Detailed Modelling of the Vulnerability of Domestic 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 over 30 years. During this time, a large database on housing performance has been collected and now forms the basis of a sophisticated 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. Topographical 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 accurately 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 over several years for Cairns, Townsville and Mackay with the assistance of Commonwealth and Local Government agencies. The CTS also 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 classes, covering 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 capacities.

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 and full-scale house testing results all conclude 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).

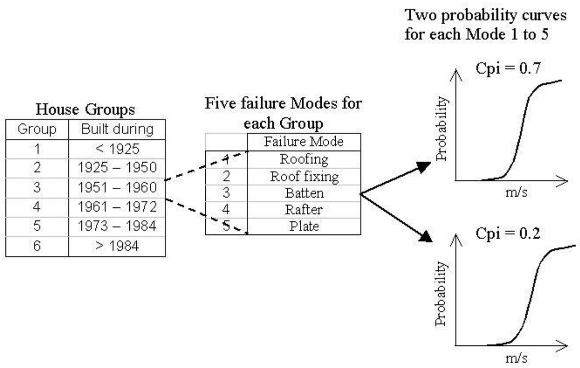

Figure 1 House group and failure mode model.

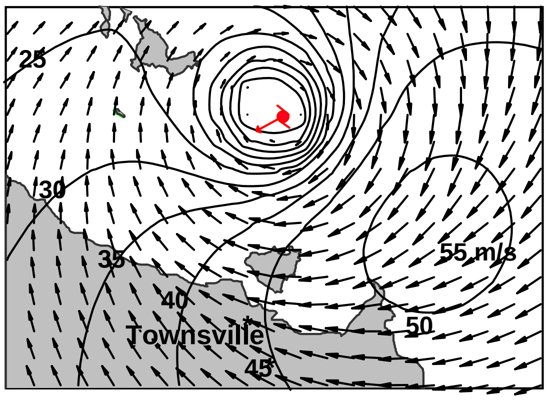

Figure 2 Cyclone *Althea* simulated windfield.

Sudden full internal pressurisation of a house occurs when there is a breach in the outer building envelope caused by wind-driven debris breaking a window or blowing-in a door and this can dramatically increase the internal wall load and upward load on the roof structure. Failures of house elements also add to the *debris* field impacting on downwind houses, which increase their risk of failure, leading to higher probabilities of further failures downwind (e.g. a “snowball” effect). Accordingly, the CTS has developed a module to estimate the numbers of houses likely to be subjected to full internal pressure as a result of the windborne debris.

4 Predictive Damage Model

The CTS housing wind resistance model was then combined with the SEA deterministic wind field model *SEACATd* to provide a user-friendly software 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 were represented in accordance with the boundary layer coefficients detailed in the Australian Wind Load Standard (Standards Australia 1989). As a verification check, the model has been tested against real damage data from Tropical Cyclone *Althea*, which impacted Townsville in 1971 (Figure 2). Overall damage levels (JCU 1972) were 16% but reached a high of 68% for one exposed coastal suburb, while the model predicts 15% and 71% respectively, comparing very favourably with the reported damage. Output from the predictive model provides the estimated number of houses damaged within each defined district and for each house group as well as the types of structural failures occurring and highlights the relative vulnerability of certain housing types caused by their terrain and topographic exposure.

5 Conclusion

The project has demonstrated a practical yet advanced methodology for estimating the community impact from tropical cyclones or other extreme wind events that is superior to more simplified models in common use. 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.

6 References

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