Cyclone Vance – Exmouth 1999

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Summary

The highest wind speed recorded on land in Australia was found in Tropical Cyclone Vance as it passed Learmonth airport. At the same time, the system was also passing over Exmouth, and there was damage to all of the communities on the Cape. In Exmouth town, there was conspicuous structural damage to around 10% of the buildings, though many more experienced hidden structural damage or damage to non-structural elements. The normal community functions were interrupted for a significant period while the infrastructure and building stock was restored. All of this happened at less than 75% of the ultimate design wind loads – the load at which we would expect structural damage to start.

The paper focuses on structural systems and the way they resist wind loads. In particular it addresses resilience of structures and the importance of detailing to resist wind.

1 The Town - Exmouth

The town of Exmouth was established in the mid 1960s to service the accommodation and support needs of the US Naval installation at North-West Cape. Many early houses were built to Housing Commission specs, and a number of US Navy houses (block houses) date to the early days of construction in the town. More than two thirds of the town's buildings were constructed during the first 10 to 15 years of the town. (Much of the building stock is 35 to 20 years old). The military installations have since been procured by the Australian government, and most of the buildings in the town have been transferred to private ownership. This includes the "block houses" and most of the original Housing Commission property. A recent boom in the tourist industry has seen a number of private dwellings being constructed in the last 10 years.

2 The Event – Cyclone Vance

Some salient points on tropical cyclone Vance from the Bureau of Meteorology report include:

- The intensities marked show that the tropical cyclone intensified fairly rapidly and had reached maturity well before crossing the coast.
- The cyclone was categorised as a Category 5 Tropical Cyclone at its land-fall. This is the highest category.
- Wind damage extended as far as Cue after travelling overland for 1000km.
- Translational speed of the event as it travelled down Exmouth Gulf was estimated at 30 km/hr. This means that the rotational windspeed necessary to produce the wind record at Learmonth was an average of 220 km/hr with gusts to 297 km/hr. This is consistent with its categorisation as a category 5 event.
- The wind direction at Exmouth changed through 120 to 150 degrees, consistent with it being in the path of the eye wall. No observations of the passage of the eye were made at Exmouth or Learmonth. However, Exmouth and Learmonth were both on the "slow" side of the cyclone where the translational speed is subtracted from the rotational speed to give the site wind speed.

Wind speeds at Exmouth

A Dines anemometer at Learmonth airport recorded wind speeds during the passage of Tropical Cyclone Vance on 23rd March 1999. The characteristics of the wind speed are as follows:

- Maximum gust wind speed is 267 km/hr (75 m/s).

- The build up in wind speed took place gradually in Exmouth from 0300 WST to 1030 WST. This is consistent with the radar image which showed intense activity in the leading edge of the tropical cyclone.
- After the passage of the eye wall, the wind speeds dropped more quickly.
- Damage observations suggest that most of the town experienced wind speeds in the range 220 km/hr to 250 km/hr.
- The recorded maximum wind speed in Tropical Cyclone Vance is 87% of the design ultimate wind velocity for region D in the Australian Wind Loading Code (AS 1170.2).

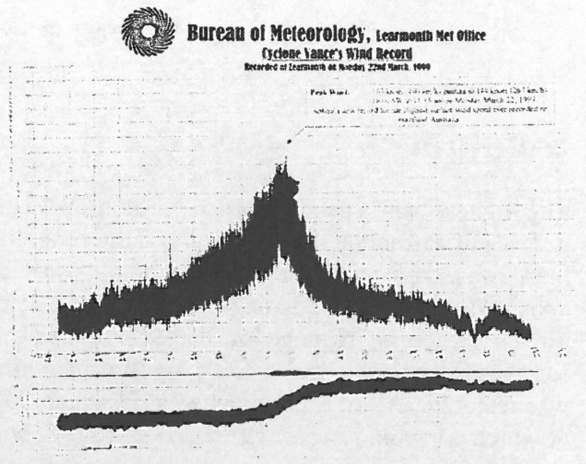

Figure 2 – Dynes anemograph TC Vance

In terms of structural performance, structural elements should be able to withstand the ultimate design wind without structural damage. Winds higher than the design ultimate wind speed would be expected to produce structural damage. There was clearly a problem with achieving sufficient strength to withstand winds significantly lower than the design strength.

3 The Damage – 10% obvious structural damage

The performance of buildings in Exmouth is summarised in Table 1

Table 1 Obvious wind damage to houses

	trns >15yrs	trns <15yrs	Hs Com	Dravo	USN block	Brck/ Msnry	Other <15 yrs	all
No dam	50.0%	57.9%	70.1%	90.0%	100.0%	68.4%	70.0%	**70.8%**
Non str	3.1%	36.8%	16.5%	2.0%	0.0%	27.6%	20.0%	**16.8%**
Min str	25.0%	5.3%	8.2%	6.0%	0.0%	3.1%	10.0%	**7.4%**
Maj str	21.9%	0.0%	5.2%	2.0%	0.0%	1.0%	0.0%	**5.0%**

Non-structural damage and minor structural damage were underestimated as it was not obvious from the outside of the building. Non-structural damage in modern housing could have been as high as 70%, and minor structural damage in older housing may have been as high as 50%.

Damage sorted by classes of houses

Table 1 indicates that there is a significant difference in performance for the different categories of houses. This is principally because different types of details were used in each of the different housing types. The main features are

- Older transportable houses with structural damage at more than 50% (4 times the town average)
- Ex Housing Commission houses with structural damage estimated at 13% (around the town average)
- US Navy "block houses" with no structural damage.

The roof structure performance was poor on many of the older buildings, but especially noticeable on the older transportable houses and on the Ex Housing Commission stock. The prime problem was the use of a single nail for batten to rafter anchorage. In some cases, the transportable houses had overbattens above the external wall lines, and in all cases, the ex Housing Commission stock had overbattens.

- Ex Housing Commission buildings had "built-up" roofs in which rafters spanned from roof to ridge board with under-purlins over lounge areas. In many cases, the ridge capping had anchored the two halves of the roof together and prevented roof loss in spite of some failures in batten to rafter connections.
- The transportable buildings had trussed roofs with the trusses in two halves, and tied together at the centre using an on-site connection. The two halves of the roof appeared to behave independently, and connection failures on one side of the ridge were not helped by the connections on the other side. In many cases, part of the roof structure simply rotated about the overbatten.

Note that Table 1 underestimated the structural damage to ex Housing Commission houses, as there were a number of cases in which a check showed that there was structural damage under the roofing, though it was not immediately obvious from the outside.

The good performance of the US Navy "block houses" was expected by the townspeople. Many took shelter in them for the whole or part of the event. The good performance was due to the resilience of the construction (which could resist substantial debris impact), and the weight of the roof which could resist the high uplift forces. Impact absorbing screens were set well away from the windows and appeared to have been effective in minimising debris damage.

Damage sorted by structural elements and details

The main problem was in roof structure anchorage and has been alluded to above. However, there are comments on improvements that could be made in most structural systems in the buildings inspected.

Roofing

Tropical Cyclone Tracy exposed the potential for roof sheeting to be damaged under the repeated loading in tropical cyclones. The duration of the maximum winds in Tropical Cyclone Vance, was a little shorter than the duration in Tropical Cyclone Tracy, however, there was very little evidence of fatigue in roof sheeting. This could also have been due to improvements in the steel from which the sheeting is made, more consistent rolling patterns, or perhaps more likely, the widespread use of "cyclone washers" in Exmouth.

Most buildings which had steel sheet roofs, used Type 17 self-drilling, self-tapping screws to fix to timber and heavy duty Tek screws to fix to steel. Both appeared to work well.

Batten-to-rafter connections

The poor performance of many of these connections has already been noted. It was not possible to justify the use of a single nail in withdrawal for the role that the batten-to-rafter connection filled. It even looked ineffective compared with the stronger sheeting-to-rafter connections.

Rafter-to-wall anchorage

In a number of cases, rafters became detached from the rest of the structure. The rafters were anchored to the walls by overbattens on many structures, but the other end was not connected to the rest of the structure. This allowed the rafters to rotate about the external walls. This type of failure featured on the two storey flats and a number of older transportable buildings.

> Anchorage load paths need to be carefully thought through to ensure that all elements are satisfactorily anchored and that the load paths are as simple as possible.
> Batten to rafter connections must be designed and constructed for the full wind loads that they will receive.
> Overbattens only really anchor one end of a rafter. The other end must also be anchored.

On a few of the more recent buildings, girder trusses appear to have separated from the walls early in the period of maximum winds. Girder trusses can support smaller trusses, and hip ends of the roof and will attract more load than other trusses in the same roof system. Where they used the same anchorage system to the anchorage of standard roof trusses, there were failures of the connection between the roof and wall structures.

Girder trusses, and other elements of the roof structure which support large areas of the roof require much stronger anchorage than other elements of the roofing. Construction detailing of these elements must reflect the area of roofing that they support.

Some modular houses made with metal framing and panelling lost substantial areas of roofing. The roof panels had holes for bolts to secure them to the wall top plate. In some cases, these holes were left empty and the rafters had been welded to the wall plates. Some welds had failed during the cyclone, but others appear to have failed long before Tropical Cyclone Vance arrived. Diurnal expansion may have caused fatigue in them.

Correct installation of connections is very important in resisting wind uplift. Careful supervision during construction supervision is necessary to ensure that the details are those specified by the designer.

Wall panels
A number of cases showed wall panels or parts of wall panels that could not resist the applied wind loads:

- The ex-Housing Commission houses had large window panels on the windward wall that were blown into the building. These showed inadequate and deteriorated connection with the wall frames.
- The Dravo houses appeared to be a North American kit home, with prefabricated wall panels and a trussed roof system. One end of the house had a side wall that spanned from front to the back of the house. Where the ceiling was inadequately connected to the wall plate, and the wind direction caused suction on the side wall, the wall could be sucked out of the house if there was any avenue for internal pressurisation.

Connection of large window panels or wall panels to the remainder of the structure is extremely important. In each of the above cases, the design made it difficult to achieve the connection and satisfy the code end and edge distances.

Some buildings showed debris damage to wall panels. Metal and plywood clad buildings had good resistance to debris impact. Houses with brittle cladding materials sustained more obvious debris damage than other types of housing in the same locality. Resilient sheeting was able to prevent debris from penetrating the building fabric through walls.

Brickwork
Many of the modern homes include external brickwork, or masonry panels. There was little sign of damage to the external cladding in these buildings. In all but one case inspected, the brickwork was part of a brick veneer system. The loads were clearly shared between the brickwork and the framing without compromising the continuity of the brickwork. However, much water had penetrated all of the cavities in the house (including the wall cavities), and the brick ties will only continue to be effective if their deterioration has not been accelerated because of the moisture.

In veneer construction, masonry elements and framing elements appear to have behaved as per design assumptions of good connectivity.

Single leaf brickwork on some industrial buildings, fences, garages and carports does not appear to have enjoyed the same good performance as the brick veneer construction. In some cases, the damage may have been caused by some debris impact, but in others, it was clearly the wind pressure that caused a classic out-of-plane failure of the panels.

Unreinforced single leaf masonry requires attachment to walls, returns or piers, or fully bonded reinforcement to deliver satisfactory performance under wind loads.

Window and doors

Exmouth had a large percentage of buildings with screens over windows and these had various degrees of effectiveness in resisting debris impact.

- The ex Housing Commission houses had screens fastened directly to the window frame. The metal was approximately 15 mm from the glass and had very little room to deflect under impact load. A number of "protected" windows were broken by debris which pushed the screen into the window pane.
- Impact absorbing screens positioned some distance from the windows performed well in providing protection from smaller pieces of debris, but were incapable of stopping roof panels from penetrating the building fabric.

Regardless of the use of debris screens, it is prudent to consider the use of full internal pressurisation in tropical cyclone-prone areas. Experience in Exmouth shows that despite our best attempts to prevent it, debris may still penetrate the external skin of buildings.

Racking response

No houses were seen in which significant racking deflection occurred. However, small amounts of racking deformation were measured on some of the Dravo houses.

A number of park homes in the caravan park had been removed from their footings and overturned. In many cases, the plywood cladding had retained the shape of the house even though it had rolled a number of times and come to rest on its roof. This attests well to the strength and stiffness of the plywood diaphragms.

Building anchorage

Aside from the park homes, there was little evidence of buildings that became detached from their footings. Most buildings either had sufficient weight, or had been anchored securely enough to resist the overturning effects of the wind.

The park homes had been anchored by chains and wire, but the hardware supplied for the anchorages (turnbuckles and shackles) did not have sufficient capacity to resist the loads applied by the wind.

In designing anchorage for park homes and other transportable buildings, it is necessary to ensure that all elements used in the load path have sufficient structural capacity.

The main message still is – that any structural system will only be as strong as its weakest link. In many cases, this proved to be the connections, and appropriate detailing at design and construction stage are necessary to ensure performance.
Attention to detail in connections is just as important for steel framed construction as for timber framed construction. In particular, the connection between the rafters and the wall attracts very high loads, but where light gauge members are used, it is important to ensure that the members can cope with the high local stresses at connections.

Resilience

It is very desirable that all structures include resilience. This concept means that a small failure should not have large consequences for the whole structure. (If something little should fail, it should be relatively inexpensive to repair it.)

It is clear from the patterns of damage that normal construction methods in most types of buildings do not incorporate intrinsic resilience. Many of the buildings that experienced significant structural damage had the failure start with damage to a small connection or detail. Failure spread rapidly to large areas of the structure. The lack of resilience in buildings studied in Exmouth was die to two main aspects of the building performance.

- *Aerodynamics of partially damaged roof structures*. A small failure in the roof structure will cause the roof to start to lift. The lifting roof changes the aerodynamics of the building and radically increases the lift on the remaining roof. The uplift loads generally increase as failure progresses.
- *Limited load sharing between connections*. The structural systems that are used in roof structures have limited ability to transfer load once a failure has started to take place. There is limited redundancy in the roof system, so that following a single element failure, the adjacent elements may find that their loads are doubled. This leads to a rapid progression of the failure through the structure. (In many of the buildings studied, the only redundancy was provided by the ridge capping).

While it may seem wasteful to over-design some critical connections, the results show that where there is a reserve of capacity, the failure of individual elements can be arrested before significant structural damage results. This builds in resilience to the structure.

Non-structural Damage

In a number of the more recent buildings, the structure performed well, but there was some non-structural damage that caused inconvenience to the occupants and made the restitution of the building more expensive. The damage resulted in significant water ingress to the structure and therefore plasterboard linings became unserviceable. In some cases, ceilings collapsed and wall linings expanded and popped away from the frames. A substantial number of new buildings will require replastering.

The main avenues for water to gain access to roof and wall spaces were:

- Water being blown around flashings in the roof (especially at valley gutters).
- Water being blown through the external cladding (especially fibre cement planking used without sarking).
- Water blown up under the eaves where eaves lining or soffit had been blown away or damaged by debris impact.

These items tended only to present problems for modern houses, as the more traditional architecture of the older houses did not have the features that had failed. Older houses had unlined eaves, straight ridge lines with no valley gutters and no large carports with extensive soffit areas.

While soffit lining and eaves lining are not often regarded as structural elements in houses, they fulfil an important role in keeping wind-driven rain out of the linings of houses. They are a cladding material, and most other cladding materials for use in cyclone regions need to satisfy stringent requirements about fixing under large and repeated loads.

Soffits and eaves linings should be able to withstand the design pressure differentials following full pressurisation of the roof space. Lining materials and fasteners need to be resilient enough to absorb small impacts and deformations without leading to a large scale failure of the material.

Flashings and fixings are generally designed for rain that falls vertically, rather than wind-driven rain with the horizontal velocities experienced in tropical cyclone Vance. Water ingress to buildings seems unavoidable to a certain extent, but plasterboard internal linings are not able to tolerate large volumes of water ingress and maintain structural integrity.

4 Acknowledgements

The original study was funded by the Department of Local Government WA. It was facilitated by Mr Helmut Schwanke who organised it, travelled to Exmouth with me, and assisted in collecting information. Departmental officers approved it including Mr Moshe Gilovitz (who was interstate at the time), and Mr Steve Cole. The study was supported by the acting Minister for Local Government, Dr Kim Hames.

The study was accommodated generously by the Shire of Exmouth and welcomed by the shire president, Mr Mike Purslowe. In particular, thanks are due to Mr Geoff Savage, Shire Health and Building Officer. Accommodation, information on damage and coordination of flights into and out of Exmouth was provided by the State Emergency Service of WA.

Mr Barry Hanstrum provided much information on the meteorology of the cyclone and gave permission for the use of some satellite photographs, wind speed records, and cyclone tracks to be published. Also Iona and David Edwards provided information on wind speeds and directions while I was in Exmouth.

Debbie Falck of Timber ED Services assisted in preparation of diagrams for the paper and photographs for the presentation.

I enjoyed cooperative and stimulating discussion of the damage with many experts including my colleagures Greg Reardon, John Ginger and David Henderson of the James Cook Cyclone Structural Testing Station, Dr John Holmes from Monash University, and with Andrew van der Meer, a Perth based consulting engineer.

Finally, the study would not have been possible without the generosity of the people of Exmouth. They shared their own personal experience, traumatic as it was, and were pleased to have me crawl over their houses in my muddy boots, and look among their personal possessions and livelihood for clues as to why their world had literally been turned upside down.