Modelling of the Vulnerability of Housing to Tropical Cyclone Winds

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1 Introduction

The James Cook University Cyclone Testing Station (CTS) in Townsville has been actively involved in the design, testing and performance of housing to resist cyclonic winds for nearly 30 years. During this time, a large database on housing performance has been collected and now forms the basis of a numerical model that can be used to assess the impacts of tropical cyclone winds on entire communities. The house structure wind resistance models and wind field model described here have been developed by the CTS and Systems Engineering Australia Pty Ltd (SEA) with support from the Queensland Government, through the Departments of Emergency Services and Natural Resources and Mines.

2 Housing Performance under Cyclonic Winds

Any city or town comprises a wide range of house types, with differences in size, shape, window size, external cladding material, roof shape, age, and methods of construction. Each of these features can have an effect on the resilience of a house to resist wind forces. Houses also have varying degrees of exposure to wind forces, with those dwellings located in a suburban environment gaining shelter from surrounding structures as opposed to houses near the sea or open terrain. Topographic features such as hills can concentrate or divert the wind flow. The wind speeds from a tropical cyclone impacting on a community will vary according to its intensity, size and distance from the community. Therefore an assessment of the wind resistance of housing requires knowledge of house types and their distribution throughout the community. All of these factors have made it difficult to predict the likely damage to a community's housing from the cyclonic winds. Domestic construction (i.e. houses and flats) also act as shelter during cyclone events. For this reason, knowledge of housing performance (resilience) is crucial for agencies involved in disaster mitigation and response, as it serves to target disaster amelioration.

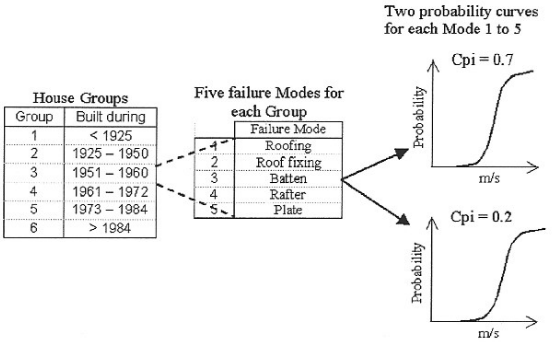
The methodology outlined here has been developed to assess the amount of damage likely to occur in the Queensland cities of Townsville, Cairns and Mackay, and to obtain a distribution of that damage over each community for a cyclone of any given intensity and path. The study did not attempt to assess the performance of individual houses or even small groups of houses but to provide a general estimation or indication of potential community-wide damage from particular cyclone events.

Comprehensive data surveys of the external features of housing were conducted for Townsville, Cairns and Mackay with the assistance of Commonwealth and Local Government agencies. The CTS conducted a physical attribute housing survey for Townsville along with detailed structural inspections of 100 houses. From knowledge of the development of the cities forming this study, a review of current and superseded building regulations, detailed internal house inspections, and an overall survey of the housing stock, the multitude of house styles were generalized into six groups. The groups covered houses from the 1860's through to present day forms, based on overall geometry and construction techniques.

3 Modelling Wind Resistance of Housing

A house frame is a very complex structure and does not lend itself to a straightforward structural analysis, as there are multiple building elements providing load sharing and in some cases full redundancy. The CTS-developed housing wind resistance models are not targeted at determining the most efficient joint or member size, but for an assessment of the likely failure mode and failure load for a representative proportion of houses. Findings from full-scale house testing, and individual component joint strength tests, have also been incorporated in the estimation of the failure loads.

The CTS housing wind resistance models focus on the chain of connections starting from the roof cladding fixings and extending through to the wall tie-down onto the base of the structure or the ground. Findings from damage surveys conducted after cyclones and severe storms, and full-scale house testing results demonstrate that the predominant mode of wind-induced failure is associated with the load capacity of the joints in the house structure. Five probabilistic failure modes (Failure at cladding, Failure at cladding to batten connection, Failure at batten to truss/rafter connection, Failure at truss/rafter to wall connection, and Failure of wall tie down connection) were developed for each of the identified six house groups for longitudinal and lateral wind directions for both full (Cpi=0.7) and partial (Cpi=0.2) internal pressure conditions (Figure 1). A lognormal (skewed) probability distribution was used for these models. Holmes (2001) employed a similar method using a lognormal probability distribution for the derivation of a theoretical wind speed vulnerability curve for engineered steel structures. Leicester and Reardon (1976) used a lognormal distribution in the analysis of damage level and type for structures in Darwin following cyclone Tracy. The wind model has not been configured to report change in wind direction at this time. As the study is examining a large population of housing, the parallel and longitudinal orientation wind resistance models were combined in equal proportion.



House Groups

Group	Built during
1	< 1925
2	1925 – 1950
3	1951 – 1960
4	1961 – 1972
5	1973 – 1984
6	> 1984

Five failure Modes for each Group

	Failure Mode
1	Roofing
2	Roof fixing
3	Batten
4	Rafter
5	Plate

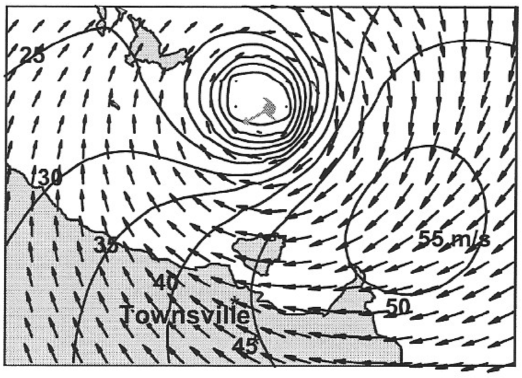


Figure 1 House group and failure mode model. Figure 2 Cyclone Althea simulated windfield.

Sudden internal pressurisation of the house can occur if there is a breach in the building envelope on a windward face such as a door blowing in or a window breaking etc. These internal loads act in concert with the external pressures greatly increasing the load on the house cladding elements and structure. Resulting dominant openings in the envelope can generate large internal pressures and an increased possibility of more serious damage. The flying debris damage potential in a windstorm is dependent upon the available upwind debris, its impact velocity and the resistance provided by the building envelope.

The failure of elements disengaging from the house structure, such as roofing, fascias, gutters, etc, leads to a snowball effect as the failed components add to the wind borne debris field, increasing the potential for full internal pressure in houses downwind resulting in more debris, and so on.

A module was developed to combine the two internal pressure cases in varying proportions depending on the modeled house group and the wind speed. Therefore for a given wind speed one modeled house group may have a higher proportion of houses with full internal pressure than another.

Consideration was given to different housing types having different features, such as large windows/doors, type of wall cladding or vented eaves, which can increase or reduce the potential for full internal pressure. Reference was also made to values given in damage assessment reports and from experience in conducting damage surveys. Factors were included to account for debris generation from the different house model groups. An assumption was made that because the model house groups are generally based on age, they tend to be situated together and so the house groups that fail earliest generate debris which impacts on the same house group.

4 Predictive Damage Model

The CTS housing wind resistance model was then combined with the SEA deterministic wind field model SEACATd to provide an efficient mechanism and interface for estimating the number of houses suffering wind-induced damage from a cyclone of given parameters (track, intensity, radius etc). Within the SEA model framework, topographic factors such as ground slope, surrounding terrain and neighbouring structures, detailed in the Australian Wind Load Standard (SAA 1989) were used.

As with any numerical model, the output needs to be calibrated and verified against field data. This is not an easy task. There is a scarcity of damage survey data available since, thankfully severe cyclones are rare events. In using the amounts and types of damage reported in various damage investigations, care is needed in interpreting the impact wind speed for use in calibrating the damage numbers. The wind speeds given in the reports are typically for a wind at +10 m height in flat open terrain. Adjustments are required to convert this 10 m high wind speed (Vref) into the actual wind speed impacting on the housing stock for comparison with the CTS wind resistance models.

Tropical Cyclone Althea, which hit Townsville in 1971, is the one event that can be used to calibrate and verify the output from the SEACATd wind model (Figure 2) and pre 1970's CTS house models.

The reported damage type observed for the majority of the badly damaged houses was a failure of the rafter connections at the ridge or top plate. The CTS housing wind resistance model methodology was verified as the predominant predicted failure mode for house Groups 1 and 2 is failure of the rafter connection at ridge or top plate and in Group 3 the predicted failure mode is shared between the batten rafter connection and the rafter ridge or top plate connection. Overall damage levels (JCU 1972) were 16% but reached a high of 68% for one exposed coastal suburb, while following calibration the model predicts 15% and 71% respectively.

There are no other events in the survey areas that can be used for the calibration of the complete system. However, damage investigations following cyclones Tracy and Vance for example, can be used for specific data points. Table 1 shows some comparisons of the house wind resistance model estimates of damage predictions with actual reported percentage damage from surveys.

Table 1: Percentage estimates of numbers of houses suffering some form of damage from wind

House group	Event	Vref (m/s)	Major terrain category	% single storey	Model damage estimate	Actual reported damage
4	Tracy	65	2.5	0	97 %	93 %
5	Winifred	55	2.5	30 %	26 %	20 – 30 %
3	Winifred	55	2.5	30 %	24 %	20 – 30 %
6	Vance	60	2.5	95 %	4 %	4 %
6	(Theory)	70	2.5/3	95 %	17 %	(?)

5 Results

Results from the study detail, for defined districts within the modeled community, the estimated numbers of houses suffering damage along with a classification of the types of structural failures, for either varying winds from a generated cyclone or a blanket wind speed across all districts.

Figure 3 shows percentage totals of the estimated number of damaged houses for a cyclone of similar parameters to that of Cyclone Althea for the modeled Townsville districts. The figure also shows the calculated Vref for each district.

In running the model with various cyclone or Vref scenarios, areas of housing stock within the modeled districts are shown to have higher relative vulnerability through combinations of topographic and building class features. For example, the model could show a district comprising older housing in a sheltered area may have a similar vulnerability to a newer suburb in an exposed terrain.

One observation drawn from the current study has shown that the modeled region of Cairns is estimated to have a lower relative overall vulnerability of its housing stock to wind loads than the other modeled regions of Townsville and Mackay, because of its greater proportion of housing built following the introduction of engineered house building requirements in the early 1980's. In assuming a societal risk level for new housing design from the BCA (2002), it could be inferred from the models estimates that, in an overall community sense, there exists a much higher residual level of risk than is desirable, due to the proportion of housing built prior to the introduction of engineered house building requirements in the early 1980's.

The assessed construction quality of the housing stock plays a large factor in the model's estimation of overall damage numbers. Further refinement of this aspect and the estimated proportion of houses that might be susceptible to full internal pressure are especially warranted.

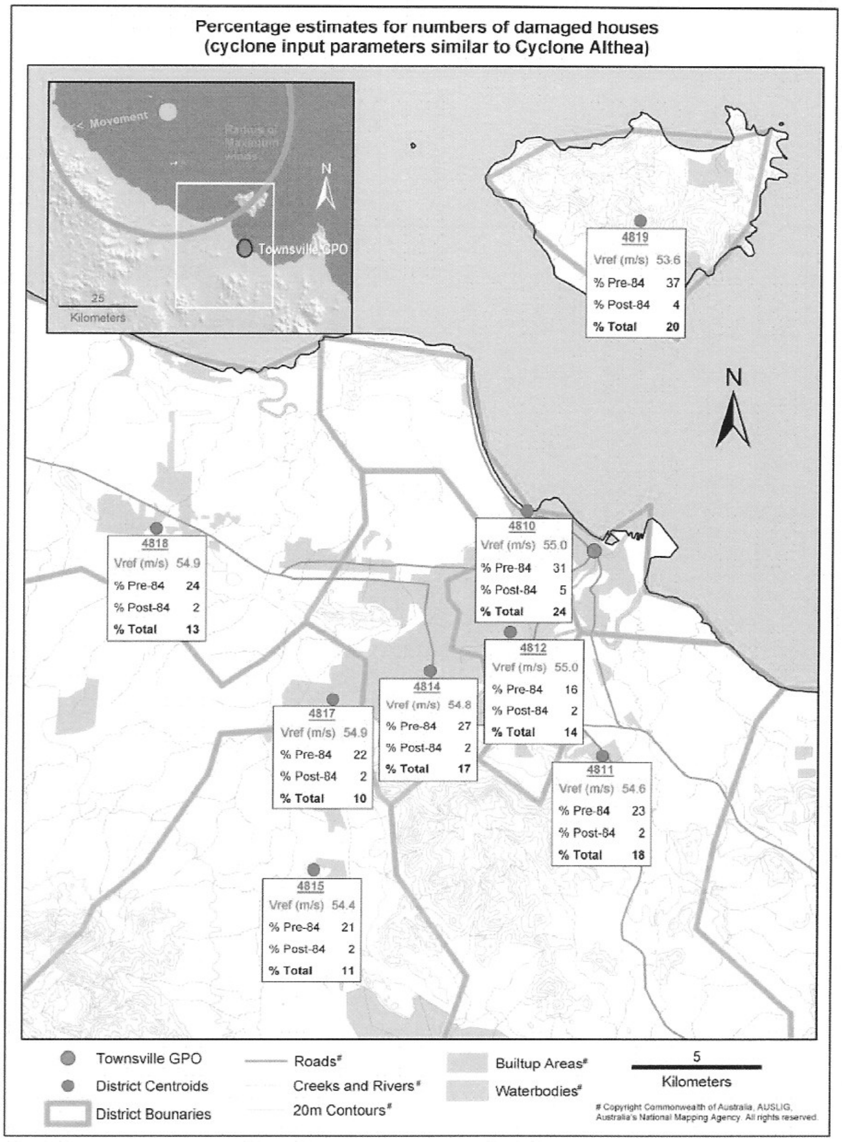


Figure 3: Percentage estimates of numbers of damaged houses for a simulated Althea event

6 Conclusion

The project has demonstrated a practical yet advanced methodology for estimating the community impact from tropical cyclones. While there is much opportunity to improve the present model, it does represent an advanced assessment of house performance for high winds undertaken in Australia. A full probabilistic version of the model is now being considered that will estimate return periods of losses.

7 References

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