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A review of the impact of cyclone *Tracy* on building regulations and insurance

George R. Walker
Senior Risk Analyst, Aon Re Asia Pacific

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Cyclone *Tracy* destroyed between fifty and sixty per cent of the houses and flats housing approximately 48 000 people living in Darwin in December 1974, as well as causing significant damage to most of the remainder as well as many of the commercial and industrial buildings. Although a significant percentage of these were government owned and uninsured, the insurance loss was several times larger than that from any previous catastrophic event in Australia, causing major problems for Australian insurance companies. The response in terms of changes in building practice and the approach to catastrophe insurance has had a lasting impact on both the building and insurance industries. This paper reviews the initial impact of the damage and the subsequent changes in practice in these industries arising from the experience of cyclone *Tracy*, including the process by which these changes occurred. This impact has greatly increased the resistance of Australia's built environment to extreme wind events and the resilience of the Australian insurance industry to major catastrophic events from which Australia continues to benefit.

Introduction

When cyclone *Tracy* hit Darwin in the early hours of Christmas Day 1974, Darwin was a Commonwealth Government city. The entire infrastructure was the responsibility of the Commonwealth Government and a large proportion of its houses were built and owned by the Commonwealth Government. Overseeing the associated construction and maintenance activities was the Commonwealth Department of Housing and Construction (DHC), at that time the largest engineering organisation in the country, employing many of Australia's finest engineers. Their own Darwin headquarters at the port end of Mitchell Street were little affected, but most of the houses they had designed and built were destroyed, particularly the more recent ones designed in the light of the knowledge gained from damage to housing in Townsville from cyclone *Althea* three years earlier. Their structural engineers had been responsible for the design, and believed them to be cyclone resistant.

It was the worst disaster due to building failure in Australian history, and it was an engineering failure. The Chief Structural Engineer of DHC at the time, Norm Sneath, was quick to recognise this. Until the causes of the failure were identified and design practices changed to take these into account there would be no reconstruction of the houses. An investigation of the damage was organised. The author, then a Senior Lecturer at James Cook University of North Queensland in Townsville, was privileged to lead it. The reconstruction of Darwin was based on the recommendations of the resulting report (Walker 1975). Today every house built in Australia embodies major lessons learnt from the investigation in respect of wind resistance.

At the time the population of Darwin was about 48000 living in about 8500 houses and 2500 flats (Cameron McNamara 1983). After the cyclone 50-60 per cent of these were classified as having being destroyed, and only 6 per cent were classified as intact apart from minor damage to wall cladding or windows. Most of the rest were regarded as uninhabitable without major repairs. The resulting evacuation of most of the population was the largest such operation ever conducted in Australia. It had long lasting social effects on many of those who experienced it, but although still the subject of controversy, it is difficult to see how they could have been looked after if they had stayed in Darwin. This was the real tragedy of cyclone *Tracy*, and the government resolved that it was never to happen again. Without this resolve it is questionable whether the impact on building design and construction would have been as great as it was.

It also had a major impact on the insurance industry, although not nearly as great as it could have been. About 40 per cent of the houses and 20 per cent of the apartments in Darwin, as well as a significant number of the commercial buildings and other constructed facilities, were owned by the

Corresponding author address: George R. Walker, PO Box 134, Mapleton QLD 4560, Australia

Commonwealth Government and were not insured (Walker 2009). Nevertheless at about $200 million in the currency values of the time, it was three times larger than the insured losses from the Brisbane floods less than twelve months earlier which in turn were over twice the largest previously recorded insured loss from a single event in Australia. It was much larger than the industry in general had thought possible and several companies had to dig into their reserves due to their reinsurance being inadequate. In addition to the magnitude of the damage a major contributing factor was the post-disaster inflation of building costs, also known as demand surge, which was close to 100 per cent. On top of a series of major losses from tropical cyclones beginning with cyclone *Ada* in January 1970 it led to a major reassessment of the risk of catastrophe insurance losses in Australia by the insurance and reinsurance industry leading to major changes in management of these risks – as well as higher premiums for many Australians.

The event

Cyclone *Tracy* was a small but very intense tropical cyclone that produced extremely high wind speeds with maximum gusts estimated to have been of the order of 70 ms^{-1}. Although small with an eye diameter of about 8 km, its slow forward speed of less than 10 kmh^{-1} meant that destructive winds were experienced for several hours.

There was a big difference between the performance of houses and other small buildings, which at that time were not fully structurally engineered, and the performance of larger buildings, which were. It was estimated that less than 5 per cent of larger engineered buildings suffered total collapse, compared with about 55 per cent of houses. Only about 5 per cent of houses suffered no or very minor damage, compared with about 40 per cent of larger engineered buildings.

A dominant feature of the damage was the loss of roof cladding, with over 90 per cent of houses and approximately 70 per cent of all other structures, including 60 per cent of larger engineered buildings, suffering significant loss of roofing. The other dominant feature, particularly in the northern suburbs, was the loss of wall cladding accompanied by gross racking distortion of the houses. There were also some spectacular roof tie down failures.

In the northern suburbs the destruction of houses was almost 100 per cent despite these being the newest houses and incorporating lessons learnt from cyclone *Althea*. Although the wind speeds were also higher in this area, they were less than the wind speeds corresponding to the assumed ultimate strength of the cladding based on testing of roof cladding and design wind pressure coefficients.

Results of investigation

Although the majority of fully engineered buildings performed relatively well under wind loads that in many cases would have been above the design loads, cyclone *Tracy* did reveal some significant failures to components and systems that had been engineered according to the codes and the accepted structural engineering practice of the day. This was particularly evident in terms of the performance of roofing systems which had been engineered.

In cyclone *Althea* the major failure in housing was of roof cladding and of roof tie down systems. At that time such systems were not engineered but largely based on so called common practice embodied in housing standards such as the 'Blue Book' published by the Commonwealth Bank. Design at the time was still largely based on working stress analysis under design working loads. The investigation of damage from cyclone *Althea* recommended that roof cladding should be tested to ultimate loads of the order of twice the working loads, and that tie down of the roof structure should meet engineering design requirements. This led to an increased number of fasteners being specified for roof cladding, and significantly increased levels of roof tie-down in cyclone prone areas.

These lessons were rigorously applied by the structural engineers in DHC in Darwin, led by their Principal Structural Engineer, Jack Gamble. Most of the houses in the northern suburbs had been built incorporating this approach. No other houses in Australia incorporated such a high level of engineering in regard to the wind resistance of their roofing systems. The main concern of Darwin structural engineers was the weakness of the earlier construction which had been shown to be deficient in cyclone *Althea*. Only a few weeks before cyclone *Tracy* they had lobbied the Commonwealth Government for funds to strengthen the older houses in Darwin. Those living in the older houses, such as Jack Gamble, would have been much more concerned as *Tracy* bore down on them than those in the newer houses in the northern suburbs. On Christmas Day, his house was damaged but still standing, like many others around it, but in the northern suburbs it was total devastation. What had gone wrong? This was the big unanswered question that faced Jack Gamble and his team on Christmas Day.

The investigation showed that two factors had contributed to most of the roofing damage:

- Fatigue failure of cladding adjacent to the fasteners
- Internal pressures not allowed for in design

The testing of roof cladding after cyclone *Althea* was based on static tests. This was over the objections of Bill Melbourne, who had warned that wind loads were dynamic not static. Before cyclone *Tracy* the warning fell on deaf ears, but DHC soon heard it after *Tracy* and organised an investigation of the fatigue strength of the common cladding systems in place in Darwin, and its significance in relation to the observed damage. In a brilliant study undertaken by Vaughan Beck and John Morgan (Morgan and Beck 1977) under conditions of extreme urgency they showed that under the level of fluctuating loading which Bill Melbourne estimated was likely to have occurred the ultimate strength of the fastening systems could have been reduced to 15 per cent of the static fatigue strength, and recommended a testing procedure that remained the requirement for roof cladding design in Darwin until very recently.

If the effect was so dramatic, why had it not been observed previously? Until after cyclone *Althea* steel roofing was primarily made from mild steel. The failure of roof sheeting in *Althea*, and of older houses in Darwin, was due to inadequate fasteners. Not long after cyclone *Althea* there was a major change to the use of thinner high strength steel. Mild steel is more ductile than high strength steel, and much less susceptible to fatigue failure, but the fastening of the new cladding was based on the same static tests as used for mild steel. The report of *Tracy* recommended that fatigue testing of roof cladding be mandatory in cyclone regions.

There was also another factor at work. At that time general practice throughout Australia was to base internal pressures used in design on the assumption that there were no significant wall openings. This led to rather small internal pressures which after subtraction of self weight loads often led to even smaller design loads with the factor of safety only applying to the difference. When windows failed on the windward side, often as a result of debris impact, the resulting large increase in internal pressures would have produced much higher loads than those assumed in design. This had particularly severe consequences for roof tie down systems where the effect of self-weight meant that working stress design tie-down forces were often very small. Such failures were common where cladding failure had not occurred in both housing and commercial and industrial buildings.

This damage highlighted the limitations of working stress design as well as design practice regarding internal pressures. The report recommended both the speedy adoption of the limit state approach to design, which was already under consideration by a Standards Australia committee chaired by Len Stevens, and the use of full internal pressures in design in cyclone areas unless the integrity of potential wall openings such as windows and doors could be ensured.

Even if all these changes had been made prior to *Tracy*, major structural damage to houses would still have occurred as a result of racking failures. At that time the most common external wall material used in timber framed housing in Darwin was asbestos cement sheeting (or 'fibro' as it was colloquially known). Internally the walls were lined with hardboard. Both of these materials were relatively strong in shear, but this strength cannot be utilised unless the sheets are fastened very securely to the timber frame. Unfortunately the latter was not the case with the sheets being only tacked to the frame. Resistance to racking was assumed to come from diagonal steel straps that had replaced the more traditional diagonal timber braces in most of the newer houses. The construction was typical of much housing construction in northern Australia at the time. It had a certain amount of strength. In cyclone *Althea* the wind loads had not been sufficient to exceed the strength, but in cyclone *Tracy* they well exceeded it.

Because such failures did not occur in cyclone *Althea*, no consideration had been given to racking strength in the recommendations that followed. It had been a case of the following the traditional approach to housing with design based on trial and error, not engineering in its full sense. In *Althea* there had been problems with cladding and tie-down, so an attempt was made to fix it. No racking failures occurred so it was assumed that traditional construction was OK in this respect. Houses were assumed to have inherent strength that was beyond the understanding of structural engineers, and not worth investigating because of the relatively low cost of housing. Cyclone *Tracy* put paid to this assumption.

A single house may have small relative value. But when all houses in a community are at risk from a single event then the cost of failure can be very large. Furthermore houses are where people are most likely to be during a tropical cyclone and even if the number of deaths from collapsing houses was not as great as might have been expected, the psychological impact on those who experienced houses collapsing around them, and the subsequent evacuation due to lack of habitable accommodation, was very large. The consequence was the most radical recommendation of all. Henceforth all buildings in tropical cyclone prone areas including houses should be engineered to resist wind loads. This meant that wall systems would need to be tested for racking strength, not just assumed to have it. But it also meant that the complete load path would need to be checked out and no assumptions made about the inherent strength of housing.

In respect of design wind speeds the report recommended an increase in the basic design wind speeds being used in Darwin from 49 ms^{-1} to 55 ms^{-1}, design at that time being based on the estimated 50 year return period wind speed with a cyclone multiplying factor of 1.15 having to be subsequently applied to allow for the steeper slope of the Gumbel distribution for cyclones than that for thunderstorm winds on which working stress material design criteria were based.

The author had in fact recommended no increase in basic wind speed but had recommended a minimum terrain reduction factor of 0.85 when used for buildings in suburban terrain in Darwin because of the nature of the topography and the limited fetch for development of a terrain Category[1] 3 wind structure, particularly as cyclone *Tracy* had clearly demonstrated that in winds of design strength vegetation could not be relied upon for surface roughness. This was based on the investigation of the damage to engineered buildings, particularly steel framed buildings, which were the most sensitive engineered buildings to wind loads (Baker and Walker 1976). This study suggested that most failures in structurally engineered buildings occurred where

1This should not be confused with the cyclone intensity scale used by the Bureau of Meteorology.

full advantage had been taken of using Category 3 terrain factors to reduce design wind loads and/or no account had been taken of the effect of increased internal pressures due to openings created by window and door failures, and/or the structure was sensitive to increased uplift loads due to limitations of the working stress design approach in ensuring an adequate factor of safety for such loads. This was one recommendation that was significantly changed by the review committee, who instead decided to increase the basic design wind speed to 55 ms^{-1} and reduce the minimum terrain factor to 0.75. For buildings in terrain Category 3 the resulting design wind load was the same, but for more exposed buildings it led to higher design wind loads.

Implementation of recommendations

All the major recommendations of the investigation were implemented in the reconstruction of Darwin (Walker and Minor 1979, Walker 1980). That this occurred is probably almost entirely due to the role of the Commonwealth Government in Darwin, and the large part played by DHC in exercising this role. The government had promised the residents of Darwin it would reconstruct a cyclone resistant city, and it was the responsibility of DHC to ensure this happened. It was a responsibility taken seriously by DHC from the top down. Once it had the report, DHC had the resources and expertise within its ranks to make its recommendations happen.

The first action was the development of a new Darwin Area Building Manual (DRC 1975) incorporating the recommendations by Geoff Anderson of the then Experimental Building Station (which was part of DHC) based on the then current Australian Model Uniform Building Code, a document aimed at unifying building regulations in Australia at a time when each State did its own thing in regard to building regulations. In implementing the design wind speed requirement the minimum terrain factor was changed from 0.75 to terrain Category 2½ to reflect the need for it to be applicable over a range of building heights. A comprehensive programme of testing housing components and systems was then developed and undertaken, wind tunnel studies commissioned to obtain a better understanding of wind loads on housing and specifications for reconstruction drafted.

Just under a year after cyclone *Tracy* the first reconstructed house was handed over, to be followed by hundreds, which became thousands, over the ensuing two or three years. The criteria became more codified with time, but otherwise have remained largely unchanged until very recently when for reasons which are not clear the requirement for a minimum Terrain Category of 2½ was relaxed by the Northern Territory Government. Most of the houses which survived cyclone *Tracy* have been upgraded and those that have not are becoming an increasingly small proportion of the total building stock in Darwin—currently probably of the order of one to two per cent. As a consequence Darwin can probably claim to be the strongest city in the world in respect of wind resistance.

Impact on Australian building regulations

Cyclone *Tracy* did not just have an effect on building construction in Darwin. Through incorporation in Australian Standards, Australian building regulations, and various design manuals for housing that have been deemed to comply with building regulations, it has had an impact on building construction throughout Australia.

One of the most immediate impacts was on design wind speeds. Prior to cyclone *Tracy*, design wind speeds in each locality were based on Gumbel analysis of locally recorded annual maximum wind speeds, and they were widely different for different localities. Because of the sparse data available in respect of cyclonic wind speeds in individual locations, and questions about their validity due to malfunctioning of the anemometers in extreme winds, this approach was considered unsatisfactory. Based on a landmark paper by Russell (1971), which underlies all modern probabilistic GIS based modelling of tropical cyclone winds, Gomes and Vickery (1976) published new Gumbel parameters for various locations, which were backed up by an independent modelling exercise undertaken internally in DHC. This led to the creation of the three cyclone zones with different wind speeds, each with separate wind speed criteria, based on these results, in the revision of the wind code that followed within a year of cyclone *Tracy* (SAA 1975). In the spirit of limit state design these design wind speeds were based on the adopted wind speed for ultimate strength which at that time was regarded as the 1000 year return period event. The modelling results suggested that the return period of the estimated maximum wind speeds in cyclone *Tracy* in Darwin was much less than had been thought, and confirmed that for Region C, in which Darwin had been placed, a basic design wind speed of 55 ms^{-1} was appropriate. Although there have been some modifications to boundaries, and to design wind speeds as a result of a decision to change the basis of ultimate strength design for wind from the 1000 year return period wind speed to the 500 year return period wind speed, the basic format has remained unchanged and there has been no major revision of the original modelling results on which the design wind speeds are based.

The experience of cyclone *Tracy* also probably hastened the introduction of the limit state approach to structural design. When the DHC adopted the recommendation to use limit state design, it did not restrict it to Darwin. Norm Sneath's deputy at the time, and later successor, Charles Bubb, ensured it was applied throughout Australia. And DHC was such a big player in the construction scene in Australia that this ensured it was rapidly taken up by the structural engineering profession generally - although it took time for the full suite of limit state design structural engineering codes to be produced.

The principle that houses should be structurally engineered to resist extreme winds in cyclone areas was also quickly adopted in Queensland, which in 1975 produced its first State wide building regulations, and incorporated this principle in them (Queensland Government 1975). However it took a considerable time for the principle to be implemented in practice with the publication of the Appendix 4 to this Building Act in 1981. Only in Townsville, due to a high level of awareness at all levels of the community in general and the building professions in particular, due to the experience of cyclone *Althea*, was it implemented on a community wide basis immediately outside of Darwin, as a result of which Townsville became the testing ground for the details of construction finally approved in Appendix 4. In the middle 1990's with the publication and national adoption of the Building Code of Australia it became a requirement for all housing in Australia, the evidence of which can be seen in the plywood shear walls which have now become a characteristic feature of framed housing construction Australia wide.

Fatigue testing of roof cladding under the testing regime recommended in the report on cyclone *Tracy* soon showed that the most economic way of satisfying the criteria was to use a screw with a large washer to spread the load which became known as a cyclone washer. The use of this washer made the cladding fastening system immune to fatigue failure, and their use became standard practice in Darwin for metal roofing until very recently. However there was a great deal of resistance to their use from manufacturers and builders in other parts of Australia, who seized on suggestions that they were a quick fix and that further research would probably show they were overly conservative. In 1977 a workshop was held at the Experimental Building Station at North Ryde in Sydney (now part of CSIRO facilities) to review the criteria adopted in Darwin after cyclone *Tracy* and make recommendations on its application to other cyclone areas. The resulting publication known as TR440 (EBS 1977) was the bible for wind resistant construction in cyclone areas apart from Darwin for several years before its recommendations became incorporated in the wind code and cladding standards.

The TR440 criteria were incorporated in the Queensland Appendix 4 requirements as were the recommendations on internal pressures and the use of the limit state approach. The fatigue loading requirements were also incorporated by reference to TR440 in the 1981 edition of the wind code. This has meant that the roof cladding manufacturers have allowed for fatigue resistance in their standard recommendations for the use of their cladding in cyclone areas since about that time.

Most of these developments were based on extensive programmes of wind engineering research and development which were funded by both government and industry following cyclone *Tracy*. This was built on existing major centres of such research at Monash University, Sydney University, and the then CSIRO Division of Building Research at Highett and Experimental Building Station at North Ryde. A newcomer in the field, which probably became the main beneficiary in this area, was James Cook University, which had only just initiated studies in wind engineering at the time of cyclone *Tracy*. As a result of its involvement in redesign of housing after cyclone *Tracy* and the establishment of the Cyclone Testing Station at the University through which much of this was undertaken, it became a major centre of research related to wind loads on housing and other low rise buildings, and the structural performance of these under such loads, which has continued to the present day.

In respect of the use of full internal pressures in the design of engineered larger buildings it has been largely left to the design engineer's discretion when to use full internal pressures and when to assume a building will remain fully sealed during an extreme event. Designers in cyclone areas, very aware of the problem, took account of it once the lessons from cyclone *Tracy* were made public, but those well away from the cyclone areas have tended to just follow code requirements which made no real mention of the problem until the 1983 edition of the wind code indicated that in cyclone areas windows should be protected from wind borne debris if the building is to be assumed to be sealed. This is probably the recommendation that has been the least fully adopted in respect of specifically engineered buildings, as opposed to housing built using standardised deemed-to-comply design manuals which generally incorporate the full requirements. Like the fatigue criteria it has remained restricted to cyclone areas, but unlike the fatigue criteria it is just as relevant to non-cyclone areas. This is probably one of the major reasons that Australia wide there continues to be cases of some modern buildings supposedly designed in accordance with current codes suffering significant structural damage when exposed to severe winds.

Impact on insurance

Prior to the 1970's the biggest catastrophe insurance loss had been the 1967 Hobart bushfires at $14 million in the currency of the day. The 1970's started with cyclone *Ada* in the Whitsunday Islands causing a loss of $12 million, to be followed two years later by cyclone *Althea* in Townsville which caused an insured loss of $25 million, and fifteen months later by cyclone *Madge* which caused an insured loss of $30 million. The numbers may not sound large now, but in today's money the total insured loss from these three events would have almost certainly exceeded a billion dollars. Ten months later the Brisbane flood caused a loss to the industry which at $68 million was more than the combined losses from these three events. (It was this event which led the insurance industry to have an aversion to flood insurance.)

The insurance industry reacted by declaring that some of the hazards they were currently covering appeared to be uninsurable by normal insurance, and set up a committee to investigate the feasibility of a natural disaster insurance scheme. In the committee's report tabled in October 1974 it was concluded that floods, earthquakes and associated natural hazards did not satisfy the criteria for insurability and it was suggested that the Commonwealth Government establish a fund for these hazards, financed by a levy on all fire insurance policies, with the government acting as a lender of last resort in the event of a shortfall in the fund following a major disaster. Surprisingly tropical cyclones were excluded from this list.

This omission did not last for long however. Just eleven months after the Brisbane flood and still in 1974, Darwin was hit by cyclone *Tracy*, the worst sudden-onset disaster in Australian history. The estimated total insurance loss was $200 million, three times the loss from the Brisbane flood. It would have been very much greater if many of the houses had not been government owned with only the contents insured. Some insurance companies went through their reinsurance cover, and had Darwin been a more typical Australian community like Cairns or Townsville the losses would have been so great that the solvency of some companies would probably have been threatened. Tropical cyclones were hastily added to the list.

How much notice the government would have taken of the committee's suggestion if cyclone *Tracy* had not occurred will never be known. In the aftermath of cyclone *Tracy*, and its severe impact on many insurance companies, the government took little convincing that it was not in the national interest to expect the private insurance industry to bear such risks and thus put the whole insurance industry at risk of insolvency. In March 1976 the Treasurer, Phillip Lynch, announced that in response to the submissions from the insurance industry, the government had decided in principle to introduce a natural disaster insurance scheme. A Working Party, which included representatives from the insurance industry, was set up to develop the proposal, and submissions were invited from State governments.

In December 1976 Eric Robinson, the Minister Assisting the Treasurer, tabled the proposal in Parliament. The public, including the insurance industry, was given a year to comment on it. At the same time a Technical Committee led by the Chief Government Actuary, Sid Caffin, was established to work on the technical aspects, and a Mitigation Committee led by Leo Devin from the Commonwealth Department of National Development was established to investigate ways and means of mitigating the losses to reduce the liability to the scheme as much as possible.

The basic proposal envisaged a pool formed by insurance companies which would provide cover for domestic contents and for domestic buildings excluding commercially owned apartment buildings, against the nominated hazards of earthquakes, floods, tropical cyclones and related hazards such as landslides and storm surge. Damage from thunderstorm winds, hail and bushfires was excluded. Premiums were to be set annually and to be differentiated on a broad zonal basis in terms of the perceived risk. The primary role of the government was to provide reinsurance at a reasonable cost, one of the major factors behind the moves for the scheme being the large increases in reinsurance costs following the events in 1974, caused by both an increase in reinsurance rates and an increase in the amount of reinsurance cover sought by companies.

This led to a couple of years of intense activity that involved a wide cross section of stakeholders including State and Commonwealth Government Departments, the insurance and reinsurance industry, hazard researchers in Universities, CSIRO, the Bureau of Meteorology and the Bureau of Mineral Resources (now Geoscience Australia), and the engineering profession. Meanwhile the original Working Committee dealt with the comments, as well as the input from the two committees, especially that from the Technical Committee, seeking to find a solution to the issues that were raised.

Despite all the good work, and the initial strong commitment of both the government and the insurance industry, it all came to nothing. A major factor was probably that in the six years following the announcement of the proposal there were no disasters causing major insurance losses, which allowed time for the insurance industry to get back on its feet, and adjust to the new perception of risk by the reinsurance community, and for the public to adjust to the increases in premiums which had followed the events of 1974. It appears that during the period of intense investigation of the technical aspects both the government and the insurance industry began to get cold feet about the scheme.

Eventually a subsequent Treasurer by the name of John Howard declared the proposal dead – apart from the recommendations of the Mitigation Committee which were to be further considered. However not much happened to these either as not long later a change of government had the usual consequence of killing off any hanging initiatives of a previous government.

This might be seen as having killed off the impact of cyclone *Tracy* on the insurance industry, but in many ways it increased the impact, because it meant that the industry had to deal with the issues themselves. One of the big consequences of the natural disaster insurance scheme investigation was that it had made the insurance industry aware of the wealth of expertise in Australian universities and research organisations in respect of natural disasters and their management. At the time of cyclone *Tracy* the insurance industry was almost completely isolated from the disaster management and research scene in Australia. When in 1976, in the aftermath of cyclone *Tracy*, the Brisbane floods and other major natural disasters that had occurred in the first five years of the 1970's, the most significant conference on natural hazards in Australia to this day was held in Canberra and attended by everyone, it seemed, who was involved in the field in Australia, there was not a single contribution from the insurance industry (Heathcote and Thom 1979). Such a situation would be unthinkable today. Since the early 1980's the insurance industry in Australia has become increasingly dependent on scientific and technical expertise in its management of catastrophe risk.

One of the most significant consequences was the development of a more rational approach to the determination of the maximum loss for which an insurance company should have protection by way of reserves and reinsurance. This was the zone accumulation method whereby zones of concentration of insured properties that could be impacted by a single catastrophic event known as the ICA Catastrophe Zones were defined along with an associated Zone PML Factor, which was the estimated probable maximum loss in each Zone as a percentage of the sum insured in the Zone. A company determined its potential probable maximum loss in each Zone by multiplying its total building property sum insured in the Zone by the Zone PML factor, and used the maximum of the estimated potential Zone losses as its probable maximum loss (PML). Reinsurance was then purchased against this PML. Although now superseded by whole of portfolio catastrophe loss modelling based on event simulation using geographical information systems (GIS) technology, this approach formed the mainstay of insurance company catastrophe loss risk management in Australia for over twenty years, and was adopted internationally as the Cresta Zone approach which is still used in many countries.

The zone accumulation method was initially developed by the Insurance Council of Australia (ICA) as an in-house tool for its members in the aftermath of cyclone *Tracy*, with the first formal version being adopted in 1978. About the same time the ICA began assembling a list of past event losses, the first publication of which appears to be due to John Staveley (1985). Towards the end of the 1980's the ICA undertook a major revision of the zones, which it published in 1990 (ICA 1990). An appendix to this document was a list of event insured losses from 1967 in terms of original dollars and the estimated then present day values. The list continues to be maintained and recently has been the subject of a major revision in the estimation of present day values which are now expressed in terms of the expected losses if the same event were to occur today allowing for the changes in exposure and building regulations including, in the case of Darwin, the significant reduction in the proportion of government owned buildings. Much of this latter work was undertaken by a research unit at Macquarie University known as Risk Frontiers which is largely funded by the insurance industry (Crompton and McAneney 2008). Had cyclone *Tracy* not occurred the Australian insurance industry would by now have been using technical expertise, but instead of being a worldwide leader it is more likely that it would have been a follower, and it is very doubtful that it would have funded a scientific research unit at a university.

Reflections

The most significant impact of cyclone *Tracy* on the building and construction industry has been the national adoption of the principle that houses should be structurally engineered for wind to the same performance levels as larger buildings. At the time of cyclone *Tracy* such a move was considered to be a very radical one. The two primary obstacles were the high cost of structural design relative to the cost of an individual house, and the conservative nature of the building industry. These were overcome by adhering to two basic principles; standardisation of design, and evolutionary change of traditional construction (Walker and Eaton 1983). However, without the widespread public awareness of the need for change, the resulting commitment to such a change by governments at all levels supported by well funded research and development, and a comprehensive programme of education and training of the building industry to handle the changes, all a result of the overall impact of cyclone *Tracy* on the Australian community, it is doubtful if this change would have occurred.

While the basic principles established after cyclone *Tracy* have remained unchanged there have been some changes in the details, of which some are significant. From the date of its introduction there were doubts expressed about the adequacy of the TR440 fatigue loading test, which were shown to be well founded by a comprehensive programme of research at James Cook University during the 1980's (Jancauskas et al. 1994). These doubts led to Darwin retaining its original test requirement and consequent use of cyclone washers. It was not until relatively recently, however, that a revised test procedure was adopted that overcame the deficiencies of the TR440 test and gained universal acceptance (Henderson et al. 2008).

The removal of the requirement for a minimum terrain category of 2 ½ in Darwin appears to have occurred without reference to the Australian wind engineering community and without regard for the reasons it was put there in the first place, being rather seen by bureaucrats as tidying up an anomaly. Its consequence is that buildings in Darwin in supposedly Category 3 situations can be designed for a strength equivalent to about two thirds of the requirements embodied in the cyclone *Tracy* recommendations. This could have significant repercussions if Darwin is hit by another cyclone of *Tracy*'s intensity. Topographically Darwin is unlike other major centres of population in cyclone prone regions. It is not situated on a flood plain that rises slowly from sea-level. Much of it is located on a domed plateau that varies from about 5 to 20 m around the coastal edge and rises to about 30 m at its peak. This is a situation that can produce significant acceleration of wind speeds over land, which was one of the reasons for having a minimum terrain coefficient, the other being the relatively short fetch of true Category 3 for many parts of Darwin.

Conclusion

The zoning of the cyclone regions and recognition of the importance of fatigue failure of cladding fastening systems and internal pressures in the wind code is a direct impact of cyclone *Tracy*, as is the nationwide requirement for housing to be structurally engineered to resist wind loads, which in many ways was probably the most radical impact.

Wind engineering research and development was another major beneficiary. Cyclone *Tracy* also probably hastened the adoption of the limit state approach to structural design in Australia.

The insurance industry has moved on significantly further from the impact on it of cyclone *Tracy*, largely as a result of the impact of the Newcastle earthquake and the adoption of GIS probabilistic modelling of catastrophe insurance loss risk which followed (Walker 2009), but if it had not been for the changes made following cyclone *Tracy*, the industry may well have been totally unprepared for the losses experienced in the earthquake. Instead they were well covered by reinsurance, even if the level of cover had been largely based on estimated potential losses from tropical cyclones. A continuing impact has been the interaction of the insurance industry with Australia's research community which began following cyclone *Tracy* and continues to increase.

'Every cloud has a silver lining' says the well known proverb based on a line in a poem written by John Milton in 1634, and this has certainly been true of cyclone *Tracy*. Although one of the greatest disasters to afflict Australia since European settlement, its impact has led to improved practices in the building and insurance industries which have greatly increased the resistance of Australia's built environment to extreme wind events and the resilience of the Australian insurance industry to major catastrophic events.

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