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A Proposal for the Review of Design Wind Speeds in Tropical Cyclone Prone Areas of Australia

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Abstract

The regional design wind speeds for tropical cyclone prone regions in the current Australian wind code are primarily based on modelling of tropical cyclone wind speeds undertaken in 1975 in the aftermath of Cyclone Tracy reinforced by similar modelling undertaken at James Cook University in the early 1980's. Since that time there have been major advances in modelling tropical cyclone wind risk as well as many more years of records of tropical cyclones on which such modelling is based. Models incorporating these advances and updated records are currently used on a daily basis within the insurance industry for estimating catastrophe insurance risk. Their use for reviewing wind speed risk for wind code purposes seems overdue. Furthermore current building design is based on the individual wind risk to buildings, which satisfies human safety requirements but not necessarily disaster mitigation requirements in terms of socio-economic impact, which over the past half century has become much more significant with the growth of concentrations of population and wealth in regions at risk from natural disasters. This paper presents a case for a review of the current regional design wind speeds in tropical cyclone prone regions of Australia taking these two factors into account.

Historical Background

From the earliest days of settlement it has been recognised that northern Australia is affected by tropical cyclones which generally produce wind speeds significantly higher than those experienced from severe wind storms in the rest of Australia. All wind loading standards produced since 1950 have explicitly recognised this.

The earliest information on wind loadings in an Australian standard dates back to at least 1933 with the publication by the then Standards Association of Australia (SAA) of SAA Code No. CA.1-1933 entitled Code for Structural Steel in Building. The wind loading information, which formed Appendix II of this standard, was very prescriptive, showed little scientific understanding of wind loading, and left designers to choose their own design wind speeds from limited information on wind speeds in the capital cities (excluding Darwin) ranging from daily maximums to those with an estimated 20 year return period. For other locations designers were left to find their own data. There was a revision of this code in 1939 but the details are unknown to the author.

Following World War II, the SAA set up a committee to develop a general structural loadings code. Under government pressure to use steel more economically in construction it was decided in December 1951 to issue the then current draft of this code as an interim standard known as SAA Int 350 entitled Minimum Design Loads on Buildings, along with an interim revision of CA1 which was published as SAA Int 351. SAA Int 350, published in 1952, was the first separate loadings code produced by Standards Australia. Approximately A5 in size, its 27 pages contained 2 parts, Part 1 dealing with dead and live loads and Part 2 with wind loads. Part 2 was effectively Australia's first wind code. Australia was divided into 2 regions, coastal areas of northern Australia and the rest. The tropical cyclone region was specified as coastal areas of Australia north of Latitude 25°S. For each region, 3 separate basic design wind speeds were specified, one for sheltered sites which effectively corresponded to current Terrain Category 3, one for open sites on flat or rolling land effectively corresponding to current Terrain Category 2, and one for exposed sites which included topographical effects. They were expressed in terms of the units and design procedures used at the time – ie in miles/hour for use with Working Stress Design (WSD). Table 1 shows these values in current terminology – ie in m/s for use with Ultimate Strength Design (USD). The cyclone region design wind speeds are surprisingly similar to the values currently used for houses in Region C, but in Int 350 they were specified as being constant with height to 300 feet (approximately 100m).

Exposure Conditions	USD Design Wind Speed (m/s)	
	Non-Cyclone Region	**Cyclone Region**
Protected	36	52
Flat Open Country	41	61
Exposed	50	72

Table 1. Int 350 regional design wind speeds expressed in current terms – ie m/s and USD (derived from Table 4 in SAA Int 350..

When Int 350 was produced it was expected to be revised within a year or so resulting in the publication of a formal wind code, but it was 1971 before the latter was produced. The interim period is now recognised as the foundation period of modern wind engineering based as it is on an understanding of boundary layer winds and modelling their effects on buildings in a boundary layer wind tunnel. Consequently the first standalone wind code produced by Standards Australia, AS34, PartII-1971: SAA Loading Code Part II – Wind Forces was much more sophisticated than Part 2 of Int 350. The specification of design wind speeds reflected this sophistication. Recognising that wind speed varied with height, terrain and topography the basic design wind speeds were specified in a similar format to that currently used - ie as wind speeds at 10m height in Terrain Category 2, with separate multiplying factors specified to account for terrain and topography. In the interim period the Bureau of Meteorology had undertaken detailed Gumbel analysis of recorded annual maximum wind speeds and the specified wind speeds in the code reflected this (Whittingham, 1964). A 50 year return period peak wind speed was standardised as the basis for WSD design of normal structures with 5, 20 and 100 year return periods being standardised for other structures of lesser or greater importance. The derived wind speeds for each of these return periods for each of 50 locations around Australia were specified as the design wind speeds along with a map of smoothed isopleths for 50 year return period wind speeds to be used for other locations – and for Cairns for which the specified derived values were considered low! Recognising that the slope of the Gumbel distribution of tropical cyclone winds was greater than that of the winds in non-cyclone areas a cyclone factor was 1.15 was specified for the cyclone region which was defined as coastal areas up to 30 miles (approximately 50km) north of Latitude 27°S.

Shortly after the publication of the 1971 code Australia changed to the metric units leading to the 1973 revision and the first version known as AS1170, Part 2. This was largely a conversion of the 1971 code into metric units, but included some changes reflecting additional knowledge gained in the interim period and some rationalisation of the wind speeds based on the smoothing of isopleths which led to a reduction of those specified for Brisbane and Rockhampton.

The destruction of Darwin by Cyclone Tracy led to a major rethink of design wind speeds in cyclone areas. It had been recognised from the beginning that because of the sparse data on maximum annual wind speeds from tropical cyclones in individual locations, using Gumbel analysis of this data to determine deign wind speeds was unreliable and could lead to anomalous results – which it did. In 1971 a landmark paper (Russell, 1971) had demonstrated a potentially more reliable approach by using the emerging technology of geographic information systems (GIS) to simulate tropical cyclone wind speeds geographically based on the characteristics of tropical cyclones such as central pressure, track, eye diameter, and forward speed, of which there was much more historical data than direct measurements of wind speeds. The use of this approach was already being studied at University of Sydney (Gomes & Vickery, 1976) and preliminary results of this analysis were made available to the wind code committee together with results from a similar study undertaken within the Australian Government Department of Construction (Martin & Bubb, 1976). This led to the hastily prepared 1975 revision of the wind code, which, based on these studies, specified a uniform design wind speed for the whole of the previously specified tropical cyclone region. It was recognised at the time to be a relatively conservative interpretation of the research results, especially in many locations, but in view of the lack of experience worldwide in using this approach this conservative approach was considered prudent.

There were no changes to regional basic design wind speeds in either the 1981 or 1983 revisions of the wind code, the latter being the last one issued in WSD terms. Major changes to the specification of basic design wind speeds occurred with the publication of the 1989 revision of the wind code, the first one presented in USD terms. This revision set the pattern for the subsequent revisions of the wind code up to the present day. The most significant changes were to divide all Australia into 4 wind regions, within each of which the specification of basic design wind speeds was uniform, and to specify 3 levels of basic wind speed in each zone, one for use with USD, one for use with WSD and one for serviceability design. The USD basic design wind speeds had a nominal return period of a 1000 years, which made them equivalent to those previously used for WSD.

There were in effect 3 cyclone regions specified. The previous cyclone region was split into 2 regions C and D, to account for the perceived higher wind risk between Latitudes 20°S and 25°S on the west coast, and an additional region, B, which was designated a transition region, was created for coastal areas up to 50km inland between Latitudes 25°S and 30°S on both the east and west coasts, and for all inland areas between 50km and 100km from the coast north of Latitude 25°S. The split between Regions C and D was based on differences shown in the original studies by Gomes and Vickery (1976) and Martin and Bubb (1976), which appeared to have been reinforced with time, as well as by a separate modelling study undertaken by Tryggvasson (1979) not long afterwards. The establishment of Region B recognised that this region was influenced by tropical cyclones but of lower intensity, the areas south of Latitude 25°S because of the lower intensity of tropical cyclones occurring in these latitudes, and areas north of Latitude 25°S because of the decrease in intensity of cyclones after crossing the coast. Consequently for strength design in Region B the basic design wind speeds were based on cyclone risk, while for serviceability design they were based on non-cyclone winds. In Region C the basic design wind speeds were decreased from those previously used by approximately 10 per cent and those in Region D increased by a similar amount, this being consistent with the earlier modelling studies, as was the USD basic design wind speed of 60m/s specified for Region B for strength design. By this time a Cyclone Intensity Scale had been established by the Australian Bureau of Meteorology and at the time it was accepted that the basic design wind speed for Region C corresponded to the middle of the Category 4 range, for Region D corresponded to well into the category 5 range, and for strength design in region B corresponded to around the top of the Category 3 range. These levels seemed reasonable in terms of the history of tropical cyclones in these regions.

The 2002 revision of the wind code introduced a modifying factor into the determination of the regional basic design wind speeds in Regions C and D to account for the uncertainty of the wind risk but the underlying return period wind speeds remained unchanged from those specified in the 1989 version. However regional design wind speeds were given for a range of return periods based on probability distributions fitted to the previously used data. In a change of practice the specification of the minimum design return period to be used was transferred to the Building Code of Australia which for normal structures adopted a 500 year return period rather than the previously adopted 1000 years. However the introduction of the somewhat arbitrary reliability factors for Regions C and D effectively meant little change in the regional design wind speed in Region C and an increase in Region D. There was also some changes in the specification of the Regions with the inland area between 50km and 100 km from the coast on the west coast between Latitudes 20°S and 25°S being changed from Region B to Region C, and areas north of Latitude 11°S and east of Longitude 14.2°E (essentially Thursday Island and the Torres Strait islands) being changed from Region C to Region B.

Some further refinements to the specification of the regions has been made in the recent 2011 version but the regional basic return period wind speeds remain the same, remaining based on the modelling undertaken in 1975 and in 1979.

Table 2 shows a comparison of how the regional design wind speeds for use with normal buildings has changed for various locations at risk from tropical cyclones with the successive versions of the wind code since SAA Int 350. It is interesting to note that since the publication of the first separate wind code in 1971 the design wind speeds have increased in all of the communities listed in Regions C and D except Darwin, the damage to which from Cyclone Tracy triggered the subsequent increases! It also shows that the design wind speeds for Brisbane and Perth have significantly reduced despite there being a tropical cyclone risk, which may be increasing as a result of global warming, and because of their size the potential for a very big disaster if either is impacted by a significant tropical cyclone – such as occurred in New York as a result of Hurricane Sandy.

Reliability of Cyclone Design Wind Speeds

The specification of design wind speeds in tropical cyclone prone regions in the current edition of the wind code is far more sophisticated than that in the 1975 edition, but the source of the basic data is the same. Detailed formula and tables for the determination of regional wind speeds for different return periods and modifying factors for uncertainty imply a high level of

Location	Regional Basic Design Wind Speeds in USD Terms (m/s)						
	1952	**1971**	**1973**	**1975**	**1981/1983**	**1989**	**2002/2011**
Brisbane	41	64	61	61	61	60	57
Rockhampton	61	60	66	77	77	70	69
Townsville	61	65	65	77	77	70	69
Cairns	61	64	63	77	77	70	69
Thursday Island	61	55	55	77	77	70	57
Darwin	61	69	69	77	77	70	69
Broome	61	64	63	77	77	70	69
Port Hedland	61	64	63	77	77	85	88
Onslow	61	86	85	77	77	85	88
Carnarvon	61	64	63	77	77	85	88
Perth	41	55	54	49	49	50	45

Table 2. Variation of regional basic design wind speeds for normal buildings with successive versions of the wind code in USD terms and m/s

accuracy of the original data on which they are based. Many users, and certainly users outside the wind engineering community, actually believe these are relatively accurate, to the extent that scientists investigating the possible effects of climate change on wind speeds use the code information as a starting point! Yet it is all based on a rudimentary conservative interpretation of results arising from modelling based on very limited information and knowledge relative to what is available now.

GIS modelling of tropical cyclone wind speed risk requires two basic sources of information:

- Knowledge of the relationship between the surface wind speeds generated by tropical cyclones and the tropical cyclone characteristics such as central pressure, forward speed and eye diameter, as a cyclone crosses from over the sea to over land;

- Historical records of tropical cyclones and their characteristics including in addition to the above characteristics their tracks.

At the time when the modelling was undertaken on which the code design wind speeds are based, only very simplistic empirical information was available for the determination of wind speeds based on cyclone characteristics. Since then there has been an order of magnitude or more increase in knowledge of this relationship.

Reliable records of the occurrences of tropical cyclones, including their characteristics and paths, only date to the beginning of satellite imagery in the early 1960's. Less than 15 years of these records would have been available for the modelling in 1975 and about 20 years for the modelling in 1982. Currently there is about 50 years of these records available. Furthermore since that time there has been a major revision of the older less reliable records which would have formed the backbone of the records used.

There have also been major advances in the techniques used in the modelling. During the 1980's it was realised that these models could be used for estimating the catastrophe insurance risk to insurance and reinsurance companies from tropical cyclone winds. Friedman (1975) had laid the basis for this approach but it was not until the late 1980's that these models reached a level of development to make them useful. The success of a model developed by Applied Insurance Research in predicting the loss from Hurricane Andrew within a day or two of its occurrence led to the rapid implementation of these models, initially in the US and subsequently globally. Nowadays such models are routinely used on a day to day basis by reinsurance brokers and reinsurers. The models are backed up by teams of researchers who keep the models up to date with the latest knowledge and records of tropical cyclones occurrences.

If the design wind speeds in the Australian wind code are to representative of current knowledge, then they need to be based on modern modelling. Such modelling will enable a more realistic set of regional design wind speeds to be established. It will also provide much more realistic information for use in undertaking studies of what changes may be necessary to allow for the effect of climate change, including cost-benefit studies (Walker & Musulin, 2012). It is quite possible that current wind risk estimates are incorrect by as much as 15-20% in some localities. Climate change predictions of an increase in wind speeds of the order of 5% are so much within the error band that any studies using the current information are unlikely to produce meaningful results.

An added reason for undertaking the revision of the underlying modelling studies is the consequences of the recent finding that the Dines anemometer wind speeds approximate averaged 0.2 second gusts, not averaged 3 second gusts as previously believed (Holmes & Ginger, 2012) . While it has not affected their use in the wind code it has affected the relationship between design winds and the Bureau of Meteorology's Cyclone Intensity Scale. In keeping with the standards of the World Meteorological Organisation this scale is in terms of 3 second averaged wind speeds. Conversion of present design wind speeds in Regions B, C and D shows they actually correspond to the middle of Category 3, upper level of category 3 and upper level of Category 4 respectively, which is considerably lower than previously believed. However a revised analysis of wind risk may show the risk is not as great as implied by the wind code for many locations, but it may show it is greater in some locations.

The Damage Mitigation Issue

Current design is based on the protection of human lives from the failure of individual buildings. In developed countries where this design philosophy has become standard practice it has resulted in a large reduction of life from natural disasters. Even globally annual loss of life from natural disasters has remained relatively static for the last 50 years despite increasing population and especially increasing concentrations of population in disaster prone regions (Swiss Re, 2011). During the same period the average annual economic loss from natural disasters has increased 10 times (Munich Re, 2011) and it has now reached the stage that this loss in conjunction with the disruption of normal activities due to infrastructure losses has become the number one concern in regard to disaster mitigation in developed countries, and of similar concern in developing countries.

Designing individual buildings to be safe for their occupants does contribute towards disaster mitigation, but it does not directly address it. The characteristic feature of disasters is that they are caused by an accumulation of losses and damage. The total loss of an individual small building may be upsetting to the owners but it is not a disaster from a community point of view. But minor to moderate damage to hundreds of thousands of buildings due to a single event may result in a major disaster, even if few or no lives are lost. This was well exemplified by the impact of Hurricane Sandy on the New York region, and on a lesser scale by the impact of Cyclone Yasi on North Queensland, even though no major city was directly hit. Had Yasi made a direct hit on Cairns or Townsville the economic loss and social impact would have been very much larger, and it would have been regarded as a major disaster even if no lives had been lost.

This is leading to proposals for a change in the approach to the development of design criteria to make disaster mitigation a direct objective in addition to human safety (Walker et al, 2011). Applying this design philosophy in addition to ensuring individual buildings are structurally safe in terms of human safety, design criteria would need to reflect the influence of damage accumulation in areas with large concentrations of population from single events. Such criteria would also need to reflect the potential growth of population centres during the actual life of buildings. A consequence of this approach would be that criteria would be community based with communities characterised by large concentrations of population and wealth requiring more demanding criteria than smaller more isolated communities. Ideally the criteria would be developed through cost benefit studies directed at optimising the level of design criteria in terms of building costs relative to disaster mitigation benefits (Walker and Musulin, 2012). However it is doubtful that sufficient knowledge of the impact of design criteria on disaster costs currently exists to adopt this approach. An interim approach might be to base design wind speeds for larger communities on the return wind speed across twice the current area of a community, instead of at a point location, the doubling of area being used to allow for future growth.

Implementation

The primary tool required to undertake the analysis of tropical cyclone wind risk is a GIS based tropical cyclone model for coastal areas of Australia. Such models are an integral component of the tropical cyclone insurance loss risk models used widely within the Australian insurance industry for managing the risk to insurance companies from tropical cyclones. There are three main international providers of such models, Risk Management Solutions (RMS), Applied Insurance Research (AIR), and EQECAT. In addition at least one major reinsurance broker Aon Benfield has an internal model, Risk Frontiers at Macquarie University has another, and Systems Engineering Australia (Bruce Harper) has another.

In addition to these tropical cyclone insurance loss risk models Geoscience Australia has a similar model which has been developed for use in developing government policy in regard to emergency risk management.

Such models depend on a combination of scientific knowledge plus expert opinion on its interpretation. As a result of the latter, no models give exactly the same answer but by using several models an indication of the epistemic risk associated with the expert opinion is obtained. Consequently most decision making in respect of the management of catastrophe insurance loss risk is based on running several models. For reliable information it would be desirable if the wind risk estimates from at least three of these models are used as a basis for establishing revised design criteria.

Although most of these models - apart from the Geoscience Australia model – have been developed for commercial purposes the author believes that the output on wind risk would be readily supplied for modest fee – since it is generated every time a model is run. The real challenge would be how to use this information to develop a more rational set of regional return period wind speeds for tropical cyclone areas for use in conjunction with the Building Code of Australia than currently exist.

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