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Multi-Sector Directional Probability Integration for Facade Cladding Pressures: Comparison Between the Multi- Sector, Load-Effects and Sector by Sector Method

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ABSTRACT

The method used to combine the directional aerodynamic coefficients, with the local wind directionality is one of the most important factors in accurately determining the design loads for a given risk or probability level. The multi-sector method (Holmes, 1990), a form of directional probability integration, has been compared against the Load Effects Method (also referred to as the Direct Method). Comparisons were repeated for three different wind climate models: two being temperate climates and based on meteorological observations and the other located in a cyclonic region and based on simulated tropical cyclone data. The comparison was found to be very good.

1. Introduction

An analysis of meteorological data for a region typically shows that high speed wind events do not occur with equal probability from all wind sectors. Additionally, the local façade cladding pressures acting on a structure will generally be dependent on the orientation of the cladding elements relative to the prevailing wind directions. Therefore the method used to combine the directional variation of the wind with the directional response of the cladding elements will influence the accuracy of the predicted façade cladding pressure response.

Façade cladding pressures can be calculated directly, by combing every extreme wind event with measurements of pressure coefficients recorded in the wind tunnel. The load effects method, often referred to as the direct method, is considered a benchmark for evaluating the accuracy of other methods (Rigato et. al., 2001). The method used in the Australian/New Zealand Standard for Wind Actions (Standards Australia, 2013) is to use wind direction multipliers. These multipliers are combined with the non-directional regional wind speed to calculate the directional wind speeds. The façade cladding pressures are then calculated for the wind occurring from each sector and each sector is analysed independently. This method is referred to as the sector or sector-by-sector method. The multi-sector method (Holmes, 1990) is an approach which uses directional probability distributions from extreme wind speeds to estimate wind responses. This method combines the directional wind speed probability distribution with the directional cladding pressure coefficients from the wind tunnel testing. The response level is then calculated by applying the constraint that the total of the directional probabilities equals the design annual probability.

In this paper the multi-sector method is compared against the load effects method using wind tunnel results from two 200m tall buildings with different floor plans. These building have been analysed using data from three different sources: non-cyclonic Australian Superstation (86 years of meteorological measurements), non-cyclonic Overseas Superstation (138 years of meteorological measurements) and a synthetic Cyclonic wind model (100,000 years of simulated tropical cyclone data).

2. Methodology

Façade cladding pressure measurements were recorded using scale models tested in Windtech's boundary layer wind tunnel. The results from these wind tunnel tests were converted to pressure coefficients referenced to the wind speed at the top of the building. The peak positive and negative pressures coefficients were calculated from the pressure histories using the up-crossing method.

The implementation process for the direct events or load effects method depends on whether the data has been sourced from meteorological measurements or from tropical cyclone simulations. For both approaches wind tunnel data for 36 wind directions has been combined with specific wind events to calculate a series of cladding pressures and no probability distribution has been fitted. When the data has been sourced from meteorological measurements, the measured monthly maximum wind speed from 36 wind directions has been considered. The maximum load effects for each month is then calculated. When the data has been sourced from tropical cyclone simulations, the response has been calculated for each tropical cyclone event. The maximum load effects are then analysed following the probabilistic approach used by Vickery (2009).

The definition of wind direction multipliers is the same as that used in the Australian/New Zealand Standard (Standards Australia, 2013) where they 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 by considering a rectangular shaped building. There are alternative methods for calculating direction multipliers, for example Holmes (2001) and Kasperski (2000). The current method is a probability corrected sector method.

The multi-sector method (Holmes, 1990) accounts for the probability of winds occurring from various directions. Briefly, the multi-sector method uses the following procedure:

1. The directional extreme wind speed probability distribution is derived from the wind climate
2. The directional façade cladding pressure coefficients of the various elements of the structure are known from the wind tunnel testing.
3. The inverse of the functions from Points 1 and 2 are combined such that the directional probability can be calculated for a given response level.
4. The response level is calculated from the functions from Point 3 by applying the constraint that the total of the directional probabilities needs to equal the design probability.

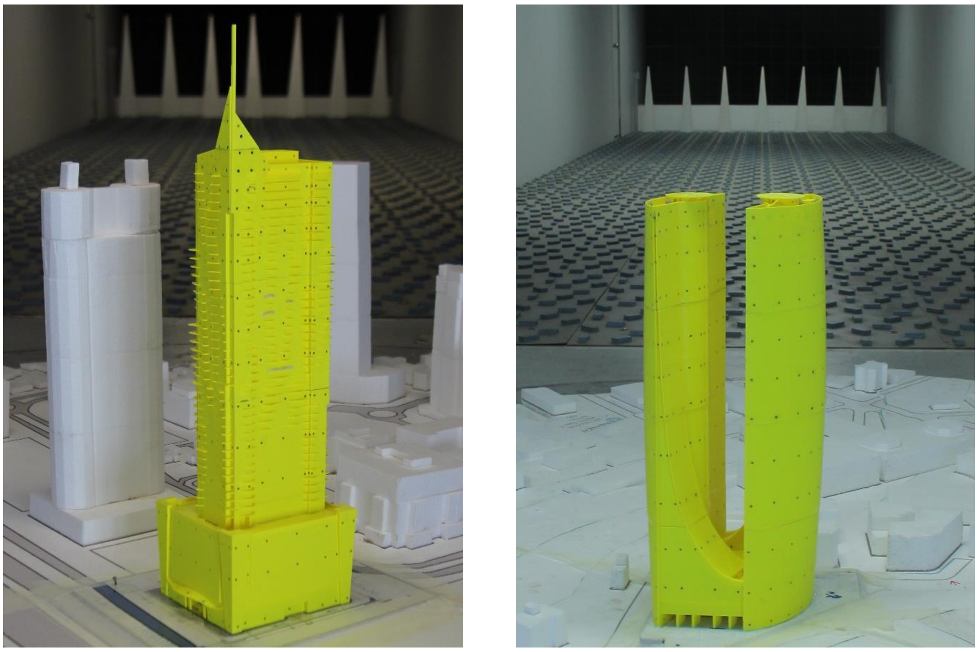

Fig. 1. Buildings A and B during Wind tunnel testing

3 Wind Tunnel Results

The wind tunnel results for two buildings were considered. Building A was a 200m tall building which is generally rectangular in plan shape and Building B is a twin tower development which has a combination of curves and straight faces (Figure 1). The cumulative distributions of the peak pressure coefficients for the two developments are shown in Figure 2. The pressure coefficients were also rotated seven times such that they were considered in eight orientations relative to the wind climate.

4 Descriptions of the Wind Climate

The pressure coefficient data for the two buildings presented in Section 3 were combined with three different wind climate data sets. These are as follows and the directional annual probability of exceedance of the 50 year wind events are shown in Figure 3:

- Non-cyclonic superstation with single dominant directions (138 years of measurements)
- Non-cyclonic superstation with multiple dominant directions (86 years of measurements)
- Cyclonic (100,000 years of simulated tropical cyclone data).

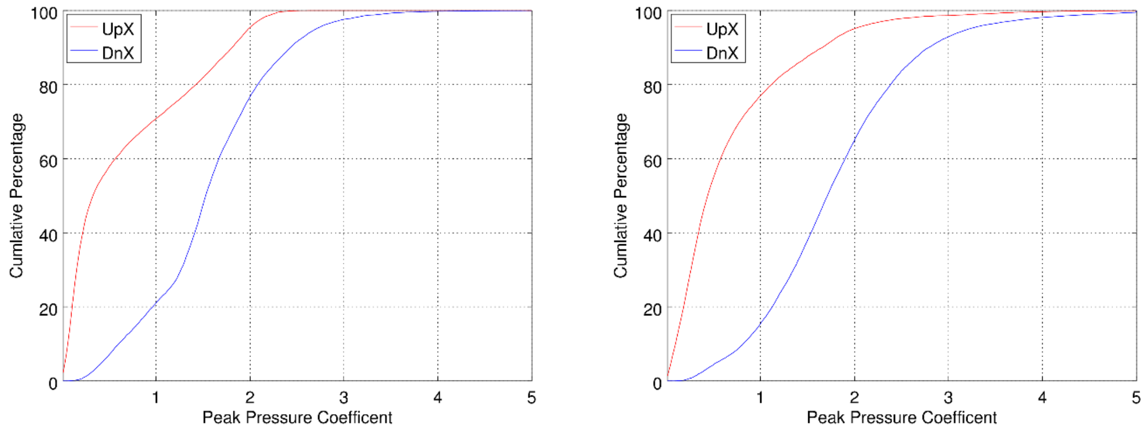

Fig. 2. Cumulative Peak Pressure Coefficients for Buildings A and B

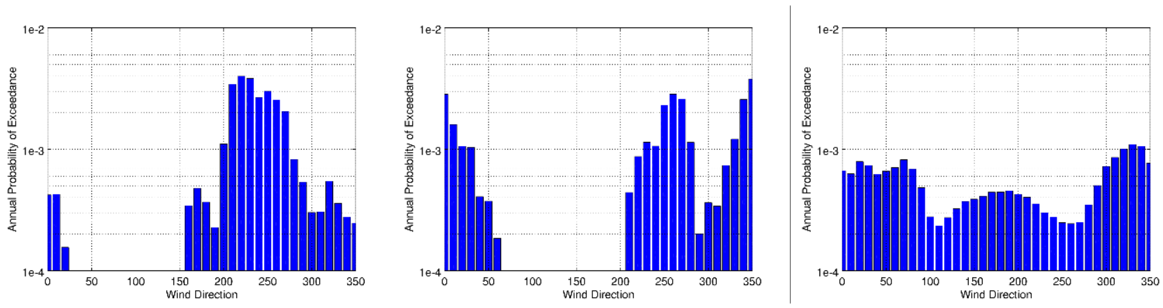

Fig. 3. Directional annual probability of exceedance

The multi-sector method requires that an extreme value probability model is fitted to the data, for these measurements a type I extreme value distribution with the Gringorten plotting method was used (Holmes, 2015). There are several methods to generate the directional probability relationships. For each of the three wind climates two methods have been compared, these are:

- Non-cyclonic 1: Perform an extreme value analysis for each wind direction, using independent events and including wind events from neighboring directions (ie overlap).
- Non-cyclonic 2: Perform a non-directional extreme value analysis combined with the directional probability of exceedance based on an analysis of a directional frequency table using independent events at several threshold levels and including a lower bound wind speed.

- Cyclonic 1: Perform an extreme value analysis for each wind direction, using independent events and including wind events from neighboring directions.
- Cyclonic 2: Perform an extreme value analysis for each wind direction, using non-independent events, including wind events from neighboring directions and a lower bound wind speed.

In both cases the first method is a 'purer' method of generating the probability model whereas the second method is practical interpretation, which is applicable to poorer quality data and account for some uncertainty in the measured or simulated wind speed.

5. Comparison of Directional Methods

Comparisons have been made between the three different directional analysis methods for the twelve combinations of building, wind climate type and wind climate model. For each pressure sensors on the development, the peak positive and negative façade cladding pressures have been calculated using the three methods. Figure 4 presents two examples of the results of these calculations.

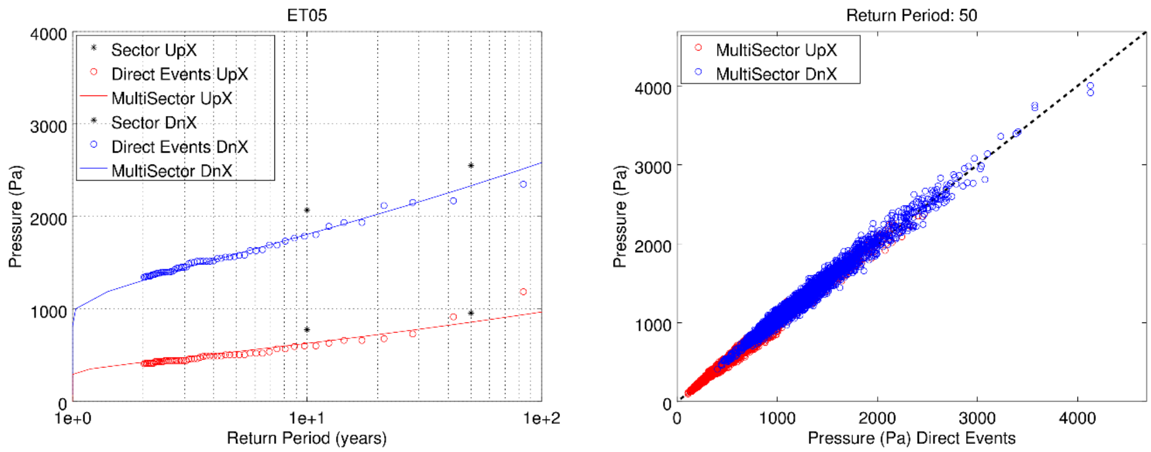

Fig. 4.(a) Example of Analysis for One Sensor Location (Building A, Multi-Directional Non-Cyclonic Climate), and (b) Comparison of all Sensors on a Building for the Multi-Sector and Direct Method s. (Building B, Single Direction Non-Cyclonic)

For all of the sensors on the development the pressure calculated using the sector-by-sector method and the multi-sector method have been compared with the pressures calculated using the direct event method. The direct event method pressures at a specific return period have been calculated by interpolating between the two nearest event pressures. Figure 4a shows an example of these comparisons. In this example the over-estimate by the sector method and the good comparison with the multi-sector method compared with the direct method can be seen.

The ratio between the pressures calculated using the sector-by-sector method and the multi-sector method to the direct event method have been calculated and analysed using a cumulative distribution plot (Figure 5 and 6). This analyse has been conducted for the six scenarios considered and for both methods of estimating the extreme value probability model for use in the multisector method. Tables 1 and 2 presents a summary of the cumulative percentages from these distributions for three pressure ratios (0.9, 1 and 1.1). For the non-cyclonic wind climates the comparison has been made at the 10 year return period. Both non-cyclonic data sets are too short such that at the 50 year probability level there are only a few extreme events greater than this level, whereas at the 10 year level a more reliable comparison can be made (eg Figure 4a). For the simulated cyclonic model the comparison have been made at the 50 year level as 100,000 years of simulated data was available.

The example shown in Figure 5 is for the non-cyclonic wind climate with two dominant directions. The multi-sector method, using the first probability model provides a very good fit to the data, the overestimate of the sector-by-sector method is also evident. An analysis of the ratios calculated from the second probability model, shows that the cumulative distributions has been shifted to the right and that this probability model will slightly overestimate the façade pressures. In this example for the peak negative pressures, for the first model, 51 percent of the pressure ratios were less than 1, whereas only 23 percent were less than 1 for the second method. An inspection of Tables 1 and 2 shows that this trend is shown for the four non-cyclonic cases analyzed.

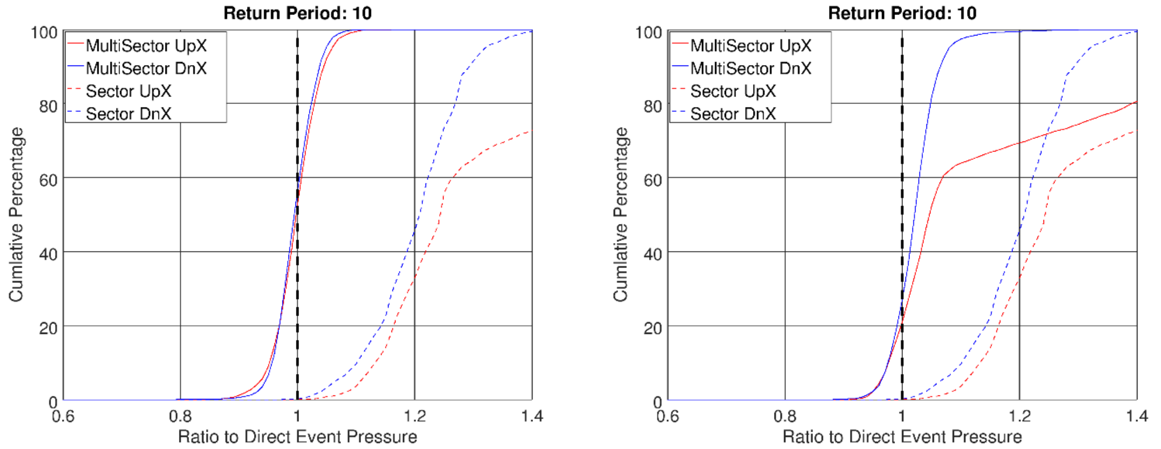

Fig. 5. Comparison of Cumulative distributions of measured pressure ratios for the two multi-sector fitting methods. (Building A, Multi-Directional Non-Cyclonic)

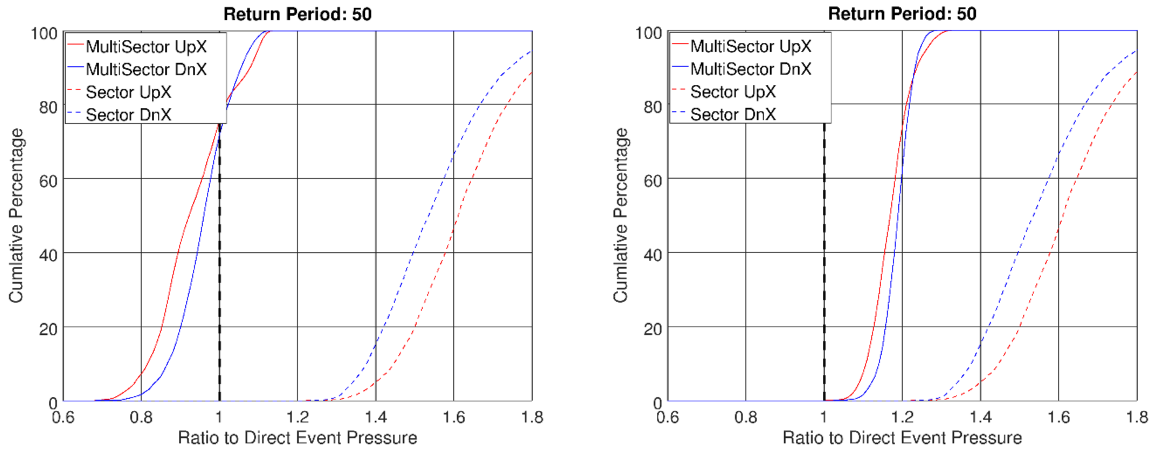

Fig. 6. Comparison of Cumulative distributions of measured pressure ratios for the two multi-sector fitting methods. (Building B, Cyclonic)

The example shown in Figure 6 is for the cyclonic wind climate. The multi-sector method, using the first probability model generally underestimates the façade pressures, with 69 percent of the peak negative pressures having a pressure ratio less than one. This is partially due to the inability of the type I extreme value distribution to represent the numerically simulated cyclonic wind speeds over the complete range of return periods. This is especially evident for wind directions were there are a limited number of events at low return period wind speeds. The use of a type III distribution may be more appropriate for these data. Furthermore, standard statistical practice is to use independent events as the basis of the data set to be fitted by the probability distributions. However, there may be some masking of non-dominate wind directions when this approach is used with simulated cyclonic data.

The second probability model uses an approach, described above, to overcome the apparent limitations of the first method for estimating the extreme value probability distribution. An analysis of the ratios calculated from the second probability model, shows that the cumulative distributions has also been shifted to the right and that this method will overestimate the façade pressures. In this example for the peak negative pressures, for the first model 69 percent of the pressure ratios were less than one, whereas less than one percent were less than one for the second method. An inspection of Tables 1 and 2 shows that this trend is shown for the other cyclonic cases analyzed. The over-estimate by the sector-by-sector method is also evident.

Table 1: Cumulative Percentages for Ratios w.r.t Direct Method - Peak Positive Pressure

Building	**Wind Climate**	**Return Period**	**Sector by Sector**			**Multi-Sector (Fit 1)**			**Multi-Sector (Fit 2)**		
			0.9	**1**	**1.1**	**0.9**	**1**	**1.1**	**0.9**	**1**	**1.1**
A	NC-MD	10	0	0	3	1	47	99	0	18	64
B	NC-MD	10	0	0	3	1	45	99	0	21	60
A	NC-SD	10	0	0	5	0	40	97	0	28	63
B	NC-SD	10	0	0	4	0	51	98	3	44	72
A	Cyclonic	50	0	0	0	33	59	96	0	0	2
B	Cyclonic	50	0	0	0	40	74	94	0	0	6

Table 2: Cumulative Percentages for Three Pressure Ratios - Peak Negative Pressure

Building	**Wind Climate**	**Return Period**	**Sector by Sector**			**Multi-Sector (Fit 1)**			**Multi-Sector (Fit 2)**		
			0.9	**1**	**1.1**	**0.9**	**1**	**1.1**	**0.9**	**1**	**1.1**
A	NC-MD	10	0	0	9	1	51	100	0	23	97
B	NC-MD	10	0	1	12	0	45	99	0	28	79
A	NC-SD	10	0	0	14	0	46	98	1	32	92
B	NC-SD	10	0	0	19	0	43	100	1	44	90
A	Cyclonic	50	0	0	0	14	63	96	0	0	3
B	Cyclonic	50	0	0	0	18	69	98	0	0	1

6. Conclusions

The multi-sector method compares well with the Load Effects Method. Compared with the multi-sector method, the assumptions of the sector-by-sector method result in a conservative estimate of façade cladding pressures for the large majority of cases and is suitable for codification purposes. However, when a detailed analysis is undertaken, such as when wind tunnel testing has been performed, a directional probability method such as the multi-sector method is generally recommended over other techniques. The multi-sector method is sensitive to how the extreme value probability distribution is generated.

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