESULTS

Fig 2 shows some typical results of the percentage of time particular wind speeds are exceeded near the base of a tall building. As can be seen, the actual data can be fitted quite well by a Weibull expression with k= 1.48.

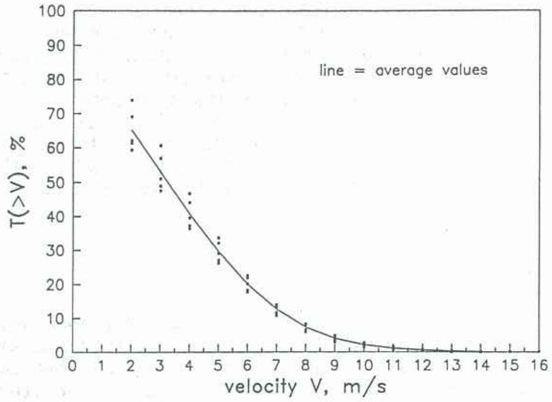

Fig 2 Typical test results for the percentage of time wind speeds are exceeded

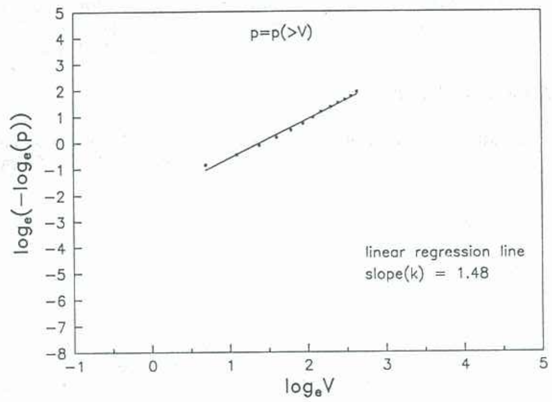

Fig 3 Typical test results for the percentage of time wind speeds are exceeded - transformed axes.

Fig 3 shows this comparison on a plot where the axes have been transformed so that any Weibull curve plots as a straight line. The value of k in Figs 2 and 3 is significantly less than 2 and was initially unexpected in view of the actual climate data. However, it is typical of many results which have been examined. In addition, this phenomenon where the wind speeds close to a building are fitted by a Weibull with a lower value of k than the upper level data has been observed before but not specifically commented on (Murakami,1983). Unfortunately it causes difficulties when trying to put areas into categories specified by Weibulls with k=2, because the data lie across several categories as illustrated in Fig 4.

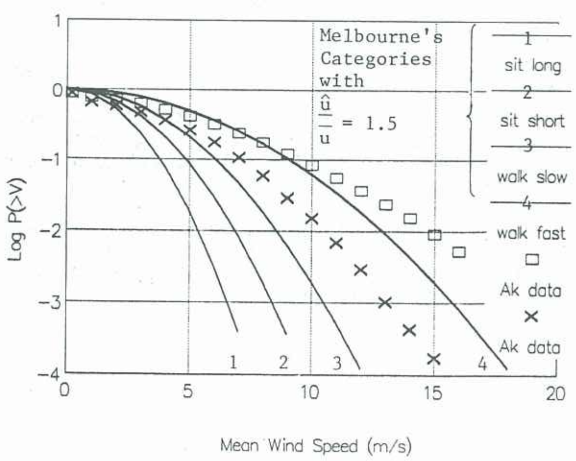

Fig 4 Comparison of Auckland test results with a Weibull curve where k=2

THEORETICAL ATTACK

To check whether the results shown here could be expected theoretically, an investigation was carried out where pairs of Weibull curves for the speed range 2 - 30 m/s were added together and a third Weibull curve fitted to the result. Effectively, this simulates what happens when the results of two directions are added together, and so is the basis of the summation process in the data reduction phase after a wind-tunnel test. The results of this analysis are displayed in Table 2.

Table 2a shows that when two Weibulls are added together with differing values of c but identical values of A and k, c approximately takes on the value (c1+c2)/2 in the fitted curve, whereas k becomes smaller the more c1 differs from c2.

TABLE 2 Summations of pairs of Weibull curves

(a) A, k constant, c variable

A1	c1	k1	A2	c2	k2	A	c	k
10	6	2	10	6	2	20	6.00	2.00
10	6	2	10	9	2	20	7.58	1.82
10	6	2	10	12	2	20	9.05	1.65
10	6	2	10	15	2	20	10.40	1.51
10	6	2	10	18	2	20	11.66	1.40

(b) A, c constant, k variable

A1	c1	k1	A2	c2	k2	A	c	k
10	6	2	10	6	1.4	20	6.1	1.54
10	6	2	10	6	1.6	20	6.06	1.70
10	6	2	10	6	1.8	20	6.02	1.86
10	6	2	10	6	2.0	20	6.0	2.0
10	6	2	10	6	2.2	20	6.02	2.06
10	6	2	10	6	2.4	20	6.06	2.09

(c) c, k constant, A variable

A1	c1	k1	A2	c2	k2	A	c	k
10	6	1.8	2	6	2.2	12	6.02	1.83
10	6	1.8	4	6	2.2	14	6.04	1.85
10	6	1.8	6	6	2.2	16	6.05	1.87
10	6	1.8	8	6	2.2	18	6.05	1.88
10	6	1.8	10	6	2.2	20	6.06	1.89
10	6	1.8	12	6	2.2	22	6.06	1.90
10	6	1.8	14	6	2.2	24	6.06	1.91
10	6	1.8	90	6	2.2	100	6.07	2.02

Table 2b shows that when Weibulls with the same values of A and c but different values of k are added together, the resulting fitted curve is biased towards the lower k value, and very approximately k=kl+(ku-kl)/4, where ku and kl are the upper and lower k values respectively. c remains approximately constant.

Table 2c gives the result of adding together two Weibull curves, one with k=1.8 and one with k=2.2, both with c=6, when A2 is progressively increased. It can be seen that c remains approximately constant at c=6, but that k rises as A2 increases. However this rise is slow, and when A2 is increased to 90 (9 times A1), k is only 2.02 - about midway between k1 and k2. Hence, again it is the smaller k value which dominates k of the fitted curve.

In summary, these results show that it is the smaller value of k which dominates the result of adding two Weibull curves together, and hence it is expected that k for areas in the close proximity of buildings should be lower than k for the upper level climate data. This is expected to occur because of the relatively high and low values of c which event from the exposed and sheltered directions respectively. This suggests that comfort criteria should be related to a lower value of k than 2.0.

PEDESTRIAN-LEVEL WIND SPEED CRITERIA FOR AUCKLAND CITY

Existing Criteria

Two wind speed comfort criteria have previously been used at the University of Auckland, those due to Melbourne(1978), and those due to Lawson(1978). Melbourne's criteria were generally applied when hot-wire anemometry was used. P(>V) was calculated at a particular value of V for the points studied to see whether it lay above or below the acceptable curve. Lawson's criteria were further sub-divided as shown in Table 3, and have generally been used more recently in conjunction with the cork erosion test technique.

Table 3 Comfort categories used earlier at Auckland

Category	Location	Probability P(>V) %	mean speed V m/s
1	plazas, entrances	<4	8
2	around buildings	5-8.5	8
3	roads, carparks	3-5.5	11
4	onset of danger	>2	14

Proposed Criteria

It was decided that wind speed criteria would be established which would be presented as zones, on a graph of cumulative probability of exceedence against mean wind speed, as originally put forward by Melbourne. Based on the findings discussed above, each curve demarking zones would be described by a Weibull expression with k=1.5, and would be forced through the point P(>V)=0.876 for V=0.0 because it is calm in Auckland for 12.4% of the time. The curves would be fitted closely to well established international criteria (Isyumov et al, 1975, Penwarden et al, 1975, Lawson,1978) in the higher range of probabilities. Comfort zones would be identified which could each be described as suitable for - sitting for long periods, sitting for short periods, walking slowly, walking quickly, and dangerous.

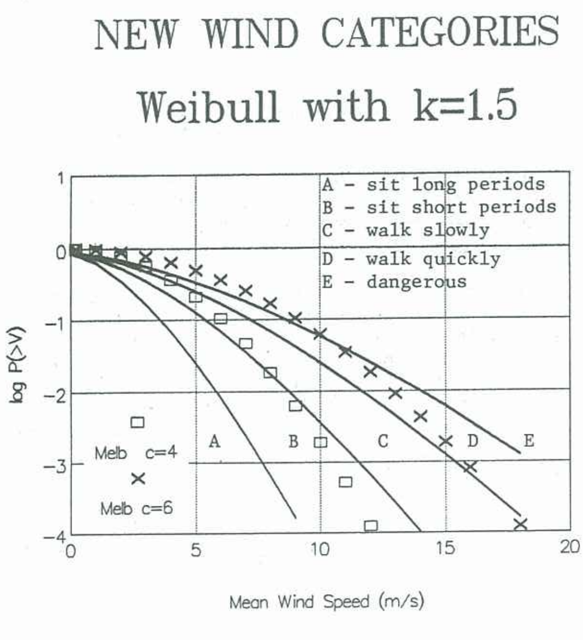

Fig 5 New Wind Acceptance Criteria

The categories devised are shown in Fig 5. It should be reiterated that they have been developed for Auckland and so may not be suitable for other areas with a different long-term wind frequency distribution. These categories have been included in Auckland's recently revised District Scheme. There is one additional criterion which has been included in the District Scheme and that is that the peak gust once per annum should not exceed 25 m/s.

CONCLUSIONS

Wind acceptance criteria have been described which it is believed are suitable for the Auckland wind climate situation, and which generally agree well with accepted international criteria. The criteria developed should be relatively insensitive to the speed V which is selected to find P(>V). In other words, it is believed that the wind frequency distribution at points under study in the vicinity of buildings in Auckland will usually lie in a single category zone, irrespective of wind speed.

ACKNOWLEDGEMENTS

The author acknowledges the fruitful discussions held with V.A.L. Chasteau, G. Farrant, B.R. Cowan, and D.J. Smedley on this topic.

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