APEC-WW Structural Report: Australia – 2011-12

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ABSTRACT: This report for Australia describes developments in the Wind Load Standard, AS/NZS1170.2, assessments following windstorms, research work presented at the 15th Australasian Wind Engineering Society Workshop (AWES), and other wind engineering projects carried out in Australia in 2011/12.
Outcomes from two projects are described in some detail:

1. The Australasian Wind Engineering Society (AWES) supported a project funded by the Department of Climate Change & Energy Efficiency (DCCEE) and carried out by a team from the Bureau of Meteorology, GeoScience Australia, JDH Consulting and the Cyclone Testing Station, to analyse the historical wind speed records collected by the Bureau of Meteorology. This study found that there was no discernible variation in wind speeds over a 60 yr period to 2000. Importantly, the study also found that the 3-cup anemometers that replaced the Dines in the 1990s significantly underestimate the peak gust wind speeds. This outcome has resulted in a redefinition of the gust duration in AS/NZS 1170.2, and correction factors to be applied to the 3-cup peak wind speeds.
2. Cyclone Yasi that impacted the North Queensland coast in 2011 caused significant damage and has resulted in revisions to regulations and standards. An assessment of the structural damage caused by Yasi was carried out by a number of groups including the Cyclone Testing Station.

KEYWORDS: Australia, AS/NZS1170.2, cup anemometer, Dines anemometer, gust duration, standards, codes, wind loads, effective area

1 REVISIONS TO AS/NZS1170.2:2011

This section summarizes the main amendments to AS/NZS 1170.2 (2011)

- The peak gust is re-defined as one with a moving average time of approximately 0.2 seconds. This revision and its implications for wind speeds and design wind loads calculated using AS/NZS 1170.2 are detailed in Section 2 of this report.
- A new clause intended for assessing high-cycle fatigue damage to structural elements under wind loading provides an equation and figure showing the number of times, N_g, that a stress level, σ is exceeded under wind loading in a lifetime L, between 20 and 100 years, is expressed as a percentage of the expected maximum stress, σ_{max}, in the lifetime, L. This has been derived from an equivalent clause in the Eurocode for wind actions.

- The definitions for Terrain Categories 1, 2 and 3 have been revised and intermediate terrain categories 1.5 and 2.5 are explicitly defined. These terrain definitions were made consistent with revisions in another Standard – Wind loads for housing AS4055 (2006). The terrain height multiplier $M_{z,cat}$, are the same for cyclonic and non-cyclonic regions under all wind conditions.
- Aerodynamic shape factor, C_{fig} for calculating net pressures for solar panels mounted parallel to the roof surface of enclosed buildings, are given in a new appendix. These values are for calculating wind loads on solar panels on buildings with aspect ratios $h/d \leq 0.5$ and $h/b \leq 0.5$, panels with a gap under the panel (s) of between 50mm and 300mm, and minimum distance between panel and roof edge of 2s.

2 DURATION OF GUST WIND SPEED IN AS/NZS 1170.2

AS/NZS 1170.2 and its predecessors in Australia from 1971 to 1989, referred to 'a gust of 2 to 3 seconds duration' as the basic wind speed, and later as a '3-second gust'. This definition originated from the report by Whittingham (1964), who stated that "the Dines anemometer gives a good indication of the speed of strong gusts of 2 to 3 seconds duration". However, questions were raised about the compatibility of the gust wind speeds measured by the Dines system and the cup-anemometers that have replaced them in automatic weather stations (AWS) in Australia in the early 1990s, even though they were both described as '3-second' gusts. For example, Reardon *et al.* (1999) noted a 15% higher peak gust recorded by the Dines situated about 20 metres away from the 3-cup anemometer during Cyclone 'Vance' at Learmonth, in 1999. Similarly, Boughton *et al.* (2011) found that the Dines gave a peak gust wind speed about 20% higher than the nearby 3-cup at Townsville, during Cyclone 'Yasi' in 2011. A project, carried out for the Department of Climate Change and Energy Efficiency (DCCEE) (Ginger ed., 2011), has shown that the Dines anemometer had an equivalent averaging time of 0.2 to 0.5 seconds depending on the mean wind speed, and version of the Dines anemometer in use; a much shorter duration than 3 seconds. Furthermore, the Deaves-Harris wind model used since 1989 in the Australian Standard for terrain-height multipliers is based on a peak factor of 3.7 (in a sample time of 1 hour). It can be shown that this corresponds to an equivalent moving average gust duration of about 0.3 seconds, not 3 seconds, as previously assumed (Holmes and Allsop, 2012).

Hence it has been necessary to re-define the gust duration in AS/NZS 1170.2 (2011). A consideration by the Standards committee, in re-defining the maximum gust duration, was the effective frontal area over which the gust could be considered to act. For example, the effective frontal area for a 0.2 second gust (for the range of mean wind speeds of interest for structural design of 25 to 50 m/s), of 10 m^2 to 40 m^2 approximates to that of a small building such as a shed or house. On the other hand a 3-second gust corresponds to a frontal area of 2000 m^2 to 9000 m^2 over the same wind speed range.

This research has resulted in design gust speed in AS/NZS 1170.2, now being re-defined as one with duration of *0.2 seconds*, with a peak factor of 3.85, as described by Holmes and Ginger (2012). This re-definition will have no immediate effect on the listed regional wind speeds, or on calculated wind loads from AS/NZS 1170.2, but is provided for analyzing historical wind data for compatibility with the Standard. However, clearly gust data recorded by the Bureau of Meteorology using cup anemometers with 3-second moving averages applied digitally, since about 1990, will need correction to be compatible with the Standard.

3 CYCLONE YASI

TC Yasi was a large diameter severe tropical cyclone that crossed the North Queensland coast near Mission Beach in the early hours of 3 February 2011. An assessment of the wind speeds and the structural performance of buildings are given in Boughton *et al.* (2011). The lowest recorded central pressure was 929 hPa near Tully during the passage of the eye and within 20 km of the cyclone's landfall. This central pressure was used to model the wind field in the study area. The cyclone had a very large eye with an estimated radius to maximum winds of over 30 km. A storm tide at Cardwell of 4.5 m was recorded. This placed the peak storm tide level at more than 2.2 m above Highest Astronomical Tide.

The estimated wind field shows that the maximum peak gust over communities is near 240 km/h or 67 m/s. The ultimate limit states wind speed for Importance Level 2 structures (which include houses) in the same region is 69 m/s.

The Cyclone Testing Station conducted an external survey of nearly 2000 houses (Boughton *et al*, 2011) in areas that experienced peak gusts of 200 km/h or more. The damage was categorized as a three digit number corresponding to the severity of roof, window and door, and wall damage. In each category of the damage, index 1 to 3 represented fairly minor damage and index 4 and above represented major damage.

Figure 1 shows roof damage segregated into Pre-80s and Post-80s houses. This classification corresponds with the introduction of requirements for engineered tie-down details into housing in Appendix 4 of the Queensland Home Building Code, (1981). There is a significant difference between the two types of houses in the zero damage index, with around 70% of the recent houses having undamaged roofs and only around 50% of the older houses. Analyzing the more significant damage presented in Figure 1, showed that the Pre-80s housing had higher percentages of more serious damage than the Post-80s housing. A total of less than 3% of the Post-80s houses had roof damage at index 4 or above, whilst more than 12% of the Pre-80s houses had roof damage at index 4 or above.

The serious roof damage in Pre-80s housing was mainly due to failure of batten-to-rafter connections as shown in Figure 2. A number of alternative engineered batten-to-rafter connections were made available in Appendix 4 (Queensland Home Building Code, 1981) and are now presented with only minor additions in AS 1684.3 (2010). In a number of cases, failures in both Pre-80s and Post-80s houses were initiated by lack of capacity due to deterioration. This included corrosion of metal, rotting of timber or loosening of connections. Builders should be trained to inspect structural elements for deterioration, tighten bolts and reapply any protective coatings when the elements are visible. Inspection and maintenance of structural elements within the roof space should be undertaken for all buildings.

While less than 3% of Post-80s housing had roof damage regarded as serious, this damage was studied in more detail to discern where improvements in building practice need to be focused. The other variable is the site wind classification used by AS 4055 (2006). The higher levels of damage sustained by houses with high wind speed classification were due to errors in interpretation of topographic factors. In a number of cases, the topography had been ignored when assigning the wind classification, but in others, miscalculations had been made. The study recommended that AS 4055 (2006) be amended to enable more reliable topographic classification of ridges and escarpments. The level of damage underlined the importance of correct modeling of topography in wind load evaluation. The street survey showed that across the study area, less than 3% of Post-80s housing sustained significant roof damage, compared with 6% of sectional doors and 29% of roller doors that were damaged. The discrepancy in performance of the roller doors is significant.

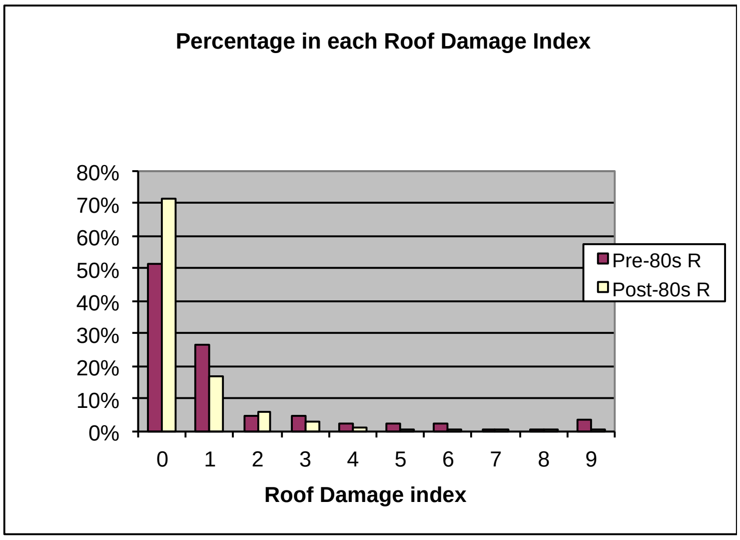

Figure 1. Cyclone Yasi: roof damage index from external survey.

Figure 2. Cyclone Yasi: Loss of battens in Pre-80s buildings

Failed elements, such as roof structures, cladding sheeting, tiles, awnings, guttering, flashings, and roller doors, as well as unsecured items stored in residential yards and vegetation were entrained in the wind stream. In some cases the roofing elements travelled hundreds of metres, highlighting the threat to life safety and potential for further damage to other structures. Figure 3 shows a house in which screens had been installed to protect windows, but in which a door had failed and still caused the high internal pressures that initiated the roof loss. Where the structure had been designed for low internal pressures, roof loss followed the creation of a dominant opening which was often caused by: failure of door furniture (latches, bolts, hinges); failure of window frames or frame anchorage; failure of garage doors under wind pressure; or failures of windows, doors and cladding under wind-borne debris impact.

Figure 3. Cyclone Yasi: Roof loss after door failure

AS/NZS 1170.2 (2011) allows design for lower internal pressures in tropical cyclone-prone areas where openings are protected against debris impact. The wind loads taken from AS 4055 (2006) use internal pressures resulting from dominant opening by default for houses in cyclone regions C and D specified in AS/NZS 1170.2. Requirements for engineered tie-down details for housing in Queensland since the 1980s have meant that construction performed to those standards generally withstood TC Yasi winds estimated at near the design wind speed for the worst affected areas. Improvements can be made by upgrading Pre-80s houses to current standards, improving wind resistance of garage doors, and amending topographic multipliers in AS 4055 to be consistent with AS/NZS 1170.2. Other specific recommendations concerned tiled roofs, internal pressures and damage from water ingress, although not seen as a life safety issue, is a major impact on the resilience of the community. Specific aspects of TC Yasi were reported in a Special session at the 15th AWES Workshop by Auden and Davidson (2012), Holmes (2012), Walker (2012) Henderson *et al.* (2012) Corby *et al.* (2012) and Mullins (2012), and at the Australasian Structural Engineering Conference, by Boughton *et al*. (2012).

4 CYCLONE SHELTER BUILDINGS

Following Cyclone 'Yasi', construction of public Cyclone Shelters has commenced at centres along the coast of North Queensland. The shelters have been designed with extensive aerodynamic treatment on the corners of the walls and roofs to reduce the shape factors, and hence the wind loads, in these areas.

The Cyclone Structural Testing Station at James Cook University carried out a wind tunnel study for the Department of Public Works, Queensland, on the proposed Cyclone Shelter Buildings, (TS#824, 2011). The building is of square plan form with a 10^{o} pitch gabled roof, and is equipped with a number of specific features intended to mitigate and reduce wind loading, as shown in Figure 4. For example, the lower walls are chamfered, and the corners of the upper walls are equipped with porous horizontal sunshades and porous vertical wing walls, all intended to reduce the effects of flow separations and to reduce wind suction pressure peaks. The corners of the overhanging roof have been vented, also designed to reduce wind loading - based on previous experience with the cantilevered roofs of sports stadia.

The Cyclone Shelter building was modeled at a length scale of 1/100 as shown in Figure 5, and tested in turbulent atmospheric boundary layer flow in the boundary layer wind tunnel at James Cook University in Townsville, Australia. The modeled approach terrain was representative of open country. Wind pressures on the building model were measured using pressure taps installed on the roof and the walls. The external pressure coefficients obtained from the wind tunnel were combined with the design wind speeds, with a 10,000 yr return period, to give design values of positive and negative external wind pressures on each face of the building. These pressures are combined with internal pressures to obtain the net design pressures on the envelope, and also used for determining wind load effects (i.e. bending moments, shear forces) for designing the structure. The venting at the corner of the roof overhangs were very effective in reducing the negative local pressures in that region by about 30%. Reductions in the negative pressures near the corners of the walls have been achieved, as a result of the porous corner features and the chamfering.

Figure 4. Queensland Community Cyclone Shelter under construction in Townsville.

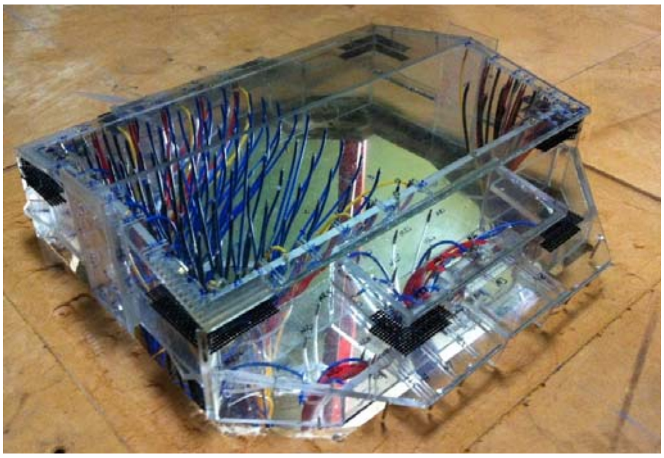

Figure 5. Wind-tunnel model of Queensland Community Cyclone Shelters tested by the Cyclone Testing Station, James Cook University.

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APPENDIX A -LIST OF RESEACH TOPICS PRESENTED AT 15AWES WORKSHOP

Keynote 1 – "Urban Physics: effects of wind on comfort, energy, health and driving rain", by *J. Carmeliet*

Keynote 2 - Innovative technologies to investigate fine-scale wind flow, by *J. Schroeder*

Analysis of evaporative cooling in street canyons, by *S. Defraeye, B. Blocken, P. Moonen, D. Derome and J. Carmeliet*

Air Ventilation Assessment (AVA) for Building Development, by *K. Kwok, K. Tse, C. Tsang and K. Wong*

Vortex formation above prismatic-shaped cliffs; an experimental and numerical investigation, by *S. Cochard, A. Montlaur, D. Fletcher, C. Letchford and T. Earl*

Study of wind speeds over hilly terrain using full-scale observations, wind tunnel simulation and CFD, by *P. Carpenter, P. Cenek, M. Revell, R. Turner, R. Flay and A. King*

Buildings used for shelter during Tropical Cyclone Yasi, places of refuge & public cyclone shelters in Queensland, by *P. Mullins*

Evaluation of HFBB analysis under the effects of surrounding buildings, by *K. Tse and K. Wong*

Estimation of torsional loads on tall buildings, by *A. Rofail and N. Truong*

Bifurcation prediction of the aeroelastic galloping model with structural and damping nonlinearities, *G. Vio*

Wind loads on extension of light towers at AAMI Stadium Adelaide, by *N. Mackenzie, J. Holmes, G. Rowland and J. Gaekwad*

In February 2012, the Australasian Wind Engineering Society (AWES) launched the Wind Loading Handbook for Australia and New Zealand: Background to AS/NZS 1170.2 Wind Actions, by J. D. Holmes, K.C.S. Kwok and J. D. Ginger. This handbook provides background information to the Standard including updates and is useful for structural designers.

The Australasian Wind Engineering Society (AWES) is offering an Undergraduate Wind Engineering prize for final-year Engineering and Architecture students in Australasia for their undergraduate thesis or project. Wind engineering topics covering Meteorology, Wind loading and Structural Response (of buildings, bridges, and towers), Aerodynamics, Ventilation, Wind Energy, Wind hazard and Vulnerability etc. are accepted. Projects may include computational fluid mechanics, wind tunnel testing, or full scale measurements broadly related to wind engineering. This is an initiative to encourage a career in Wind Engineering and associated research.