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

Wind Engineering for the new Royal Adelaide Hospital

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Abstract

The $1.85bn new Royal Adelaide Hospital (nRAH) in Adelaide, South Australia is a world-class tertiary hospital designed to serve South Australians for the next 100 years. The Building Code of Australia (now called the National Construction Code (NCC)) requires major hospitals and other important facilities that are required to operate post disaster (Importance Level 4) to be designed for wind speeds corresponding to an annual probability of exceedance of 1 in 2000. In 2007, the CSIRO produced a report in conjunction with the Bureau of Meteorology titled “Climate Change in Australia – Technical Report 2007” that quantified the predicted increases in both average and extreme wind events over the next 70 years in Adelaide. The design wind speed adopted for the nRAH design was increased based on the predictions of this report. A wind tunnel assessment was carried out and compared to design pressures determined using AS1170.2 (Structural Design Actions, Part 2: Wind Actions). The comparison identified that all positive pressures measured in the model were near, but below pressures required by the Standard, and that negative pressures were generally below code values.

Keywords: Wind Engineering, Climate Change, Wind Tunnel

Project Background

The new Royal Adelaide Hospital (nRAH) is the biggest building infrastructure project in South Australia’s history and when completed, will be Australia’s newest and most advanced major Hospital.

The South Australian Government is developing the new Royal Adelaide Hospital under the SA Public Private Partnership (PPP) framework with a consortium including Pacific Partnerships, Hansen Yuncken, Leighton Contractors, Spotless and HPE. Wallbridge & Gilbert Consulting Engineers (W&G) and KBR partnered in joint venture to provided structural and civil engineering design services.

The hospital has been designed to function as one large building as opposed to multiple buildings interconnected by ‘bridge’ or ‘link’ structures. The building is 370m long from East to West and 215m wide from North to South and has eleven floor levels. As a result, the nRAH is one of Australia’s largest single building structures, and with that comes one Australia’s largest façade systems.

The typical design life for new buildings in Australia is 50 years. The new Royal Adelaide Hospital however, is designed with a 100 year design life with consideration of the changes in Australia’s climate that are predicted to occur during that period.

With over 10,000 façade panels and 70,000m^2 of external windows, it was important to optimise the façade design. The design wind load was one of the major governing criteria. A wind tunnel assessment was carried out and compared to design pressures determined using AS1170.2 (Structural Design Actions, Part 2: Wind Actions). An additional wind tunnel test was conducted to measure the environmental wind speeds to predict the influence of the building on wind speed around the development and therefore pedestrian comfort levels.

This paper outlines the approach taken for the wind engineering for the new Royal Adelaide Hospital as a case study.

Figure 1 - The new Royal Adelaide Hospital (photo courtesy of SA Health)

Wind Design for Buildings in Australia

In the absence of a more rigorous analysis, Australian Standard AS1170.2-2002 “Structural Design Actions – Wind Actions” is used by designers to determine wind actions for buildings in Australia. This standard does not take into account any possible future trend in wind speed due to climate change.

At the time of design for the new Royal Adelaide Hospital, the Building Code of Australia (now known as the National Construction Code) required buildings with a post disaster function (Importance Level 4) to be designed to resist wind actions with a return period of 2000 years.

AS 1170.2-2002 specifies a basic regional ultimate design wind speed for the Adelaide Region corresponding to a 2000 year return period of 48ms^{-1}. This is an extreme wind speed based on a maximum three second gust and is considered appropriate for structural design purposes.

Climate Change in Australia

The original design brief for the new Royal Adelaide Hospital required the facility to withstand wind velocities 26% greater than that required by AS170.2-2002 to account for changes in climate over the 100 year design life of the building. This is a significant increase in the design loads for the façade and building structures that would significantly impact the cost and weight of the facade. Given the huge extent of façade, the design team conducted a review of available material to validate this increase and optimise the design.

In 2007 the CSIRO, in conjunction with the Australian Bureau of Meteorology, produced a report entitled “Technical Report 2007: Climate Change in Australia” that included detailed predictions of climate change in Australia over the next 70 years.

The report is based on the combined experimental results of 23 climate models from research groups around the world including Australia. Referred to as the Coupled Model Intercomparison Project 3 (CMIP3) database, the combined set of systematic model experiments provide a powerful representation of the Earth’s climate system. The mathematical equations used in these models were based on well-established laws of physics, such as conservation of mass, energy and momentum. The predictions of the models were compared against observational data from the natural world with positive results thereby giving a firm level of confidence in their ability to predict changes into the future.

To provide a basis for estimating climate change, the Intergovernmental Panel on Climate Change (IPCC 2000) prepared 40 greenhouse gas and sulfate aerosol emission scenarios for the 21st century that combine a variety of assumptions about demographic, economic and technical factors. Each scenario represented a variation within one of four 'storylines': A1, A2, B1 and B2. The IPCC produced a Special Report on Emissions Scenarios (SRES) that defined the storylines as follows:

A1: A future world of very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The A1 storyline develops into three scenario groups that describe alternative directions of technological change in the energy system: fossil intensive (A1Fl), non-fossil energy sources and technologies (A1T), or a balance across all sources (A1B).

A2: A very heterogeneous world. The underlying theme is self-reliance and preservation of local identities with a continuously increasing population.

B1: A convergent world with the same global population as in the A1 scenario (peaks mid-century then declines) but with rapid change in economic structures towards a service and information economy with reductions in material intensity and the introduction of clean and resource efficient technologies.

B2: A world in which the emphasis is on local solutions to economic, social and environmental sustainability. A world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines.

The CMIP3 database was then used to predict climate change within each of these scenarios. The results of the analyses represent the most advanced foresight available into climate change in Australia for the next 70 years. The Technical Report is a summary of the findings of those analyses relevant within Australia.

The design brief for the new Royal Adelaide Hospital referenced this report and appeared to be based on the predictions of the Technical Report for average wind speeds.

Average wind speeds can be relevant to human pedestrian comfort, the dispersion of gas from flues and noise levels within the Facility, however for the purpose of structural design engineers must consider the more severe extreme wind speed environment. Extremes in wind contribute directly to hazardous conditions causing damage to the built and natural environment. The default extreme wind speed adopted for the purpose of structural design in Australia is the maximum three second gust noted earlier.

Appendix B of the CSIRO Technical Report provided climate change projections using a probabilistic method for 14 selected sites including Adelaide. The results are indicative in that they are based on the results of global climate models for the locations but do not take into account local topographical effects. The changes are relative to 1990.

According to the Technical Report, the wind-speed (presented in Table 1) are increases in average wind speeds at 10m above ground as a percentage of those measured in 1990. The results show that the SRES fossil fuel intensive scenario 'A1Fl' is estimated to cause the greatest increase in average wind speed in Adelaide (+19% for the 90th percentile) which occurs during the summer season of the year 2070. The maximum annual wind-speed increase is predicted to be +10%.

Season	2030 A1B 90p	2070 B1 90p	2070 A1Fl 90p
Annual	+3	+5	+10
Summer	+6	+10	+19
Autumn	+5	+8	+15
Winter	+4	+6	+11
Spring	+5	+8	+16

Table 1 - Projected wind-speed (%) changes for Adelaide (Table B2 of the Technical Report 2007) presented against the various SRES scenarios for the 90th percentile using the probabilistic method.

Having determined the predictions for average wind-speed change, the Technical Report considers the relationship between the change in extreme wind speed and change in average wind speed. An analysis was conducted to determine whether the extreme winds change in a manner that is consistent with the average (mean) wind change.

Four of the 23 CMIP3 models recorded data enabling the calculation of extreme winds. The percentiles were calculated seasonally and annually over two regions: one covering the mid-latitude region of Australia including Adelaide (from 110-155˚E and 30-44˚S) and one covering the tropical region of Australia. The results of the four analyses of the relevant mid-latitude region were plotted for summer, winter and annual data and are provided in Figure 2. The four coloured lines and associated correlations represent each of the four CMIP3 models used in the analysis.

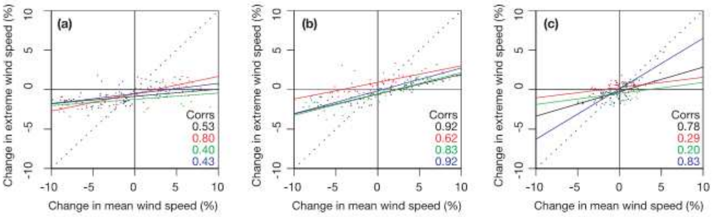

Figure 2 - Relationships between changes in extreme (99th percentile) wind speed and changes in mean wind speed for mid-latitude Australia for **(a) summer**, **(b) winter** and **(c) annual data**. Changes are percentage per ˚C of global warming.

The analysis showed that all models predicted that changes in extreme wind-speeds would be smaller than changes in mean (average) wind-speeds. This was particularly evident in the results for summer, but there was less correlation for annual events.

Based on the results of Figure 2 (a) the most adverse correlation for summer suggests a change in extreme wind speed of less than 20% of the change in mean wind speed. For annual events, there is lower correlation with an upper limit of 60% comparatively.

For the design of the new Royal Adelaide Hospital, the design team elected to adopt a conservative correlation between extreme and mean wind speeds. A correlation of 60% was adopted as an upper bound (annual), but this was conservatively applied to the most extreme predicted mean wind speed increase (summer).

In this way, the greatest increase in average wind speed in Adelaide of +19% which occurs during the summer season was reduced by 60% to achieve an estimated increase in the extreme wind-speed of 11.4%.

Based on the results of the Technical Report and the conservative approach nominated above, the design team was able to re-negotiate the originally specified 26% wind speed increase required in the project brief.

The design wind speed for the new Royal Adelaide Hospital was therefore: $V_{des} = 48ms^{-1} \times 11.4\% = 53.5ms^{-1}$.

Wind Tunnel Testing – Design Pressures

With over 10,000 façade panels and 70,000m^2 of external windows, it was important to optimise the façade design and the high design wind load was one of the main governing criteria. To assist in this optimisation, the design team engaged MEL Consultants Pty Ltd to construct a scale model of the new Royal Adelaide Hospital and measure wind pressures using a wind-tunnel.

A 1/400 scale model of the building was constructed based on the digital architectural model and drawings including façade fins and canopies (Figure 3). The model was instrumented with approximately 1100 individual pressure tappings, with the density of tappings increased near corners and building discontinuities.

Figure 3 - The 1/400 scale model of the New Royal Adelaide Hospital constructed by MEL Consultants with the SA Health and Medical Research Institute (SAHMRI) in the foreground (photo courtesy of MEL Consultants)

Roughness elements and vorticity generators were placed upstream of the model to imitate the building surroundings and achieve scaled natural wind properties. Based on the calculated model to full scale time ratio, 1.0 hour in full scale was equal to approximately 32 seconds at model scale and the model scale frequency response was 113Hz to give a full scale frequency response of 1Hz.

Wind tunnel model measurements are always conducted using mean wind speeds rather than three second gusts. The Deaves and Harris Model was used to correlate the three second gust wind speed with a mean wind speed for the model. The conversion was based on the Ultimate Limit State, 2000 year return period maximum three second gust of 53.5ms^{-1} that was adjusted for future climate change as explained in the previous section.

Based on a building height of 45m, the climate change adjusted mean wind speed calculated was 33ms^{-1}.

The analysis assumed an equally permeable façade and included an internal pressure of -573Pa or 0Pa on the positive and negative design pressures respectively as the most severe combinations.

The MEL report provided examples of the highest positive and negative pressures measured in the model and compared them to the pressures calculated using AS1170.2:2011 for a building of rectangular plan form, Terrain Category 3 and for a basic Ultimate Limit State design wind speed of 53.5ms^{-1} with allowance for internal and local pressure coefficients. Comparisons of the results are summarised in Tables 2 and 3.

Negative pressures calculated by AS1170.2 vary depending on the position of the local pressure zones (for example SA3, SA4 and SA5). The maximum negative pressure readings from the model are located in equivalent SA4 or 5 zones near the corners of the building. The negative pressures recorded in the model for more general SA3 type areas were also found to be below the calculated pressures.

Maximum Negative Pressure		
Modelled Pressure	AS1170.2 Calculated Pressure	
	SA4 Areas	SA5 Areas
-2163 Pa	-2485 Pa	-3727 Pa

Table 2 - Maximum negative pressures measured by the MEL model compared to calculated AS1170.2 values assuming zero internal pressure

Maximum Positive Pressure	
Modelled Pressure	AS1170.2 Calculated Pressure
2789 Pa	2867 Pa

Table 3 - Maximum positive pressures measured by the MEL model compared to the calculated AS1170.2 values assuming -0.3 internal pressure coefficient

The MEL report was able to summarise that all of the positive design pressures recorded during the analyses were either near, but below, the magnitudes that would be calculated using AS1170.2:2011, while the negative pressures recorded were all generally well below the calculated values.

Figure 4 - An example of the negative wind pressures measured across one partial elevation of the building (extract from the MEL report)

The report provided detailed pressure measurements for all tappings including maximum, mean or minimum design pressures or pressure coefficients arranged by wind direction. A series of plans and elevations showing tapping numbers as well as positive and negative pressure distributions assisted in the interpretation of the results. Figure 4 shows an example of the latter for just one of the many building elevations. These results provided a powerful database to optimise the façade and building envelope design.

Wind Tunnel Testing – Environmental Wind Conditions

In addition to the measurements of building pressures, MEL Consultants Pty Ltd were also engaged to conduct a measurement of the environmental wind speeds to predict the influence of the building on wind speed around the development. Prior to MEL's engagement, a preliminary wind study was conducted by Cyclopic Energy Pty Ltd for development planning purposes. This study was conducted as a desktop analysis using Computational Fluid Dynamics based on the architectural 3D model of the building, contour maps sourced from the State Government, a simple massing model of surrounding buildings based on publicly available information, and wind data from the

Bureau of Meteorology's Automated Weather Stations in Kent Town and the Adelaide Airport.

The wind tunnel assessment was conducted to more accurately assess and confirm the findings of the preliminary wind study. The assessment used the same wind tunnel model but with added trees to assess their effect on the local amenity at plaza levels. The criteria used for assessment was based on a paper by W.H.Melbourne. This paper suggests that it is the forces caused by peak gust wind speeds and associated gradients which people feel the most and the criteria have therefore been stated in terms of gust wind speeds. The basic criteria can be summarised as follows.

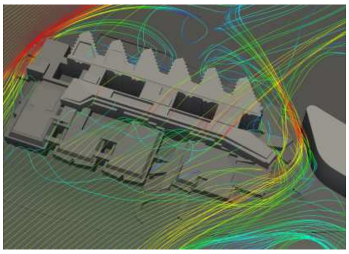

Figure 5 - Computational Fluid Dynamic model created for the preliminary wind study by Cyclopic Energy

For main public access-ways:

a) **Unacceptable** if the peak gust speed during the hourly mean with a probability of exceedance of 0.1% in any 22.5˚ wind direction sector exceeds 23ms^{-1} (the gust speed at which people begin to get blown over).
b) Generally unacceptable for walking in waterfront locations if the peak gust speed during the hourly mean with a probability of exceedance of 0.1% in any 22.5˚ wind direction sector does not exceed 20ms^{-1} (which results in 75% of the wind pressure of a 23ms^{-1} gust).
c) Generally acceptable for **walking in urban and suburban areas** if the peak gust speed during the hourly mean with a probability of exceedance of 0.1% in any 22.5˚ wind direction sector does not exceed 16ms^{-1} (which results in 50% of the wind pressure of a 23ms^{-1} gust).

For more recreational activities:

d) Generally acceptable for **stationary short exposure activities** (window shopping, standing or sitting in plazas) if the peak gust speed during the hourly mean with a probability of exceedance of 0.1% in any 22.5˚ wind direction sector does not exceed 13ms^{-1}.
e) Generally acceptable for **stationary long exposure activities** (outdoor restaurants, theatres) if the peak gust speed during the hourly mean with a probability of exceedance of 0.1% in any 22.5˚ wind direction sector does not exceed 10ms^{-1}.

The probability of exceedance of 0.1% relates approximately to the annual maximum mean wind speed occurrence for each wind direction sector.

The paper by Melbourne provides environmental wind criteria for the City of Adelaide expressed in terms of peak velocity pressure ratios. Refer Figure 6.

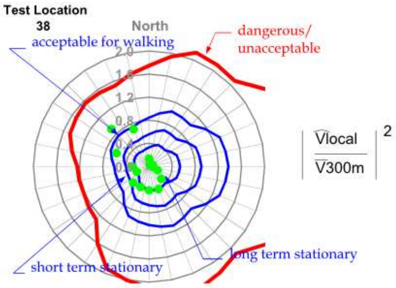

Figure 6 – Results for a test location in the plaza area at Level 3 (shown in green) compared to the environmental wind criteria for the City of Adelaide expressed in terms of peak velocity pressure ratios (red and blue lines) for given wind directions.

The MEL report concluded that wind conditions around the majority of the building were either on or within the criterion for walking comfort. However, wind conditions on elevated terraces and concourses, particularly near corners of the building along the north and around to the west side were shown to exceed the criterion for walking comfort for a number of wind directions. The addition of landscaping trees around the site was shown to improve wind conditions, particularly for the ground floor plazas, but they had little effect on the wind conditions on the elevated terraces and concourses.

Conclusion

The new Royal Adelaide Hospital (nRAH) is the biggest building infrastructure project in South Australia's history. With a 100 year design life, the brief for the project required consideration of increases in design wind speed due to climate change over that period.To assess the effects of climate change, the design team referred to the report created by the CSIRO in conjunction with the Australian Bureau of Meteorology produced a report entitled "Technical Report 2007: Climate Change in Australia" which included detailed predictions of climate change in Australia over the next 70 years. The design team adopted a conservative approach to estimate the increase in design wind speed as an additional 11.5% of that calculated by Australian Standard AS1170.2:2011.

Given the scale of the project, detailed wind tunnel modelling and analyses were conducted to optimise the design of the façade and attached structures. The wind tunnel analyses included allowance for the increased wind speed derived from the Technical Report 2007. Results of the wind tunnel analysis showed that all of the positive design pressures recorded during the analyses were either near, but below, the magnitudes that would be calculated using AS1170.2:2011 (adjusted for the 11.5% increase in wind speed), while the negative pressures recorded were all generally well below the adjusted calculated values.

An additional environmental wind speed assessment was conducted to guide the design of the landscape, shape of the built form and planning for restaurants and plaza activity areas. The assessment found that the addition of trees assisted in providing acceptable amenity levels for key functional areas around the building.

Wind engineering was thereby effective in reducing the design loads and optimising the design of the façade and attached structures for the new Royal Adelaide Hospital, as well as guiding the design of external areas towards higher amenity levels.

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