17th Australasian Wind Engineering Society Workshop
Wellington, New Zealand
12-13 February, 2015

AS/NZS 1170.2 – Past, present and future

J.D. Holmes[1]

[1]JDH Consulting
Mentone, Victoria, Australia 3194

Abstract

This paper reviews the history of the Australian/New Zealand Standard for Wind Actions, AS/NZS 1170.2, and the predecessor standards in both countries. The present issue of internal pressures, and the probable future changes required to incorporate the local, non synoptic storm events, and the predicted effects of global warming are also covered.

Introduction

AS 1170.2 first appeared in Australia in 1973 incorporating metric (SI) units, although it was preceded by a similar document in imperial units – CA34 of 1971. New Zealand introduced NZS 4203 in 1984 – a document closely based on AS 1170.2. A formal merger took place in 2002 with the introduction of AS/NZS 1170.2:2002.

After more than forty years of development, it seems an appropriate time to review the standard, its role in the regulatory process, and to contemplate technical changes that may be required in the near and more distant future.

History – the nineteen-seventies

The introduction of AS 1170.2-1973 (Figure 1) coincided with a worldwide interest in a more scientific approach to the wind loading of structures, and the introduction of the boundary-layer wind tunnel. Similar 'advanced' wind standards appeared, at about the same time, in the United Kingdom (BS CP3 Ch.V Pt. 2), the United States (ANSI A58.1), and Denmark (DS 410.2, 1977).

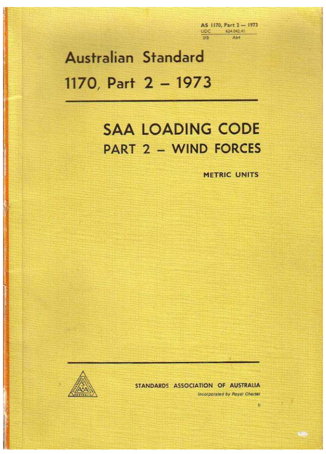


Figure 1. The first version of AS 1170.2 published in 1973

All these documents incorporated the statistical approach to extreme wind speed prediction using techniques pioneered earlier by Gumbel (1958), Whittingham (1964) and Shellard (1963), and knowledge of the properties of the turbulent atmospheric boundary layer in large synoptic-scale wind events based on work by Jensen, Cermak and Davenport.

All these 'new generation' wind standards adopted the format embodied in the 'wind loading chain' of Davenport (1977) – a version of which is shown in Figure 2.

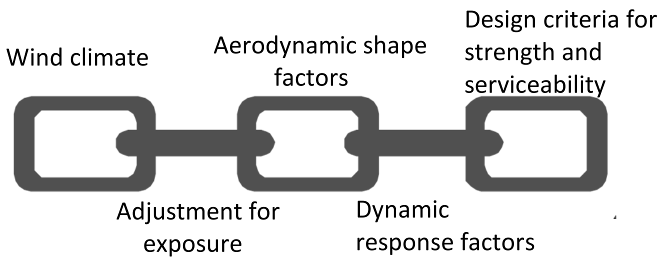


Figure 2. The wind loading chain of Davenport (1977)

All modern wind loading standards incorporate the first four 'links' (starting from the left) in one form or other. The fifth 'link' incorporating criteria such as limiting acceleration criteria for tall buildings, may also involve wind engineers, but, in the case of the AS/NZS standards, such criteria are in AS/NZS 1170.0 (General principles), rather than AS/NZS 1170.2.

The occurrence of Cyclone Tracy in late 1974 provoked a 're-think' about the way design wind speeds were being derived at locations affected by tropical cyclones. It was realized that recorded annual maximum wind gusts were often not produced by tropical cyclones, and therefore not representative of the winds of interest for structural design against failure. The first reaction in AS 1170.2-1975 was to introduce zonal strips for the coastline north of 27° latitude (See Figure 3).

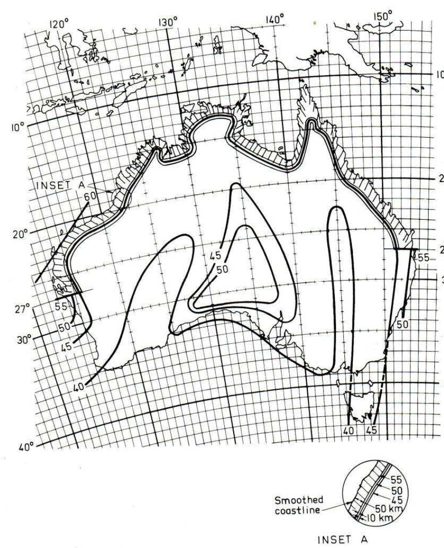


Figure 3. Wind speed map in AS 1170.2-1975 (50 year return period gusts)

The special needs of tropical cyclone-affected regions also inspired some pioneer work on Monte-Carlo techniques for simulating cyclonic wind speeds by Martin and Bubb (1976), and Gomes and Vickery (1976). However, the results of this work were not incorporated into the Standard until 1989.

With regard to the dynamic effects of wind on tall buildings, the 1973 and 1975 versions of AS 1170.2 incorporated an Annex with a version of the gust (response) factor approach to along-wind response, based on random vibration theory – an approach that had originated in the mid nineteen–sixties.

The nineteen-eighties

The early nineteen-eighties saw, for the first time, the introduction of external shape factors for low-rise buildings that had been derived from tests in the turbulent flow of boundary-layer wind tunnels. An 'area reduction factor' for the pressures produced by the separated flow over roofs and side walls also made an appearance in AS 1170.2-1983. These changes satisfied a 'rebel' group in Western Australia, which to this point had not yet adopted AS 1170.2 on the grounds that it was too conservative for wind loads.

NZS 4203: 1984 was the first stand-alone New Zealand loading standard loading to include wind loads – that part closely resembled AS 1170.2-1983.

Limit states design was a key target for the Australian and New Zealand structural design standards in the 1980s. For AS 1170.2, this culminated in AS 1170.2-1989, which incorporated a return period of 1000 years for design wind speeds for ultimate limit states. Although this was a relatively radical step at the time for wind loading, it was not new for earthquake engineering, in which the Chairperson of BD006-02 at the time, Charles Bubb, had a background. This approach incorporates a wind-load factor of 1.0 in the load combination formulae, and had the advantage of eliminating the 'cyclone factor' of 1.15, that was applied to cyclonic wind speeds in the 1970s and early 1980s to account for the greater slope of the wind speed/ return period plots compared to non-cyclonic regions. Interestingly the high-return-period approach has recently been adopted for ASCE-10 in the United States for similar reasons.

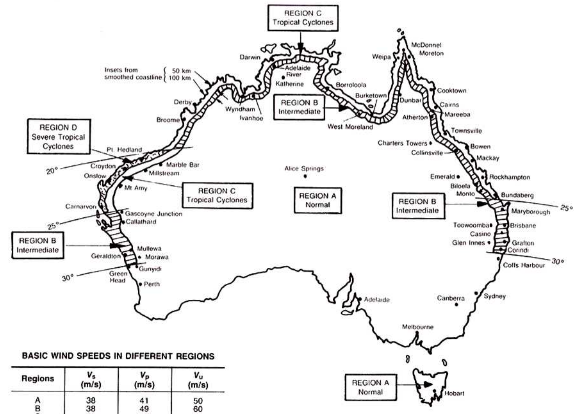
There were many other changes in the 1989 edition of AS 1170.2 including: a zonal system for the whole of Australia (Figure 4), directional wind speeds for the capital cities, new multipliers for shielding and topography, new shape factors for many structural shapes, and cross-wind response for tall buildings. The Appendices included flow-charts for the now more complex document – a feature that is, unfortunately, missing from the current Standard.

The 1989 version of AS1170.2 was supported by a stand-alone Commentary published separately by the Australian Wind Engineering Society (Holmes, Melbourne and Walker, 1990). This was the start of the involvement of AWES in the Standard, one that continues to the present day.

The nineteen-nineties

A new version of NZS 4203 was published in 1992. This closely resembled AS 1170.20-1989, but incorporated more complex rules for topographic effects – particularly the effects of downslope winds driven by gravity waves – a relatively common phenomenon in the Canterbury Plains of the South Island.

Work started on a new version of a combined Australian/New Zealand Standard in 1996 under the chairmanship of Greg Reardon. This culminated in the first wind Standard of the new century - AS/NZS 1170.2:2002.



BASIC WIND SPEEDS IN DIFFERENT REGIONS

Regions	V_s (m/s)	V_p (m/s)	V_u (m/s)
A	38	41	50
B	38	49	60
C	45	57	70
D	50	69	85

Figure 4. Zonal system introduced in AS 1170.2-1989

Post-2000 developments

The first combined Australian/New Zealand wind actions standard, AS/NZS 1170.2:2002 was one of the suite of joint loading standards that resulted from the Closer Economic Relations (CER) initiative – a free trade agreement between the two countries that started in the 1980s. That version of the Standard was also influenced by the ISO Standard on Wind Actions, ISO 4354, following directions to Standards Australia by the Australian Government of the time. However, the influence did not extend beyond adopting to similar format and symbols to the ISO Standard. Unfortunately, that was somewhat futile, as the later (2009) version of the ISO Standard adopted a completely different format and set of symbols.

AS/NZS 1170.2:2002 continued with all the innovations introduced in 1989 in Australia, and 1992 in New Zealand. However, there was an important difference with respect to the return period for the design wind speeds. The user of AS/NZS 1170.2:2002 could not (and still cannot) obtain the required return period for the wind speed from the wind standard; he, or she, must go elsewhere. In Australia that 'elsewhere' is the Building Code of Australia (BCA), where 'average recurrence intervals' for environmental loading are specified, depending on the defined 'importance level' of the structure. For non-BCA structures in Australia (e.g. for mining or communication structures), and for New Zealand structures, that information is obtained from AS/NZS 1170.0 (General Principles).

Another significant change in AS/NZS 1170.2:2002 was a clear indication that the design process accounts explicitly for wind direction. This takes account of climate-related directional characteristics of the regional wind speed, but also directional variations in terrain, topography and shielding, at a site. There is, in fact, a three-stage process in determining design wind speeds as illustrated by the wind-speed chain of Figure 5.

The *regional wind speed*, V_R, is a gust speed assumed to occur at the standard meteorological height of 10 metres over flat, open terrain. The *site wind speed*, $V_{sit,\beta}$ is corrected for wind direction, and for site-specific factors, terrain-height, shielding and topography – normally there are 8 of these values for the cardinal points of the compass, i.e. N, NE, E … etc. For a building of rectangular planform, these are reduced to four values of design wind speed by taking the largest value of site wind speed within 90 degree arcs, centred on the wind directions normal to the building walls.

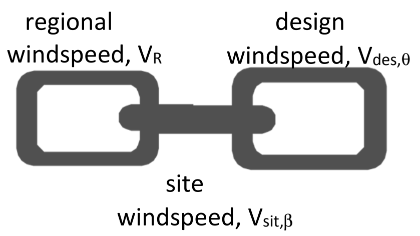


Figure 5. The wind speed 'chain' of AS/NZS 1170.2

This process allows for the fact that the Standard only provides shape factors for those orthogonal wind directions, although, in some cases (e.g. for cladding loads), they have been adjusted upwards to account for the higher values that may occur for oblique wind directions.

Unlike earlier versions, the 2002 and 2011 Standards are completely based on gust wind speeds, including when dynamic response factors are calculated. After re-assessing the response characteristics of the anemometers previously used in Australia to record daily maximum gusts, the nominal duration of the gust in the Standard has recently been re-defined as 0.2 seconds - based on the moving average definition, as is the convention in the digital age (Holmes and Ginger, 2012). This duration also conveniently provides a filtering of atmospheric turbulence that is equivalent to the averaging by the frontal area of a small building at design wind speeds, as shown in Figure 6.

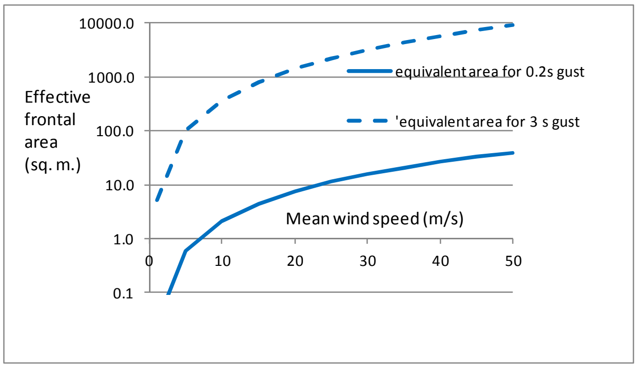


Figure 6. Effective frontal areas for 0.2 sec and 3 sec moving average gust durations

The much larger effective frontal area for a 3-second moving average gust is also shown in Figure 6. It is, in fact, equivalent to that of a city-centre tall building at design wind speeds.

Calibration of AS/NZS 1170.2

Although the shape factors and dynamic response factors in the Standard have been derived from reliable sources, usually wind-tunnel tests, experimental and data processing techniques change and on-going calibrations of the information provided in AS/NZS 11870.2 are desirable and advisable. Wherever possible, reliable full-scale measurements should also be used as a benchmark.

An example of recent amendments to the Standard following this approach, includes the changes to Table 5.3(C) for long low-rise buildings of high roof pitch, for which previous versions of the Standard were found to significantly underestimate load effects such as frame bending moments (Ginger and Holmes, 2003). Another example, which was based on *full-scale* data from the Texas Tech Building, is the recent increase to the local pressure factor for the corners of low-pitched roofs.

A comparison (Holmes, 2014) of the base bending moments on a benchmark tall (180m) building for both along-wind and cross-wind response calculated by AS/NZS 1170.2 and from several different boundary-layer wind-tunnel groups were very favourable. In particular, for along-wind response, AS/NZS 1170.2 performed better than two other national standards and codes (Figure 7).

For low-rise buildings, recent comparisons have been less conclusive. Measurements at James Cook University, as part of their study on solar panels, indicated good agreement for roof pressures on the underlying building roof (Ginger *et al*., 2011). However, other measurements (from a different wind tunnel) processed by Ginger *et al*. (2014) suggested that AS/ZS 1170.2 may produce un-conservative load effects in the first inboard frame of a low-pitch industrial building. Further investigations should be carried out to shed more light on this.

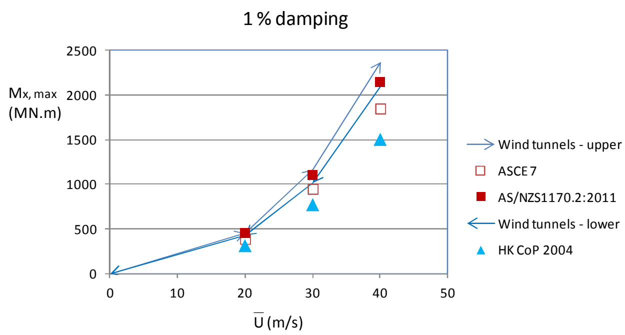


Figure 7. Along-wind response of a benchmark tall building – comparison of base moments from AS/NZS 1170.2 with the range of predictions from seven wind tunnel groups

The functions of AS/NZS 1170.2

By virtue of it being called up by the Building Codes of Australia and New Zealand, AS/NZS 1170.2 has an implied regulatory function, and it is important that the wording of the Standard is clear and unambiguous. A building that is designed correctly for wind loads using the Standard is hence by implication is compliant with the Building Codes.

Note that a structure for which wind loads have been determined by other means – such as wind-tunnel tests – is not compliant with the BCA in Australia, but is deemed to have had a 'special study', or 'alternative solution'. Appendix A in AS/NZS 1170.0 gives a few guidelines on how such studies should be undertaken and reported, but there is actually very little control of the methodologies. There is clearly a need for a more formal checking and review process for such studies, and there is a role for the AWES Quality Assurance Manual (AWES, 2001) in such a process.

As well as its regulatory function as part of the building codes, AS/NZS 1170.2 is relied on for wind loads by other structures in Australia and New Zealand, such as industrial structures used in petrochemical plants and mining operations.

The current (2011) version of AS/NZS 1170.2 is supported by a comprehensive handbook (Figure 8), prepared by the AWES

(Holmes, Kwok and Ginger, 2012). This performs a similar function to that of the 1990 Commentary to AS 1170.2-1989. As well as giving a comprehensive technical background information to the Standard, it provides additional information that could be used by designers, such as: shape factors for attachments to the walls of buildings, a method for allowing for the effect of large internal volumes on peak internal pressures, and a more detailed method for calculating the cross-wind dynamic response of structures with circular cross section.

Figure 8 Wind loading Handbook (AWES-HB-001-2012)

Future issues for AS/NZS 1170.2

It is becoming harder to make changes to the Standard due to pressure from the many stakeholders, and the increase in bureaucratic procedures required to initiate a project to amend it. However, there are several issues still to be addressed. Some of these are being addressed by small working groups:

a) The possible effects of climate change on regional wind speeds and regional boundaries, particularly the boundaries of the cyclonic regions in Australia. This important topic is addressed further in the following sections.

b) Small-scale non-synoptic winds, such as downbursts produced by thunderstorms, are the governing type of extreme wind for low-rise structures in many parts of Australia and New Zealand. Introducing appropriate multipliers for height and terrain and topography is a priority for the Standard, although little progress has been made to date, due largely to a lack of reliable full-scale data.

c) The rules for internal pressure determination in *Clause 5.3* of AS/NZS 1170.2 are leading to a variety of interpretations and assumptions on dominant openings, particularly on windward walls. Some designers of industrial buildings, particularly in cyclonic regions, are not willing to make realistic assumptions due to competitive pressures in the marketplace. New rules are currently being drafted to attempt to produce a more 'level playing field' on this question.

d) Solar panels on roofs have become very common in the last few years. The wind loads on the panels themselves are important requiring shape factors to be incorporated into the Standard. A start on this has already been made (*Section D6* introduced in Amendment 2), and more configurations are planned in the future.

e) Information on shape factors in the Standard that can be used for industrial structures has been rather sparse. In particular, the shielding and aerodynamic interference effects for equipment consisting of many closely-spaced elements, such as the shiploader shown in Figure 9, needs to be addressed. Although generic wind tunnel testing would be desirable, information from recent tests on specific mining and oil/gas structures may be available for this purpose.

Figure 9. Example of an industrial structure- a shiploader

Climate change effects on cyclonic wind speeds

In 2008 and 2011, I reported to the Australian Building Codes Board on the potential effects of climate change on design wind speeds on the cyclonic regions in Australia. The brief for the 2011 review (Figure 10) was:

To determine whether there was sufficient information and justification, to change design wind speeds in AS/NZS 1170.2,

a) with reference to currently available wind data,
b) with reference to extreme events such as Cyclone Yasi,
c) with particular reference to climate change.

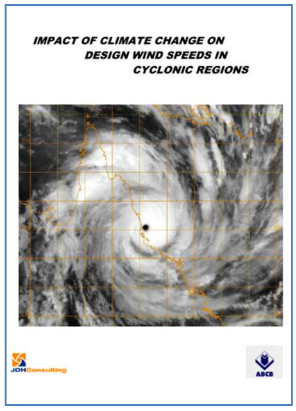


Figure 10. 'Impact of climate change' report (2011)

It is known that tropical cyclones require an ocean temperature of at least 26^{o} Celsius to form, and it seems logical that global warming, resulting in increased temperatures in the ocean, should produce greater numbers of tropical cyclones. However, the situation for the generation of cyclonic activity in the tropical oceans is more complex. Numerical models play an important role in weather prediction, but until recently their spatial resolution has been a limiting factor in relation to the prediction of the formation and life-history of tropical cyclones. However, these models are consistently predicting the occurrence of tropical cyclones at higher latitudes in the Coral Sea (i.e. further south) – this is potentially a threat to the more populated parts of southern Queensland.

The 2008 report recommended the extension of the Region C boundary on the Queensland coast from 25^{o} S to 27^{o} S (i.e.

incorporating the northern part of the Sunshine Coast), and the 2011 report proposed an extension of the boundary of Region D in Western Australia, to the northeast from 20º S to 15º S. Neither of these were accepted by the ABCB on economic grounds (ABCB, 2012), although it should not be forgotten that the strip from 25º S to 27º S on the east coast was deemed to be a cyclonic region from 1975 to 1989 (see Figure 3).

A later study by Geoscience Australia and CSIRO (Cechet *et al*., 2011) indicated that the design wind speed on the Sunshine Coast under the *current* climate should be about 5 m/s higher than it is at present (i.e. V_{500} of 62 m/s instead of the present 57 m/s for Region B), with little change predicted for SE Queensland under two climate change scenarios. This suggests consideration of an intermediate wind region between B and C in the future.

The 2011 ABCB report was written shortly after the occurrence of Cyclone Yasi earlier in that same year. This was a major event – the strongest cyclone to hit the Queensland coastline for fifty years – but the damage to recently-constructed, and to engineered, buildings was relatively small (Boughton *et al*., 2011), a credit to the changes to the codes and standards of the previous thirty years.

Another recommendation of both the 2008 and 2011 reports was that portable anemometers be deployed to monitor gust wind speeds in land-falling tropical cyclones. It is encouraging that David Henderson of the Cyclone Testing Station at James Cook University is now implementing this successfully (Henderson *et al*., 2013).

Decaying cyclones of tropical origin can also affect parts of the North Island of New Zealand, with a potential to increase their strength as a result of global warming (e.g. Burgess *et al*., 2006). This may require some attention to the current zoning system in AS/NZS 1170.2 for New Zealand, as well as Australia.

Climate change effects on non-cyclonic wind speeds

There is less information on possible global warming effects on other extreme wind types – i.e. gales from extra-tropical depressions, or local severe storms from thunderstorms (i.e. downbursts and tornados).

However, recent simulation studies with climate models are suggesting increased thunderstorm activity, due to increased convective available potential energy (CAPE), in both the United States (Diffenbaugh *et al*. 2013), and in Australia (Allen *et al*., 2014). This seems to be supported anecdotally by increased numbers of reported windstorms in Australia (e.g. Holmes, 2013), although this may also be a result of changes in monitoring and reporting procedures (Mason and Klotzbach, 2013), and increases in population density.

AS/NZS 1170.2, AS 4055 and housing

The 'Wind loads for housing' Standard, AS 4055 (Figure 11), has performed a useful role as a complement to AS/NZS 1170.2 since 1992. Limited to single houses less than 8.5m in height, it includes pre-calculated wind pressures and forces for six non-cyclonic and four cyclonic wind classifications. The latter are determined based on assessment of terrain, shielding and topography.

AS 4055 is called up by the National Construction Code/Building Code of Australia for wind loads as an alternative to AS/NZS 1170.2. It has undoubtedly contributed to a reduction in the wind damage to housing in tropical cyclones

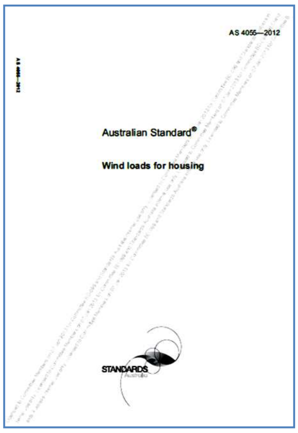


Figure 11. AS 4055-2012, Wind loads for housing

Recently (2012) the terrain category descriptions in AS 4055 and AS/NZS 1170.2 were aligned and are now identical. One result of this is that a Terrain Category 2.5 was introduced into AS/NZS 1170.2. However, there are significant differences between the two Standards in the assessment of topography and shielding.

The assessment of the topographic classification in AS 4055 is based on an average slope, averaged over all directions, i.e. 360º. Thus the slope for a site on a ridge can be as low as one half the maximum slope – potentially leading to a significant underestimation of the topographic effect if the maximum slope happens to coincide with a prevailing wind direction.

For assessment of shielding, AS 4055 appears to allow 'partial shielding' for houses in 'wooded parkland' in Regions A and B, and full shielding in 'permanent heavily wooded areas'. This is in contrast to AS/NZS1170.2, which states: 'Shielding from trees or vegetation is not permitted in this Standard'.

Reliance on trees for protection in windstorms is questionable – even in non-cyclonic regions. In fact, they regularly fail at wind gust speeds of around 30 m/s, well below ultimate design speeds, and trees close to houses are more likely to cause damage to a building than prevent it.

Conclusions and Acknowledgments

I have been fortunate to work with many motivated and informed committee members on AS 1170.2 and AS/NZS 1170.2. Thev have all contributed to make the document possibly the world leading standard for wind actions – certainly one of the top two or three internationally, despite little government funding or support in the last 20 years. This important document continues to be maintained by volunteers, who generally receive no travel support, let alone compensation for any time spent. Although some of these are partially supported by their employers, many are not, and some are retired or semi-retired. It is a tribute to all involved that this document has been able to be supported and maintained to its present level.

The following is a partial list of those members who should be recognized for their significant contributions to the Standard over forty years:

Geoff. Boughton, Charles Bubb, Neil Davis, Chris. Dorman, Mark Edwards, Richard Flay, John Ginger, Tom Glass, Bruce Harper, Kourosh Kayvani, Andrew King, Kenny Kwok, Chris. Letchford, Alan McKenzie, Bill Melbourne, David Morato, Bill

Moriarty, Peter Mullins, Leo Noicos, John Nutt, Tony Rofail, Peter Russell, Scott Woolcock, Steve Reid, Peter Russell, Greg. Reardon, Len. Stevens Richard Turner, Barry Vickery, George Walker, Richard Weller, Graeme Wood.

References

Allen J T, Karoly D J and Walsh K J (2014) Future Australian severe thunderstorm environments. II The influence of a strongly warming climate on convective environments, *J. Climate,* Vol. 27, pp 3848-3868.

American National Standards Institution Inc., (1972) Building code requirements for minimum design loads in buildings and other structures, ANSI A58.1-1972, ANSI, New York.

Australian Building Codes Board (2012) Proposal to revise the National Construction Code requirements for construction in cyclonic regions, Regulation impact statement, February.

Australasian Wind Engineering Society (2001) Wind engineering studies of buildings, Quality Assurance Manual, AWES-QAM-1-2001.

Boughton G N and nine others (2011) Tropical Cyclone 'Yasi' – structural damage to buildings, James Cook University, Cyclone Testing Station, CTS Technical Report 57, April.

Burgess S, Salinger, J, Gray, W and Mullan B (2006) Climate hazards and extremes – New Plymouth district: Cyclones of tropical origin, NIWA Client Report WLG2006-27, June.

British Standards Institution (1972) Code of basic data for the design of buildings. Chapter V. Loading. Part 2. Wind loads. CP 3: Chapter V: Part 2: 1972.

Cechett R P, Sanabria A, Yang T, Arthur W C, Wang C H, Wang X (2011) An assessment of severe wind hazard and risk for Queensland's Sunshine Coast region, *19th International Congress on Modelling and Simulation*, Perth, Western Australia, December 12-16.

Dansk Ingeniorforening (1977) Norm for last pa baerende construction, 2. Vindlast, NP-134-T. Dansk Standard DS 410.2 (Code of practice for Actions on Building Structures 2. Wind load).

Davenport A G (1977) The prediction of risk under wind loading, *2nd International Conference on Structural Safety and Reliability (ICOSSAR2)*, Munich, Germany, September 19-21.

Diffenbaugh N S, Scherer M and Trapp R J (2013) Robust increases in severe thunderstorm environments in response to greenhouse forcing, *Proc. Nat. Acad. Sc.,* Vol. 110, pp 16361-16366.

Ginger, J D and Holmes J D (2003) Effect of building length on wind loads on low-rise buildings with a steep roof pitch, *J. Wind Eng. & Ind. Aerodyn.*, Vol. 91, pp 1377-1400.

Ginger J D and four others (2011) Investigation on wind loads applied to solar panels mounted on roofs, James Cook University, Cyclone Testing Station, CTS Report 821, December.

Ginger J D, Henderson D J, Humphreys M, Konthesinghe C, Stewart M (2014) Wind loads on the frames of industrial buildings, *Advances in Wind and Structures (AWAS14)*, Busan, Korea, August 24-28.

Gomes L and Vickery B J (1976) Tropical cyclone gust speeds along the North Australian coast, *Civ. Eng. Trans. I.E. Aust*., Vol. CE18, pp 40-48.

Gumbel E J (1958) Statistics of extremes, Columbia University Press, New York.

Henderson D J, Mason M and Ginger J D (2013) Wind-speed measurements of land-falling tropical cyclones using SWIRLnet, a portable anemometer network, *16th Australasian Wind Engineering Workshop*, Brisbane, Queensland, July 18-19, Proc. pp 22-24.

Holmes J D (2008 & 2011) Impact of climate change on design wind speeds in cyclonic regions, JDH Consulting and Australian Building Codes Board, June 2008 and June 2011, (2008 version available at: www.abcb.org.au).

Holmes J D (2013) Windstorms in Victoria and southern NSW, March 21, 2013, *16th Australasian Wind Engineering Workshop*, Brisbane, Queensland, July 18-19, Proc. pp 25-28.

Holmes J D (2014) Along- and cross-wind response of a generic tall building: comparison of wind-tunnel data with codes and standards, *J. Wind Eng. & Ind. Aerodyn.*, Vol. 132, pp 136-141.

Holmes J D and Ginger J D (2012) The gust wind speed duration in AS/NZS 1170.2, *Aust. J. Struct. Eng*., Vol. 13, pp 207-217.

Holmes J D, Kwok K C S and Ginger, J D (2012) Wind loading handbook for Australia and New Zealand, Australasian Wind Engineering Society, AWES-HB-001-2012.

Holmes, J D, Melbourne W H and Walker G R (1990) A Commentary on the Australian Standard for Wind Loads, Australian Wind Engineering Society, 1990.

Martin G and Bubb C T J (1976) Discussion of "Tropical cyclone wind speeds along the North Australian coast", *Civil Engineering Transactions, Institution of Engineers, Australia*, Vol. 18, pp 48-49.

Mason M and Klotzbach P (2013) A preliminary analysis of convective windstorm environments across Australia, *16th Australasian Wind Engineering Workshop*, Brisbane, Queensland, July 18-19, Proc. pp 33-36.

Shellard H C (1963) The estimation of design wind speeds, *International Symposium on Wind Effects on Buildings and Structures*, Teddington, England U.K., June 26-28.

Standards Australia (2002), Structural design actions. Part 0: General principles, Australian/New Zealand Standard AS/NZS 1170.0:2002.

Standards Australia (2011) Structural design actions. Part 2: Wind actions, Australian/New Zealand Standard AS/NZS 1170.2:2011.

Standards New Zealand (1984) Code of practice for general structural design and design loadings for buildings, NZS 4203:1984.

Whittingham H E (1964) Extreme wind gusts in Australia, Bureau of Meteorology, Melbourne, Australia, 1964.