Lessons in Resilience from Tropical Cyclone Ilsa

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ABSTRACT

Severe Tropical Cyclone Ilsa (TC Ilsa) crossed the coast near Pardoo Roadhouse in the Pilbara region of Western Australia as a Category 5 system just before midnight on Thursday, 13 April 2023. Pardoo Roadhouse is around 130 km east of Port Hedland and is on the northern border of wind region D.

Anemometers, road signs (used as peak gust "windicators"), vegetation damage, the information provided by residents and a numerical model of cyclone wind speeds all contributed to the development of the maximum wind speed map. It showed that the peak 0.2-sec wind gust in standard conditions was higher than V500 from AS/NZS 1170.2:2021 as it crossed into each wind region.

In these remote areas, evacuation in the face of an extreme event is not possible. Isolated communities must be able to provide safe shelter for all occupants and have resilient power, communication, water and other essential services to continue functioning immediately after the event. Resilient buildings with good protection for windows and openings performed well during TC Ilsa. Buildings built for a higher wind region also performed well. This is an effective strategy to improve resilience in tropical cyclone areas. By contrast, many sheds in the area did not perform well.

More than 90% of solar panel systems throughout the study area sustained significant damage caused by bending failure of the panels, failure of the connection between the panels and the supporting frame, and failure of the connection between the roof-mounted panel support rails and the roof. Damaged solar panels became wind-borne debris that damaged other solar panels or buildings.

After TC Tracy the engineering community started mapping a course to improve the wind performance of housing. TC Ilsa has highlighted the need to examine all attachments to buildings (such as vents, awnings, and solar panels) to ensure that communities have resilience in future wind events.

SEVERE TROPICAL CYCLONE ILSA

Track of TC Ilsa

Severe Tropical Cyclone Ilsa (TC Ilsa) crossed the coast as a Category 5 system just before midnight on Thursday, 13 April 2023 near Pardoo Roadhouse in the Pilbara region of Western Australia (Bureau of Meteorology, 2023). Pardoo Roadhouse is around 130 km east of Port Hedland and is on the northern border of wind region D.

Damage investigation

The Cyclone Testing Station (CTS), the Department of Energy, Mines, Industry Regulation and Safety, Building and Energy Division (Building and Energy), and the WA Department of Fire and Emergency Services (DFES) undertook a joint field investigation (Boughton et al, 2023). The aim of the investigation was to establish the wind field of TC Ilsa and investigate damage to buildings in the affected area. The field study commenced on 26 April 2023 and concluded on 1 May 2023. The two-person investigation team included a representative from the CTS and one from Building and Energy. DFES provided data on damaged buildings and the contact details of people in the area.

Wind speeds in TC Ilsa

The wind field in TC Ilsa was estimated using a combination of techniques:

- Converting anemometer records to 0.2-sec gusts relative to standard conditions to compare with design wind velocities for the same location.
- Modelling the cyclone wind speeds using the Holland model (SEA, 2020), the identified track, size and pressure characteristics of TC Ilsa.
- Calculating capacities of road signs to obtain upper bound estimates (where the sign was still standing) and lower bound estimates (where the sign had failed by bending the pole(s)).
- Establishing rough wind speed contours by identifying locations with similar vegetation damage (focusing on one tree species because different species have different strengths).
- Confirming wind directions from damage to trees, prevailing lean of vegetation, termite mounds, and damaged structures.
- Identifying the location of the eye using observations from residents.

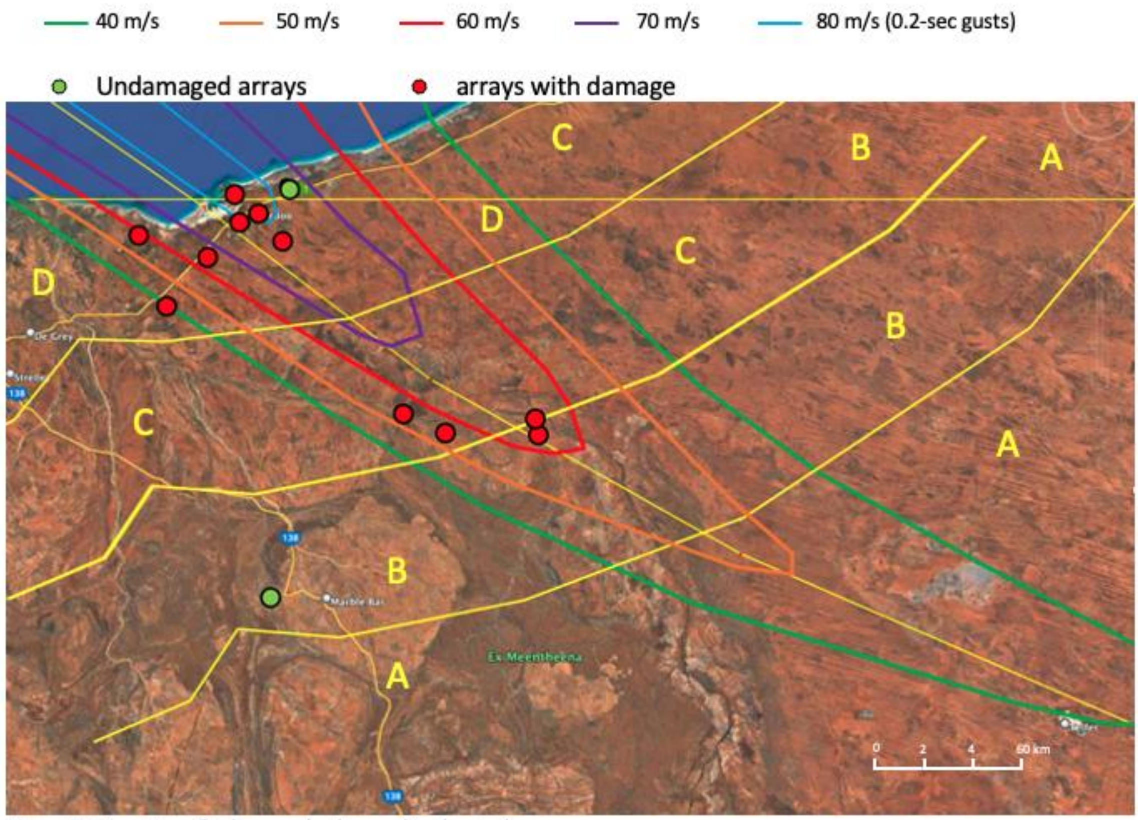

Figure 1. Wind field in TC Ilsa and the location of the solar panel installations studied.

The resulting wind field is shown in Figure 1, which also shows the locations of solar panels studied during the investigation. Green dots indicate the location of undamaged installations and red dots the location of damaged installations. The yellow lines separate the wind regions in 2023 with the letters indicating the wind regions assigned in AS/NZS 1170.2:2021 (Standards Australia, 2021). Coloured contours show the peak gust (0.2 second duration – compatible with AS/NZS 1170.2) wind speeds.

PERFORMANCE OF SOLAR PANELS IN TC ILSA

Undamaged panels in TC Ilsa

Figure 1 shows only two installations that were undamaged in the inspection area. One near Marble Bar, was well outside the zone of maximum winds and experienced a peak gust of around 25 m/s. The other was a ground mounted array near Pardoo that experienced peak gusts around 70 m/s. The good performance of this array indicated that it is possible to design ground-mounted systems to resist severe tropical cyclones.

Damaged panels in ground-mounted arrays in TC Ilsa

Figure 2 shows a ground-mounted array that illustrates the two modes of failure explained below.

Figure 2. Examples of failure of ground-mounted solar panels

Bending failure of panels

The lower panels in Figure 2 failed by bending of the panel as a plate. In this case, the wind had been on the face of the panel, but in other cases, the wind had been on the underside of the panel and had caused upward bending. Many panels that had flexed upwards moved far enough to disengage from the panel chassis and the panel was completely lost.

Detachment of panels

The upper panels in Figure 2 failed by detachmenbt of the clips or brackets that held the panels to the rails. In some cases, the clips had broken, and in others, they had moved sufficiently to release the panels. Where the clips were bolted to the aluminium chassis of the panel, the bolts tore the chassis, which caused detachment.

Figure 3. Failure of clips on roof-mounted PV arrays

Damaged panels on roofs in TC Ilsa

Failure of clamps

Figure 3 shows detachment of panels clipped to rails parallel to the roof.

These failures were caused by either overloading of the clips or by movement of the clips under repeated cyclic loads on the panels typical of long-duration cyclonic events.

Failure of roofing screws

In some cases, the brackets holding down the rails overloaded the roofing screws into the batten – the rails and the panels they supported were lost. Figure 4 shows a roof with missing rails (indicated by the yellow lines) and missing roofing screws (highlighted by red circles).

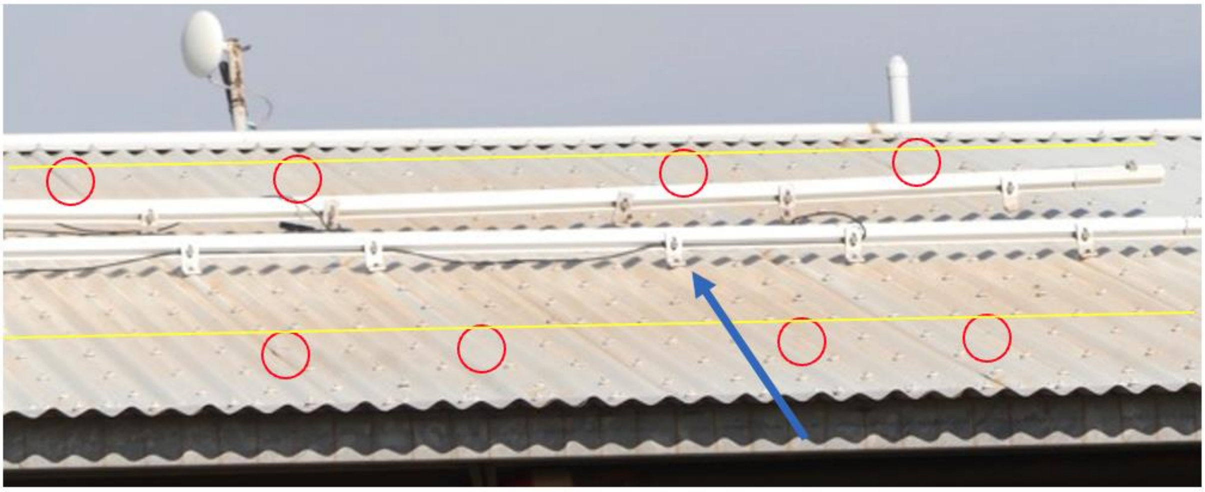

Figure 4. Loss of roofing screws at brackets that held the PV rails

Structural damage to roofs under solar panels

Figure 5 shows a building with solar panels where the batten fixings under the panels had failed. Two identical buildings built at the same time and in the same orientation as the damaged building did not have solar panels installed. There was no damage to the battens, batten fixings or roof of the buildings that did not have the solar panels installed.

Figure 5. Damage to batten fixings under roof-mounted solar panels in TC Ilsa WA 2023

BUILDING PERFORMANCE

A number of buildings performed well. Some of these were older homesteads made with solid stone walls, strong roof framing systems that had withstood many previous events and typically were equipped with fold down verandas that functioned as large wind-borne debris screens over the walls, windows and doors.

Other more recent buildings had been designed to resist wind region D loads even though they were in region C or B2. The higher design specification worked well to give a level of resilience that was able to withstand the wind speeds that were in some cases up to 110% of the design wind speed for the location.

Failures of buildings were triggered by:

- Inadequate wind rating – often where dongas (trasnportable buildings) had been brought into a high wind area from a low wind area.
- Loads from roof-mounted solar panels as shown in Figure 5, or impact from solar panels as wind-borne debris.
- Failure of attachments such as verandas or awnings.
- Internal pressures following failure of doors or windows, or in the case of open sheds, the blockage by the contents of the shed generated internal pressure in an otherwise open shed.
- Deterioration of structural elements such as tie-down provisions

RISKS FROM ATTACHMENTS TO BUILDINGS

Damage investigations have shown that attachments to buildings may compromise the building itself under wind actions. Verandas, patios and pergolas attached to the main building roof transfer wind actions to the main building roof. Where these extra loads have not been anticipated in the design of the roof, it can lead to overloading of otherwise compliant details or members. In some cases, load redistributions following the failure of elements in the attachment (e.g. a veranda post), may overload elements in the main building roof and lead to a cascading failure in the main roof.

Some attachments to the roof may attract additional wind actions that have not been anticipated by the building designer. These attachments may include air-conditioner condensors, satellite dishes, vents or flues and solar panels. Where these elements are fitted to an existing roof, the current structure must be checked for the additional wind loads attracted by the attachments. In many cases, local strengthening of part of the roof is required to ensure sufficient wind resistance of the structure.

In some cases the use of the building dictates the attachment and its location can be anticipated in design. This may include flues for kitchens and laboratories. In many other cases, it is not possible to anticipate the location of future attachments, so it is more difficult to design for the wind actions added to the main structure from the future additions. This includes solar panels, water heaters or air-conditioning condensers. There are three options for this type of attachment:

- Design the whole roof structure for the anticipated extra loads from this type of attachment. This gives ultimate flexibility in positioning attachments without either having to strengthen the roof or limit the number or position of future attachments. This is a very safe option, but will be expensive for buildings with very large roofs.
- Design the roof structure for the anticipated extra loads from this type of attachment in specific areas of the roof. All future attachments of this type must be installed in the designated area. If all of the attachments can be accommodated within the designated area, then no strengthening of the existing roof is required. Where some of the attachments fall outside of the designated area, then the roof must be checked and potentially strengthened in

those areas. This option will cost less than the first, but will be restrictive in where attachments can be installed.

- Ignore future attachments in the intial design of the building. In this case, installation of any future attachments requires checking of the roof structure for additional wind loads and potentially upgrading the existing roof structure. This option is the status quo and at present, many designers of attachments do not consider the additional loads transferred to the roof sturcture.

CONCLUSIONS

Since TC Tracy in 1974 (Walker, 1975), there has been continual improvement in engineering buildings to withstand wind actions on the building itself. At the same time of the improvement in the estimation of wind actions, there has been an increased adoption of optimised structural design of buildings. Optimisation of structural design has seen a reduction in strength reserves above the minimum required for compliance and the potential for buildings to be less resilient. This has highlighted the additional wind loads attracted by attachments to the building.

The study into TC Ilsa highlighted the resilient performance of some buildings where buildings had been designed for higher wind loads than required in AS/NZS 1170.2. Heavy duty metal shutters were seen to be effective at protecting windows, but light meshes were not.

Many attachments such as solar panels, flues, verandas, patios, and carports place additional wind actions on the building. Where these have not been anticipated in the original structural design, the additional loads must be evaluated and the existing structure checked for its capacity to carry those extra loads. If the existing structure cannot safely carry the extra loads, then strengthening may be required.

Alternatively, where the additional loads associated with future additions can be estimated, it is cost-effective to include them in the initial design so that there is flexibility in installing them, and no further strengthening of the structure is required. The assumed extra loads must be well documented and records kept to facilitate future additions of building attachments.

Most ground-mounted solar panels in the study area did not perform well and attention needs to be given to wind actions on the inclined systems, particularly differential pressures across the panels and the net forces on anchorage points.

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