Cyclones - assessing the risk

Each year, about 75 severe tropical cyclones — or typhoons or hurricanes as they're known north of the equator — develop around the world. One in five of these forms off Australia. From not far north of Perth in the west round the north coast to near Brisbane in the east, every part of the coastline may find itself, some time or other, in the path of a summer cyclone. Severe effects can be felt up to 50 km inland.

The cyclone can be a long time in coming. Before Christmas morning 1974, when Tracy laid it low, Darwin had not been hit by a cyclone since 1937, when a much less severe one passed through. Bowen, on the Queensland coast, experienced no cyclones for 74 years; its turn came in 1958 and again a year later. Brisbane has never suffered a direct hit, and maybe never will. There is some doubt about whether its location puts it at risk of a full-scale cyclonic battering.

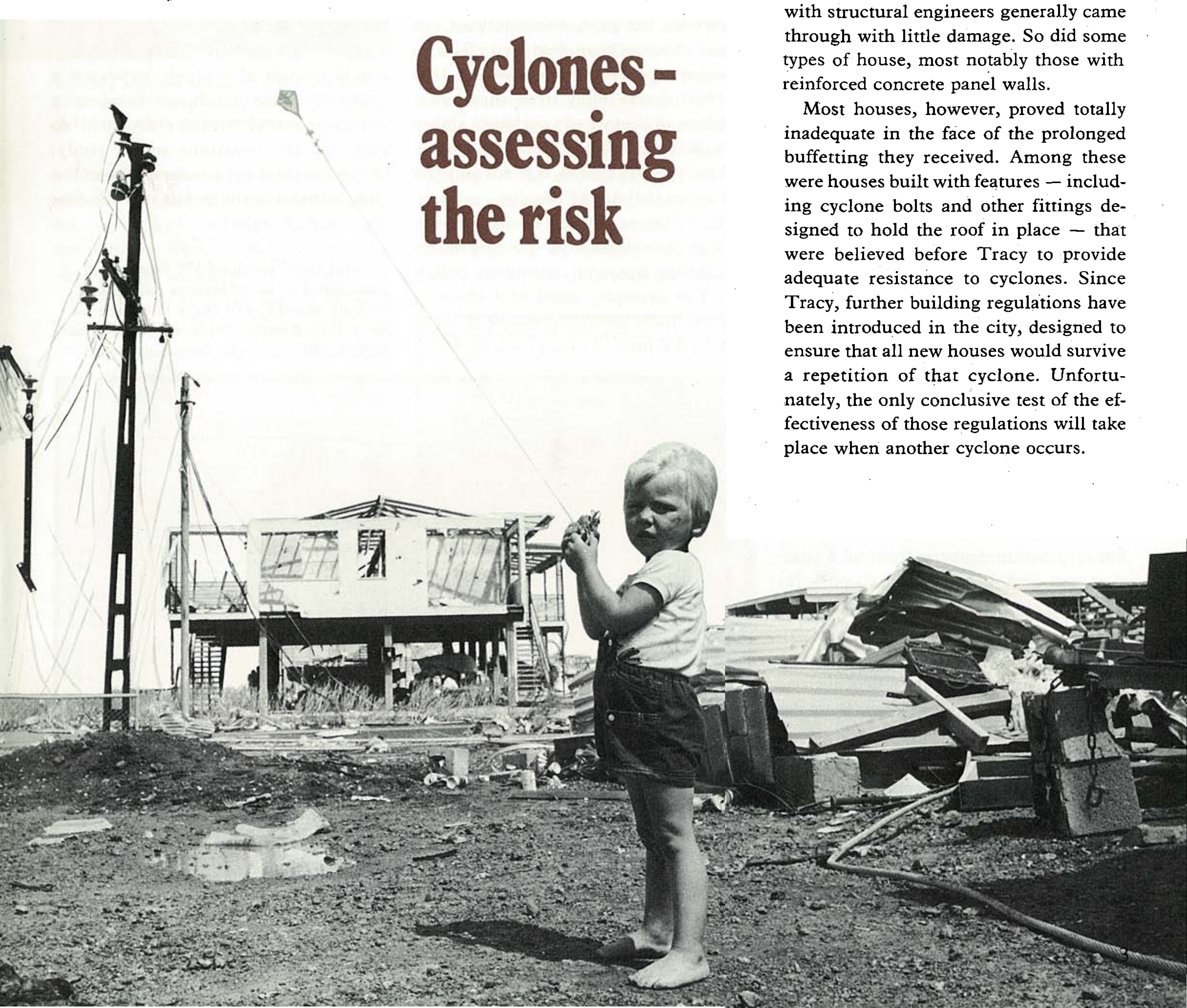
Vast unoccupied stretches separate the population centres along the exposed coastline, with the result that many cyclones pass by without causing problems. Tracy gave Australians a frightening view of the awesome power they possess. Maximum gust speeds probably exceeded 250 km per h, and buildings were exposed for substantial lengths of time to winds up to 200 km per h. More than 5000 of Darwin's 8000 houses were damaged beyond repair, and only 400 remained habitable. It took 3 years' work and something like $500 million to return the city to normal.

Tornadoes and severe thunderstorms can produce wind speeds approaching those experienced during cyclones, but they cause much less devastation for two main reasons. The first is the area affected: strong winds typically extend 10–30 km from the moving eye of a cyclone, whereas only a very small area around the path of a tornado or storm is affected. The other reason is the duration of the winds, measured in minutes for tornadoes and storms but in hours for cyclones.

As an illustration of the difference, a tornado that passed through Brisbane in 1973 caused building damage similar to that produced by Cyclone Tracy in Darwin, but only in portions of four suburbs. If a cyclone of similar force passed through Brisbane, enormous devastation would result.

However, the Darwin experience, as well as providing graphic evidence of the damage cyclones can do, also demonstrated that well-designed and constructed buildings can withstand the severest cyclonic winds. Buildings — such as shops, industrial buildings, and office blocks — designed in collaboration with structural engineers generally came through with little damage. So did some types of house, most notably those with reinforced concrete panel walls.

Most houses, however, proved totally inadequate in the face of the prolonged buffetting they received. Among these were houses built with features — including cyclone bolts and other fittings designed to hold the roof in place — that were believed before Tracy to provide adequate resistance to cyclones. Since Tracy, further building regulations have been introduced in the city, designed to ensure that all new houses would survive a repetition of that cyclone. Unfortunately, the only conclusive test of the effectiveness of those regulations will take place when another cyclone occurs.



Two houses on stilts — severe racking distortion (above) and total demolition (below) above floor level.

The people who live in a cyclone-prone city obviously have the most direct interest in ensuring that damage is kept to a minimum. Cyclone Tracy killed 49 people in Darwin — most of them apparently crushed by falling walls or other parts of buildings — and injured many more. Property destruction was enormous; many people lost virtually everything they owned.

But others also have a strong interest in seeing that the least possible damage results — notably governments and insurance companies. The federal government found it necessary to spend approximately $170 million per year — about one-third of its building construction budget — on Darwin in the 2 years following Tracy. The insurance payout was enormous, amounting to a figure equivalent to the entire premium income from all house-owners' and householders' policies throughout Australia for a year.

Risk around the coast

To find out more about the risk of cyclone damage in Australia, a group from the CSIRO Division of Building Research and the Commonwealth Department of Housing and Construction recently conducted a wide-ranging study. The aim was to assess the risk facing some of the main cities and towns that may find themselves in the path of a cyclone.

The group — Dr Bob Leicester and Mr Don Beresford, from CSIRO, and Mr Charles Bubb and Mr Chris Dorman, from the Department — drew on meteorological data and information about the buildings in each centre to produce their risk assessments. They derived estimates of how often damaging winds could be expected in each area and of their likely gust speeds, and linked these with assessments of the general strength of the buildings and their exposure to the wind.

In Western Australia, they looked at Geraldton, Carnarvon, four small towns in Roebourne Shire (Roebourne, Karratha, Wickham, and Dampier), and the three small towns Port Hedland, South Hedland, and Finucane Island, which were considered together as Hedland. In the Northern Territory, only Darwin was considered. Cairns, Townsville, Mackay, and Brisbane were the Queensland centres included in the study (see the map).

Wind strength

For each location, the scientists derived figures for the peak 3-second gust, 10 metres above an open field, that could be expected in periods such as every 10, 100, or 1000 years. They used these gust speeds as indicators of a cyclone's ability to cause damage. They stress that, when a cyclone actually strikes, it is not only the peak gusts that do the damage.

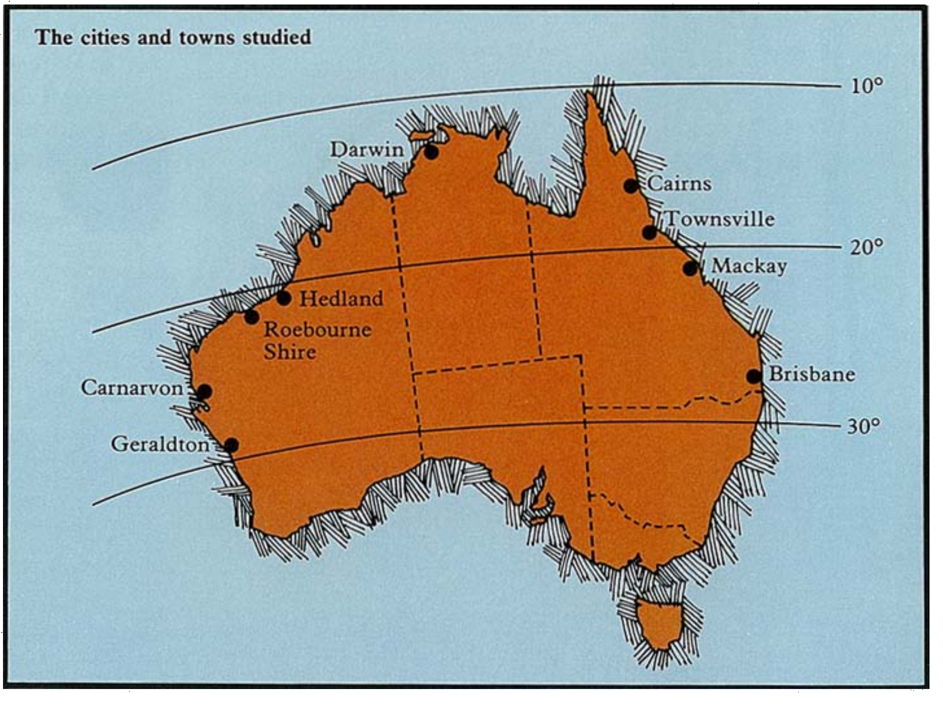
Much damage probably results from the gradual deterioration of building materials during hours of continuous buffeting. For example, metal roof sheeting may rise under the wind pressure and drop back 10 000 times during a cyclone. Metal fatigue around roof fastenings, caused by this type of movement, appears to have been a significant factor in the damage caused by Cyclone Tracy.

Tracy gave Australians a frightening view of the awesome power cyclones possess.

The scientists derived their gust velocity figures from Bureau of Meteorology records. Information covering the past 20 years is fairly detailed, and some goes back as many as 60 years. However, the records are clearly inadequate to show the maximum gusts that can be expected after long intervals, say every 100 years.

The only way to obtain the required figures was by extrapolation. The group used a method, known as the Monte Carlo simulation technique, that has also been used in assessments of hurricane occurrence in the Mexican Gulf coastal area of Texas. This involves generating fictitious records of cyclonic winds on a computer and matching them, in a statistical sense, with the data that do exist for the locations under study. Obviously there is considerable room for error in the procedure, but it is the best that currently exists.

Coastal areas north of 27° South are considered to be at serious risk from cyclone attacks, and there is some risk for a considerable distance further south, particularly along the west coast.



A new house designed for cyclone-resistance.

Another Darwin scene — cyclones can lift and toss aeroplanes, boats, caravans, and much else, large and small.

The diagram on page 6 shows the results of the simulations, and indicates that, in terms of wind risk alone, the mining industry towns of Roebourne Shire and Hedland are the worst situated.

However, most of the houses in these towns have been built fairly recently, and with the risk of cyclones taken firmly into account. As a result, the scientists concluded that the risk of cyclone damage there is not significantly greater than in the other towns surveyed.

Building strength

They based their assessments of the strength of the buildings in each town on ten factors related to design, approval, supervision, and construction. Examples are the sensitivity of particular types of building to wind, the structural engineering ability of the approval authority, the number and variety of structures supervised by an inspector, and the quality of the structural materials used. Account was taken of the results of various field investigations of wind damage, including studies of the damage caused by Cyclone Tracy.

They found that, in most of the centres, the houses could be usefully grouped into three categories — those built before 1950, those built between 1950 and the early 1970s, and new houses built since Cyclones Althea (which hit Townsville in 1971) and Tracy.

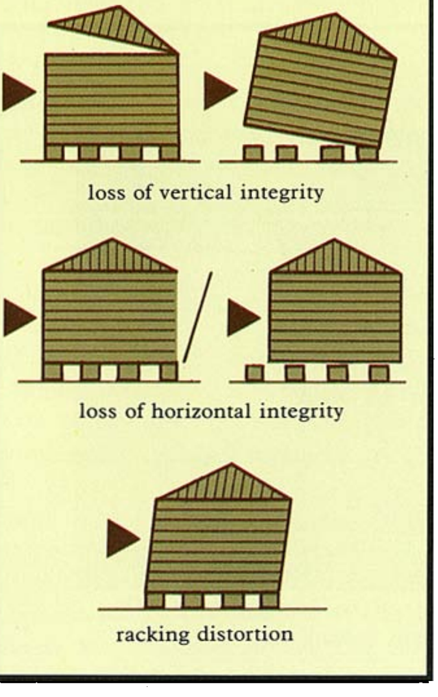
Houses in the first group are usually quite small and have steep hip roofs and vertical board linings that provide a structural tie between the rafters, wall top plates, and floor joists. These features give them substantial wind resistance.

Experience suggests that they are usually stronger than those in the second group, which generally have internal linings of sheet materials that are not fixed in such a way as to provide a vertical structural tie. In addition, many houses in this group have gabled roofs that are often inadequately braced and end walls that may be inadequately tied back to the ceiling.

The cyclones uncovered the weaknesses in this form of construction, and the third group of houses contains features designed to overcome them.

The team classified buildings in five categories, depending on their assessed ability to stand up to the wind. Category A houses, the type most likely to blow down, would be expected to suffer minor damage if exposed to a gust at 125 km per hour and major damage if a 160 km per hour gust struck. Both gust speeds are below those to be expected near the eye of a cyclone. Figures for the middle category (C) are 160 km per hour for minor damage and 215 km per hour for major damage. Houses in the top category (E) are expected to come through any conceivable wind buffeting without significant damage.

Common types of wind-caused structural failure



Brisbane was the city that came out worst when the percentage of each category of house in each centre was calculated. More than two-thirds of its houses ended up in category A, and the rest — except just 1% in category C — are in category B. The figures for Geraldton, W.A., are nearly as bad, with only 9% in category C and none in categories D and E. In Carnarvon, Cairns, Townsville, and Mackay, more than half the houses are in the two riskiest categories, A and B.

Darwin now has only 2% in category A, and a fairly even scatter through the other categories including 17% in the safest category E. Hedland and Roebourne Shire, the centres with the highest wind risk, probably have the safest collections of houses. Hedland has none in the two lowest categories (A and B) and Roebourne Shire has none in category A and just 3% in category B. Most of the houses in both centres are in category D.

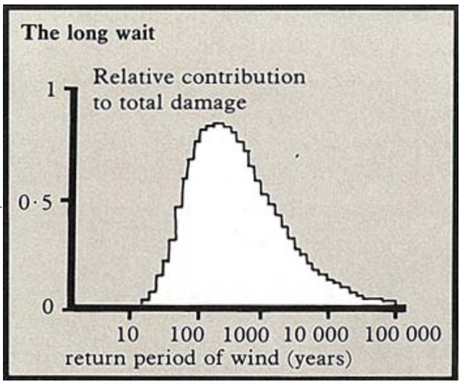
Exposed or sheltered

The factor, other than winds and building strengths, considered in the risk assessments was the degree to which the terrain and other buildings shielded houses from the full blast of the cyclonic winds. The scientists distributed the houses in each city and town among three 'terrain categories'. The windiest of these, category 1, comprises open sea coasts and flat, treeless plains. Category 2, slightly less exposed, represents areas such as open fields. Category 3 sites, typically wooded areas, suburbs, and industrial areas, are more shielded.

In Brisbane, the group estimated that 90% of houses were sufficiently shielded to be placed in category 3 — the highest percentage for any of the centres surveyed. In the other three Queensland cities and in Darwin and Geraldton, 70% or more of houses were placed in that category. Carnarvon and the Roebourne Shire and Hedland centres are much more exposed. Most open to all winds are the houses in Roebourne Shire, only 28% of which were placed in category 3.

Drawing together all the information, the scientists derived risk assessments for each centre. They expressed these in terms of a damage index derived by dividing the annual cost of repairing the damage caused by cyclones (averaged over an infinite period of time) by the initial cost of the buildings. Effects of inflation were eliminated from the calculations.

Carnarvon scored the highest damage



This chart, which averages results for all the centres, shows that most damage can be expected from winds experienced infrequently.

Large and dangerous errors can arise if damage risks are estimated solely on the basis of recent experiences.

index, more than four times the figure for Cairns, which achieved the lowest score (see the chart at right). The figures for Brisbane and Darwin were among the lowest.

The rare mighty wind

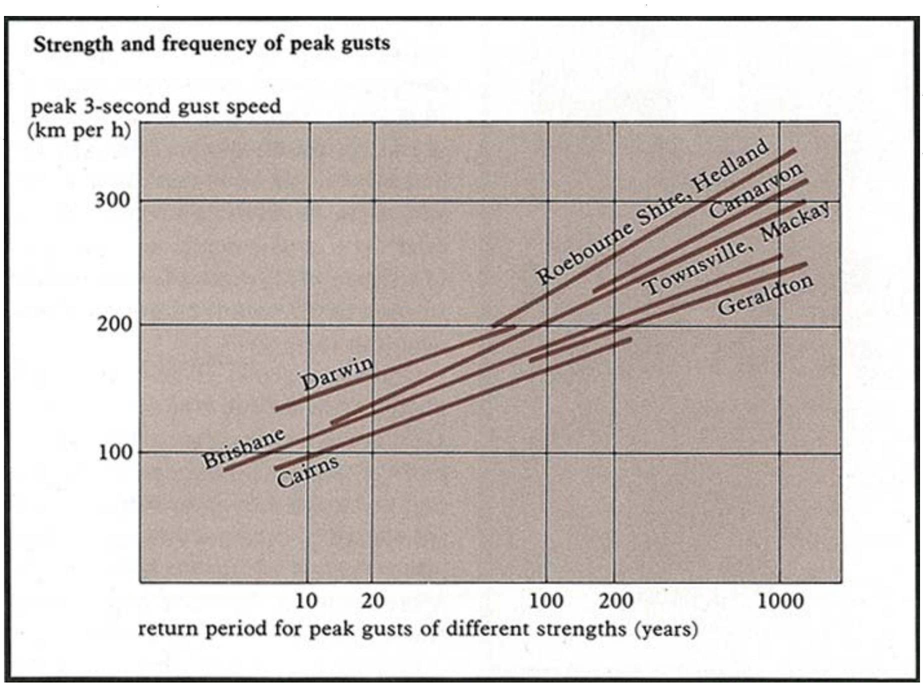
Among the main conclusions that the scientists draw from the study is that most damage can be expected from winds with strengths likely to be encountered once in a period of 100 years or longer (see the chart above). A related conclusion is that, typically, there is roughly a 50% chance that average annual damage for any 20-year period will be less than 15% of the expected annual damage averaged over a very long period of time.

Both these results demonstrate clearly that large and dangerous errors can arise if damage risks are estimated solely on the basis of recent experiences. In Darwin, winds experienced during Cyclone Tracy were more than three times as strong as any recorded during the previous 20 years.

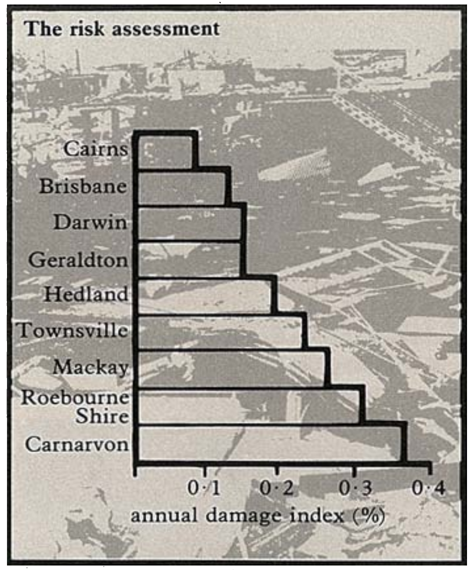
Another conclusion is that it is wise to build in sheltered locations. In Queensland, only 20% of the houses surveyed in the study were in the exposed locations signified by terrain categories 1 and 2. According to the calculations, however, they account for 60% of expected total damage.

The scientists estimate that a house built with sufficient strength to stand up to a severe cyclone costs 5–15% more than an equivalent house conforming to normal building codes. They have proposed a method, based on risk assessment, for deciding whether the building regulations for a particular centre should insist on the construction of high-strength houses.

It involves working out hypothetical damage indices for the centre, assuming that all structures are in either strength category A (most at risk of wind damage) or category C (strong enough to withstand most cyclones). The idea is that, if a theoretical change from type A to type C houses reduces a town's damage index by more than 15% over a 30-year period, high-strength houses should be insisted on.



These estimates of peak gust speeds and their frequency of occurrence for each centre were derived using existing wind records and a simulation technique.



The annual damage index for the buildings in each centre represents the average annual cost of repairing cyclone damage as a proportion of the cost of the buildings.

Houses like this, with reinforced concrete panel walls, stood up well against Tracy's battering.

The scientists' calculations show that this is the case in four of the centres surveyed — Darwin, Carnarvon, Hedland and Roebourne Shire — and they suggest that all houses built there should be in the high-strength categories (C, D, and E). As it turns out, these are the centres that now have the greatest proportions of such houses. Their experience of high winds — rather recent experience in Darwin's case — has already produced an appreciation of the advantages of building for strength.

Robert Lehane

More about the topic

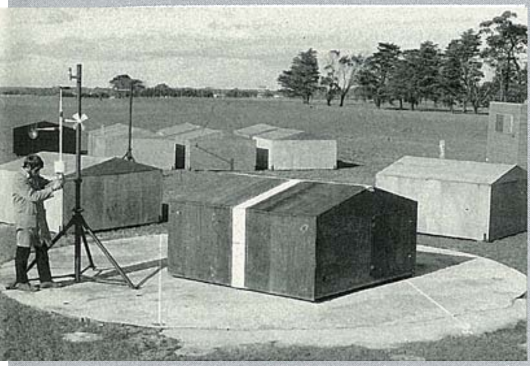
An assessment of potential cyclone damage to dwellings in Australia. R. H. Leicester, C. T. J. Bubb, C. Dorman, and F. D. Beresford. *Proceedings of the Fifth International Conference on Wind Engineering, Colorado, U.S.A., July 1979* (in press).

Building to resist tropical cyclones. R. H. Leicester. *Proceedings of the Annual Conference of the Australian Institute of*

Building, Singapore, 1978, 1978.
A statistical analysis of the structural damage by Cyclone Tracy. R. H. Leicester and G. F. Reardon. *The Civil Engineering Transactions of the Institute of Engineers, Australia*, 1976, **18**, 50–4.
Measurement of wind loads with one-third-scale model structures. R. H. Leicester and B. T. Hawkins. *Conference Papers, The Institution of Engineers, Australia, Diamond Jubilee Conference, Perth, 1979*, 1979.
Coming to terms with cyclones. *Ecos* No. 5, 1975, 13–19.
Resistance of house-wall sheeting to flying debris. P. U. A. Grossman and C. E. Mackenzie. *CSIRO Division of Building Research Technical Paper (Second Series)* No. 15, 1977.
'Wind Damage in Australia — a Pictorial Review.' R. H. Leicester and G. F. Reardon. (CSIRO Division of Building Research: Melbourne 1976.)

Holding houses together

As part of their assessment of the damage caused by Cyclone Tracy, Dr Leicester and his colleague Mr Greg Reardon (now in charge of the Cyclone Testing Station at James Cook University, Townsville) made rough estimates of the threshold wind speeds for different degrees of damage to houses. First, they used damage statistics to estimate the velocities of the peak 3-second gusts experienced in different parts of Darwin during the cyclone; in general, maximum gusts in the northern suburbs, where the wind came straight off the open sea onto a very flat plain, were assessed as being considerably stronger than those in the southern suburbs. Then they used these gust-speed estimates to assess the wind resistance of the houses.



Some of the one-third-scale houses used in wind-force tests.

The threshold gust speed for loss of all roof sheeting from a house on stilts — the traditional Australian tropical design — turned out to be less than 150 km per h, and for loss of the entire roof structure about 160 km per h. For loss of half the walls, it was 170 km per h.

Single-storey ground-level houses fared better, particularly those with brick walls. For them, the threshold speed for loss of all roof sheeting was about 170 km per h, and for loss of half the walls it was about 190 km per h.

The scientists noted that the transition from minor to major damage involved only a small increase in wind velocities. They attribute this to the fact that, in houses built by traditional cottage construction methods, any structural failure increases the possibility of other failures occurring. For example, loss of the roof reduces the stability of the walls.

Dr Leicester likens this type of house to a series of links in a chain: if one link fails, all the others can be affected. He suggests that this problem could be overcome by incorporating reliable 'anchor structures' in buildings. Their purpose would be to ensure that, if one part of a building — such as the roof or a wall — failed, collapse of the whole building would not follow. Typically they would be frames, of wood, steel, or reinforced concrete, capable of withstanding all the forces imposed by a cyclone without any assistance from the roof or wall cladding. He suggests that inclusion of a sound anchor structure should not add more than 5% to the cost of a new house.

In Darwin and some other cyclone-prone areas, the building approval process now sets out to ensure that all new houses satisfy established engineering standards for resistance to cyclone-strength winds. These standards are much tighter than those imposed by traditional house-building regulations.

The Darwin experience showed that engineered buildings resist strong winds very successfully. In fact, there is a considerable body of opinion among engineers that current wind-loading codes are too conservative when applied to low-rise structures such as houses, and that building costs could be reduced if they were made more realistic.

For a project aimed at assessing these codes and, generally, at finding out more about the nature of the forces exerted on buildings by winds, Dr Leicester and colleagues at the Division of Building Research have built a village, exposed to Melbourne's winds, of moveable, one-third-scale houses. One of them contains force-measuring instruments. It can be placed on its own or among the other houses, which can be arranged in any pattern to provide different degrees of shielding or wind channelling.

In the instrumented house, load-sensing panels are substituted for areas of wall or roof-cladding. Measurements are made continuously and recorded, enabling the total wind effect on the panels to be derived.

In the past, most information on wind loadings has been obtained from wind tunnel tests, using model houses not much bigger than cigar boxes. The Building Research team is planning also to conduct tests of this kind in a wind tunnel recently built at the CSIRO Division of Mechanical Engineering.

However, the models used in wind tunnels are too small to be instrumented in a manner giving anything like the detail on wind forces obtainable from the scaled-down village. The main difficulty with the village experiments is that only the houses, not the wind, are at one-third scale. This gives rise to problems in interpreting the results. Early experiments indicate, however, that these problems can be dealt with satisfactorily.

The scientists also conduct experiments to test the strength of various structures and building materials. One experiment has shown that the use of plywood sheets nailed onto timber wall frames can provide effective resistance to cyclone wind forces. In other work, the resistance of different types of plywood and fibre-cement sheeting to damage from flying debris has been tested. Sharp and blunt missiles dropped from varying heights simulated the wind-driven debris in these tests.

A considerable proportion of the damage and injury in cyclones is caused by flying debris. Even if it was possible to guarantee that houses would hold together and not fling parts of their roofs or walls at neighbouring houses, this danger would remain. Cyclones make a very good job of picking up caravans, garden sheds, oil drums, and much else, and of tossing them at houses.