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# IMPROVING THE RESILIENCE OF EXISTING HOUSING TO SEVERE WIND EVENTS

**Annual project report 2015-2016**

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Cover: Housing damage from a cyclone. Photo by the Cyclone Testing Station.

# TABLE OF CONTENTS

# EXECUTIVE SUMMARY

Damage investigations carried out by the Cyclone Testing Station (CTS) following severe wind storms have typically shown that Australian houses built prior to the mid-1980s do not offer the same level of performance and protection during windstorms as houses constructed to contemporary building standards. Given that these older houses will represent the bulk of the housing stock for many decades, practical structural upgrading solutions based on the latest research will make a significant improvement to housing performance and to the economic and social well-being of the community.

Structural retrofitting details exist for some forms of legacy housing but the uptake of these details is limited. There is also evidence that retrofitting details are not being included into houses requiring major repairs following severe storm events, thus missing the ideal opportunity to improve resilience of the house and community. Hence, the issues of retrofitting legacy housing, including feasibility and hindrances on take-up, etc., must be analysed.

The primary objective of this research is to develop cost-effective strategies for mitigating damage to housing from severe windstorms across Australia. These evidence-based strategies will be (a) tailored to aid policy formulation and decision making in government and industry, and (b) provide guidelines detailing various options and benefits to homeowners and the building community for retrofitting typical at-risk houses in Australian communities. Specific task items include:

- Categorise residential structures into types based on building features that influence windstorm vulnerability using Geoscience Australia and CTS survey data. From these, a suite will be selected to represent those contributing most to windstorm risk
- Involve end-users and stakeholders (i.e. homeowners, builders, regulators, insurers) to assess amendments and provide feedback on practicality and aesthetics of potential upgrading methods for a range of buildings. Cost effective strategies will be developed for key house types
- Vulnerability models will be developed for each retrofit strategy using survey data, the authors' existing vulnerability models, and the NEXIS database of Australian housing characteristics. Case studies will be used to evaluate effectiveness of proposed retrofit solutions in risk reduction. Economic assessment using the same case studies will be used to promote uptake of practical retrofit options

# END USER STATEMENT

**Leesa Carson,** *Community Safety and Earth Monitoring Division, GEOSCIENCE AUSTRALIA*

The majority of wind risk is in the older existing housing stock. This project will provide evidence-based cost-effective solutions to improve resilience of existing housing from severe windstorms. The project is currently on track and has delivered its scheduled outputs.

The team has been proactive in communicating their research through journal papers, technical reports and presented their research at a number of conferences. In addition, researchers have been invited to present at pre-season briefings, insurance forums, and Standards Committees.

The project engagement with social media to connect with the broader community is great way to raise awareness. The pilot webinar series providing information to home owners and builders is a good example of different way to communicate and educate end users.

The project team took advantage of the opportunity to survey houses that were to be demolished in Adelaide to gather information on the performance of aged timber structures which will be an important input into retrofitting legacy housing.

The team has developed a project utilisation plan to ensure the project outputs will be used by end users. The development of practical retrofit solution for at risk houses with cost benefit analysis that is useful for a range of stakeholder would be an important output.

# INTRODUCTION

Damage investigations carried out by the Cyclone Testing Station (CTS) following severe wind storms have typically shown that Australian houses built prior to the mid-1980s do not offer the same level of performance and protection during windstorms as houses constructed to contemporary building standards. Structural retrofitting details exist for some forms of legacy (pre-1980s) housing but the uptake of these details is limited. There is also evidence that retrofitting details are not being included into houses requiring major repairs following severe storm events, thus missing the ideal opportunity to improve resilience of the house and community. Hence, the issues of retrofitting legacy housing, including feasibility and hindrances on take-up, etc., must be analysed. The primary objective of this project is to develop cost-effective strategies for mitigating damage to housing from severe windstorms across Australia. Strategies will be (a) tailored to aid policy formulation and decision making in government and industry, and (b) provide guidelines detailing various options and benefits to homeowners and the building community for retrofitting typical at-risk houses in Australian communities.

Tropical Cyclone Tracy caused significant damage to housing in December 1974, especially in the Northern suburbs of Darwin [1]. Changes to design and building standards of houses were implemented during the reconstruction. The Queensland Home Building Code (HBC) was introduced as legislation in 1982 (with realisation of the need to provide adequate strength to housing). By 1984 it is reasonable to presume that houses in the cyclonic region of Queensland were being fully designed and built to its requirements.

Damage investigations of housing, conducted by the Cyclone Testing Station (CTS) over the past fifteen years have suggested that the majority of houses designed and constructed to current building regulations have performed well structurally by resisting wind loads and remaining intact. However, these reports also detail failures of contemporary construction at wind speeds below design requirements, in particular for water-ingress related issues. The poor performance of these structures resulted from design and construction failings, poor connections (i.e. batten/rafter, rafter/top plate) (Figure 1 and Figure 2), or from degradation of construction elements (i.e., corroded screws, nails and straps, and decayed or insect-attacked timber). Hence, the development of retrofit solutions for structural vulnerabilities are critical to the performance longevity of both legacy and contemporary housing.

Damage surveys invariably reveal some failures due to loss of integrity of building components from aging or durability issues (i.e., corrosion, dry rot, insect attack, etc.). The CTS conducted a detailed inspection of houses built in the 1970s and 1980s in Darwin [13]. Although the majority of surveyed houses appeared in an overall sound condition, they had potential issues like decay of timber members, corrosion at connections, missing/removed structural elements, etc. The damage survey after Cyclone Yasi showed substantial corrosion of roof elements in houses less than 10 year old [6]. This study confirmed that ongoing maintenance is also an important part of improving community resilience in severe weather.

FIGURE 1. WIND-INDUCED FAILURE OF A NEW (< 1 YEAR) METAL CLADDING ROOF ON AN OLD HOUSE AT THE RAFTER TO TOP-PLATE CONNECTION DURING CYCLONE MARCIA (2015) IN YEPPOON, AUSTRALIA - THERE APPEARED TO BE NO RETROFITTING OF THE WEKER CONNECTIONS.

FIGURE 2. WIND-INDUCED FAILURE OF A METAL CLADDING ROOF (LEFT) AT THE BATTEN TO RAFTER CONNECTION (RIGHT) DURING CYCLONE MARCIA (2015) IN YEPPOON, AUSTRALIA.

The issues of poor construction practices in renovation, degradation of materials (lack of advice for maintenance), etc. are not constrained to northern Australia. Damage investigations in Brisbane, Dubbo and Perth revealed similar issues.

Considering the prevalence of roofing failures due to inadequate upgrading techniques, current building industry literature for upgrading the wind (and water-ingress) resistance of existing Australian housing were reviewed. In parallel, a brief internet-based questionnaire was distributed to a wide range of Australian building industry constituents in order to identify specific limitations of current upgrading guidelines.

# PROJECT BACKGROUND

## WIND LOADS ON HOUSING AND STRUCTURAL PERFORMANCE

The wind field within a cyclone is well known to be highly turbulent. Dynamic fluctuating winds subject the building envelope and structure to a multitude of spatially and temporally varying loads. Generally, the structural design of housing uses peak gust wind speeds for determining the positive and negative pressure loads the structure must resist. The storm duration and temporally varying forces are important for assessing elements of the envelope and frame (i.e., roofing, battens, connections, etc.) that may be subject to low cycle fatigue.

Maintaining a sealed building envelop is critical to the wind resistance of buildings. If there is a breach on the windward face, (i.e., from broken window or failed door), the internal pressure of the house can be dramatically increased. The internal loads act in concert with external pressures, increasing the load on cladding elements and the structure. Depending on the geometry of the building, the increase in internal pressure caused by this opening can double the load in certain areas, increasing the risk of failure, especially if the building has not been designed for a dominant opening.

Residential structures in cyclonic regions designed in accordance with contemporary design standard AS4055 Wind Loads for Housing [3] are required to incorporate load cases for internal pressure increases created by envelop breaches. Houses in non-cyclonic regions designed to AS4055 are not required to account for this load case, resulting in a higher probability of failure if such an opening were to occur.

The National Construction Code [18] is continually reviewed to ensure that it supports acceptable performance of new housing. However, only a small fraction of our housing stock is replaced per annum, therefore most Australians will spend the majority of their lives in houses that are already built. Further, from an emergency management, community recovery, and insurance perspective, the majority of the risk is in housing stock that already exists.

The complexity of housing structures does not lend them to simple design and analysis due to various load paths from multiple elements and connections with many building elements providing load sharing and in some cases redundancy. Different types of housing construction will have varying degrees of resistance to wind loads. From a review of building regulations, interviews, housing inspections, and load testing, the CTS classified housing stock in the North Queensland region into six basic classifications [14].

For each of these classifications, the CTS developed preliminary housing wind resistance models to give an estimate of the likely failure mode and failure load for a representative proportion of houses. The models focus on the chain of connections from roof cladding fixings down to wall tie-downs and incorporate parameters like building envelop breach.

The Geoscience Australia NEXIS data base will be used to establish common housing classifications for various regions around Australia [17]. Vulnerability models for these types of building systems will be derived.

AS/NZS 1170.2 [2] provides information for selecting the design wind speed related to the return period. Using vulnerability curves developed by CTS, Figure 3 **Error! Reference source not found.** shows the percentage of housing damaged versus the return period for homes in a typical cyclonic region C, suburban site. These curves show the significant decrease in damage to housing that could be achieved if pre-1980s houses were upgraded with protecting openings and improved connections.

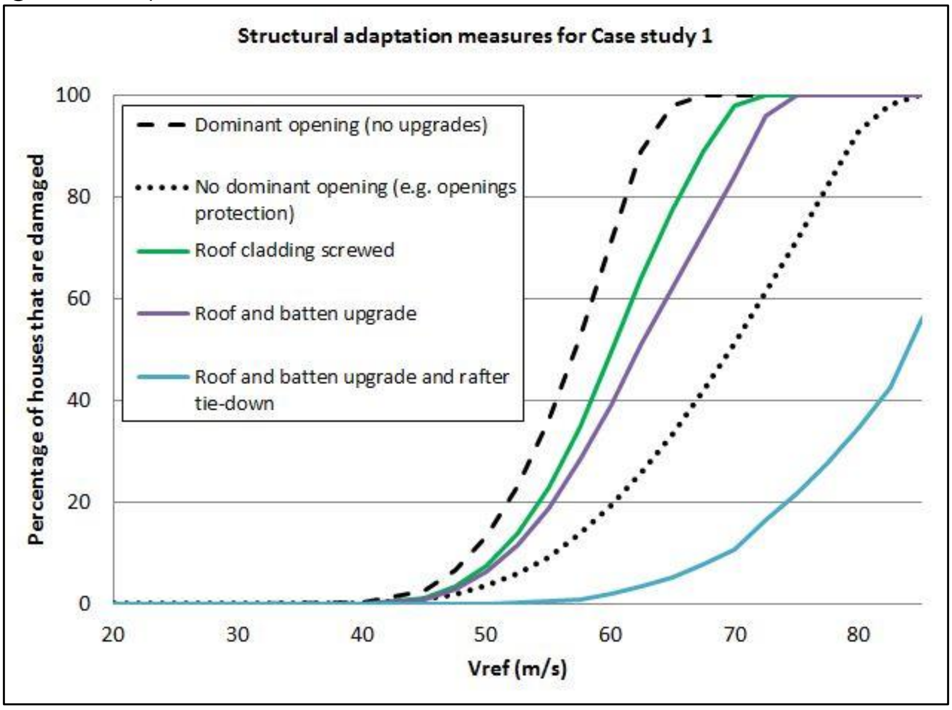


FIGURE 3 ESTIMATED DAMAGE FROM WIND LOADS TO HOUSES WITH DIFFERENT STRUCTURAL ADAPTATION MEASURES FOR HOUSE MODEL AS SHOWN IN **ERROR! REFERENCE SOURCE NOT FOUND.** (KING ET AL. 2013)

## POST-EVENT DAMAGE OBSERVATIONS

Following Cyclone Yasi in 2011, Boughton et al [6] showed that homes correctly designed and constructed to the Australian building standards introduced in the 1980s generally performed well under wind load actions. Damage survey results indicated that in the most highly affected areas, ~3% of post-1980s homes experienced significant roof damage, in contrast to ~15% for pre-1980s homes. Greater than 20% of the pre-1980s housing experienced significant roof loss in some areas. The relatively low incidence of roofing damage to post-1980s buildings indicates that modern building practices deliver better performance for the roofing structure in severe wind event conditions.

A damage survey following Cyclone Larry [7] showed that although wind-induced structural damage was minimal for 95% of contemporary housing, these houses experienced water ingress damage from wind-driven rain. A survey conducted by Melita [10], details building envelope failures during Cyclone Larry. Approximately 75% of post-1985 homes experienced water ingress through breaches in the building envelope (i.e. broken windows, punctured cladding, failed fascia or guttering, etc.). In many cases replacement of internal components and owner contents were required.

These observations are similar to those of other other post-event damage assessments in Australia (e.g. Cyclone Winifred [11], Cyclone Vance [12], Cyclone Ingrid [8], and Cyclone George [5]). Consistent findings include:

- In general, contemporary construction performance for single family residential housing was adequate under wind loading
- Significant structural damage to legacy (pre-1980s) housing was typically associated with loss of roof cladding and/or roof structure. There were many examples of legacy housing with relatively new roof cladding installed to contemporary standards (i.e. screwed fixing as opposed to nailed) but lacking upgrades to batten/rafter or rafter/top-plate connections, resulting in loss of roof cladding with battens attached
- Corrosion or degradation of connections and framing elements initiated failures
- Where wind-induced structural failures were observed for contemporary housing, they were often associated with either poor construction practice or design faults
- Breaches in the building envelope (i.e. failed doors and windows, debris impact, etc.) exacerbated failure potential from increased internal pressures
- Extensive water ingress damages were observed for structures with and without apparent exterior building damage

These observations suggest the majority of contemporary houses remained structurally sound, protecting occupants and therefore meeting the life safety objective of Australia's National Construction Code (NCC) [18]. However, contemporary homes did experience water ingress (resulting in loss of amenity) and component failures (i.e. doors, soffits, guttering, etc.) with the potential for damage progression to other buildings, thus failing to meet specific objectives and performance requirements of the NCC.

# PROJECT ACTIVITIES

## PROJECT RECRUITMENT

*Mitchell Humphreys, PhD Student*

Mitchell received a BNHZ-CRC PhD top-up scholarship to his APA Scholarship for his project on characterising internal pressures in buildings. The project is supported with an ARC Linkage grant with the ASI. Buildings, particularly vulnerable to wind damage as a result of being designed with unreliable internal pressure data. Mitch will be conducting wind tunnel model, full scale and analytical internal pressure studies on a range of building configurations. The outcomes from Mitch's research will provide more reliable internal pressure design data.

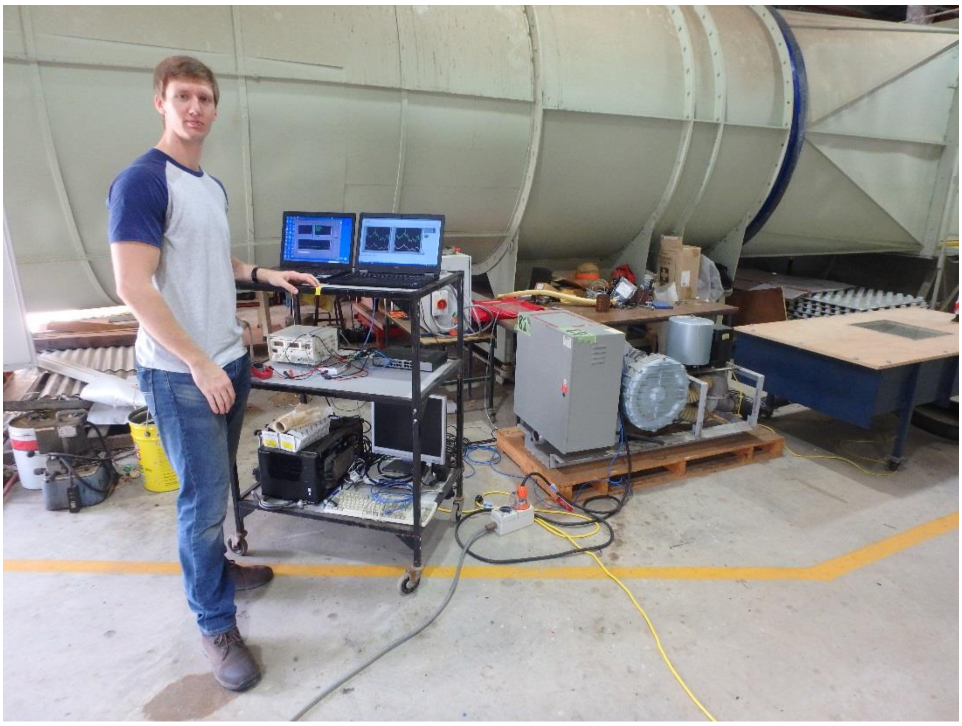

FIGURE 4. MITCHELL HUMPHRIES

## TROPICAL CYCLONE & THUNDERSTORM ANALYSIS

The 2014-15 year was very active from a severe wind event perspective, with five landfalling tropical cyclones in Australia and the pacific islands and several severe thunderstorm events. These events provide unique opportunities for the project to learn more about the vulnerabilities of residential construction. In contrast, the 2015-16 year was relatively inactive in Australia due to El Nino conditions in the tropical Pacific. However, cyclone activity was observed in neighbouring pacific islands (i.e. Cyclone Winston in Fiji). Public reports by the CTS from the 2014-15 events were discussed in the 2014-15 Annual Project Report and links to each are provided below.

Brisbane Thunderstorms

https://www.jcu.edu.au/cts/publications/content/technical-reports/tech-report-tr60/view

Tropical Cyclone Nathan

https://www.jcu.edu.au/cts/publications/content/cyclone-nathan-rapid-damage-assessment-report/view

Tropical Cyclone Marcia

https://www.jcu.edu.au/cts/publications/content/TCMarciaRapidAssessmentReport20_02_2015.pdf/view

https://www.jcu.edu.au/cts/publications/content/overview-of-cyclone-marcia-wind-speeds

https://www.jcu.edu.au/cts/publications/content/cyclone-marcia-article-in-engineers-australia/view

https://www.jcu.edu.au/cts/publications/content/weathering-the-storm/view

Tropical Cyclone Olwyn (2015)

https://www.jcu.edu.au/cts/publications/content/cyclone-olwyn-rapid-damage-assessment-report/view

## CONFERENCE PAPERS AND PRESENTATIONS

### Australasian Fire & Emergency Services Authorities Council (AFAC, 2015)

Daniel attended the AFAC conference in Adelaide where a project poster was presented. CRC PhD student Korah Parackal also presented on preliminary findings from an analysis of the November 2014 Brisbane thunderstorms. Meetings were held aside from the conference with project partners from Geoscience Australia. In particular, potential upgrades to the vulnerability modelling program VAWS were discussed.

### Second International Conference on Performance-based and Life-cycle Structural Engineering (PLSE, 2015)

Daniel presented two papers related to the project at PLSE in December 2015. The first paper included a preliminary estimation of cost-benefit analysis for various retrofit upgrades to older housing based on manipulation of claims data from Cyclone Yasi. The second paper discussed the underlying program logic for a proposed prototype vulnerability assessment tool that suggests potential mitigation solutions for wind damages to homeowners. John Ginger also presented a paper discussing recent experimental work at the CTS to better how wind loads are transferred through the various structural elements of a home.

### Australasian Wind Engineering Society Workshop (AWES, 2016)

Papers were presented by Daniel, Korah, and Mitch at the 18th AWES workshop in Adelaide. Daniel's paper reviewed vulnerability modelling to date for Australian housing and recent findings from analysis of Cyclone Yasi claims data. Mitch's paper discussed internal pressure fluctuations in industrial buildings. Korah's paper discussed correlation of peak wind loads at batten-truss connections. John Ginger also presented during the wind loading day of the conference on aerodynamic shape factors for buildings, freestanding structures and attachments, etc.

### Engineers Australia Engineering Resilience Workshop

David was an invited speaker at Engineering Workshop presenting on "Improving the resilience of buildings to severe wind events" based on CTS research activities and damage investigations.

## STAKEHOLDER ENGAGEMENT

### Queensland Building and Construction Commission

The CTS hosted the Queensland Building & Construction Commission (QBCC) Board in Townsville in July 2015. The QBCCC has been auditing construction and certification of houses in North Queensland, to ascertain the level of compliance with codes and regulations. David Henderson gave a presentation on the Scope and Progress of this project noting aspects of interest to QBCC. Follow up meetings have focussed on system for certification/acknowledgement of retrofitting load path in older house construction.

### Queensland Tropical Cyclone Consultative Committee (QTCCC)

David gave a presentation to the Queensland tropical cyclone consultative committee (QTCCC) meeting in Brisbane in May 2016. The committee is joint chaired by the head of the Qld BoM and QFES. Its role is to provide information and respond to issues from across the local, state and federal levels in relation to cyclone awareness, preparation, planning, response and recovery.

### Northern Australia Insurance Premiums Taskforce

The CTS presented information on damage and loss to housing in cyclonic and thunderstorm regions to the Taskforce. Drivers of loss, and potential mitigation measures to improve resilience of already constructed housing were discussed.

The importance of homeowners incorporating mitigation measures to reduce risk has been highlighted with the release of the Northern Australia Insurance Premiums Taskforce's report.

http://kmo.ministers.treasury.gov.au/media-release/020-2016/

The report places a great emphasis on mitigation strategies. An extract from the Executive Summary; "*Mitigation to reduce the risk of damage from cyclones is the only way to reduce premiums on a sustainable basis… Further, without action on mitigation, the benefits of any measures taken by the Government to lower premiums would be reversed upon government exit.*"

The CTS is proud to have contributed to the Taskforce's findings through our damage surveys and building product testing experience and our research projects such as the Bushfire and Natural Hazards CRC project "*Improving the resilience of existing housing to severe wind events*" and our report on "*Mitigation benefits for resilience of homes"* for Suncorp.

It is great to see the Station's work informing and making positive changes through this taskforce report along with the recent insurance product launches (Suncorp and RACQ) for reductions in premiums for retrofitting of older housing.

## Webinars for home owners and builders

The CTS has developed a pilot webinar series published on YouTube to provide information bites for:

- Home owners – who need to be informed of the importance of making appropriate decisions at various stages of the building process.
- Builders, Certifiers and Designers – highlighting issues that have caused failures and providing information on various aspects of building to resist wind loads.

**https://cyclonetestingstation.com.au/educational-videos/home-owner-occupier-education**


## QFES Pre cyclone season briefings

David Henderson was invited by QFES to present findings and recommendations from CTS damage investigation following Cyclone Marcia at their pre-season briefings at Mackay and Rockhampton. Attendees at the briefing sessions were local and state government agencies.

### AS 2050 Committee Meetings

Daniel Smith is on the Standards Australia BD-008 Roof Tile Committee. The committee passed revisions to AS2050 (e.g., sarking requirements, updates to match AS 4055, consistency of wording, etc.) and AS4046.8 in 2015. Daniel proposed changes to wind load testing and design considerations for tiles, which the committee agreed to discuss in further detail at a later date. The Roofing Tile Association of Australia (RTAA) commissioned the CTS to investigate wind loads on roofing tiles in 2015. A draft final report on this research has been submitted to RTAA for review. The likely outcomes include deeper understanding of wind loads under which tiles are removed from the roof. This a critical step towards improving the wind resistance of construction with tiled roofing.

### AS/NZS 1170.2 Committee Meetings

John Ginger is in the BD 6/2 committee responsible for recent revisions related in the wind loading standard AS/NZS1170.2. The latest revisions in to AS/NZS1170.2 are awaiting ratification from the ABCB and its counterpart in New Zealand. These changes will be presented at the upcoming AWES Wind Loading day on 6 July 2016.

### AS 4055 Committee Meetings

David Henderson is in the BD99 committee responsible for recent revisions related in the wind loading for housing standard. David reported to members on the issues of damage to housing and critical connections from the recent damage surveys.

### Cyclone awareness/preparation events in Townsville and Cairns

The CTS participated in the community awareness events in Townsville and Cairns to promote home owner preparations (general home maintenance and inspections prior to season, and immediate preparations prior to cyclone).

# BNHCRC COLLABORATIVE MEETINGS

## BNHCRC RAF - Brisbane (2015 November)

Daniel Smith and John Ginger (project leader) attended the meeting at QUT in November 2015. In addition to presenting a project update and discussing overlap with other projects in the cluster, project team members discussed methods to select house types for which the project would assess the benefit of mitigation against severe wind.

# ADDITIONAL RESEARCH ACTIVITIES

## Adelaide Housing Survey and Connection Harvesting

Supported by the Bushfire and Natural Hazards CRC, the CTS has collaborated with the University of Adelaide and the Department of Planning Transport and Infrastructure (DPTI) to study 1960's housing in Adelaide. In January 2016, CTS research fellow Daniel Smith and Ph.D. student Korah Parackal travelled to Adelaide to survey these houses that are soon to be demolished. Sixteen houses were surveyed and their connection details and structural systems recorded, providing valuable data for the two current CRC projects on retrofitting legacy housing and progressive failures to wind loads.

Most of the houses surveyed were single storey with double brick walls and pitched frame hip and valley roofs (Figure 5). Other properties included two storey double brick apartment units, skillion roofed houses and newer brick veneer houses with prefabricated trusses. The exterior details of each house (i.e. wall cladding, window details) were recorded and for houses with tiled roofing, a small opening was made in the roof edge to document rafter to wall connections and the wall framing. The roof space was also accessed through the ceiling manhole from inside the house to examine the overall roof framing scheme.

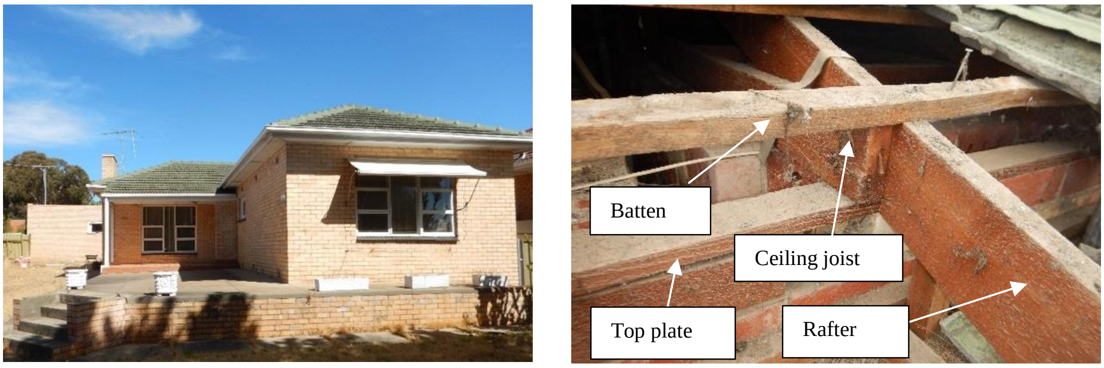


FIGURE 5 TYPICAL 1960S HOUSE SURVEYED (LEFT ) AND ROOF TO WALL CONNECTION DETAILS (RIGHT)

The performance of aged timber connections is not well understood. The second stage of this Adelaide housing survey project involved collecting in situ batten-rafter connections that are to be tested in the CTS laboratory. Figure 6 shows CTS Researcher Dr Daniel Smith PhD student Mr Korah Parackal harvesting connections. This will allow the effects of changes in moisture content and the degradation of the timbers and fasteners to be captured.

Furthermore, connections will also be tested to fluctuating time history loads determined from a wind tunnel study using a Pressure Loading Actuator (PLA). The CTS has constructed a new test rig to undertake the realistic load testing in a first for Australia. Such dynamic load testing will account for the effects of accumulated damage during a severe wind event through the incremental pull out of nails as well as any energy dissipation effects through hysteresis. Effects of varying load rate on the response of the nailed connections can also be determined.

FIGURE 6 CTS RESEARCH FELLOW DR DANIEL SMITH AND PHD STUDENT MR KORAH PARAKKAL HARVESTING CONNECTIONS FROM HOUSING

FIGURE 7 TESTING OF TIMBER CONNECTION IN INSTRON (LEFT) AND NEW DYNAMIC LOAD RIG FOR SIMULTIONG FLUCTUATING WIND LOADS ON THE SALVAGED ROOF CONNECTIONS (RIGHT)

## Advance Queensland Fellowship

In March 2016 Daniel commenced a research fellowship in partnership with the Queensland Government and Suncorp to build on the current CRC project scope. The goal of the fellowship project is to develop an actionable, research-based approach to mitigation in Queensland and other wind-prone regions of Australia. As previous the CRC research to date has identified drivers of loss, this project will also identify drivers of homeowner engagement. Coupling the engineering analysis with effective methods of incentivising homeowner engagement, a vehicle for communication will be developed in the form of a prototype smartphone application. The aim of this decision-support tool will be to stimulate mitigation among homeowners in wind-prone regions of Australia.

Key project tasks include:

*Task 1: Rational engineering analysis for comparing building resilience features*

CTS will expand the previous analysis of Suncorp claims data to include additional events (e.g., Cyclones Larry and Marcia). The analysis will not be limited to cyclonic regions and may include wind events across Australia in non-cyclonic regions (e.g., 2014 Brisbane storms). Based on this analysis CTS will develop empirical vulnerability curves for typical housing types.

*Task 2: Identification of key drivers for community engagement with mitigation*

To inform an effective mitigation program, homeowners in Queensland will be profiled based on their likelihood of accepting different types of incentives. Owners who do, and do not, perform different types of damage mitigation behaviours will be interviewed, enabling the delivery of targeted communication and tailored incentive programs aiming to increase desirable behaviours. Using a robust survey methodology, the project will investigate how social and community characteristics, information seeking behaviour and preferences, past extreme weather event experiences, and perceptions of threat and risk, influence behavioural preparedness.

*Task 3: Resilience rating system*

Based on the engineering analysis and findings from the behavioural study, a tiered (e.g., perhaps gold, silver, bronze) rating system for resilience will be developed. The rating system will outline which construction features and mitigation upgrades are appropriate for each tier of the system. This system will be used within the content of the decision support tool.

*Task 4: Operationalise a smartphone decision support tool for mitigation*

A smartphone application is proposed as a self-assessment tool that also educates and engages homeowners in cyclone-prone regions to make better decisions regarding mitigation. The CTS will leverage the efforts already invested in a US-based version of a similar application, entitled "ResilientResidence", and currently in development phase with UF. The framework for the app, currently provides a personalised wind risk assessment of the user's home, including the anticipated losses that would occur in a scenario event (e.g., Category 3 cyclone). Further, based on the self-assessment data supplied by the user, the app provides retrofit solutions that are specifically tailored to reducing wind-induced losses for that home. The core objective of application is to promote decision-support for homeowners to engage in mitigation activities and information reporting. However, as the application is based on Florida-specific research, construction features, and demographics, this project will develop an Australian-based version of the application using the engineering analysis, behavioural drivers of engagement, and the retrofitting guidelines and rating system developed in Tasks 1-3.

## Wind Tunnel Testing

Wind loads on the roof of representative houses were obtained from a wind tunnel model study carried out in the 2.0m high × 2.5m wide × 22.0m long boundary layer wind tunnel in the Cyclone Testing station at James Cook University. The approach atmospheric boundary layer representative of suburban terrain was simulated at a length scale of 1/50 over a fetch by using a 250mm high trip board at the upstream end followed by an array of blocks on the tunnel floor.

A model of the typical gable end 10m × 19.8m × 2.7m low rise house with 0.6m roof overhang defined using the survey data and discussions with GA, was constructed at a length scale of 1/50 as shown in Figure 8. The wind loads were measured on tributary areas representing cladding fixings, and on rafters spaced 900mm apart. Each rafter tributary area was divided into patches. Each patch represents a conventional batten-to-rafter connection tributary area which is used for fragility/vulnerability assessment of connections to wind loads. External pressures were obtained for approach wind directions θ = 0° to 360° in steps of 10°. Pressure taps on each patch were connected to a transducer using a tubing system via a pressure measurement system. The fluctuating pressures were cut off at 625Hz and sampled at 1250 Hz for 30 seconds, and presented as pressure coefficients ($C_p(t) = p(t)/\frac{1}{2}\rho\overline{U}_h^2$) for a length scale ratio of 1/50 and a velocity ratio of 2/5. This results in an equivalent full scale observation time of 10 minutes and a time scale of 1/20. These pressure coefficients were statistically analysed to obtain mean ($C_{\bar{p}}$), maximum ($C_{\hat{p}}$) and minimum ($C_{\check{p}}$) pressure coefficients in a single run.

Wind loading standards typically provide design pressure coefficients for wind directions perpendicular and parallel to the ridge. The nominal peak pressure coefficients ($C_{P_N}$) derived from Section 5 of AS/NZS1170.2 is $C_{pN} = C_{fig} \times G_U^2$, where $C_{fig}$ is the external aerodynamic shape factor and $G_U = \hat{U}_h/\overline{U}_h$ is the velocity gust factor which is 1.875 in this study as per AS/NZS 1170.2 Here, $\hat{U}_h$ and $\overline{U}_h$ are gust wind speed and mean wind speed respectively at mid roof height.

The load transmitted to the batten-to-rafter connection is dependent on the cladding and structural support system including their directional stiffness properties.

The pressure fluctuations on the roof system (ie. batten to rafter and rafter to top plate etc) are being analysed and tested in detail by Korah Parackal (a BNHZ-CRC PhD top-up scholarship recipient) as part of his PhD study. In addition, the following undergrad students are conducting BE thesis projects at JCU:

“Structural response of houses and retrofit options” by Dylan Marshall, Chloe Madden

“Structural response of batten to truss/rafter connections” by Sarah Hall, Lachlan McGinnity

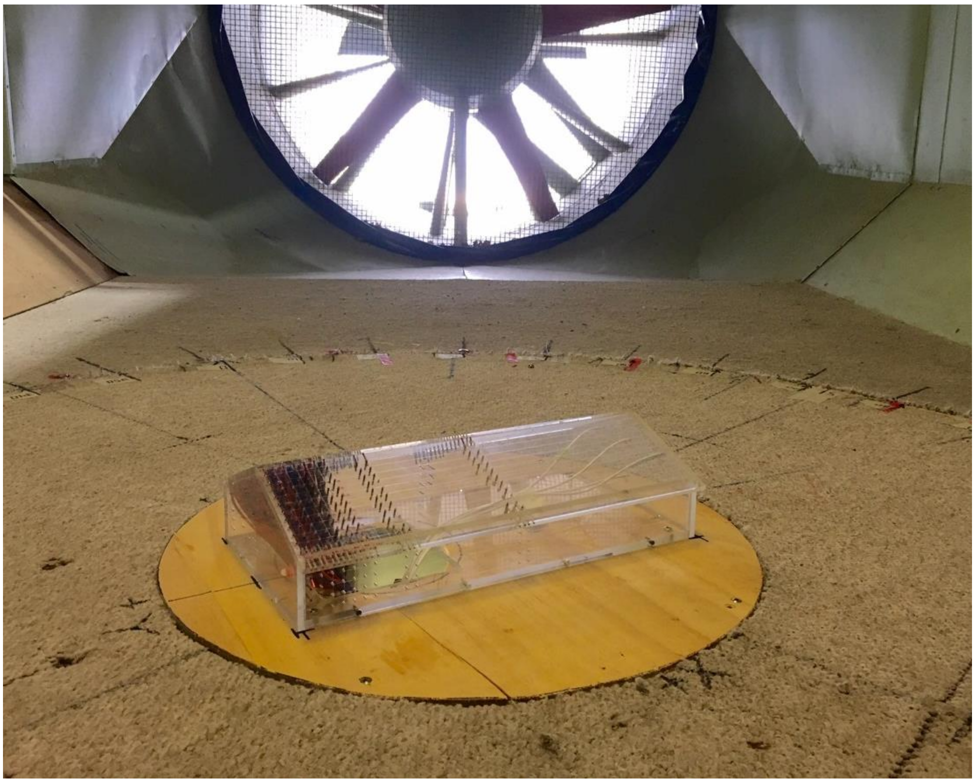

FIGURE 8 10M X 19.8M X 2.7M REPRESENTATIVE HOUSE

## Interim report on 1960's south-eastern Australia house geometry survey

### *Introduction*

Of the house types selected by the project team for investigation into the benefits of mitigation, the house types of south-eastern Australia are the least well understood categories in terms of geometry. To address this, a survey of Canberra houses typical of the 1960's has been commenced with the aim of determining the most common geometries and hence providing data to enable a generic 1960's house from south-east Australia to be identified.

### *Survey*

The survey has been undertaken via desktop examination of aerial imagery and Google Streetview imagery. The scope is to survey all houses in a Canberra suburb that was constructed in the early 1960's. Houses that are obviously constructed at a later date or original houses that have undergone obvious alterations, such as extensions, are excluded.

### *Results to date*

To date 467 houses have been surveyed, the majority of which have been single storey, detached houses. Summary statistics are presented in Tables 1 and 2.

TABLE 10. SUMMARY STATISTICS OF SURVEYED CANBERRA 1960'S HOUSES

| Wall material | Roof material | Number | Percentage of population | Average area ($m^2$) | Average ground floor height above |
|---|---|---|---|---|---|

| | | | | | ground (m) |
|---|---|---|---|---|---|
| Brick | Tile | 444 | 95.5 | 141.5 | 0.61 |
| Brick | Metal | 16 | 3.4 | 164.7 | 0.61 |
| Weatherboard | Tile | 3 | 0.6 | 127.7 | 0.52 |
| Weatherboard | Metal | 2 | 0.4 | 121.5 | 0.52 |

TABLE 2. SUMMARY STATISTICS OF SURVEYED CANBERRA 1960'S HOUSES

| Plan Shape | Number | Number by roof shape | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | G, G | G, H | H, H | G, G, G | H, H, H | G, G, G, G | H, H, H, H | G, H, H |
| R | 231 | 218 | 0 | 13 | NA | NA | NA | NA | NA |
| RC | 37 | 37 | 0 | 0 | NA | NA | NA | NA | NA |
| RS | 5 | 5 | 0 | 0 | NA | NA | NA | NA | NA |
| L | 115 | 65 | 5 | 45 | NA | NA | NA | NA | NA |
| U | 6 | 2 | 0 | 4 | NA | NA | NA | NA | NA |
| T | 63 | 4 | 0 | 0 | 51 | 7 | NA | NA | 1 |
| Z | 7 | 3 | 0 | 4 | NA | NA | NA | NA | NA |
| H | 1 | NA | NA | NA | NA | NA | 1 | 0 | NA |

## Interim report on VAWS software upgrades

### *Introduction*

The BNHCRC project 'Improving the Resilience of Existing Housing to Severe Wind' entails the assessment of the vulnerability of a number of legacy Australian house types to severe wind. Vulnerability assessment is required for both the existing condition and following a range of mitigation actions to enable the calculation of a benefit / cost ratio for each strategy. It is proposed to use the Vulnerability and Adaptation to Wind Simulation (VAWS) software tool to undertake the vulnerability assessment.

The VAWS tool was developed during a collaborative project, partially funded by the then Department of Climate Change and Energy Efficiency, between Geoscience Australia, James Cook University and JDH Consulting in 2009 – 2010. Through the project a single house type was enabled into the software. The BNHCRC project will require modifications to the software and development of input data for the house types that the project will consider.

The BNHCRC project will develop a requirements document for software modifications during the calendar year 2016 with programming scheduled to occur during 2017. This report is an interim report providing a background description of the software and a preliminary list of identified software modifications.

### *Overview of the VAWS software tool*

#### OVERALL LOGIC

The tool takes a component-based approach to modelling building vulnerability. It is based on the premise that overall building damage is strongly related to the failure of key connections.

The tool generates a house by randomly selecting parameter values from predetermined probability distributions using a Monte Carlo process. Values include component/connection strengths, external and internal pressure coefficients, shielding coefficients, wind speed profile, building orientation, debris damage parameters, and component masses. Then, for successive gust wind speed increments, it calculates the forces in all critical connections using influence coefficients, assesses which connections have failed and translates these into a damage scenario and costs the repair. Using the repair cost and the full replacement cost, it calculates a damage index for that wind speed.

Failure of roof sheeting or roof batten connections triggers a redistribution of load to adjacent intact connections, thus making allowance for member continuity in these elements. Failure of roof structure connections revises the influence coefficients for the roof structure load effects depending on the specific connection that failed, thus making allowance for redistribution of forces within the roof structure. Connections that have failed and the effects of redistribution are preserved for successive wind speed increments, thus ensuring that increasing wind loads act on the damaged structure rather than beginning anew with an intact structure.

The effect of high level structural (i.e. cladding) failures removing load from lower level structure (e.g. battens) is modelled by a hierarchical approach to assessing component failures at each wind speed. Roof sheeting connections are assessed first, and any necessary redistribution from failed roof sheeting connections is undertaken. Batten connections are then assessed and wind loads redistributed before roof structure connections are assessed. Similar approaches are used to determine failures in wall cladding, wall structure and lower storey structure.

Once the tool has determined which connections have failed, it transposes the extent of damage in a group of connections to a percentage damage for a building damage scenario such as loss of roof sheeting, damage to wall cladding, loss of roof structure, etc.

The tool's debris damage module calculates the damage from windborne debris.

The simulation tool's water ingress section calculates the damage to internal linings via predefined cumulative normal distribution curves relating water ingress to gust wind speed and degree of envelope damage.

A costing module then gives a total repair cost for the accumulation of damage scenarios at a particular gust wind speed. After the set maximum wind speed is reached, a new, undamaged, house is generated with new randomly selected parameters and the process repeated.

At the completion of the simulations of a user specified number of houses of the same basic type, each at a number of wind speeds, a vulnerability curve is generated and fragility curves calculated.

### *SUMMARY*

To date the tool has been developed to model the damage to roof sheeting, roof battens, roof structure, wall cladding, lower storey structure, damage from windborne debris, and damage from water ingress.

Data has been enabled into the tool for a single house type: a high-set, fibro clad Queenslander type house dominant in residential building structures in the 1960's and early 1970's from south-east Queensland to Darwin, typified by the house in Figure 4.

### *Interim list of identified requirements and upgrades to the VAWS software tool*

The following list of requirements and upgrades was developed during a project meeting held in April, 2016.

- VAWS to be able to run on a desktop computer
- VAWS to run under a Windows operating system
- Speed of computation should enable a 20 simulation run to complete in under 15s and a run with several thousand simulations to complete in tens of minutes.
- Structure down to roof / wall connection will be modelled.
- Wall collapse and racking will not be explicitly modelled, rather modelled by empirical relationships with roof loss.
- Output to store results from each simulation.
- Programme to be able to output heat maps of each simulation / wind speed combination.
- Logic and code for assessing internal pressurisation accounting for venting through loss of roof and downstream wall cladding to be developed.
- Programme to cater for failures of wall coverages due to wind pressure as well as debris impact (currently coded).
- Algorithm for redistributing loads following sheeting and batten failures to be re-examined.
- Algorithm for redistributing loads following roof structure failures to be re-examined with the aim of simplifying input data requirements.
- The programme need only consider buildings with plain rectangle plan shapes.
- The GUI is desirable as the visualisation of loss curves and heat maps are very useful for following damage progression.
- Necessity of editing input such as connection strengths 'on the fly' without editing input data files is confirmed.
- Noted that it is desired to simplify the costing module. The necessity of sourcing new QS data for the selected house types offers an opportunity to re-examine how VAWS calculates damage from a knowledge of failed connections.
- The following bugs will need to be addressed:
- Fitting a log-normal curve to the loss data causes the heat map to be wiped.
- The plan arrangement of wind directions on the heat maps appears to be orientated with north to the bottom of the page.
- The debris module logic has to be altered to correctly model the number of debris items generated at low wind speeds and small wind speed increments (currently models no debris items if a very small wind speed increment is chosen).

### *Investigations into the redistribution logic to date*

Investigations to date have focused on the implementation of redistribution of loads upon connection failure. The implementation of redistribution in the software currently imposes computational and input data imposts on the program. The issues associated with redistribution are discussed below.

### *Existing VAWS logic*

Currently in VAWS, forces in connections are related to pressures on *Zones* of cladding via influence coefficients with each connection being loaded by pressures on one or more zones. This works well while the structure is intact. However, once connections start to fail, the system becomes less representative of reality. For example, if a batten to rafter connection fails then the load path from the overlying zone to underlying roof structure is removed and load from the affected zone is redirected elsewhere.

VAWS attempts to account for the altered structural system by 'redistributing' at each wind speed step. The redistribution is undertaken as the last item before the wind speed is incremented.

For cladding and batten connections that have failed, load is redistributed to the next intact connection is each direction along the affected cladding sheet or batten as appropriate. The redistribution is achieved by apportioning the product of zone area and external pressure coefficient to the zones associated with the next intact connection and setting the zone area associated with the failed connection to zero. This logic is an attempt to model the loss of cladding as connections progressively fail.

For roof structure connections, the redistribution logic is to modify the influence coefficients for connections adjacent to the connection that has failed. Thus if a connection has failed on a particular rafter line, the influence coefficients for the remaining connections on that rafter line and the rafter lines to either side are updated. Once a connection has failed, influence coefficients for that connection are never updated, that is, a failed connection cannot attract further load. This logic requires a large input data file containing all the new influence coefficients required for each roof structure connection. Clearly it is impossible to provide a set of new influence coefficients for every possible combination of failed roof structure connections. The input data file of influence coefficient updates only considers a single roof structure connection to have failed; hence the requirement for the logic above whereby influence coefficients for a failed connection are never updated.

### *Shortcomings*

The current logic has several shortcomings:

- The system of using influence coefficients relating pressures on cladding zones to connection loads inherently leads to problems with modelling connection failures lower down in the structure than cladding connections.
- The redistribution logic used for cladding and batten connection failures makes no allowance for distribution to adjacent connections. For example, on the failure of a batten connection no allowance is made for some of the load being redistributed to adjacent intact cladding connections; all load is redistributed along the batten to the next intact batten connections.
- The input data file for influence coefficients for roof structure failures is large (>10,000 entries) even for a simple roof structure.

### *Options for improvement*

#### Option 1

The overall program logic is altered to remove the memory of damage from wind speed to wind speed. An undamaged house is modelled at each wind speed step (using the same properties generated before the first wind speed step), connections assessed for failure and repair cost generated as existing logic. This option substantially simplifies the input data requirements. Preliminary analysis suggests that while this modification may alter the predicted damage index from individual simulations, the effect on the mean damage index over a large number of simulations is minimal (Figure 9).

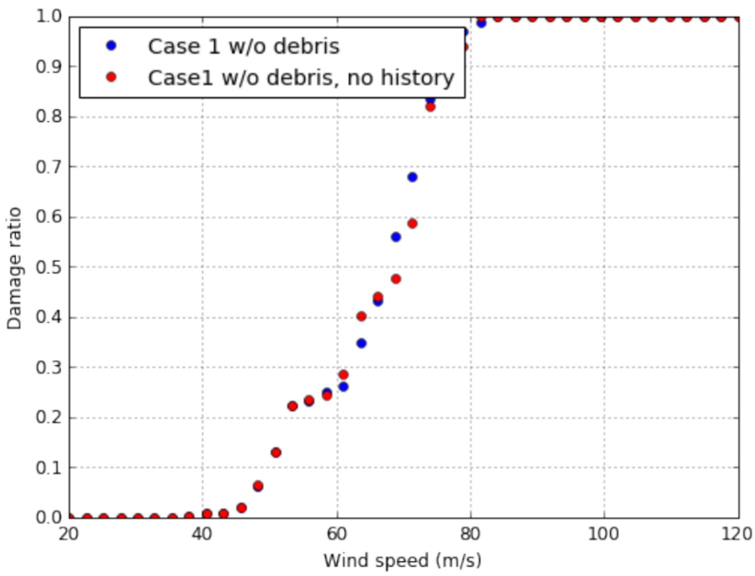


FIGURE 9 THE EFFECT OF MODELLING AN INTACT HOUSE AT EACH WIND SPEED (RED DOTS) COMPARED TO THE CURRENT CODE (BLUE DOTS). DEBRIS MODULE TURNED OFF.

#### Option 2

The overall program logic is altered to remove redistribution. All other parts of the code remain as currently coded. This option substantially simplifies the input data requirements. Preliminary analysis suggests that while the removal of redistribution functionality may alter the predicted damage index from individual simulations, the effect on the mean damage index over a large number of simulations is minimal (Figure 10). Further analysis indicates that this behaviour persists at smaller wind speed steps (Figure 11).

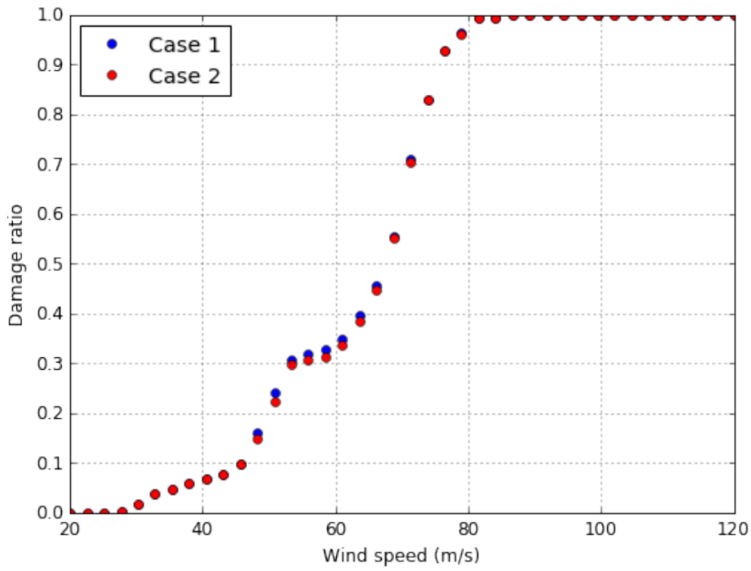


FIGURE 10 OUTPUT FROM VAWS FOR THE JCU GROUP 4 HOUSE WITH REDISTRIBUTION ENABLED AS CURRENTLY CODED (BLUE DOTS) AND DISABLED (RED DOTS).

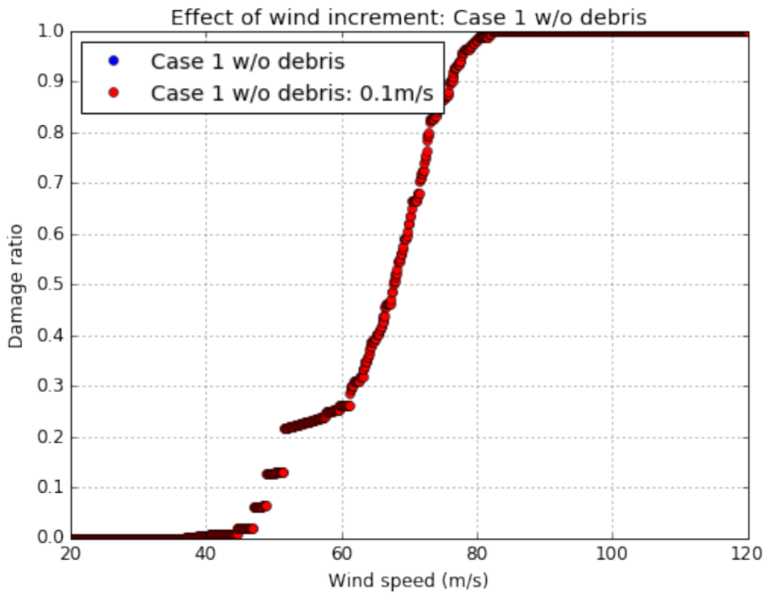


FIGURE 11 THE EFFECT OF REDUCING THE WIND SPEED STEP SIZE IS SHOWN TO BE MINIMAL.

## Option 3

Redistribution for cladding and batten connections remains as coded in VAWS but redistribution in the roof structure is not considered. Preliminary analysis indicates that this option has little effect on the mean damage index (Figure 12).

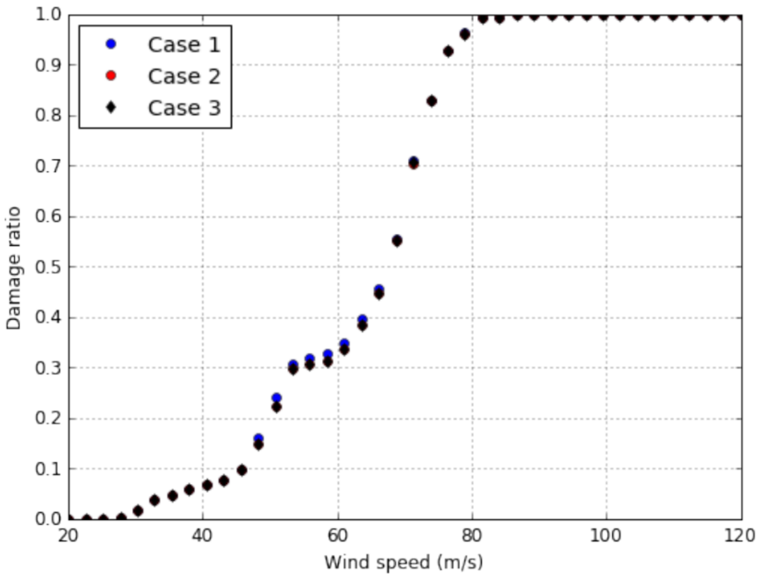


FIGURE 12 OUTPUT FROM THE CURRENT VAWS SOFTWARE WITH REDISTRIBUTION IN THE ROOF STRUCTURE TURNED OFF (BLACK DIAMONDS) COMPARED TO REDISTRIBUTION OCCURRING IN ROOF SHEETING, BATTENS AND ROOF STRUCTURE (BLUE DOTS) AND NO REDISTRIBUTION OCCURRING IN ANY ELEMENT (RED DOTS).

## Option 4

Influence coefficients are still used but instead of all influence coefficients relating pressure on cladding zones to connection forces, the influence coefficients relate connection force to where the force is coming from. That is:

- Cladding connection forces are related to pressures on cladding zones.
- Batten connection forces are related to cladding connection forces.
- Roof structure connection forces are related to batten connection forces.

Using this system of influence coefficients means that if, say, a batten connection fails then the load it applied to the underlying roof structure is automatically removed since a failed connection can carry no load.

The requirement to update influence coefficients for roof structure connections still exists with the redistribution logic remains as existing.

## Option 5

As for Option 3 but redistribution logic for cladding and battens is refined to account for shedding of load to lines of connections parallel to the line on which a failed connection lies. This will require considerable complexity as the proportion of load shed transversely to the member on which the failed connection lies will depend on (a) the existence of intact connections transverse to failed connection and (b) the number of consecutive failed connections. For example, consider a failed batten to rafter connection. If the roof cladding connections immediately upslope and downslope from it are not intact, minimal load will be shed through the roof cladding. On the other hand, if the failed connection comprises a string of four consecutive failed connections, the roof cladding will tend to carry more of the load as the batten has to span four bays and hence will be significantly less stiff.

Note that this entails a programming issue as failure of a batten to rafter connection requires modifications to cladding connection influence coefficients. Hence the program needs to know which cladding connections are related to a particular batten connection. This may require an additional input data file.

This option does nothing to reduce the requirement for a roof structure influence coefficient update file, nor the approximate way of dealing with successive roof structure connection failures.

## Insurance Claims Analysis

A direct relationship between observed damage modes and societal cost is needed to inform cost-benefit analysis of retrofit mitigation solutions. In a research effort supported by Suncorp Group Limited, policy data from one insurer in the North Queensland region of Australia during Cyclone Yasi (2011) were analysed to identify correlations between claim value, typical damage modes, and construction age. This was achieved by extracting qualitative and quantitative insights from aggregated insurance policy data from one insurer at the time of the event. The aggregated data included information on policies both with and without a claim for Cyclone Yasi. The regional analysis, including a wind map for the most severely affected area, is included in Figure 13.

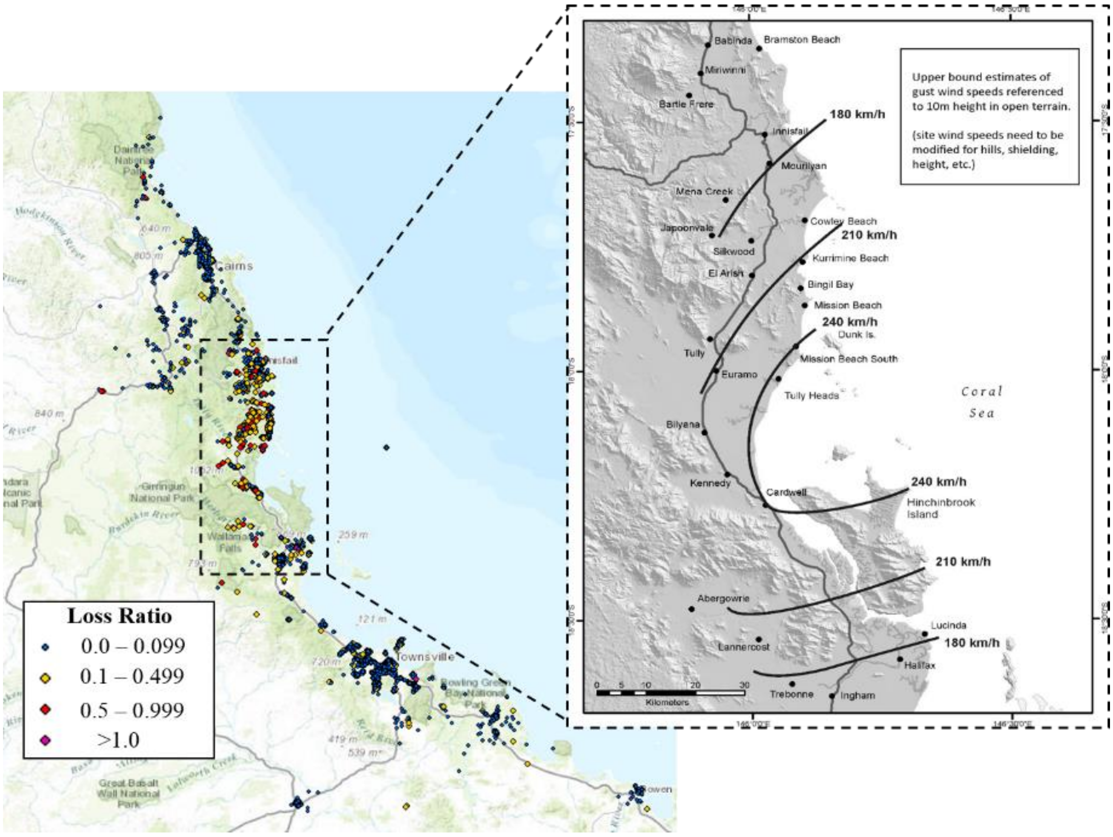


FIGURE 13. NORTH QUEENSLAND COASTAL REGION IMPACTED BY CYCLONE YASI (2011) WITH DISTRIBUTION OF CLAIMS SUBDIVIDED BY FOUR LOSS RATIO BINS (CLAIM VALUE/INSURED VALUE) AND WIND FIELD ESTIMATION [6] (SMITH ET AL. 2015 "INSURANCE LOSS DRIVERS AND MITIGATION FOR AUSTRALIAN HOUSING IN SEVERE WIND EVENTS")

To isolate a relatively high population of housing subjected to a similar wind field characteristics (i.e. velocity, direction, and duration) and rainfall intensity, preliminary analysis focused on the Townsville region. Peak 3-second gust wind speed measured at the Townsville airport weather station (10 m) was 135 km/h during Cyclone Yasi.

To estimate the benefits of the selected mitigation solutions, vulnerability of North Queensland homes to cyclone-induced damages was estimated (before and after mitigation upgrade) based on year of construction. Three groups were established (pre-1960s, 1960-80s, post-1980s) based on typical construction trends in each era. Three mitigation solutions were analysed:

- Structural roof upgrading (i.e. connection upgrades, etc.) (pre-1960s and 1960-80s only)
- Opening protection (i.e. window shutters, roller door bracing, etc.)
- Community preparedness (i.e. unblocking roof-gutters, removing shade coverings, etc.)

The cost of implementing mitigation solutions was estimated via component costs, claims data, and scenario based estimates by selected builders and assessors.

Research found that the presence of coordinated, planned and implemented mitigation programs in Australia with the aim of increasing homeowner engagement in mitigation strategies to strengthen their home is lacking. Also a "one size fits all" approach to mitigation programs is not appropriate as individuals are motivated by different incentives.

Programs must be appropriately marketed to individuals and communities based on identified key motivators for engaging in mitigation strategies. These motivators will differ between individuals and communities based on their level of experience with extreme weather events, perceptions of risk and responsibility, connectedness and trust towards others and the availability of assistance and resources. Research is needed to characterise key motivators for Northern Australia communities so that a future mitigation program is efficient and optimised for community engagement.

Based on the literature review and CTS experience as a long-term proponent for cyclone mitigation practices, two frameworks for a mitigation program are outlined in the report. The first includes a more traditional approach where inspections are completed by a qualified inspector, while the second makes use of smart-phone technologies allowing consumers to "self-assess" with periodic "spot checks" for quality assurance and continued improvement to the process. An effective mitigation program may also require a combination of the options considered.

There is an opportunity for the whole community to benefit from an increased focus on mitigation:

- Homeowner – increased security during storm, promoted increase in house market value if retrofits undertaken, reduction in insurance premiums
- Government – reduction in drain on community services during and after severe event, more resilient community
- Industry – niche market for retrofitting and upgrading products as well as the building trades to professionally undertake retrofitting

The report detailing the results is; Mitigation benefits for resilience of homes

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