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Assessing the Reliability of Directional Multipliers from a Single Station

N.K. Truong and A.W. Rofail

Windtech Consultants

19 Willis St, Wolli Creek, NSW 2205, Australia

Abstract

The calculation of directional multipliers is an important step in the analysis of the wind climate for a subject region. These values have been documented in countries such as Australia. However, this is often not the case in developing countries, where there is often only one meteorological station in the region where extensive wind climate data is recorded. In these areas it is useful to be able to assess the reliability of the calculated directional multipliers by benchmarking against values of statistical parameters from high quality long-term meteorological data. This paper presents a sample of such statistical parameters.

Four methods of calculating wind direction multipliers have been applied to three Australian meteorological stations. Ninety percent confidence intervals for the directional multiples have been calculated. Comparisons between the methods and stations have been conducted using a t-test.

A parameter which describes the overall error associated with each technique was found to be useful in assessing the directional multipliers. The results of the t-test were found to have limitations. It is suggested that in areas where there is uncertainty in directional wind speeds, an allowance for uncertainty in the directional wind speeds can be incorporated into the final wind load calculations by calculating the directional multiplier using a wind speed at the upper bound of a confidence interval.

Introduction

The analysis of recorded meteorological data for a city or region typically shows that the wind events do not occur with equal probability from all wind sectors and that high wind speeds do not occur with equal probability from all wind sectors. Additionally, as the wind induced pressure distribution around a structure is shape dependant and the structural frame within a building will have a specific orientation, the response of a structure to wind loading will generally be dependent on the orientation of the structure relative to the prevailing wind directions. Due to these two factors it is important to analyse the directional variation of the wind to accurately predict how the structure responds to winds from various directions.

The method used in the Australian/New Zealand Standard for Wind Actions (Standards Australia, 2011) is to use wind direction multipliers (M_d). These multipliers are combined with the non-directional regional wind speed to calculate the directional wind speed. The wind loads on the structure are calculated for the wind occurring from each sector and each sector is analysis independently. This method is often referred to as the sector method.

In general long term high quality meteorological data, for varying averaging times is available for all major urban areas in Australia. The availability of this data greatly assists in the determination of direction multipliers. However, multiple nearby stations with long term high quality data is not always available in other countries, especially in areas experiencing rapid modernisation.

One method of increasing the users' confidence in the accuracy of the directional multipliers for these areas is to calculate them using several different methods and determine a level of repeatability between the methods. Before this can be conducted a reference standard of repeatability is required.

In this paper several methods for calculating directional multipliers for use in the sector analysis method have been applied to meteorological data for two airports in Melbourne and one Sydney airport. Statistical parameters for the various methods have been calculated and compared, with the aim of providing a range of expected statistical values that may be compared with directional multipliers from other countries in order to objectively determine whether the calculated directional multipliers are sufficiently reliable.

Methods

Direction Multiplier Definition

The definition of wind direction multipliers calculated in this paper is the same as that used in the Australian Standard. The wind direction multipliers in the Australian Standard are derived from the probability distributions of recorded meteorological data. They are based on the hypothesis that the majority of the combined probability of exceedance of a load effect comes from two 45-degree sectors (Melbourne, 1984). It is then assumed that the probability of exceedance for each 45-degree sector is half that of the non-directional analysis. The assumption is also made that the directional data is uncorrelated. The hypothesis was developed from considering a rectangular shaped building. For example, if the probability of exceedance is 0.001 for a non-directional analysis, then for directional analysis of 45-degree sectors the probability of exceedance is 0.0005.

Direction Multiplier Calculation Techniques

Direction multipliers may be calculated from the recorded meteorological data using several techniques. The relative merits of the four techniques will not be discussed in depth in this paper. For further information on directional wind speeds and the calculation of directional multipliers see ESDU (1990), Holmes (2001) and Kasperski (2000).

The following four methods were trialled in this study:

1. Directional wind speeds are calculated for each sector using a fit to data in a frequency table derived from a continuous wind speed data (Parent Distribution)

2. Directional wind speeds are calculated for a fixed probability level using data in a frequency table derived from daily maximum wind speeds.
3. Directional wind speeds are calculated using probabilities for a fixed wind speed level using data in a frequency table derived from daily maximum wind speeds combined with a non-directional wind speed fit.
4. For each directional sector, wind speeds are calculated using a type 1 extreme value fit to annual maximum data using Gringorten plotting parameters.

For method 3, the probabilities were selected using wind speeds at an upper level and a maximum from the mid and upper levels. It is important to note that the wind speed measurements used in method one cannot be assumed to be fully independent measurements as they are derived from the full parent wind speed distribution.

Ninety percent confidence intervals were calculated for each of the four techniques. To calculate the confidence intervals, for data derived from frequency tables a Poisson process was assumed and for the fitted data a t-distribution was used. The square root of the sum of the squares of the confidence interval half width was used as a measure of the overall error associated with each technique. A t-test for samples with difference variances was used to compare the significance of the differences between the calculated directional multipliers.

Metrological Data and Stations

The meteorological data was corrected using the ESDU 82026:2002 ESDU 83045:2002 method. Mean wind speed data was used in this analysis, to avoid the need to correct the measurements due to the changes in recording equipment.

The three meteorological stations that were analysed were:

1. Sydney Airport
2. Melbourne Airport
3. Essendon Airport

The record lengths for these three airports (25 to 40 years) are in range that is typically found for data in developing countries. The "superstationing" of data was not used as multiple reliable nearby stations is often not available in developing countries.

Results

Direction Multipliers

Figures 1 to 3 present the calculated wind direction multipliers for the three Australian sites. The error bars shown are for the 90% confidence interval. A minimum directional multiplier of 0.70 was used.

Comparison Statistics

Table 1 presents the square root of the sum of the squares of the confidence interval half width and this is used as a measure of the overall error associated with each technique. To provide context for this parameter, a value of 0.18 is equal to all 12 sectors having a half width error of 0.05.

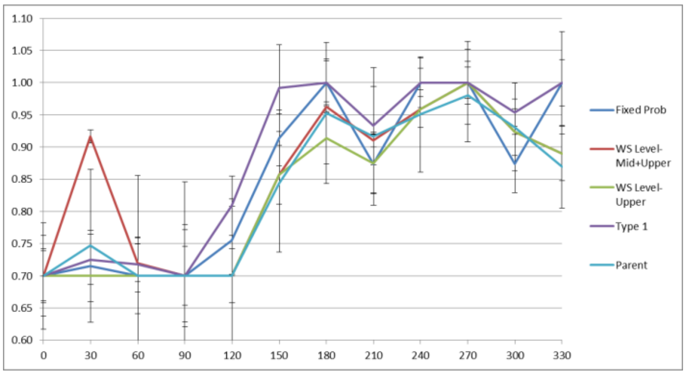

Figure 1. Comparison of Directional Multipliers for Sydney Airport.

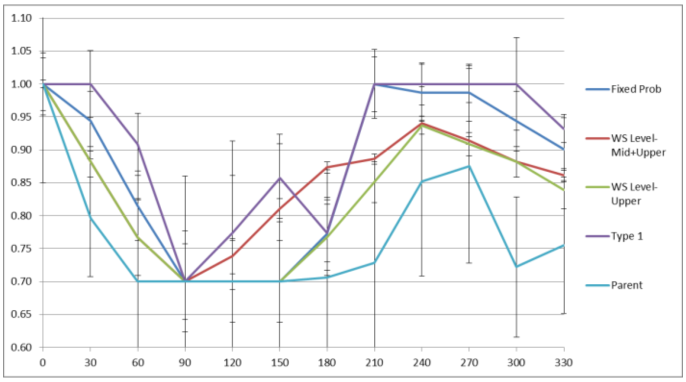

Figure 2. Comparison of Directional Multipliers for Melbourne Airport.

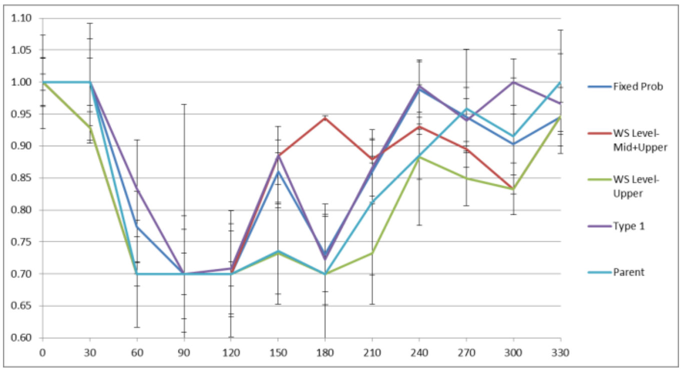

Figure 3. Comparison of Directional Multipliers for Essendon Airport.

	Sydney	Melbourne	Essendon
Fixed Probability	0.17	0.18	0.19
Wind Speed Level - Mid+Upper	0.12	0.09	0.07
Wind Speed Level – Upper	0.10	0.10	0.14
Type 1	0.18	0.19	0.19
Parent	0.37	0.52	0.41

Table 1: Comparison of Errors of the Australian Stations.

A t-test was used to determine if the difference between two nominated methods was significant using a 90% confidence interval. The percentages of sectors that do not satisfy the 90% confidence in the t-test are presented in Table 2.

Method 1	Method 2	Sydney	Melbourne	Essendon
Parent	Fixed Prob	8%	42%	8%
Parent	WS Level - Mid+Upper	8%	42%	17%
Parent	WS Level - Upper	0%	17%	8%
Parent	Type 1	17%	50%	25%
Fixed Prob	WS Level - Mid+Upper	58%	58%	50%
Fixed Prob	WS Level - Upper	42%	50%	58%
Fixed Prob	Type 1	17%	17%	8%
WS Level - Mid+Upper	WS Level - Upper	17%	33%	42%
WS Level - Mid+Upper	Type 1	50%	67%	50%
WS Level - Upper	Type 1	42%	67%	58%

Table 2: Comparison of the significance of the difference between the direction multiplies for each station.

Discussion

Direction Multipliers

An inspection of the direction multipliers and their confidence intervals presented in Figures 1 to 3 shows that there is notable variation in the mean values of the directional multipliers and that there is a wide range in the expected value.

For the Sydney station the five methods are in broad agreement with the exception of the 30 degree wind direction. The north-easterly wind direction is a frequent low wind speed event and the wind speed level probability method which uses a mid-level wind speed has picked up this direction. Interestingly, the method relying on wind speed fit parameters from the parent distribution has not emphasised this direction, despite the frequency of this direction.

For the Melbourne and Essendon stations, for the wind directions between the two domination wind directions there is poor agreement between the methods, for example for the north-easterly direction. This may be related to the direction “spread” of the measurement of the extreme wind events. The frequent but less intense southerly winds have also been picked up by the wind speed level probability method which uses a mid-level wind speeds.

Comparison Statistics

Table 1 shows that other than for the parent distribution method the range of the square root of the sum of squares is less than 0.2. This can be attributed to the directional multipliers from the parent distribution method having a broader confidence interval relative to the other methods which is due to the uncertainty in the fitting of the wind speed – probability distribution to the recorded data. This large confidence interval is not unexpected as the parent distribution data will include wind recordings generated by several different climatological mechanisms, which makes fitting a single distribution difficult. The approaches and difficulties to fitting statistical model to these types of data sets is well documented.

There is not a clear difference between the other four techniques for the three stations shown, although the probability from the fixed wind speed methods have narrower intervals than the fixed probability and Type 1 methods.

The t-test results of the comparison between the methods for the various stations show that the parent distribution method compares favourably with the other methods. However, this is due to the large absolute value of the width of the confidence interval of the directional multipliers from the parent method. Of the remaining techniques the closest agreement is between the fixed probability and the Type 1 fit methods.

Due to the inherent sensitively of the t-test to the width of the confidence interval the ability to draw clear conclusions from the test t-test results is limited to cases where the confidence interval of both techniques are similar. Overall this method may not be the most appropriate is assisting with the validation of wind direction multipliers.

Application of these methods to other stations

The calculation of these parameters is useful in providing an indication of the overall uncertainty in the calculated directional multipliers. Based on these stations, the parameter based on the square root of the sum of the squares of the confidence interval half width is the simplest to use and interpret. The use of the t-test as a method for validating directional multipliers should not be completely ignored. For example, in the cases where the confidence intervals are wide and the t-test results show that the majority of the directional multipliers from two different techniques are not the same, then this negative result would imply significant uncertainty in the directional multipliers.

An important consideration in developing and applying these parameters is that that exactly the same procedure needs to be applied to the reference station data (such as the stations used in this paper) and the subject station data.

Incorporating Uncertainty into Directional Multipliers

For areas where there is large uncertainty in the in directional wind speeds it may still be desirable to calculate directional multipliers. However, these values should be within the limitations of the available data.

A suggested approach for allowing for the uncertainty in the directional wind speed in subsequent calculations is to replace the expected mean value of the directional multiplier with a value closer to the tail of the confidence interval. For example, in this application the directional multiplier may be calculated based on a wind speed at the upper bound of a confidence interval with a width of sixty-seven or ninety percent.

Using the upper bound of a confidence interval with a width of sixty-seven percent new directional multipliers were calculated for the three stations for all of the methods. The maximum increase in the direction multiplier across the three stations was 0.05 for all the methods other than for the parent distribution technique, which had an maximum increase of 0.13. The addition of an extra 0.05 to the directional multiplier corresponds to an increase in the design loads of approximately ten percent.

Conclusions

From the analysis of the meteorological data from the three Australian recording stations considered, the following conclusions may be drawn:

- The statistical parameters described in this paper provide a method to assess calculated directional multipliers from the same recording station.
- The parameter based on the square root of the sum of the squares of the confidence interval half width is the simplest to use and interpret.
- There are limitations in using a t-test to compare directional multipliers calculated using different techniques.

It is suggested that by calculating the directional multiplier using a wind speed at the upper bound of a confidence interval, an allowance for uncertainty in the directional wind speeds can be incorporated into the final wind load calculations.

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