Coming to terms with cyclones

Most houses fared awfully during cyclone Tracy.

Flats and other engineered buildings stood up quite well.

By about 9 p.m. the breeze had become a gale; it increased steadily. The first really strong gust struck just before 1 a.m., but the very strongest winds of cyclone Tracy did not really set in for another hour. By 5 a.m., when the winds abated, Darwin lay in ruins.

Cyclone Tracy had been by far the most destructive cyclone ever to hit Australia. The official death toll in Darwin was 49, and another 16 people were missing, presumed drowned at sea.

Along the coast of northern Australia tropical cyclones are a fact of life. On average, more than three cross or come close to our shores each year. We will have to come to terms with them if we intend to live along our northern coastline. As more people live there and towns become larger, the cost of cyclones—in terms of both human misery and material destruction—must become steadily greater unless we do something about it.

Three very destructive cyclones have hit heavily populated areas during the last 5 years—cyclone Ada in January 1970, which wrought havoc on Hayman Island and other nearby resorts and Proserpine; cyclone Althea, which did a lot of damage in Townsville on Christmas Eve, 1972; and cyclone Tracy. As rough estimates, these three cyclones cost $12 million, $25 million, and $500–1000 million respectively.

During the last decade the Bureau of Meteorology has made large strides in finding ways to warn people of approaching cyclones. Cyclone Ada killed 13 people, but the much larger cyclone Althea caused only three deaths—at least partly because the inhabitants of Townsville were better informed as a result of the Bureau's efforts. Considering the total devastation of large parts of Darwin, one can only marvel that the death toll there was not much higher.

But warning people of approaching cyclones and advising them what precautionary measures they should take cannot be the whole answer. To know a cyclone is coming doesn't help people that much if their houses blow down. Some way will have to be found to at least greatly reduce the damage to buildings. The experience of Darwin suggests that we can build reasonably cyclone-resistant shops, office blocks, and factories, but can we build cyclone-proof houses?

Little research

Here in Australia we have not done much research into how buildings withstand cyclonic winds. Dr George Walker at the Engineering Department of the University of Townsville carried out detailed studies of the damage done in Townsville by cyclone Althea, and on his recommendation the local Queensland building codes, and also that used in Darwin, were tightened considerably.

To know a cyclone is coming doesn't help people that much if their houses blow down.

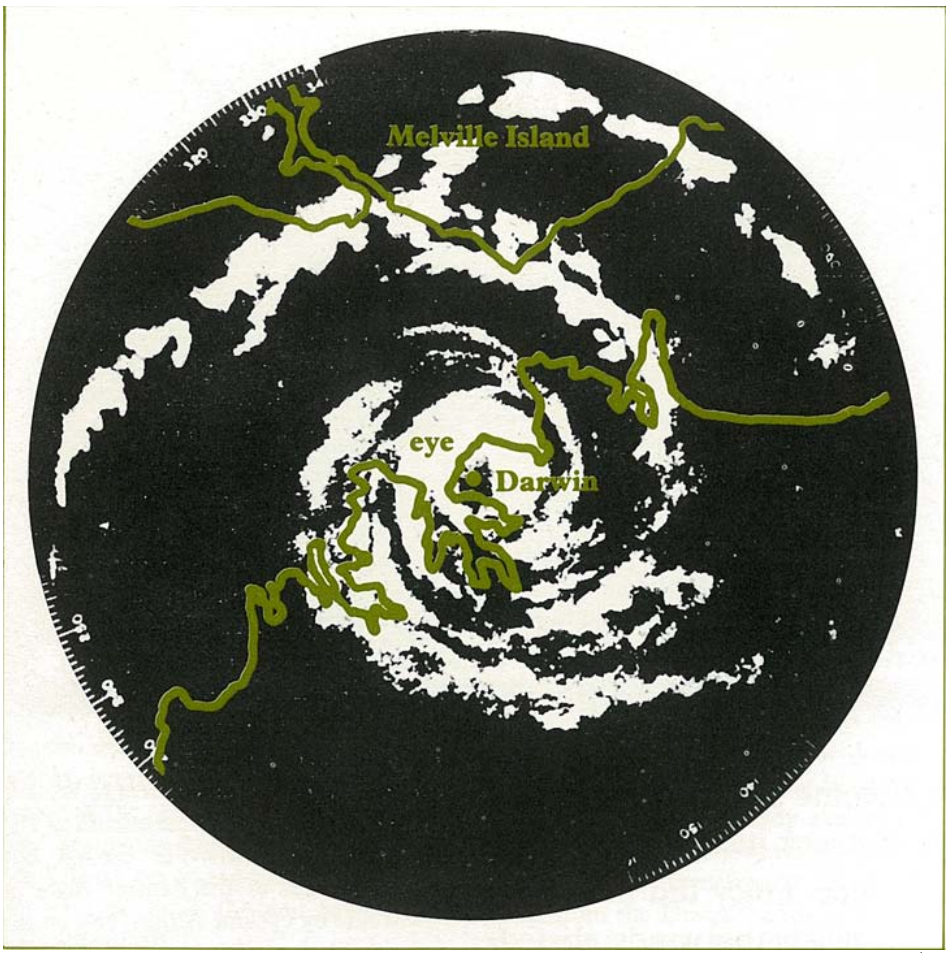
Several expert groups surveyed the destruction in Darwin immediately. The Australian Department of Housing and Construction brought together the largest team, which included Dr Walker among its number. The Department flew him in from the United Kingdom, where he and his family were on sabbatical leave at the time of the cyclone. It also commissioned the private company Halpern, Glick Pty Ltd to assist Dr Walker.

Dr Bob Leicester and Mr Greg Reardon from the Design Science Section of the CSIRO Division of Building Research made a separate survey.

All the investigators agree that it is possible to build houses as well as other buildings that can withstand cyclones, but this will require a radically new approach. It could also be rather more expensive.

All buildings will have to be 'engineered'. The traditional cottage-construction methods of building houses—described by one investigator as using 'a pile of timber members fastened to each other with a few nails'—has proved completely inadequate.

Designing cyclone-resistant buildings requires an understanding of what tropical cyclones really are. As the map shows, tropical cyclones form over all tropical

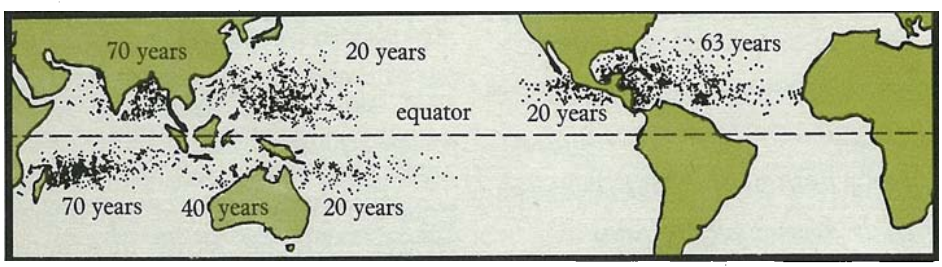


Cyclone Tracy seen by radar over Darwin airport at 4.15 on Christmas morning.

Tracy's winds — how fast?

		maximum gust (km per hr)
anemometer (failed)		
Bureau of Meteorology calculations		
	method 1	330
	method 2	310
	method 3	248
Dr Walker		234–252
Halpern Glick (from signs and poles)		> 263
Dr Leicester		306
actual		280?

Where tropical cyclones form.



oceans except the South Atlantic. They form in two bands located between 8° and 20° latitude each side of the equator. They start as areas of low pressure and cloud located over areas of warm water, which must be above 25·5°C. The sea has to be this warm because, for a cyclone to form, the air above the water must rise to 12 km and still remain warmer than the surrounding air at that level. When the right conditions exist, the low-pressure area may (but by no means always will) develop into a tropical cyclone.

In a mature cyclone, warm moist tropical air is continuously sucked in at the base. It spirals in towards the centre of the storm until it reaches the area of the eye wall. Here the winds usually blow in a circle around the comparatively still eye, and the warm air rises some 12 km to the upper troposphere, where it flows out into the surrounding colder air. Winds blow clockwise in the Southern Hemisphere, and anti-clockwise north of the equator.

Once a cyclone moves over land, or moves across the cooler waters of the higher latitudes, the supply of warm air to be sucked into the centre dries up. The cyclone then gradually degenerates.

Cyclones, hurricanes, typhoons

Here in Australia we refer to a tropical low-pressure area as a tropical depression if its wind speeds are less than 62 km per hour, (39 m.p.h.), as a tropical cyclone where the winds are between 62 and 117 km per hour, and as a severe tropical cyclone where the winds exceed 117 km per hour (73 m.p.h.). The Americans refer to such severe tropical cyclones as hurricanes, and countries bordering on the China Sea or the Bay of Bengal call them typhoons.

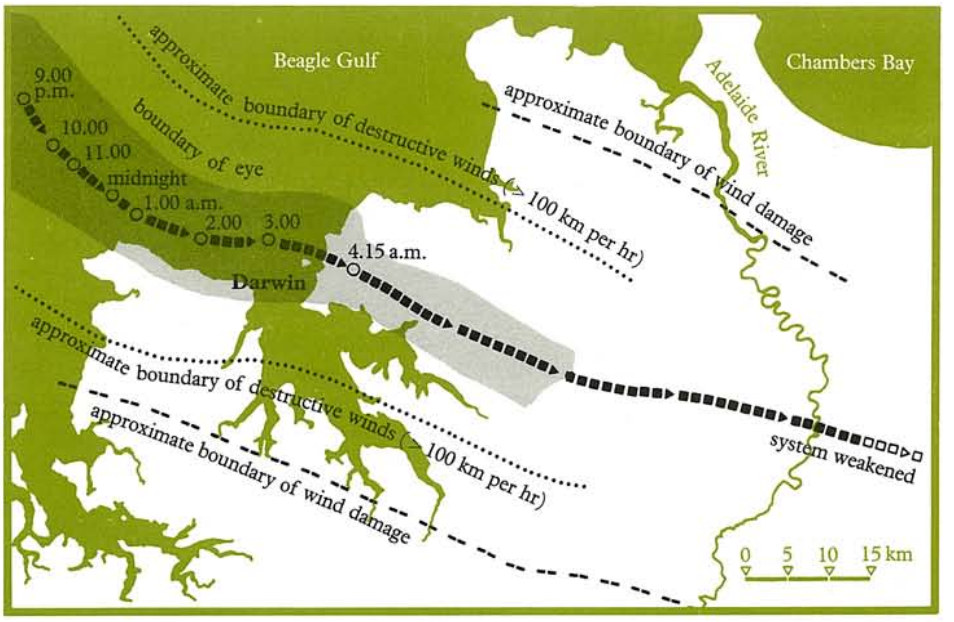
Estimated maximum speeds of wind gusts at Darwin were between 230 and 270 km per hour (140 and 160 m.p.h.), at Townsville 200 km per hour, and at Hayman Island 160 km per hour. A piece of flying debris put the anemometer out of action before the eye of the cyclone reached it at Darwin, but it had already recorded 215 km per hour. Incidentally, hurricane Celia, which caused severe damage in the Texas city of Corpus Christi in 1970, produced wind speeds of up to 260 km per hour—similar to those of cyclone Tracy.

Often, rain pouring into de-roofed houses, warehouses, or other buildings causes as much costly damage as the winds themselves. Typically, tropical

cyclones produce between 250 and 500 mm of rain, which is distributed within the cyclone in spiral bands. These bands provide a means of tracking the cyclones, since they can be seen on a radar screen. In fact, the Bureau of Meteorology operates a network of radar cyclone-tracking installations that covers the entire eastern Australian coast from north of Cooktown to the region of Grafton in New South Wales. If located on high ground, such radar installations can give accurate fixes of a cyclone's position up to a distance of about 330 km.

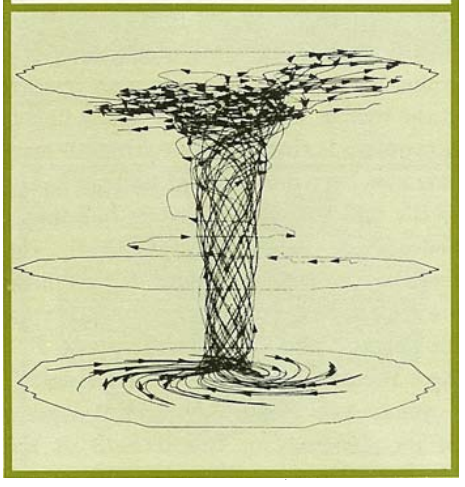
At the CSIRO Division of Building Research at Highett near Melbourne, Dr Leicester and Mr Reardon, of the Design Science Team, have for the past 3 years been studying wind (and flood) damage to buildings all over Australia. High winds don't only occur during tropical cyclones. Strong gusts that damage buildings may occur anywhere on the Australian continent. During cyclones the gusts may or may not be stronger, but they are much more frequent and prolonged. For example, the highest recorded gust in the Melbourne area was 163 km per hour at Point Henry—3 km per hour higher than the highest recorded at Hayman Island during cyclone Ada.

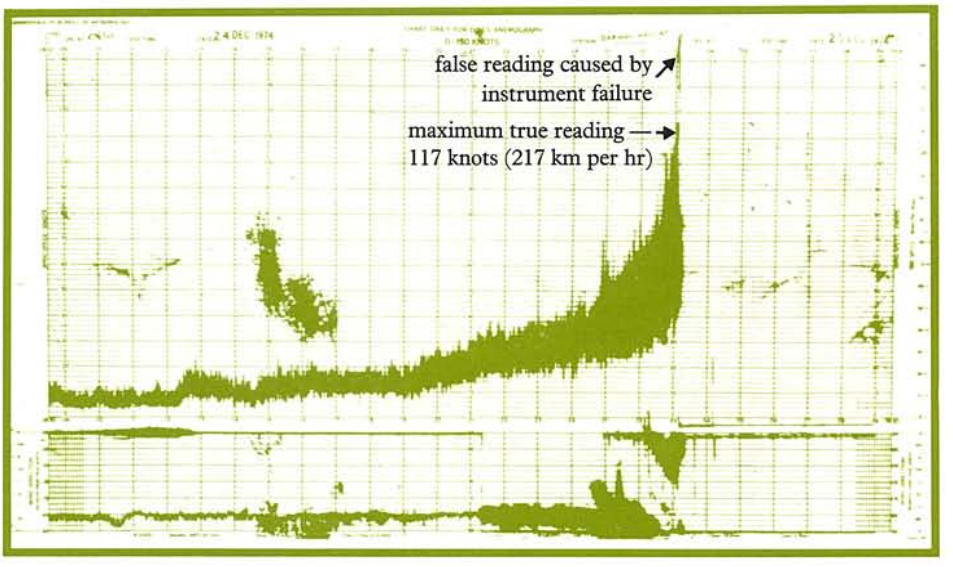
Sooner or later gusts of up to 120 km per hour occur on every suburban building block in Australia. Such gusts are strong enough to lift heavy tile roofs. Lightweight sheet-metal roofs may lift at wind speeds as low as 50 km per hour. Unlined sheet-metal warehouse roofs tend to be particularly vulnerable to these lower-speed winds. Even the presence of insulation and roof linings increases the



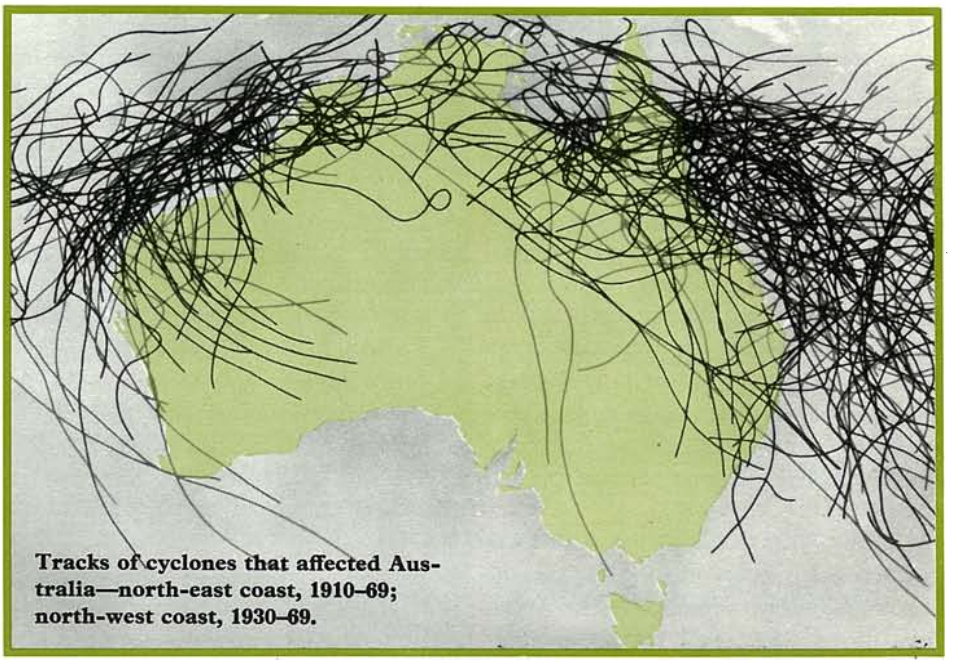
How Tracy crossed Darwin.

Computer simulation of how air moves in a cyclone.





Anemometer record, Darwin airport, December 24–5, 1974.



Tracks of cyclones that affected Australia—north-east coast, 1910–69; north-west coast, 1930–69.

weight of a roof considerably—and hence also the upward force required to lift it.

Wind speeds of up to 160 km per hour occur during violent thunderstorms and tornadoes (they can go up to more than 300 km per hour in tornadoes in North America). Such a storm hit Jindabyne in the Snowy Mountains area of southern New South Wales in 1973. This lifted a scout hall completely off its piers. Total devastation of conventional types of 'cottage construction' occurs at wind speeds of around 200 km per hour.

As a result of their investigations into the effects of storms such as the one at Jindabyne, Dr Leicester and his colleagues have been able to suggest a number of ways in which conventional buildings can be strengthened to withstand higher wind speeds.

They concluded that the main source of weakness was the roof attachment. If the roof could be prevented from blowing off, then the complete house should have enough rigidity to resist very strong winds indeed.

At the University of Townsville, Dr Walker concluded much the same thing from his study of the damage produced by cyclone Althea. Consequently the main change brought into both the Queensland and Northern Territory building codes for cyclone areas was that strong cyclone bolts and other special fasteners should be used to firmly secure the roof of a house through its walls to its floor. If this were properly done, the house should at least be able to survive the winds of up to 200 km per hour experienced during cyclone Althea.

Pundits caught out

Cyclone Tracy, with its maximum wind speeds possibly as high as 280 km per hour, was another matter. Darwin's newest suburbs, Tiwi and Anula, had been built following the modified code. Nevertheless, practically every house in these two suburbs was destroyed.

On the whole, Darwin's engineered buildings like flats, the larger motels, schools, and city buildings, which had been designed in consultation with a structural engineer to withstand high winds, survived well. Most of the damage was done to parts such as the roofs, where traditional cottage construction had been used, and neighbouring parts of the top floor.

Houses built wholly using traditional cottage-construction techniques, on the other hand, fared very badly. More than 50% of all houses in Darwin were destroyed, and only about 5% had only minor damage and were considered to be intact. Single-storey houses at ground level tended to do better than those raised on stilts, and newer houses of both designs fared worse than older ones.

Nevertheless, Dr Leicester points out, this does not necessarily mean that the traditional tropical house raised on piers is unsuitable for cyclone-prone areas. He regards the problem of building cyclone-resistant houses as an engineering one, not an architectural one. He does not think that architectural features like the actual shapes of houses were critical factors in their ability to survive the high winds. He suggests a number of reasons why the older houses of both the raised and ground-level types fared better. Not least is that their roofs were more securely tied down and held together. These houses were also better braced and had less window space in their walls. In addition, they were built of heavier and more suitable materials. In other words, from the engineering point of view, they were better engineered (albeit, more often than not, accidentally).

Newer houses of both designs fared worse than older ones.

According to Dr Walker's observations, the design that did best of all was the older single-storey house with brick cavity walls on a concrete floor. The corrugated-iron timber-framed hip roof was supported by a continuous reinforced concrete beam that was securely anchored some 1½ metres down in the brick walls. Probably less than 10% of these houses were damaged beyond repair. A small group of precast concrete houses built to an almost identical design, except that the brickwork was replaced by hollow concrete panels, performed equally well.

More recently built single-storey houses tended to have a timber-framed structure with brick veneer on the end walls. They didn't do at all well. The brick veneer frequently collapsed, and the timber frame buckled in the same way as those in the houses mounted on piers.

For a number of reasons, a still more recent design with masonry walls did even worse—almost all were destroyed.

Rigidity lost

The course of events that led to disintegration of a timber-framed house usually followed one of two patterns. In the first case, part of the metal sheeting on the roof blew off, and often more followed. Consequently, the roof structure lost some of its rigidity, since it depended on the sheet metal to keep it solid. The rigidity of the rest of the house depended on the roof being in place, so once the roof was damaged the timber frame of the walls often began to sway sideways (technically known as racking). Finally the whole structure collapsed and blew away.

In the second case the first event was damage to the windward wall by flying debris. One of the most commonly used materials for covering the timber-frame walls (cladding) was asbestos–cement sheeting. This material is cheap, but very brittle, and wind-borne missiles like roofing iron and smaller objects shattered it very easily. The outer layer of brick in brick-veneer houses often blew in or was broken by such missiles too. Regardless of why the wall cladding failed, the wall became weakened because it depended on the cladding for structural strength. Once again racking often ensued, which finally led to disintegration of the house.

In both cases the house finally disintegrated because part of its strength resided in the roof or wall cladding, which failed. A problem is that very few strength tests have ever been done on cladding materials, so it's difficult to know when building a house how much extra strength the cladding can yield. In addition, very little research has been done in any country on the damage caused by flying debris. For these reasons, in Dr Leicester's opinion, a cyclone-proof house should not depend on its cladding for its strength at all. Ideally, he thinks, such a house should contain a frame that is capable of withstanding all the forces likely to be put on it by a cyclone without any assistance from the roof or wall materials.

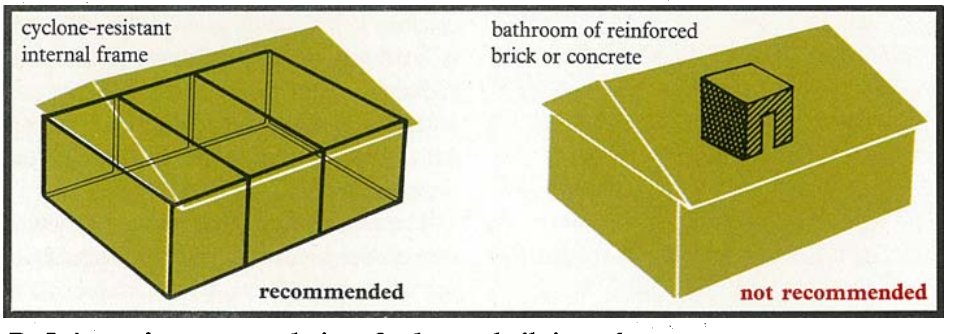
This idea sounds simple, but in fact it is a revolutionary approach to building houses. The house-building industry is based on tradition. It uses methods handed down from one generation to the next, and building techniques are the end product of years of trial and error. Usually a building practice is only modified or discontinued when it is found wanting. For cyclones as intense as Tracy, Dr Leicester thinks that the whole traditional approach to house-building has been found wanting, and the other investigators of the effects of the cyclone agree to a greater or lesser extent.

Of course, Dr Leicester's approach has two difficulties—builders would be reluctant to use it, and it may prove more expensive. However, the new building

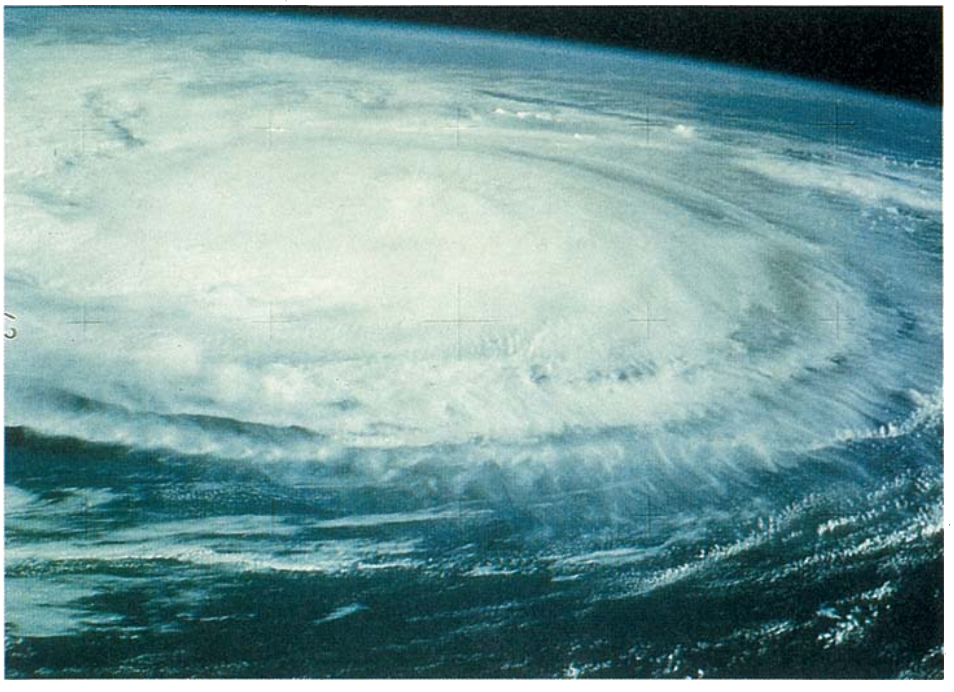
Condition of Darwin's houses — Dr Walker's survey

	number	%
total in Darwin	about 8000	
surveyed	6981	
destroyed	3675	53
declared intact (minor damage only)	408	6
declared repairable (roof damage only)	1730	25
declared repairable (roof and wall damage)	1168	16

Example of racking.



Dr Leicester's recommendations for houses built in cyclone-prone areas.



codes for Darwin do specify that every house design must be checked for strength by a structural engineer, which has never before been specified in Australia. Nevertheless, most of the houses built in the Western Australian company towns of Dampier and Port Hedland are engineered to resist cyclones, so the idea is not entirely untried.

Roofing iron

Failure of the metal roof sheeting surprised everybody. Dr Walker's studies

Keeping on the roofing iron would reduce the flying debris.

had revealed that in Townsville whole roofs had been blown off in large numbers, but in Darwin the roof frame often remained firm, at least to start with, and the metal sheets tore off around the washers on the screws that held them down.

Dr Leicester and his colleagues were puzzled when they did strength tests on the various metal sheeting materials and their fasteners, because the loads that the metal sheets could carry were many times those that could have possibly been applied during the cyclone. Then it became apparent that the failures were connected with the fact that during a cyclone the sheets would not remain stationary, resisting the forces upon them, but would vibrate up and down. Quite probably they would do this 10 000 times during the cyclone, with the result that metal fatigue might well occur around the fastenings.

Subsequent laboratory tests carried out by the Department of Housing and Construction in fact revealed that corrugated iron would be only one-sixth as strong in this situation as it would be if a single load was being applied to it. Both the Department and CSIRO are now

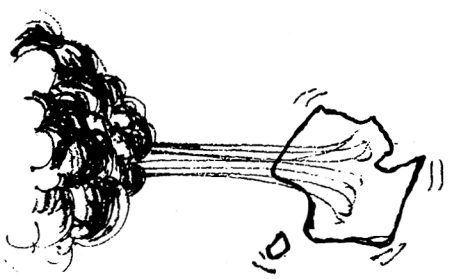
Hurricane Ellen over the Atlantic as seen from Skylab 3, September 1973.

testing modified fasteners to see if they can overcome the problem.

In practice, the decision on whether it is desirable to build completely cyclone-proof houses depends on their cost, and the likely frequency of cyclones in the area in question. The Darwin cyclone was undoubtedly the strongest to strike an Australian city, but was it an isolated case not likely to happen again in the foreseeable future?

Darwin has been struck by four cyclones in living memory—Tracy in 1974, two much less devastating ones in 1917 and 1937, and one that was probably as devastating as Tracy in 1897. The city has also had a number of near misses.

At 12° South, Darwin is close to the northern limit of where cyclones can form. The map of cyclone paths around northern Australia shows that the Northern Territory coast suffers them relatively infrequently compared with coastal areas of the northern half of Western Australia and Queensland. In fact, the most cyclone-prone areas are the Queensland part of the Gulf of Carpentaria, the region between Cooktown and Rockhampton on the Queensland coast, and the Roebourne to Wyndham region of the Western Australian coast. While the Western Australian company towns like Dampier and Port Hedland are comparatively well designed for cyclonic conditions, the same cannot be said for the towns along the Queensland coast.



Records too short

The problem with deciding the cyclone risk for any Australian town is that reasonably accurate records have only been kept for about 60 years, which is too short a period for making accurate predictions.

Take the case of Bowen. It experienced no cyclones for 74 years—between 1884 and 1958—and the myth had arisen among the local people that the town was

Can we modify tropical cyclones?

The Americans are the only people doing research in this field. Their results suggest we can. It's a difficult and frustrating field of research, but at the National Hurricane Research Laboratory, Miami, Florida, Project Stormfury has been in operation since 1961. This program aims at reducing the maximum wind speeds within hurricanes by seeding them with silver iodide.

One of the main problems is that Mother Nature is very erratic. Up to 1973, only two really suitable hurricanes had entered the Laboratory's experimental areas.

The experiments have mainly been conducted from aircraft flying from either Puerto Rico or Florida, and the storms must be within 1100 km of the operating base because the aircraft need to remain on station for several hours to monitor the results. Hurricanes close to land are unsuitable for seeding. Closeness to land modifies the storm, making it even more difficult than usual to evaluate the results. Also, if the storm moved inland after seeding and caused widespread damage and loss of life the legal problems might be colossal.

On October 13, 1947, Dr I. Langmuir seeded a hurricane for the first time. He used dry ice. Dr Langmuir had no way of knowing whether his efforts really had much effect, but with the wisdom of hindsight, it seems unlikely.

During September 1961, a team from the Weather Bureau and the Navy succeeded in seeding hurricane Esther, with such encouraging results that Project Stormfury was set up.

The Stormfury researchers had to wait until hurricane Beulah came along in 1963. Seeding this hurricane again yielded encouraging results.

A further 6 years passed before the next suitable one, hurricane Debbie, arrived in 1969. On August 18 this storm was seeded five times in 8 hours. The maximum winds decreased from 160 km per hour to 125 km per hour 5 hours after the final seeding—a reduction of 30%. The winds intensified again on August 19, and the hurricane was again seeded five times the next day. This time the reduction of maximum wind speed was about 5%—from 184 km per hour to 155 km per hour—within 6 hours after the final seeding.

Up to 1973 no other suitable hurricanes had entered the experimental areas.

Hurricane seeding aims at reducing the maximum winds by dispersing the energy that is normally concentrated in a relatively narrow band curving around the centre of the storm. Introducing silver iodide provides particles on which supercooled water droplets can condense and freeze to form ice crystals.

In the process of freezing, the water droplets release latent heat. Thus the main effect of dropping silver iodide particles into a hurricane is to add heat to it.

Theoretical calculations suggest that the best place to add heat to a hurricane is just outside the eye wall—and this location usually coincides with the belt of greatest winds.

Experience has shown that it should be possible to create a new eye wall outside the old one using silver iodide seeding. Increasing the diameter of the eye wall in this way should have the effect of decreasing the maximum winds.

In practice, monitoring the results of seeding experiments is very difficult, so it is hard to decide whether a wind speed reduction was a result of the seeding, or a natural variation. Nevertheless, the hurricane Debbie results do suggest a real reduction.

The force on a building or other structure on the ground varies as the square of the wind speed. Thus a reduction of 10% in the wind speed would mean the force exerted by the wind would fall by about 20%. Artificial reductions of 10–15% in the wind speed do therefore seem worth producing.

Hurricanes and tropical cyclones may devastate coastal areas, but many semi-arid inland regions depend on these weather systems for their rainfall. From their experience and calculations, the researchers at the Hurricane Research Laboratory do not think that seeding hurricanes actually reduces the amount of rain these storms produce, or changes their course. So it looks as though seeding a hurricane or cyclone off the coast will not affect the rainfall inland.

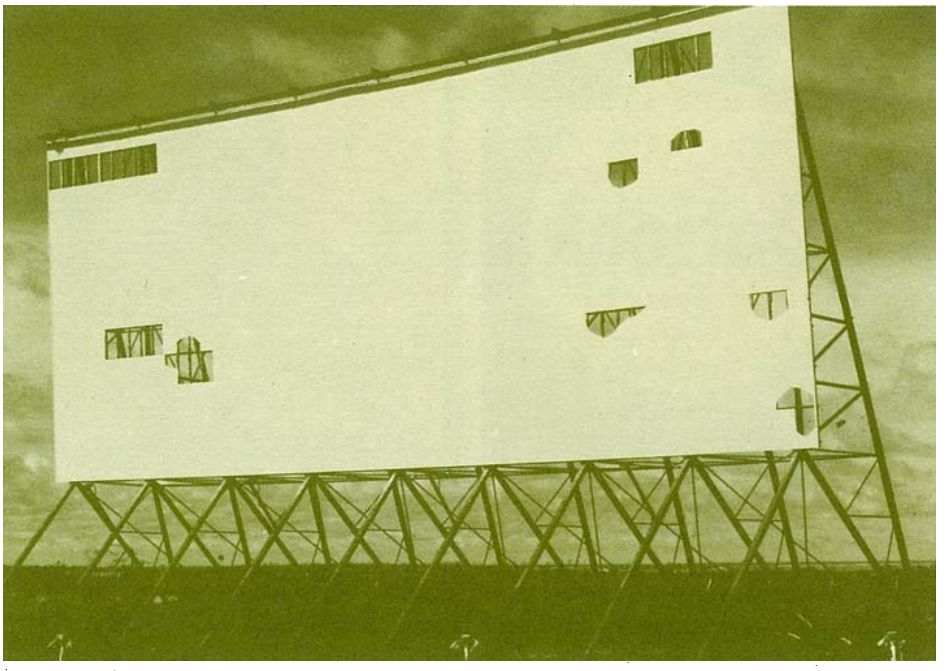
Artificial modification experiments for tropical cyclones. R. C. Gentry. In 'Department of Science Regional Tropical Cyclone Seminar, Brisbane, 1973'. (Australian Government Publishing Service: Canberra 1973.)

sheltered from these storms. Then two tropical cyclones struck the town in successive years—in 1958 and 1959.

Nevertheless, an indication of the most cyclone-prone towns can be gained from the Bureau of Meteorology's statistics for the years 1940–69. A town located within 55 km of the centre of a cyclone would usually have felt at least some of the force of its destructive winds. During those 30 years, cyclone centres came seven times or more within 55 km of Onslow, Mandora (250 km north-east of Port Hedland), and Broome in Western Australia, and Cooktown, Cairns, Townsville, Bowen, and Mackay in Queensland. Only four cyclone centres came within 55 km of Darwin during that 30-year period.

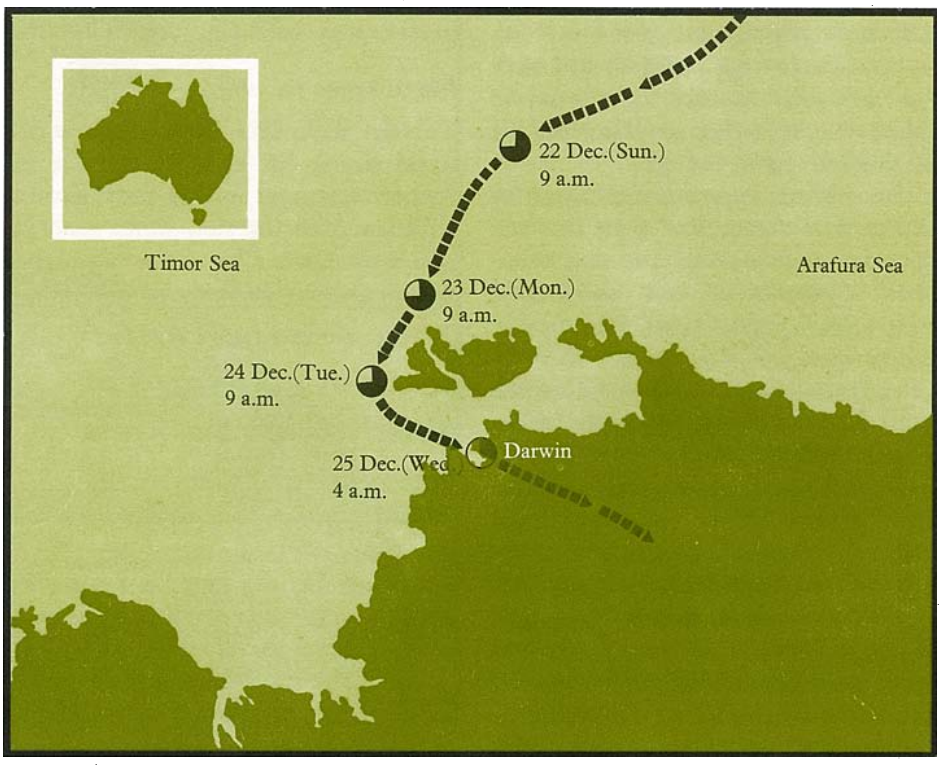
One other feature of tropical cyclones may occasionally be even more damaging than all the wind and the rain. As the cyclone crosses the coast and moves inland, the sea level may rise dramatically, causing massive flooding. This is known as storm surge, and on a straight coastline like Australia's the rise can vary from 1·5 metres to as much as 8 metres. In an enclosed bay like the Bay of Bengal the surge can raise the level much more, causing great loss of life. Such a surge combined with the waves whipped up by the cyclone can be much more devastating than the wind and the rain combined.

Mercifully, here in Australia the circumstances have not yet been right for this to happen, but they may be one day. Both at Darwin and Townsville the cyclones crossed the coast when the tide was fairly low. At Darwin the storm surge was a relatively small 1·6 metres. At Townsville it was a rather greater 2·7 metres, and water from the Ross River did in fact cover the main street of the city. If a storm surge of this size coincided with a spring tide at a low-lying city like Mackay or Cairns, the prospect would be too ghastly to even contemplate.



It is possible to design against cyclones—the eye passed right over the drive-in.

Path of cyclone Tracy.



More about the topic

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