AWES Workshop, Darwin, 28-29 June 2004

The Impact of Cyclone Tracy on Building Design in Australia

George R Walker

Abstract

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 built and owned 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. Today every house built in Australia embodies the major lessons learnt from the investigation in respect of wind resistance.

At the time the population of Darwin was about 40,000 living in about 8,000 houses. After the cyclone 50-60% of these were classified as being destroyed, and only 6% were classified as intact other than 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. It 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.

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 m/s. Although small with an eye diameter of about 8 km, its slow forward speed of less than 10 km/h meant that destructive winds were experienced for several hours.

Apart from housing, buildings whose structural strength had been certified by a structural engineer before construction performed reasonably well structurally, despite the estimated maximum wind speeds being in excess of the design wind speeds in many cases. A dominant feature of the damage was the loss of roof cladding, with over 90% of houses and approximately 70% of all other structures 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 was also some spectacular roof tie down failures.

In the Northern suburbs the destruction of houses was almost 100 percent despite these being the newest houses and incorporating lessons learnt from Cyclone Althea. Although the wind speeds were also larger 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

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 this 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. No mention was made of racking strength as no significant racking failures had occurred.

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 their wind resistance. The main concern of Darwin structural engineers was the weakness of the earlier construction. 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, Jack's 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 and his team on Christmas Day.

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

- Fatigue failure of cladding fasteners
- Internal pressures not allowed for in design
- Lack of design for racking forces.

The testing of roof cladding after Cyclone Althea was based on static tests – over the objections of Bill Melbourne it should be said, who 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 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 be reduced to 15% of the static fatigue strength, and recommended a testing procedure that is still the requirement for roof cladding design in Darwin.

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. Not long after there was a major change to the use of thinner high strength steel. Mild steel is more ductile than high strength steel, and less susceptible to fatigue failure. The report recommended that fatigue testing of roof cladding be mandatory in cyclone regions.

However 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 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. This damage highlighted the limitations of working stress design as well as design practice regarding internal pressures. The report recommended the speedy adoption of the limit state approach to design 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, significant damage 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'. 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. 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. The result 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 assumption made about the inherent strength of housing.

Implementation of Recommendations

All the major recommendations of the investigation were implemented in the reconstruction of Darwin. That this occurred is probably almost entirely due to 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. A comprehensive programme of testing housing components and systems was developed and undertaken, wind tunnel studies commissioned to obtain a better understanding of wind loads on housing, probabilistic modelling of cyclonic wind speeds using newly emerging GIS technology initiated, 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 to the present day. Most of the surviving buildings have been upgraded and those that have not are becoming an increasingly small proportion of the total building stock in Darwin – probably of the order of 2%. As a consequence Darwin can probably claim to be the strongest city in the world in respect of wind resistance.

Impact Beyond Darwin

Cyclone Tracy did not just have an effect on building construction in Darwin.

ıost immediate influence was on design in other cyclone prone areas of Australia. Fatigue testing of cladding and allowance for full internal pressures became a standard requirement in these ;, particularly in Queensland. In 1977 a workshop was held at the Experimental Building Station ydney (then part of the Department of Housing and Construction and now the North Ryde oratory of CSIRO Building Construction and Engineering). The object of this workshop was to :w the criteria adopted in Darwin after Cyclone Tracy and make recommendations on its ication to other Cyclone areas. The resulting publication known as TR440 was the bible for wind tant construction in cyclone areas apart from Darwin for several years before its mmendations became incorporated in normal standards and codes. The fatigue testing criteria ted at that time is still used for cyclone areas other than Darwin.

he impact has not been limited to cyclone areas. When DHC adopted the recommendation to use state design, it did not restrict it to Darwin. Norm Sneath's deputy at the time, and later essor, Charles Bubb, ensured it was applied throughout Australia. And DHC was such a big er in the construction scene in Australia, this ensured it was rapidly taken up by the structural neering profession generally. The adoption of an engineering approach to the design of houses in one a[illegible]s led to knowledge on the structural performance of houses under wind loads that was lly ap[illegible]cable to non-cyclone regions. Although fatigue testing of cladding and the assumption of nternal pressurisation is still restricted to cyclone areas, most houses built in Australia today rporate an engineered solution in their structural design for wind, generally implemented in the of tables and charts. Shear walls to provide racking strength are now part of normal house gn everywhere – a direct consequence of the lessons learned from Cyclone Tracy.

rent Issues

pite the passage of 30 years there are still unresolved issues regarding the wind resistant design of dings that can be traced back to Cyclone Tracy.

most significant for cyclone regions is the fatigue test criteria. The TR440 test was never pted in Darwin, partly because it led to the acceptance of fastening systems that seemed little rent to those which failed in Darwin. An extensive 6 year programme of research at James Cook ersity in the mid-1980's confirmed these doubts, indicating that at least in respect of corrugated the test was unconservative. A test more representative of the sequence of wind loads rienced by cladding during a cyclone was recommended by Mahen Mahendren, but politically it not welcome. Legislators did not want to know that a test they had been specifying for many s wa[illegible]dequate, and neither did the cladding manufacturers. However lately there seems to been [illegible]ome relaxation of these attitudes, driven by a recognition that the differences between win and the rest of Australia on the issue need to be resolved for efficiency of manufacturing.

lack of recognition outside of cyclone areas of the role of internal pressures is also an anomaly. total uplift forces on a roof can more than double when openings occur on the windward face ng extreme winds. This type of failure is a common feature of wind damage in non-cyclone areas, it also seems that it is something neither the legislators nor the building industry want to know ıt. It is easier to blame shoddy building practices.

other issue is the effect of private certification. After Cyclone Tracy a high level of building rol was exercised in most cyclone prone areas in relation to wind resistant construction details. ate certification is not as transparent a process as public certification and the jury is still out on its ctiveness. Perhaps the next big cyclone will enlighten us.

other big issue is who would replace the Commonwealth Department of Housing and struction in the event of another event like Cyclone Tracy?