Wind and Building Damage Issues for Coastal Cities

Understanding the critical components

Geoffrey N Boughton (Director, Timber ED Services)
Debbie J Falck (Engineering Assistant, Timber ED Services)

1. Introduction

Every year some Australian communities are affected by strong wind events. These may come in the form of short summer storms, widespread winter gales or high impact tropical cyclones.

There are risks associated with high winds in all Australian coastal cities:

- Tropical Cyclones are an accepted part of life during the summer months in northern Australia. Fortunately, many cyclones either track out at sea and weaken before crossing the coast, or make landfall over sparsely populated areas and cause no damage to buildings or infrastructure. However, there have also been a number of cyclones that have affected coastal cities in recent times. For example, Townsville (Cyclone Althea, 1972), Darwin (Cyclone Tracy, 1974), Exmouth (Cyclone Vance, 1999) and Innisfail (Cyclone Larry, 2006).
- Australia’s southern cities are also vulnerable to the effects of wild weather that generates strong, potentially destructive winds. In January, 1991 a severe thunderstorm moved across the northern suburbs of Sydney causing damage to 7,000 houses, and loss of power to 164,000 homes. Large hail and flash flooding was reported in several locations. The total insurance payout on the storm was around $215 million (1997), although the total damage bill may have been nearly 3 times this amount. In May 1994, some areas of Perth experienced maximum wind gusts of 143 km/h, while winds averaged 107 km/h over a 30 minute period in nearby Fremantle. One-third of Perth was without power due to downed powerlines caused by fallen tress.

Many of these events have been etched into the national history, but certainly all of them are etched deeply into the local history and into the lives of the communities affected. However, the building industry has learned from these experiences and the whole community must continue to make changes to lessen the impact of future events.

Strong wind events are powerful in affecting the physical aspects of coastal cities and also the social and economic fabrics of these communities. An understanding of wind action on buildings will enable communities to develop resilience to wind events and be better equipped to address repair issues.

2. Impact of Gales, Severe Storms and Tropical Cyclones

Very strong winds can be caused by a number of meteorological phenomena including:

- Gales,
- Severe Thunderstorms and
- Tropical Cyclones

Each of these differ in their origins, the winds they generate and the scale and magnitude of the effects on the communities.

2.1 Gales

Synoptic events – often associated with cold fronts, and are reliably predicted often in advance. Winds may build slowly over some time, but generally, the duration of extreme winds is relatively short. Further, it is often cells embedded in the front that cause the damage, so the damage can be significant in small localities, but overall – not particularly wide spread. They can occur at any time of year, but are most severe in the south of nation and during the Autumn and Winter seasons.

Synoptic gales may cause significant tree damage, be associated with flooding, and may also produce roof damage, particularly in exposed buildings. Pockets of damage may be more severe, but most coastal cities would be able to respond to wind damage from gales with little outside assistance.

2.2 Winds associated with Severe Thunderstorms

Severe Thunderstorms are more difficult to predict some time ahead of their occurrence. It is possible to predict a high risk of thunderstorm activity 24 hours or more ahead, but the severity of an individual storm or the path of the extreme winds may only become apparent within hours of the event.

Severe thunderstorms can generate many kinds of wind events, but the two most devastating are downbursts and tornados.

- Downbursts are caused by high velocity jets of air being directed at the ground as a result of turbulence and instability in the thunderstorm itself. Downbursts are close to uni-directional and can cause strips of significant damage in their path. Downburst wind speeds can approach the design wind speed for buildings in most parts of Australia, though the chances of a particular building being struck directly by a downburst are very low.
- Tornados are rapidly rotating funnels of air that drop out of the platform cloud at the back of a severe thunderstorm. The rotation in a tornado is very fast and can lead to wind speeds at the ground of well in excess of Australian Design Wind speeds. Structural damage from severe tornados is quite comprehensive, but the edges of the damage zone are clearly defined by the edge of the rotation. (Houses on one side of the street can be undamaged, while those on the other side have been totally destroyed by a tornado.) Table 1 presents the Fujita scale for assessing the intensity of tornados.

Table 1 – Fujita Scale – intensity of Tornados

F number	Speed (km/h)	Damage
F0	64-116	Some chimneys damaged, twigs and branches broken off trees, shallow-rooted trees pushed over, signboards damages, some windows broken
F1	117-180	Surface of roofs peeled off, mobile homes pushed off foundations or overturned, outbuildings demolished, moving autos pushed off the roads, trees snapped or broken;
F2	181-253	Roofs torn off frame houses, mobile homes demolished, frame houses with weak foundations lifted and moved, large trees snapped or uprooted, light-object missiles generated
F3	254-332	Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted, heavy cars lifted off the ground and thrown, weak pavement blown off the roads
F4	333-418	Well-constructed houses levelled, structures with weak foundations blown off the distance, cars thrown and disintegrated, trees in forest uprooted and carried some distance away
F5	419+	Strong frame houses lifted off foundations and carried considerable distance to disintegrate, automobile-sized missiles fly through the air in excess of 300 feet, trees debarked, incredible phenomena will occur

http://www.windows.ucar.edu/tour/link=/earth/Atmosphere/tornado/fujita_scale.html

Both of these wind events can develop very rapidly and unpredictably. Damage is very localised with damage strips being up to 100 metres across and a few kilometres long in some instances. However, the damage is frequently very spectacular and will require a very significant repair investment. Australia has many tornados each year, but their magnitude (frequently F0 to F3) is less than that publicised in the US and many of them may not be seen – just a damage path noted after the event.

The probability of any single building being impacted by a tornado in its lifetime is very low, and it is not a requirement to design structures to resist tornado winds. Downbursts are a little more frequent and design wind speeds cover most downburst events.

2.3 Tropical Cyclones

In contrast to tornados, tropical cyclones are large-scale meteorological events sometimes a few 100 kms in diameter. They can clearly be recognised on satellite photographs and satellite imaging is the main method of detecting and characterising Tropical Cyclones.

Tropical cyclone systems form over warm tropical waters and derive their energy from the latent heat of evaporation of water. The rotation of the cyclone can generate wind speeds of up to 300 kph as shown in Table 2. Fortunately Category 5 events are relatively rare, though Cyclone Vance (Exmouth 1999) was a category 5 cyclone.

Table 2 – Tropical Cyclone Categories

Category	Wind Speed (km/h)	Damage
1	< 125	Negligible house damage. Damage to some crops, trees and caravans. Craft may drag moorings.
2	125 – 169	Minor house damage. Significant damage to signs, trees, and caravans. Heavy damage to some crops. Risk of power failure. Small craft may break moorings.
3	170 – 224	Some roof and structural damage. Some caravans destroyed. Power failure likely.
4	225 – 279	Significant roofing loss and structural damage. Many caravans destroyed and blown away. Dangerous airborne debris. Widespread power failure.
5	> 280	Extremely dangerous with widespread destruction.

http://www.bom.gov.au/info/cyclone/

Because of their size, a tropical cyclone may take between 4 to 16 hours to pass a given point, so will buffet buildings with a large number of severe gusts. This can lead to progressive damage to the building in that time.

Most Australian tropical cities, if in the path of a tropical cyclone would be completely enveloped by the zone of extreme winds and hence nearly all buildings would experience gusts close in speed to the peak gust in the event. Where the cyclone is particularly severe, then there is the chance of large-scale damage from a single event. Severely damaged towns and cities would almost certainly need assistance during the recovery phase.

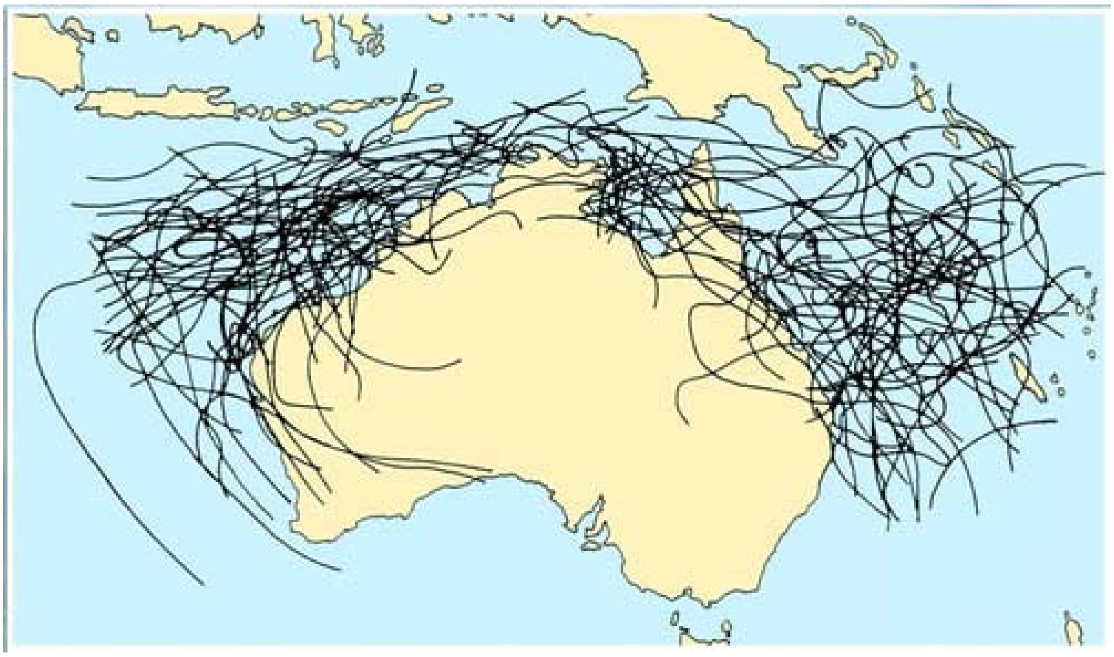

Figure 1 Tropical Cyclone paths

Because tropical cyclones are generated over warm tropical water, they are a phenomenon that is most common in the north of the country. They also decline in magnitude as soon as they are cut off from their energy source (warm water), so become less of a threat as they move inland. Figure 1 shows Tropical Cyclone paths for the 20th Century in Australia.

3. Buildings – structure, resilience and weaknesses

Wind causes pressures on surfaces of buildings. These lead to loads on the structure and where the loads applied by the wind are bigger than the capacity of the structural elements, then the elements fail.

- In general, where the wind flow lines are moving towards the building, then there is a pressure on the surface (tending to blow the surface inwards). This is always the case for the windward wall of a building.
- However, where the air has a component of its movement that is away from the building, then the wind causes suction on those surfaces (tending to pull the surface outwards). This is often the case for roof surfaces and for side and leeward wall surfaces.

3.1 Typical failure modes for buildings

External roof surfaces tend to have suctions that apply uplift loads to the roof sheeting. Most building failures in high winds involve loss of some part of the roof.

In addition, wind pushes inwards on the wall facing the wind. This inward pressure can be increased by impact from debris that is part of the wind stream. Debris can be branches of trees outdoor furniture, or in extreme cases, caravans, cars or parts of damaged buildings. The wind pressure and extra load from debris impact can cause failure of elements in the windward wall of buildings – typically windows, doors and sometimes cladding elements.

Where a significant hole in the windward wall is made, then the wind pressures from that wall can be applied to all inside surfaces of the building. The sudden increase in internal pressures pushes upwards on the underside of the roof and this can increase uplift forces on the roof structure.

In long duration wind events, such as tropical cyclones, debris presents significant problems. Because there are a large number of very high velocity gusts in the event, one can loosen the debris, another lift it into the air stream, and further gusts roll it along in the air. If the debris should hit the ground other gusts may even pick it up and entrain it in the air stream again. The large number of gusts in an event increase the probability of airborne debris colliding with other structures. In short duration events such as downbursts, debris is less likely to pose a problem, as the event is often a single gust.

3.2 Structural elements

A large number of structural elements must be operational in order for buildings to remain undamaged in high wind events. These include:

- Roof sheeting – must act as a plate bending element to resist the uplift pressures.

- Roofing anchorage – screws and nails that hold the roofing to the battens or purlins
- Battens or purlins – act as beams that carry the loads to the rafters or trusses
- Batten or purlin anchorage – connections between battens or purlins and their supporting elements – rafters or trusses
- Rafters or trusses – act to carry the uplift forces to the walls or columns that support the roof.
- Rafter or truss anchorage – connects the roof structure to the wall systems.
- Walls or columns – normally act to support the weight of the roof, but under high winds must hold the roof structure down.
- Building anchorage – in many cases, the uplift on the building can be greater than the weight of the structure itself, and the whole building must be tied into the ground.

Each and every one of these elements must be functioning correctly to avoid wind damage. As well, there are other structural systems that resist the lateral loads on buildings. These include bracing walls and systems, and connections between these systems and the rest of the structure.

While all of these elements are necessary in resisting wind, few of them would be designed by engineers in houses. The performance of the house relies on correct implementation of building practice outlined in section 4.

3.3 Weakness and Resilience of buildings

If any element in a building fails under wind loads, then the loads on the adjacent similar elements increase immediately. Resilient structures have a reserve of strength that means elements can cope with the increased redistributed load.

Where each element has the bare minimum strength, then there is no reserve to cover loss of strength in any one of the hundreds of elements required to carry the wind loads to the ground. Loss of performance can be due to any of the following elements:

- Deterioration with age – corrosion, rot, embrittlement, oxidation can all reduce the strength of elements.
- Incorrect installation – there is a chance that one or two elements in a building may not have been properly installed. Examples include timber splitting as a fastener is driven into it, screws missing the battens or purlins as they are driven through the roof sheeting.
- Over-tightening of screws causing deformation or cracking of metal elements.
- Damage accumulated over previous events. This may be the case in cyclone areas, where previous cyclones may cause cracking of some elements that may be undetected in post-event inspections, but significantly weaken the element for resisting future events.

4. Current Construction Standards

Historically, building methods have evolved in such a way as to deliver appropriate performance for the building environment. For example, building in Scandinavia has developed techniques for sealing buildings effectively against the cold while building in Malaysia has developed to attract breezes and circulate air. The same applies to resistance to expected hazards.

The process of learning from experience and improving aspects of building in response to past failures has been formalised in the suite of codes and standards that are used to control building. Each of the events mentioned in the introduction (and many more) were used to check on inadequacies in current building practice, codes and standards, and revisions were structured to correct those problems.

The main document for building in Australia is the Building Code of Australia. It is updated each year, and basically it calls up a number of Australian and industry standards that set minimum construction standards. In the context of wind loads, it is applied slightly differently for housing and for other structures.

4.1 Housing

For housing, a number of wind speed classifications have been devised. These prescribe the expected site wind speed and all elements should be designed or selected to comply with that classification.

- The classification is defined in AS4055 – Wind loads for houses. This document is based on the wind loading standard and can be applied by builders, house designers or building supervisors.
- The wind classification can be used to select roofing and roof anchorage systems from information published by manufacturers, or used as an input to the design of trusses.
- Framing members and other structural elements can be selected from AS1684 – Residential timber-framed construction, or from deemed to satisfy documents published from the steel framing industry. The wind classification is an input into that selection.
- Windows and doors have other standards that enable them to be specified to resist the designated wind classification.
- Responsibility for the selection of many of these elements rests with the builder, and engineers would generally only be used to design special load transfer beams.

4.2 Other structures

For other structures, the structural design involves engineers directly.

- Wind loads are determined from AS1170.2 – Wind actions. This document needs engineering skills and judgement to apply correctly.
- Once wind loads have been found, structural materials standards are used to select elements that can resist the required wind actions. Steel, timber, concrete and aluminium all have their own structural design standards.
- In these cases, responsibility for the selection of structural elements rests with the structural engineer.
- Installation of the elements is covered by drawings, specifications and other contract documents.

All of these standards have been checked against good and poor performance in wind events. Almost all damage can be traced to either a mis-application of the standards, structural deterioration, or unexpected circumstances such as debris attack.

5. Factors affecting a community's vulnerability to wind damage

In an ideal world, a severe wind event would uncover all of the weaknesses in all buildings, repairs would be effected in such a way as to improve the resilience of the buildings and builders would learn from the experience so that all new buildings incorporated the lessons learned from the previous wind events. A subsequent event in this ideal world would cause minimal damage.

Sadly, this is far from our experience – we do not seem to be learning from damage the way we should. The conclusions from the investigation of damage after Cyclone Winifred (1986 Innisfail) were virtually identical to the conclusions after Cyclone Larry (2006 Innisfail).

5.1 Resilient communities

Resilience can be built into communities by appropriate planning and detailing. This applies for a number of specific hazards including flooding, bushfire, earthquake and wind.

For wind, appropriate processes have been written into codes and standards, and it is through application of these with due diligence that the resilience of communities will be improved.

It is particularly important to take care in determining correct wind classification. As a check, classification can be related to the view from the site:

- no view will be N1 or C1,
- a view past the surrounding few houses will be N2 or C2,
- a view over part of a suburb will be N3 or C3 and
- a fantastic view will require special design.

5.2 State of repair of properties

Buildings need regular maintenance to continue to perform their structural function. Many failures under wind load can be traced to the following:

- Deterioration of elements with time – rust, rot, abrasion. This can be easy to remedy with inspections. Typically, a detailed inspection at about the same period as repainting will give adequate protection. Where a tropical cyclone has crossed the property, water ingress is to be expected. This can accelerate degradation due to rot or rust.
- Damage in previous events. Storms and cyclones can cause damage to some elements but not all. For example, one house had appeared to perform well in Cyclone Winifred in Innisfail, but a roof anchorage bolt had been broken in that event. Its location in the house made it non-critical for the later part of that cyclone, and its loss was undetected until Cyclone Larry affected the same house, but with a different wind direction. The loss of the bolt was

crucial to the performance of the roof and the roof was lost with the first large gust after the passage of the eye.

- These principles apply equally well to add-on features such as pergolas, carports, verandahs and garden sheds. Damage to these can compromise the adjacent buildings.

5.3 Reconstruction issues

Not all structural elements are easy to view. Many may have to be inspected by removing part of the structure. In general, at least part of the roofing may have to be removed to make an assessment of the condition of the roof structure.

- In some cases, significant damage within the roof space cannot be seen from the outside and it is only flattened ridge capping or new gaps at the eaves that give a clue to the problems within the roof.
- Any structural damage not repaired will be a contingent liability for future events.
- Water damage in tropical cyclones is inevitable. Wind is driving water horizontally behind flashings on buildings and water will gain access to roof and wall spaces. This can cause wetting of plasterboard and the development of moulds and bacteria cultures that may make otherwise undamaged houses uninhabitable. It is expected that as our possessions, decorations, and building materials become more sophisticated, they also become more susceptible to water damage.

6. Conclusions

Wind events have the potential to cause significant damage to the buildings and infrastructure of Australian coastal cities, affecting the lives and livelihoods of their inhabitants, and costing the community billions of dollars. The majority of Australia’s population live in coastal cities, and must address the ever-present threat of potential wind damage.

Much of the damage to buildings can be attributed to deficiencies in building design and construction.

- Compliance with current building standards will ensure effective tie-down of roof structural elements, and prevent or resist full internal pressurization of buildings if and when a severe wind event occurs.
- The effects of topography should not be underestimated; buildings in elevated positions must be constructed with details that are capable of withstanding higher wind speeds than buildings on flat ground in the same area.

The extent of damage to buildings in a severe wind event is largely dependent upon the age and condition of the building, and on the environment in which it is built (corrosion is more evident in coastal areas). Resilience can be built into all structures.

- Regular and competent maintenance of structural elements will ensure that all elements have their intended capacity.
- After an event, detailed inspection must locate and repair any damage to ensure performance in future events.
- Reconstruction must be undertaken to current codes and standards and executed by builders and tradespeople with experience in local construction practices.

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