17th Australasian Wind Engineering Society Workshop
Wellington, New Zealand
12-13 February, 2015

Improving the Wind Resistance of Australian Legacy Housing

D.J. Smith, D.J. Henderson and J.D. Ginger

Cyclone Testing Station
James Cook University, Townsville, Queensland 4811, Australia

Abstract

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.

Introduction

Tropical Cyclone Tracy resulted in extreme damage to housing in December 1974, especially in the Northern suburbs of Darwin (Walker, 1975). 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 realization of the need to provide adequate strength in 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) in NT, QLD, and WA, from cyclones over the past fifteen years have shown that the majority of houses designed and constructed to current building regulations have performed well structurally by resisting wind loads and remaining intact (Reardon et al, 1999; Henderson and Leitch, 2005; Henderson et al, 2006; Henderson et al, 2010; Boughton et al, 2011). However, these reports also detail failures of contemporary construction at wind speeds below design requirements. The poor performance of these structures (Figures 1 and 2) resulted from design and construction failings 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 all ages of housing.

This research project is in the preliminary stages. Therefore, the current paper is an initial review with focus on cyclonic regions of Australia, although the overall project encompasses housing types across the country. The work will:

- Categorize 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.

Figure 1. Removal of roof cladding and battens from the windward face of a residential structure.

Figure 2. Roof cladding section flipped to leeward side with battens still attached.

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 in determining the positive and negative pressure loads the structure must resist. The wind duration and temporally varying forces are important in assessing elements of the envelope and frame (i.e., roofing, battens, connections, etc.) that may suffer degradation from load cycle fatigue.

Maintaining a sealed building envelop is critical to the wind resistance of structures. If there is a breach on the windward face, (i.e., from broken window or failed door) (Figure 3), 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 envelop. 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 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 (2014) 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.

Figure 3. Typical lock and damaged door after being blown inward during Cyclone Yasi in 2011.

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 (Henderson and Harper, 2003).

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 (Edwards and Wehner, 2014). Vulnerability models for these types of building systems will be derived.

AS/NZS 1170.2 provides information for selecting the design wind speed related to the return period. Using vulnerability curves developed by CTS, Figure 4 shows the percentage of housing damaged versus the return period for 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 to the wind resistance of contemporary post-1980s houses.

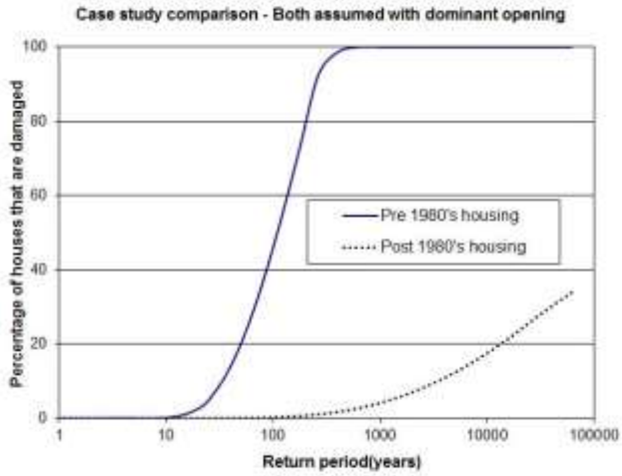

Figure 4. Vulnerability curves for pre-1980s and post-1980s residential structures with increasing return period (King et al, 2013).

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 over 20 houses built in the 1970s and 1980s in the tropics. Although the majority of surveyed houses appeared in an overall sound condition, the majority (all but two) had potential issues like decay of timber members, corrosion at a 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. This study confirmed that retrofitting for improved wind resistance is only part of the process. Ongoing maintenance is also an important part of improving our community's resilience in severe weather.

Existing Upgrade Provisions

There are existing guidelines for upgrading of older houses in the form of handbooks (HB132) published by Standards Australia in 1999. However, the uptake of prescribed details in these handbooks has not been effective in light of recurring severe wind damage to older structures. These details and methods will be reviewed to consider reasons for lack of use. This project will access state of the art knowledge to improve the literature detailing general upgrading of structural connections in houses and other similar buildings. Where appropriate, it will also include targeted structural upgrade details for more specific types of housing. This study will also provide an opportunity to assess what amendments might be warranted to current literature. The effectiveness of current literature in supporting upgrading of older houses and whether other mechanisms may be needed to support implementation will also be considered. The involvement of stakeholders (i.e., professional builders associations, insurers, ABCB, BCQ, etc.) will be sought for input.

If initial findings from surveys and engagement with stakeholders show that the biggest impediment to upgrading is that the existing HB132 details are all too expensive, excessive, and in home owners eyes not aesthetic (Figure 5), then subsequent research should focus on development of new details. However, if the results indicate that the details are acceptable, but that there is no incentive to apply them or there is lacking understanding of reasons for upgrading and maintenance, then the research will focus on development of information to inform mitigation decisions including dedicated web-based strategies to educate homeowners, designers, and builders.

Vulnerability studies combined with cost benefit analysis are a critical component to informing mitigation. This work will include analysis from wind tunnel model studies and load tests, and construction and load testing of "upgraded" representative sections of housing for both proof-testing and generating video material for education and guides.

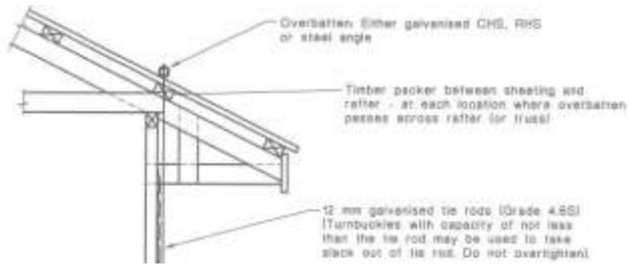

Figure 5. Stud frame external tie rod (i.e. overbatten) detail per SAA HB132.2 "Structural upgrading of older houses – Part 2: Cyclone areas"

Effectiveness of Existing Upgrade Provisions

An online survey was distributed nationally to members of Building Codes Queensland (BCQ), Housing Industry Association (HIA), Master Builders Association (MBA), Australian Institute of Building Surveyors (AIBS), BNHCRC, and AFAC. Objectives of the survey were to estimate the extent of HB132 usage and determine what other references/practices (if any) are used in retrofit construction.

From research and informal interviews with builders, regulators, and homeowners it was apparent that common themes of limited knowledge and access to appropriated retrofitting literature may be a factor. This information helped inform the basis of the survey.

The survey was 12 questions and included both short answer and multiple choice responses. The breakdown of question topics was as follows:

- Participant occupation/location = 3 questions
- Typical retrofit practices and literature = 3 questions
- Format preference for literature = 1 question
- Knowledge of HB132 and its effectiveness = 4 questions

As a closing question, participants were also provided the opportunity to leave a name and contact information for project updates and future work. The survey was distributed via email or social media to the members of each participating organization.

A total of 245 survey responses have been collected to date. However, participants were not required to answer all questions thus response totals vary. The occupations of 221 participants were predominantly certifiers (65%), regulators (24%), and builders (10%). Other occupations included engineers (5%), architects (3%), homeowners (3%), and roofers (<1%). Additional responses (36 total) were collected via an "other occupation" comment box that included building inspectors, designers, and surveyors.

The state/territory in which participants performed their occupation was recorded for 244 participants. The majority of responses were from Queensland (38%) and New South Wales (20%). A significant number of responses were also recorded for Victoria (14%), Western Australia (11%), and South Australia (10%). Responses from Tasmania, Australian Capital Territory, and Northern Territory totalled approximately 3% each.

Participants were asked to provide their formatting preference for occupational reference literature. Over 62% of participants prefer access to both hardcopy and electronic versions of reference materials, 28% prefer electronic only, and 10% prefer hardcopy only. Based on these results, an effective guide for construction retrofit techniques should be developed with strong consideration of both electronic and hardcopy distribution.

AS 1684 Residential Timber Framed Construction is a four-part Australian Standard covering design criteria, building practices, tie-downs, bracing and span tables for timber framing members. It is the primary reference publication for housing throughout Australia during new construction projects. Although the standard does not address retrofit construction practices, it is often used for reference during structural upgrading of existing residential structures. In order to determine the extent to which this occurs, participants were asked if AS 1684 is referenced during alteration or reroofs to timber framed structures. Of the 240 responses recorded for this question, over 84% claimed to use AS 1684. In contrast, when participants were asked whether or not they were familiar with HB132, 91% responded they were not. Therefore, nearly all of the Australian residential construction industry is utilizing a reference document that is not designed for retrofitting and furthermore are unaware that a document d for retrofitting does exist.

If participants indicated they were familiar with HB132, they were asked to comment on utility of the document. Of the 22 responding participants, 27% found HB132 "very useful", 36% found it "somewhat useful but could be improved", and 36% found it "not useful at all". When asked why they found HB132 useful or not, typical responses included "details are not architecturally acceptable to clients" and "the cost of each part of HB132 is $70, as it is only an advisory document, this is a disincentive for its use".

Participants were asked to identify what improvements could be made to HB132. A total of 19 responses were recorded. Most indicated that the cost of access to HB132 is too expensive. Furthermore, because HB132 is a handbook as opposed to a statutory document, there is reduced motivation for purchasing it. One response suggested moving the retrofit details "into AS1684 so more people know about them".

The preliminary survey results indicate that cost, requirements for use, literature format, and architectural acceptability of structural details are all critical to uptake of proper retrofitting techniques. Each of these factors will be used to ensure appropriate outputs for the project.

Conclusions

Due to the preliminary state of this research project, conclusive findings are not yet available for discussion. While the HB132 survey data has provided valuable insight into factors limiting the dissemination of proper retrofit techniques, the survey is still underway and therefore the analysis is incomplete. It is hypothesized that the uptake of retrofitting and maintenance of housing structures will increase community resilience and reduce the needs of response and recovery following severe wind events. It is important that homeowners understand the positive outcomes of retrofit investment. Vulnerability modeling will be used to estimate the structural benefits of proposed retrofit techniques. Incentives to encourage homeowner participation through insurance and government initiatives can be developed based on the economic modelling from this project.

Acknowledgments

The authors would like to thank the Bushfire and Natural Hazards Cooperative Research Centre for sponsoring the research. Additional thanks to Master Builders Association (MBA), Building Codes Queensland (BCQ), Housing Industry Association (HIA), Australian Institute of Building Surveyors (AIBS), and the Australasian Fire and Emergency Service Authorities Council (AFAC) for project support and assistance in distributing the online survey. This research will be presented with updates and further detail at the 14^{th} International Conference on Wind Engineering in June 2015.

References

Boughton G., Henderson D., Ginger J., Holmes J., Walker G., Leitch C., Somerville L., Frye U., Jayasinghe N. and Kim P., (2011) Tropical Cyclone Yasi: Structural damage to buildings, Cyclone Testing Station, James Cook University, Report TR57. http://www.jcu.edu.au/cts/research_reports/index.htm

Edwards, M. and Wehner, M. (2014), Improving the Resilience of Existing Housing to Severe Wind Events - Preliminary Building Schema, BNHCRC progress report, GEOSCIENCE AUSTRALIA, ACT

Henderson, D.J. and Ginger, J.D. (2008). Role of building codes and construction standards in windstorm disaster mitigation. Australian Journal of Emergency Management, Vol 23 No 2

Henderson, D., Ginger, J., Leitch, C., Boughton, G. and Falck, D. (2006) Tropical Cyclone Larry – Damage to buildings in the Innisfail area. Cyclone Testing Station. Townsville, James Cook University.

Henderson, D. and Harper, B. (2003). Climate Change and Tropical Cyclone Impact on Coastal Communities' Vulnerability. CTS Report TS582 for Dept Emergency Services and Dept Natural Resources and Mines, Queensland Government_http://www.longpaddock.qld.gov.au/about/publications/vulnerabilitytocyclones/stage4.html

Henderson, D. & Leitch, C. (2005) Damage investigation of buildings at Minjilang, Cape Don and Smith Point in NT following Cyclone Ingrid. Cyclone Testing Station, Townsville, James Cook University.

Henderson, D.J., Leitch, C., Frye, U., Ginger, J.D., Kim, P., Jayasinghe, N.C., (2010). Investigation of Housing and Sheds in Procerpine, Midge point, and Airlie Beach, Following Tropical Cyclone Ului. Cyclone Testing Station, James Cook University, Townsville.TR 56.

Henderson, D. & Somerville, L. (2012) TIO Housing survey (Built 1975 to 1980). TS859, Cyclone Testing Station, Townsville, James Cook University.

King D, Ginger J, Williams S, Cottrell A, Gurtner Y, Leitch C, Henderson D, Jayasinghe N, Kim P, Booth K, Ewin C, Innes K, Jacobs K, Jago-Bassingthwaighte M & Jackson L (2013) Planning, building and insuring: Adaptation of built environment to climate change induced increased intensity of natural hazards. National Climate Change Adaptation Research Facility (NCCARF), 361 pp. ISBN: 978-1-921609-75-6

Reardon, G., Henderson, D., Ginger, J., (1999). A structural assessment of the effects of Cyclone Vance on houses in Exmouth WA Cyclone Testing Station. 1999, James Cook University, Townsville.TR48.

Standards Australia (1999). HB 132.1:1999 Structural upgrading of older houses, Part 1: Non-cyclonic areas, Standards Australia, Sydney, NSW

Standards Australia (1999) HB 132.2:1999 Structural upgrading of older houses - Part 2: Cyclone areas, Standards Australia, Sydney, NSW

Standards Australia (2011), AS/NZS 1170.2:2011 Structural design actions Part 2: Wind actions, Standards Australia, Sydney NSW, Australia.

Standards Australia (2011), AS 4055 Wind Loads for Housing, Standards Australia, Sydney, NSW.

Standards Australia (2010), AS 1684.3:2010 Residential timber-framed construction – Cyclonic areas, Standards Australia, Sydney, NSW, Australia.

Walker, G. (1975). Report on Cyclone Tracy – Effect on buildings – Dec 1974. Australian Dept of Housing and Construction.