18th Australasian Wind Engineering Society Workshop
McLaren Vale, South Australia
6-8 July 2016

Determination of turbulence intensity and roughness length from AWS data

J.D. Holmes[1]

[1]JDH Consulting
Mentone, Victoria 3194, Australia

Abstract

This paper describes a procedure used to determine the turbulence intensities and roughness lengths for winds from all available directions, from anemometers at automatic weather stations in the Melbourne area. About 2000 gust factors were recorded in medium to strong wind events between 2013 and 2015. The procedure relies on theoretical peak factors, and averaging of gust factors from up to 140 samples per direction sector. Using the calculated roughness lengths, tentative correction factors for peak gust wind speeds for Melbourne (Tullamarine) and Moorabbin Airports have been derived.

Introduction

The Bureau of Meteorology (BoM) records automatic weather station (AWS) data on wind speeds and direction every half hour from 685 stations (number as of September 2015). The wind speeds are 10-minute averages, and maximum 3-second gusts during that 10-minute period. The ratio of these two values, gives gust factors which can provide useful information on the turbulence intensity, and hence the effective roughness length and terrain category, by direction sector. This in turn can be used to derive correction factors for correcting measured mean wind speeds and peak gusts to the standard terrain conditions of 10-metres height in flat, open terrain.

Database

For the present study, data recorded by the BoM from AWS in the Melbourne area in the period 2013 to 2016 were used. Data is normally available online within a few minutes of recording, and remains there for 72 hours after recording.

For the present study a minimum 10-minute mean of 10 knots was set, and the data was collected more or less randomly from days with strong wind events. An attempt was made to cover all sixteen cardinal direction sectors at each station, although this was not possible for some sectors in which medium to strong winds rarely occur (typically from the eastern quadrant in the Melbourne area).

Figure 1 (taken from the BoM web site) shows the AWS in the Melbourne area that record wind speed and direction.

Of the eleven stations shown, Coldstream and Avalon are well outside the metropolitan area, the latter being closer to Geelong than Melbourne. Several of the others are poorly sited – i.e. ‘Melbourne Olympic Park’ is adjacent to several large sports arenas, and ‘St. Kilda Harbour’ is on top of a yacht club building.

Melbourne Airport (Tullamarine), Essendon Airport, Moorabbin Airport and Laverton have been selected as potentially the most useful, being located on flat, open land and generally free from the direct influence of buildings. However, it should be noted that the airfield at Laverton has been decommissioned, and is the site of the new suburb of Williams Landing; hence data from the AWS there may be of less use in the future. The Essendon AWS is also now completely surrounded by changing suburban development.

Figure 1. Automatic weather stations in the Melbourne area

Fawkner Beacon in Port Phillip Bay is also of interest, as it is completely surrounded by water, for at least 5 kilometres in all directions. However, wind over water surfaces has its own special characteristics, and data from that station will not be included here, but may be the subject of a future paper.

Table 1 shows the number of 10-minute samples used for the results in this paper, for the four selected stations and all direction sectors. There is no shortage of data for the prevailing N and WSW winds. However, the lack of data from the NE, ENE and E is common to all four stations. From a wind loading viewpoint these directions are clearly of little interest in the Melbourne area. For these stations, all the data was obtained at the standard meteorological height of 10 metres.

Direction	Essendon AP	Laverton	Melbourne AP	Moorabbin AP
N	137	85	123	131
NNE	12	13	13	2
NE	0	0	0	0
ENE	0	0	0	0
E	0	0	0	0
ESE	1	37	1	120
SE	33	32	9	18
SSE	20	13	42	17
S	43	41	40	9
SSW	13	6	10	34
SW	22	27	64	30
WSW	63	82	68	44
W	42	43	37	47
WNW	13	15	17	17
NW	33	49	47	18
NNW	49	40	33	47
Total	**481**	**483**	**504**	**534**

Table 1. Number of samples of gust factor used for this paper

Procedure

For the total of 2002 samples of gust factors (i.e. max 3-second gust/ 10-minute mean) obtained, the following procedure was used to derive turbulence intensity and roughness length for each station-direction:

- For each sample with known mean wind speed, a theoretical 'expected' peak factor, g_u, was calculated using the approach described by Holmes et al. (2014), based on random processes, and assuming the von Karman spectral density given in AS/NZS 1170.2 (Standards Australia, 2011), with an integral length scale of 85m.
- A turbulence intensity was then calculated for each sample from Equation (1).

$$I_u = \frac{G-1}{g_u} \qquad (1)$$

where G is the recorded gust factor for that sample.

- The resulting turbulence intensities were then averaged over all the samples available for each station-direction set.
- Equation (2) was then used to get an estimate of aerodynamic roughness length, z_0, from the turbulence intensity.

$$I_u(z) = \frac{1}{\log_e(z/z_0)} \qquad (2)$$

That is for z equal to 10 metres, and inverting Eq. (2):

$$z_0 \cong 10.\exp(\frac{-1}{I_u}) \qquad (3)$$

Although there are a number of assumptions made, these are consistent with AS/NZS 1170.2 and accepted models of strong winds used in wind engineering, for synoptic winds.

The recorded data included a few cases with high gust factors (i.e. exceeding 2). Since this study focussed on synoptic scale boundary-layer winds, such data were assumed to result from convective gusts and were not included in the processing described above.

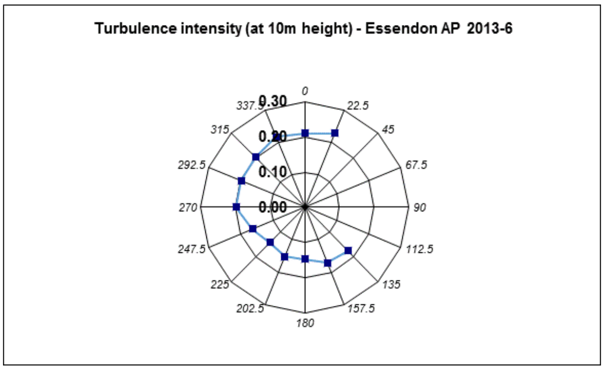
Results

Turbulence Intensities

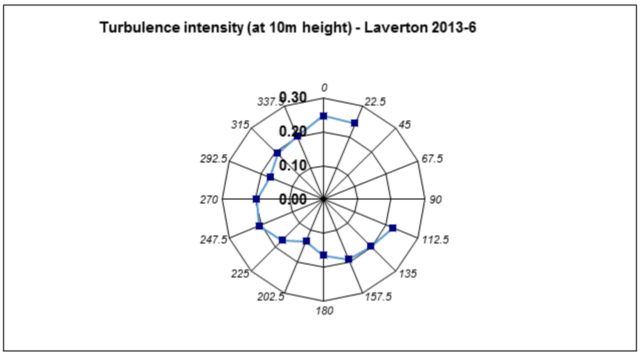
Figure 2 shows the turbulence intensities in the form of polar plots for the four stations as a function of wind direction, calculated as described in the previous section. Generally, the values fall in the 0.15 to 0.20 range – a range expected for flat open country (i.e. Terrain Category 2 in AS/NZS 1170.2). Exceptions, for which higher values than 0.20 occur, are: Laverton for N and NNE, Melbourne Airport (Tullamarine) for NW, and Moorabbin Airport for directions from SW to NW.

Roughness Lengths

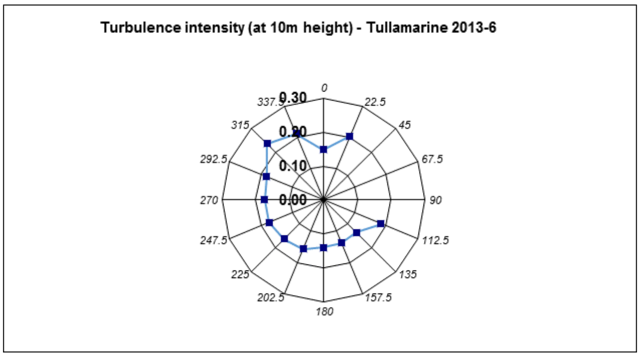
Effective roughness lengths were calculated using Equation (3), and compared with values of z_0 associated with the Terrain Categories in AS/NZS 1170.2. These values are plotted for the four stations in Figure 3. The roughness lengths associated with Terrain Categories 1, 2 and 3 in AS/NZS 1170.2 are also shown – i.e. 2mm, 20mm and 200mm.



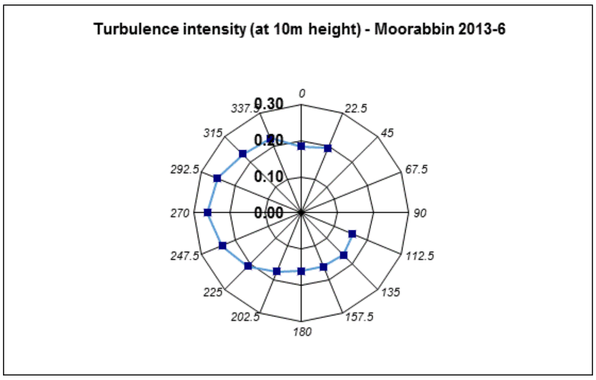
(a) Essendon Airport



(b) Laverton RAAF base

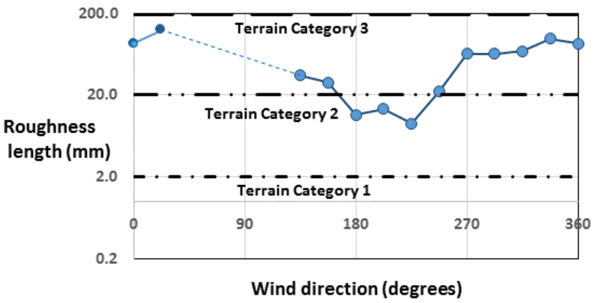


(c) Melbourne Airport

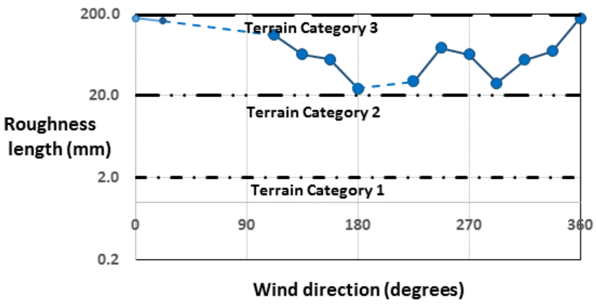


(d) Moorabbin Airport

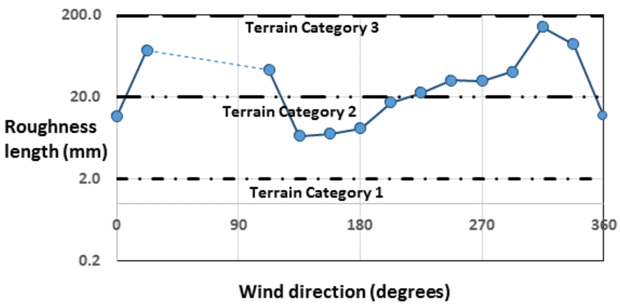
Figure 2. Turbulence intensity as a function of wind direction



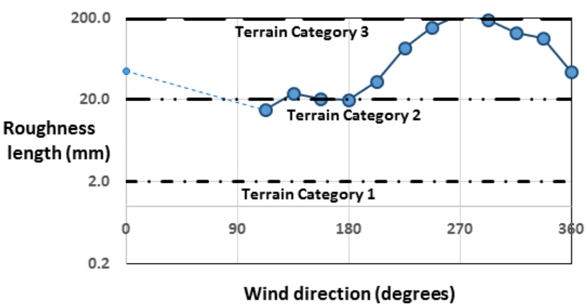
(a) Essendon Airport



(b) Laverton RAAF Base



(c) Melbourne Airport



(d) Moorabbin Airport

Figure 3. Roughness length as a function of wind direction

Discussion

The roughness lengths for Essendon Airport (Fig. 3 (a)), for northerly and westerly winds, are greater than they are for southerlies. This is difficult to understand as the anemometer is apparently located close to the centre of the airfield, and roughly equidistant from the surrounding buildings for most directions.

Similar values of z_0 occur for Laverton (Fig. 3(b) as for Essendon – i.e. falling between the values for Terrain Category 2 (20mm) and for T.C.3 (200mm). However, the suburban re-development of the Laverton site has probably started to introduce changes in roughness with time.

Melbourne Airport shows roughness lengths close to that for TC2 for most directions (Fig. 3(c)); however; there is a local peak in z_0 for NW and NNW winds. This can probably be explained by the dense clump of trees located about 500-1500 m from the anemometer in those directions (ringed in red on Figure 4).

Figure 4. Melbourme Airport showing anemometer location (yellow 'pin') and forest of trees to the north west (red circle)

The AWS at Moorabbin Airport is located on the west side of the airfield, close to the buildings of the airport, with dense suburbia further west, and a DFO shopping centre to the north west, with an industrial area to the south west. This location explains the high roughness – approximating that of Terrain Category 3 - for wind from the SW-NW quadrant (Fig. 3(d)).

For wind engineering purposes, the anemometers at Melbourne Airport (Tullamarine) and Moorabbin Airport appear to be the most useful for predictions of the future wind climate in the Melbourne area. The changes to the surrounding terrain in recent decades, have been relatively small and the two stations can give a good representation of the extreme wind climate for the north and west, and south and east sides of the metropolitan area respectively. However, it is clear from the Figures 3(c) and 3(d) that corrections to mean and gust wind speeds from both AWS are required for some directions. A tentative set of directional correction factors for both Tullamarine and Moorabbin is proposed in the following section.

Correction factors for terrain

AS/NZS 1170.2 is based on regional gust wind speeds that are nominally obtained from 10-metres height in flat, open country terrain (i.e. Terrain Category 2 in the Standard). Hence, for application to the Standard, recorded gust data should be corrected to that terrain-height condition for all wind directions.

Tables 2 and 3 show tentative correction factors for maximum gust wind speeds for the AWS anemometer data at Melbourne and Moorabbin Airports, respectively. The corrections to gust speeds also include a correction for the averaging time, since the BoM currently records 3-second moving-average gusts, whereas AS/NZS 1170.2 is based on a 0.2 second gust (Holmes and Ginger, 2012).

Direction	Correction for terrain	Correction for gust duration	Combined correction factor
N	0.98	1.10	1.07
NNE	1.11	1.12	1.25
NE	-	-	-
ENE	-	-	-
E	-	-	-
ESE	1.05	1.11	1.17
SE	0.94	1.09	1.03
SSE	0.94	1.09	1.03
S	0.95	1.09	1.04
SSW	0.99	1.10	1.09
SW	1.00	1.10	1.10
WSW	1.04	1.11	1.15
W	1.04	1.11	1.15
WNW	1.05	1.11	1.17
NW	1.18	1.13	1.34
NNW	1.11	1.12	1.25

Table 2. Tentative correction factors for Melbourne Airport max gusts

Direction	Correction for terrain	Correction for gust duration	Combined correction factor
N	1.05	1.11	1.17
NNE	1.09	1.12	1.22
NE	-	-	-
ENE	-	-	-
E	-	-	-
ESE	0.99	1.10	1.09
SE	1.02	1.11	1.12
SSE	1.00	1.10	1.10
S	1.00	1.10	1.10
SSW	1.04	1.11	1.15
SW	1.11	1.12	1.25
WSW	1.18	1.13	1.34
W	1.20	1.14	1.38
WNW	1.20	1.14	1.37
NW	1.16	1.13	1.31
NNW	1.16	1.13	1.31

Table 2. Tentative correction factors for Moorabbin Airport max gusts

The correction factors for terrain were derived by firstly, converting the roughness length, z_0, into an equivalent fractional terrain category using the inverse of the relationship in Eq. (4):

$$z_0 = 2 \times 10^{TC-4} \qquad \text{(in metres)} \qquad (4)$$

Then the correction factor for terrain was taken as the reciprocal of the terrain-height multiplier for the height of 10m, obtained, using interpolation, from *Table 4.1* in AS/NZS 1170.2.

The correction factors for gust duration were derived using the calculated turbulence intensities (see Fig. 2), and expected peak factors for 0.2 sec and 3 sec moving average gusts (see Holmes et al., 2014, *Table 2*)

$$\text{i.e.} \quad CF_2 = \frac{1+3.4\,I_u}{1+2.5\,I_u} \qquad (5)$$

Equation (5) is applicable to a 600 second (10-minute) sample time.

Conclusions

This paper has demonstrated that useful information on turbulence intensities, and equivalent aerodynamic roughness lengths, can be obtained from 10-minute mean and 3-second maximum gusts routinely reported by the BoM from AWS around the country. This can lead to correction factors for gust wind speeds to the equivalent flat, open country (TC 2) value required by AS/NZS 1170.2. However, this procedure is a supplement to, and should not completely replace, site inspection through satellite images (e.g. Google Earth).

For the Melbourne area, the AWS data from Melbourne and Moorabbin Airports appear to be the most useful, with both Essendon and Laverton apparently being affected by recent urban developments. Tentative directional correction factors for peak gusts recorded at Melbourne and Moorabbin Airports have been presented.

References

Holmes, J.D., Allsop, A.C and Ginger, J.D. (2014) Gust durations, gust factors and gust response factors in codes and standards, Wind and Structures, 19: 339-352.

Holmes, J.D. and Ginger, J.D. (2012) The gust wind speed duration in AS/NZS 1170, Australian J. Struct. Eng., 13: 207-217.

Standards Australia and Standards New Zealand, *Structural design actions: Wind actions*, Australian/New Zealand Standard AS/NZS 1170.2:2011, Standards Australia, Sydney, and Standards New Zealand, Wellington.