Preliminary Report on Cyclone Yasi
- Personal Impressions

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General Comments

- Contrary to much of the reporting in the media Cyclone Yasi was not a catastrophic Category 5 tropical cyclone when it crossed the coast. In terms of the current definitions of tropical cyclone categories it was probably on the boundary of Categories 3 and 4 in the Australian scale and a Category 2 hurricane on the US Saffir-Simpson Scale.

- The damage to older buildings in the areas suffering the most wind damage was very similar to the damage in the most damaged areas in the Whitsunday Islands from Cyclone Ada in January 1970, Townsville from Cyclone Althea in December 1971, and older buildings in Innisfail from Cyclone Larry in March 2006, not much greater than in the worst affected areas of Cyclone Winifred in 1986, and an order of magnitude less than the damage to Darwin from Cyclone Tracy in December 1974 – ie there is nothing remarkable about the wind damage from Cyclone Yasi.

- The most striking feature of the building performance was the generally excellent performance of modern buildings, with the exception of garage doors, tiled roofs and water leakage through windows and roofs from wind driven rain. This has substantially reduced the level of damage and subsequent losses from what they would have been if the radical changes in the design of houses made following Cyclone Tracy had not occurred.

- Because the general wind speeds appear to have been significantly less than design wind speeds the exceptions to this good performance should be of concern, but also owners and occupants should not assume that the buildings would perform as well in a major Category 4 or a Category 5 tropical cyclone on the Australian scale.

- Cyclone Yasi was somewhat different from other major tropical cyclones that have impacted Queensland in recent years in two respects – the size of the storm surge and its overall size geographically.

- The level of damage from storm surge is probably the greatest in Queensland since that caused by the two great cyclones of 1918 which hit Mackay in January and Innisfail seven weeks later in March, both of which caused extensive storm surge damage and associated loss of life.

- The large geographical size of the Yasi meant that a large area of coastal Queensland was impacted by strong to severe winds lasting many hours from south of Townsville to north of Babinda, resulting in what may be the most widespread and long lasting failure of electricity that has been experienced anywhere in Australia, causing major consequential problems to infrastructure such as telecommunications, water supply and sewerage, and to commercial, industrial and public organisations throughout the area of impact.
• There appear to be strong similarities between Hurricane Ike which hit the Texas Coast in September 2008 and Cyclone Yasi, the major difference being the much higher population density of the region impacted by Hurricane Ike.

Wind Damage

• Preliminary modelling of wind speeds in Yasi by wind engineering experts in combination with a number of recorded maximum wind speeds suggests the maximum 3 second gust wind speeds at landfall were of the order of 200 – 220 kph in the Cardwell area, with lesser maximum wind speeds in most other areas other than Tully where funnelling could have amplified the local wind speeds to a similar magnitude to those experienced in Cardwell. (See Appendix for discussion on wind speed specification.)

• Based on the author’s previous experience in investigating damage from tropical cyclones, which goes back 41 years to Cyclone Ada which hit the Whitsunday Islands in January 1970, the wind damage to older buildings – ie buildings predating current code levels of design - in Cardwell and Tully is consistent with the level of damage expected from exposure to wind speeds gusting in the range of 180 kph to 220 kph for several hours.

• Maximum wind speeds over land from Cyclone Yasi of the order of 220 kph would correspond to a tropical cyclone intensity on the boundary between Australian Category 3 and Category 4 – which is in the middle of Category 2 on the Saffir Simpson Scale used in the US. (See Appendix for discussion on tropical cyclone intensity scales.)

• With the exceptions discussed later there was very little structural damage to buildings constructed since 1980 – ie to the Australian wind code requirements which since then have required normal buildings to be designed to resist a basic wind speed of the order of 250 kph. (See Appendix for discussion on history of the design of buildings for wind resistance in Queensland.)

• The most common damage to newer buildings was failure of garage doors on houses, and large industrial doors on commercial, industrial and agricultural buildings, dislodged roof tiles on the small percentage of buildings with tiled roofs, and a small to moderate level of damage to guttering, fascias, eaves linings and awnings. It has been well recognised for many years that garage doors, particularly those of the roller door, panel door and tilt-a-door type, which do not satisfy wind code requirements have been permitted to be installed in cyclone prone areas by the building certifiers, despite their poor performance in severe winds. Consequently there was no surprise that they did perform poorly. A similar situation exists for tiled roofs with more stringent control being exercised in regard to metal roofs than tiled roofs.

• While there would have been extensive water damage in older buildings due to damage to them, the overall level of water damage in more recent construction, although common, in general appeared to be small to moderate in comparison with that in older buildings, and due more to water being forced through leaky windows and into roof cavities via the roof corrugations, than from damage to the envelope, other than in tiled roof houses, and in ground floor areas exposed to rain entry when garage doors failed. In aggregate however water damage losses could be considerable. As a percentage of overall damage losses, losses due to water damage appear to be increasing, partly due to the lower level of losses from structural damage, and partly due to the increasing relative value of contents and internal fittings and linings susceptible to water damage.
• An exception to the good performance of newer buildings was the performance of what may be loosely termed manufactured sheds – ie sheds purchased off the shelf in kit form and assembled often by owners. More common on rural properties and lifestyle blocks, they did not appear to perform well in general, and because they were often located close to a dwelling were often the cause of subsequent debris damage to the dwelling. Garden fences also performed poorly in many cases, although not to the extent of producing a great deal of windblown debris.

• While damage to vegetation was severe from Townsville to Innisfail, the level of debris damage to new homes was very limited. This appeared to be due to most new homes being in areas of modern development where the level of windblown building debris was very small, windblown tree debris being limited to leaves and small twigs which didn’t seem to have resulted in much damage, and despite a large number of trees being blown over, few falling on houses, may be because owners have been wary of allowing tall trees to grow too close to buildings.

**Storm Surge Damage**

• Storm surge and central pressure are no longer part of the cyclone intensity scales but on the original Saffir Simpson Scale the maximum storm surge would have corresponded to the boundary between Category 4 and Category 5. (The central pressure would have corresponded to Category 4.)

• The maximum recorded storm surge height appears to be 5.5 m, one of the highest levels ever recorded from a tropical cyclone in Queensland and the largest since Cyclone Mahina, which is believed to be the most intense tropical cyclone to hit Australia since European settlement, hit Bathurst Bay on the Cape York Peninsula in 1899 causing over 400 deaths. The storm surge levels were mitigated by the relatively low tide level at the time Yasi crossed the coast – which occurred at about one third tide. At the time the area was experiencing very large tides and had Yasi crossed 4 hours earlier the storm surge damage would probably have been catastrophic from Forest Beach near Ingham to Mission Beach, and even severe in Townsville. (The following high tide in Townsville some 8 hours later caused considerable inundation of streets without a significant contribution from the storm surge.)

• The most intense damage caused by Yasi was storm surge damage at the small beach community of Tully Heads where a significant number of houses, most of them post 1980, were inundated of the order of one to two metres by the storm surge, resulting in almost total loss of windows, doors and all interior fittings and contents at the ground floor level - although there was little or no damage at the upper floor and roof levels in the case of post-1980 2-story homes – and a number of single story homes being completely washed away.

• In other coastal areas either side of Tully Heads, inundation was significantly less, due it seems to the size of the storm surge decreasing to the north, and buildings in general being located on higher ground above mean sea level to the south. In Cardwell where the level of the combined tide and storm surge heights would have been similar to that at Tully Heads, inundation of buildings was more of the order of 200 mm, sufficient to cause considerable water damage to floor coverings, water sensitive wall linings and contents on the ground floor, but insufficient to cause major damage as at Tully Heads except in some isolated instances.
At Port Hinchinbrook adjacent to Cardwell the combined height of the storm surge and tide resulted in a major loss of boats in a marina due to the floating pontoons to which they were moored floating off the top of the columns which held them in place.

Although no cases of coastal erosion causing significant structural damage were observed, there was significant damage to seawalls constructed to protect land from erosion with subsequent loss of land from beachside properties from Cardwell to Mission Beach.

There was significant damage to roads and streets close to the sea as a result of the large quantities of sand carried inland by the inundation and associated wave action. This was also a problem for buildings which were inundated.

Some Implications for Insurance

The total insured loss is likely to relatively moderate – much less than some of the estimates being published immediately after the event based on the media reports of a Category 5 tropical cyclone, and also probably much less than the losses due to the succession of floods in Queensland and elsewhere in Australia this summer.

While the major source of individual losses in terms of percentage of sum insured is likely to be older buildings, the total loss may be dominated by a large number of small to moderate losses, many relating to modern construction and arising for instance from garage door failures, tile failures and water entry.

The level of storm surge damage will inevitably create a problem for insurance companies who exclude damage due to sea water inundation, especially in areas like Cardwell and Mission Beach where generally the losses appear to have been a combination of wind, water and storm surge damage.

Business interruption losses could be a significant proportion of the total losses due to the impact of the loss of electricity on commercial and industrial enterprises in Townsville as well as the other areas impacted.

In 1918 Mackay experienced a tropical cyclone whose characteristics appear to have been somewhat similar to Cyclone Yasi with the storm surge being the primary recorded cause of the destruction. Seven weeks later Innisfail and the surrounding areas experienced a tropical cyclone which appears to have been much more intense. The risk of a repeat of 1918 is significant, even if relatively small, and insurers should ensure they are prepared for it – ie they should not assume that because Yasi was a major cyclone there will not be another major cyclone this season. History suggests that the period following a major event is the period when the risk of another one is highest. In 1974/75 Cyclone Tracy was followed within the following 12 months by Cyclone Joan and Cyclone Trixie, two of the most intense tropical cyclones to impact on Western Australia in recent times. It was the last time the Pacific Decadal Oscillation combined with the La Nina cycle of the Southern Oscillation to cause an enhanced risk of tropical cyclones in the Australian region.

Yasi has again highlighted the vulnerability of pre-1980 construction, particularly houses. Had Yasi had a direct hit on Townsville or Cairns the losses arising from damage to such houses would have been much greater. During the 1990’s the Insurance Council of Australia sponsored the development of guidelines for upgrading the wind resistance of old houses in coastal areas of Queensland which were subsequently published by Standards Australia as
Because of the increasing significance of water damage in modern construction there may be value in the insurance industry providing incentives to policyholders to provide a more weatherproof building envelope.

**Appendix**

**Definition of Wind Speed**

- In the lower few hundred metres of the atmosphere, the wind is highly turbulent and the average wind speed varies with height, averaging time, and the nature of the upwind terrain and topography.

- The standard method of expressing wind speeds in terms of height, terrain and topography is at a height of 10m in flat open terrain similar that of an airfield – which is where many official anemometers tend to be located. Wind speed defined in this manner is known as the basic wind speed.

- In Australia basic wind speeds are normally expressed in terms of the maximum 3 sec gust – ie the maximum average wind speed over a period of 3 seconds – while in the US they are normally expressed in terms of the maximum average wind speed over one minute – which is generally referred to as the one minute mean wind speed. It is also common to measure the average wind speed over 10 minutes to give the 10 minute mean wind speed.

- There is not a fixed relationship between the wind speeds averaged over the different averaging times but for the standard height, terrain and topography used for describing basic wind speeds a 3 second gust is generally about 30 percent higher than the one minute mean and a little over 50 percent higher than the ten minute mean.

**Tropical Cyclone Categories**

- As currently defined by both the National Hurricane Centre in the US and the Bureau of Meteorology in Australia, tropical cyclone categories are solely based on the estimated maximum wind speeds of a tropical cyclone when the centre is at a particular position on its track. For a particular tropical cyclone the Category will usually vary along its track. In general tropical cyclones reach their maximum intensity while the eye and adjacent highest wind bands are still over the sea, and decrease in intensity as the band of extreme winds and eye wall move over land. An exception to this occurs when the eye wall collapses in size on approach to land resulting in a sudden increase in wind speeds as momentum is conserved, as occurred in Cyclone Tracy. For a given central pressure in general the larger the eye and overall size of the tropical cyclone system, the lower the maximum wind speeds. The reason for this is that wind speed is primarily dependent on pressure gradient, and the pressure gradients in large systems is less than those in small systems.
• The systems used in the US and Australia are significantly different. The Australian system is based on estimated maximum 3 second gusts and the US system, known as the Saffir System Scale, is based on one minute mean winds. An approximate comparison based on converting the one minute mean wind speeds in the Saffir Simpson Scale to 3 second gust wind speeds assuming the latter are 30 percent higher is shown in the following table.

<table>
<thead>
<tr>
<th>Category</th>
<th>Maximum Wind Speeds (kph)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Australia</td>
</tr>
<tr>
<td>1</td>
<td>90-124</td>
</tr>
<tr>
<td>2</td>
<td>125-164</td>
</tr>
<tr>
<td>3</td>
<td>165-224</td>
</tr>
<tr>
<td>4</td>
<td>225-279</td>
</tr>
<tr>
<td>5</td>
<td>&gt;279</td>
</tr>
</tbody>
</table>

• When originally developed the Saffir Simpson Scale included central pressure, wind speeds and storm surge heights. This system appears to be is still widely used by non-meteorologists. The central pressure and storm surge height ranges are shown in the following table.

<table>
<thead>
<tr>
<th>Category</th>
<th>Central Pressure (hPa)</th>
<th>Surge Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt;980</td>
<td>1.2–1.5</td>
</tr>
<tr>
<td>2</td>
<td>965-979</td>
<td>1.8-2.4</td>
</tr>
<tr>
<td>3</td>
<td>945-964</td>
<td>2.7-3.7</td>
</tr>
<tr>
<td>4</td>
<td>920-944</td>
<td>4.0-5.5</td>
</tr>
<tr>
<td>5</td>
<td>&lt;920</td>
<td>&gt;5.5</td>
</tr>
</tbody>
</table>

• The systems have been primarily developed for warning purposes and when originally developed were recognised to be only approximate descriptions of intensity, the intention being to give the public an indication of their potential to cause damage. The relationship between central pressures and maximum wind speed, and central pressure and maximum storm surge height are complex and dependent on many factors not taken into account in the table. In the case of storm surge reliable forecasting of potential maximum storm surge heights taking account of the complexities is now widely available and used for forecasting. It was as a consequence of this, and recognising the poor correlation between central pressure and maximum wind speeds, that tropical cyclone categories are now based solely on estimated wind maximum wind speeds by the Australian Bureau of Meteorology and the National Hurricane Centre. (Despite this it often seems that if the central pressure is low and a large storm surge is anticipated a high value of Category is assigned even if the estimated maximum wind speeds may not justify it since the public is more attuned to responding to the Category of a tropical cyclone than to a forecast storm surge level – which is how they were originally used.)
Wind Design of Queensland Buildings

- In describing the wind resistance of buildings in Queensland it is common to use 1980 as marking a step change in the resistance of buildings in Queensland. In practice there was a transition over a few years either side of 1980, beginning with the 1975 Queensland Building Act which among other things required all new buildings to be constructed in accordance with Australian structural engineering standards, and ended in July 1982 from which date the regulation was enforced for single family dwellings. During this period the building industry had been gradually implementing the consequent changes in the design of houses, with an increasing proportion of houses being designed to meet the wind code requirements during this time.

- Prior to 1975 building control in Queensland was exercised by local government authorities, with the degree of control varying considerably throughout Queensland. Larger centres of population such as the capital Brisbane, and regional centres like Townsville and Cairns, exercised considerable control, while some more rural shires exercised very little control. In almost all cases there was little control over the structural design of houses, which was largely left in the hands of lending authorities. The so-called ‘Blue Book’ issued by the Commonwealth Bank was regarded as the bible for house construction by many builders. The degree of control over larger commercial and industrial buildings tended to vary with size with larger ones getting more attention than smaller ones, the latter often being little better constructed structurally than houses.

- In respect of houses, prior to 1975 the most common special structural requirement in tropical cyclone regions was for a specified number of so-called ‘cyclone bolts’ extending from the top of the wall to the bottom of wall for the purpose of tying down the roof. However their placement was left to the builders and many were placed in locations that served no structural purpose at all. Furthermore the same number of bolts was used irrespective of the size of the house. The fixing of roof claddings was left to the manufacturers. In the tropical cyclone areas timber framed buildings with corrugated iron roofs, weatherboard or fibre cement external wall cladding, and timber (especially pre-2nd World War), hardboard or plasterboard internal linings was the dominant form of house construction. Windows and doors were the same as used in non-cyclone areas of Australia. Experience has shown that roof cladding failures in houses from this period tend to initiate at basic gust speeds of the order of 140-150 kph, become serious in the range of 160-180 kph, with reasonably extensive structural damage occurring in houses exposed to basic gust wind speeds of the order of 200 -220 kph and total destruction of houses common at wind speeds of the order of 240-260 kph. After Cyclone Tracy in 1975 the fixing of the cladding to many older roofs was upgraded, but in many cases while it may have delayed the onset of damage it has resulted in large sections of roofs failing due the poor connections within the roof structure, with winds of the order of 160-180 kph being sufficient to cause significant failures of this type.

- In respect of commercial and industrial buildings the roof claddings were often fixed to the same specifications as houses, and non-structural items like doors and windows were accorded no special attention, so many were just as vulnerable in this respect. The structure of the buildings was increasingly required to be designed by a structural engineer to the wind code, although until 1975 the structural design process was much less rigorous than it is now. Structural engineering design is based on a prescribed design wind speed. Prior to the early 1950’s structural engineers would have been responsible for making their own judgement on
the design wind speed unless the local authority specified it. Since 1952 there has been a
national approach to it. The method of prescribing this design wind speed and how it is used
in design has however changed significantly since then.

- The current design wind speed for most buildings in Australia can be described as the
  estimated basic 3 second gust wind speed, as defined above, having an estimated frequency of
  exceedance in any year of less than of order of 0.2 percent at the locality of the proposed
  building. For structures deemed of special importance the design wind speeds is based on a
  lower frequency of exceedance and for buildings deemed to be of lesser importance they are
  based on a higher frequency of exceedance. Design wind speeds derived in this way are
  known as basic design wind speeds since they define the wind speed at a height of 10m in flat
  open country.

- The determination of basic design wind speeds is an inexact science and the specification of
design wind speeds reflects this with Australia being divided into 4 major wind zones, two of
them cyclone zones, one a transition zone, and one where the design wind speeds are
primarily based on thunderstorm winds. The Queensland coast north of Latitude 27°S is in
Region C, one of the tropical cyclone regions. When the current wind regions and design
wind speeds were defined, the specified values of design wind speed for normal buildings
were considered to be conservative estimates of the actual basic wind speeds with a frequency
of exceedance of 0.2 percent in most if not all of the region.

- This method of defining design wind speeds is different from that in most countries where
they are commonly defined in terms of the basic wind speed with an estimated frequency of
exceedance of 2 percent. However in Australia they are treated as the ultimate wind speeds
which a structure should resist without significant failure occurring, whereas in the countries
using the lower level of wind speeds – known as working load wind speeds - factors of safety
have to be applied to the calculated wind loads to obtain the failure loads. The use of ultimate
design wind speeds in Australia was driven by a desire to make the meaning of design wind
speed more transparent to non-engineers.

- The actual design wind speed of a building is determined by modifying the basic design wind
speed to take account of the height of the building, the upwind terrain and the topography. (In
non-cyclone areas the directional characteristics of strong winds can also be taken into
account.) The actual design wind speed is then used to calculate the wind loads which the
building and its components are required to resist. These in turn will depend on whether or
not internal pressurisation due to openings created by the wind is allowed. These loads are
then combined with other loads using other loading standards, and the building designed
using other design codes based on the materials of construction. In many countries, including
Australia, the process of converting the specified basic design wind speeds into wind loads is
standardised in national wind codes in addition to the specification of basic design wind
speeds, as is the specification of other loads and the design criteria for the various
construction materials in determining the actual structural details of a building. As the
definition of wind speed and the standardised procedures differ significantly between
countries direct comparison of design outcomes between countries is not possible.
 International standards have been developed to overcome these differences but to date they
have not been widely adopted by many of the major developed countries.

- In Australia the first national standardisation of wind speeds and the procedures for deriving
wind loads from them occurred in 1952. It specified actual design wind speeds, not basic
design wind speeds, for two regions, coastal areas north of 25°S and the rest of Australia, with no adjustment for the height of buildings less than about 100m tall. Just 3 different wind speeds were specified for each regions depending on the degree of exposure in terms of terrain and topography. In coastal areas north of 25°S these design wind speeds were approximately 185 kph, 215 kph and 255 kph when converted to the equivalent ultimate design wind speeds. There was no requirement to design for the internal pressures that arise if an opening is created by the wind, and the design for tie down was also unconservative with the contribution of the self weight of roof components being overestimated. Nor was there any recognition of the high local negative pressures on roof cladding adjacent to the edges and ridges. In the cyclone region for small buildings in a typical urban environment the specified design wind speeds were of the same order of magnitude as the actual design wind speeds used today because of the allowed reductions in basic wind speeds for terrain effects for buildings in an urban environment now used. However the lack of recognition of local high negative pressures on roof cladding, internal pressures arising from openings due to failure of windows and doors which were not designed for wind, and deficiencies in respect of tie down design, resulted in the roof cladding being very vulnerable to wind damage, and roofs being vulnerable to failing in uplift at wind speeds less than the prescribed wind speeds. Nor were there any requirements for windows and doors to be designed for these wind speeds. Consequently while complete structural failure may have been averted these buildings are highly vulnerable to roof damage and to water damage.

• The first modern wind code in Australia based on the basic design wind speed was issued in 1971. Tables were given for converting basic wind speeds to actual design wind speeds based on 4 terrain categories and the height of the building, and there was a simple very approximate method given for taking topographic effects into account. The basic design wind speeds were presented in the form of smoothed isopleths of the estimated 50 year return period maximum gust wind speeds derived from analysis of annual extreme gust speeds at individual locations. In coastal regions north of 27°S these values were to be increased by a 15 percent cyclone factor. The maximum basic design wind speeds before application of the cyclone factor were in the Southeast corner of Queensland and Northern New South Wales, with Brisbane having the highest basic design wind speed in Australia other than Onslow and Willis Island - and just less than Townsville and significantly higher than Cairns after application of the cyclone factor! In terms of the ultimate basic wind speeds now used, the basic design wind speeds after allowing for the cyclone factor for Cairns was about 200 kph and for Townsville about 230 kph. For heights up to nearly 7 m in urban areas these basic design wind speeds could be reduced by 30 percent giving actual design wind speeds for these buildings of the order of 140 kph and 160 kph respectively for Cairns and Townsville – much less than had previously been used. While there was recognition of local pressures there was still no recognition of internal pressures generated by openings due to damage or the weakness in the tie down design, and nor was the code applied to windows and doors. This code was replaced in 1975 after Cyclone Tracy had shown up its deficiencies, but there are implications for buildings built to this code. It is particularly significant for the region hit by Yasi as the design wind speeds of buildings in the area affected by Yasi which were designed to this code was of a similar order to the estimated maximum wind speeds in Yasi, and the other design limitations would mean they are much more vulnerable to winds less than the design wind speeds than buildings built to the code would be today.

• The damage due to Cyclone Tracy had a big impact on wind design as it exposed the weaknesses of design up to that stage. A major consequence was that it was resolved that
houses should be structurally engineered to resist wind loads. Although it took some years for this to be implemented nationally it was adopted for the reconstruction of Darwin, and gradually implemented in Queensland until fully implemented in July 1982. There were also major changes to the wind code. The specification of basic design wind speeds in the tropical cyclone areas was completely revised with the adoption of the two cyclone wind regions which with some modification remain in place today. In these regions the basic design winds were derived by Monte Carlo modelling of a large sample of possible tropical cyclones determined from historic records of tropical cyclone intensities, tracks, eye diameters, and forward speeds. It was one of the first uses of this approach which now underpins catastrophe loss risk modelling from tropical cyclone winds. For the Queensland coast north of 27°S for most buildings the basic design wind speed in ultimate wind speed terms became of the order of 280 kph, but for low rise buildings in urban areas the reduction for terrain effects was much greater than now used resulting in similar actual design wind speeds for low rise buildings to those used today.

- Apart from the widespread destruction of houses, a dominant feature of the damage in Darwin from Cyclone Tracy was the widespread failure of roof cladding despite fixing details having been improved to meet the 1971 code requirements, which for Darwin specified a basic design wind speed for most buildings of the order of 250 kph, and a relatively high factor of safety having been used. Investigation showed that many of the failures had occurred as a result of fatigue failure of the metal cladding in the vicinity of the fasteners, a form of failure that had arisen as a result of a change in the cladding material from ductile mild steel to more brittle high strength steel. This resulted in a recommendation that in cyclone areas roof cladding systems should be tested for fatigue under the anticipated fluctuating wind loads during a cyclone. Another dominant feature was structural failure due to internal pressures accentuated by the deficiency in the tie down design. This led to a recommendation that in cyclone regions windows and doors should be designed to resist the specified design wind speed, and unless windows were protected from debris damage low rise buildings should be designed for full internal pressures arising from a dominant opening. Criteria were also developed for testing debris protection systems. Although not incorporated in the wind code these were embodied in a separate publication, Technical Record 440, published by the Australian Government’s Experimental Building Station in 1977 which was adopted by most local authorities in cyclone prone areas. The design process for tie downs was also modified to remove the inherent deficiency in the previous approach.

- The overall effect of these changes was to greatly improve the structural resistance of houses and significantly increase the structural resistance of commercial and industrial buildings to tropical cyclones. In Darwin there were many commercial and industrial buildings which had been designed using the 1971 wind code due to rapid expansion of Darwin in the early 1970’s. Despite the shortcomings of the code only about 5 percent suffered major structural failure while about 20 percent suffered major loss of roof cladding, mainly due to these shortcomings. As the basic wind speeds in Cyclone Tracy were probably between 250 kph and 300 kph – ie higher than the basic design wind speed – this suggests that buildings designed to the 1975 code could be expected to perform very well up to the specified basic design wind speed, and to perform reasonably well at wind speeds considerably higher than the design wind speeds.

- Since 1975 there have been several revisions of the wind code and related codes but the net effect has been that the actual design wind speeds, especially for low rise buildings have not
changed very much. Both the internal pressure requirements and the fatigue requirements are now included in codes and a more realistic approach to the determination of topographic multipliers was introduced in 1989. Significant changes have occurred to the fatigue loading criteria as a result of a significant deficiency that became apparent as a result of detailed research in the 1980’s, but which was not corrected until about 2005. This did not affect Darwin, but did affect Queensland, where it is likely that the roof cladding on many buildings built prior to that date may be vulnerable to fatigue loadings if exposed to wind speeds of significant duration approaching but less than the design wind speeds. Had the wind speeds in Yasi been 20 percent higher this may have occurred due to the duration of the period of very strong winds.

- The result is that there is now a general confidence that buildings designed and built according to the current building codes should perform very well in terms of structural behaviour if exposed to basic wind speeds less than the specified basic design wind speeds, with some specific exceptions such as garage doors and tiled roofs which at this stage do not appear to meet the wind code requirements in cyclone areas in general. A small percentage of failures would be expected apart from garage doors and tiled roofs due to a variety of reasons including errors in the design and construction, but, providing their duration is relatively short, most would be expected to resist considerably higher winds than the basic design wind speeds due to conservativeness and redundancies in the design process as well as the natural variability of the strength of materials, with design being based on a lower limit of these. However in urban areas where failures occur, an amplification of the damage can be expected due to the debris arising from them.

- The following diagram summarises in probabilistic form the approximate anticipated performance of pre and post 1980 houses relative to the current basic design wind in the coastal Queensland section of cyclone Region C in the Australian wind code.

![Diagram showing probability density of basic wind speed for pre-1980 and post-1980 houses]

- There can be less confidence in the ability to resist water damage. Water penetration during heavy rain is the subject of a different standard than the wind code. It makes no distinction between cyclone and non-cyclone areas and assumes relatively low wind pressures. There is
considerable evidence that despite improvements in the design and installation of windows in respect of structural behaviour in tropical cyclones there has been little improvement in the tendency of many of them to leak seriously during the combination of high winds and heavy rain typical of severe tropical cyclone conditions. This leakage is not restricted to windows but extends to doors, the edges of roofing, and dislodged eaves linings, including overflowing of guttering not designed for the heavy rainfall. Failure of garage doors and tile roofs adds to this, as well as failure of windows from debris arising from structural failures, which may be to adjacent more vulnerable structures such as older buildings, farm and garden sheds, and fences. As the value of contents and internal linings susceptible to water damage increases relative to the value of the buildings themselves this can be expected to become an increasing proportion of the total losses incurred by owners and occupants during severe tropical cyclones.

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Typical Performance of Post 80 House in most areas – this one in Cardwell. Garage doors have failed, fence has failed, but house undamaged and no water damage

Badly damaged older house in rural area
Most older buildings performed better than this even in Cardwell and Tully
Typical tile roof failure on modern house in areas of most severe winds
Tiles became missiles and caused debris damage in some instances

Severe damage to boats at Port Hinchinbrook due to storm surge
But modern houses undamaged behind them
Typical modern 2 story house at Tully Heads – beach side home
Ground floor windows washed out, ground floor inundated but little damage upstairs

Typical single story buildings at Tully Heads
Building on right has been completely washed away, that on left totally washed out
Storm surge damage at Port Hinchinbrook
Marks on chair and cane settee show level of inundation – left inch thick layer of sand and mud

Modern farm sheds did not perform as well as modern houses
In this case because of inadequate foundations – loss of roofing was a subsequent failure