Nineteenth Australasian Wind Engineering Society Workshop, April 4-6, 2018, Torquay, Victoria

Modelling Residential Mitigation Effectiveness for Severe Wind

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ABSTRACT

Modelling the effectiveness of retrofit to legacy houses requires a quantitative estimate of the houses' vulnerability to severe wind and how the vulnerability is affected by mitigation work. Historical approaches to estimating vulnerability through either heuristic or empirical methods do not quantitatively capture the change in vulnerability afforded by mitigation. To address this information gap the Bushfire and Natural Hazards CRC project "Improving the Resilience of Existing Housing to Severe Wind Events" has augmented a software tool which models damage from wind loads and associated repair cost. In this paper the development process is described including the establishment of a suite of test cases to assess the effectiveness of the software. An example of the validation work is presented along with the augmentation of the software from the previous version. Finally, use of the software in assessing the incremental effectiveness of a range of mitigation strategies in economic terms is described.

1. Introduction

The resilience of Australian communities to severe wind events is greatly influenced by the vulnerability of community assets. This is particularly the case for residential dwellings which are the primary place of shelter for households. Severe storm events, such as TC's Larry, Yasi and Debbie, continue to highlight the high vulnerability of some older residential building types in regions of high wind hazard. Information is needed on cost-effective measures to make these structures more resilient.

Modelling the effectiveness of mitigation requires knowledge of the vulnerability of building assets and how this changes with selected mitigation actions. In Australia past efforts at establishing vulnerability relationships between building damage and severe wind have centred on empirical data regression from damage surveys or insurance losses and heuristic techniques, for example Smith et al (2016), Smith et al (in prep), Wehner et al (2010-1). While these techniques provide valuable insights into existing vulnerability, neither of these methods quantitatively model the reduction in vulnerability achieved by mitigation work.

The Bushfire and Natural Hazards CRC (BNHCRC) project "Improving the Resilience of Existing Housing to Severe Wind Events" is led by James Cook University (JCU). The project is developing a software tool called Vulnerability and Adaption to Wind Simulation (VAWS) through the project partner Geoscience Australia which is integrating JCU research to give quantitative vulnerability models for Australian house types.

2. The software tool

The software tool, VAWS, was originally developed during 2009 and 2010 under a project partly funded by the then Department of Climate Change and Energy Efficiency. The tool's overall logic is summarised in Wehner et al (2010-2). Current development has augmented the original tool to improve computational performance, update the logic to model structural behaviour more realistically, improve usability and extend the range of building types which can be modelled.

It is based on the premise that overall building damage is strongly related to the failure of key connections or key envelope component failures that may promote internal pressurisation. The software uses a Monte Carlo approach whereby numerous realisations of a single generic house type are subjected to an increasing gust wind speed and the loss at each wind speed is calculated. Each realisation of the house varies from others as many key building parameters, such as connection strengths, external pressure coefficients and wind direction are sampled from probability distributions. The modelling of mitigation options is readily accomplished by re-analysing a house modelled with upgraded connection strengths from a probability distribution.

The structural behavior of domestic house structures loaded by wind is complex with non-structural components such as plasterboard linings, roofing and fascia boards carrying considerable portions of the load. Furthermore the roof structure is redundant with significant load sharing between rafters afforded by relatively stiff battens. This behavior has been investigated by full scale testing and detailed finite-element modelling by JCU, for example Satheeskumar et al (2017-1) and Satheeskumar (2017-2). VAWS does not attempt to model the structural complexity directly. Rather it uses influence coefficients to relate loads on envelope zones or connection forces to forces in other connections. The influence coefficients are derived from the testing and modelling noted above and form part of the input data to VAWS.

VAWS models debris induced damage as direct damage requiring repair and also as a method by which openings in the envelope are created leading to internal pressurisation. The debris model logic is described in Holmes et al (2010) and Wehner et al (2010-3). Recent work to VAWS has enabled assessment of internal pressurisation following the logic in AS1170.2 (Standards Australia (2011)) with openings in walls created either by debris impact or direct wind pressure induced failures of wall cladding or doors.

Besides structural damage and debris impact, damage can also occur during a severe wind event from water ingress. Water ingress is a complicated issue to model directly. The degree of water ingress depends on rainfall intensity, droplet size, wind speed, size and location of envelope openings, etc, as reported in Pita et al (2012). As a further complication interior linings and fittings which may be damaged by water ingress may have already been damaged by failure of the building envelope and structure. VAWS models loss due to water ingress empirically using the relationships, shown in Figure 1, which relate degree of water ingress to gust wind speed and degree of envelope damage. Once the degree of water ingress is determined, the consequential repair cost is determined from tables of repair costs dependent on degree of water ingress and envelope damage state, and then added to the repair costs for structural damage, envelope damage and debris damage.

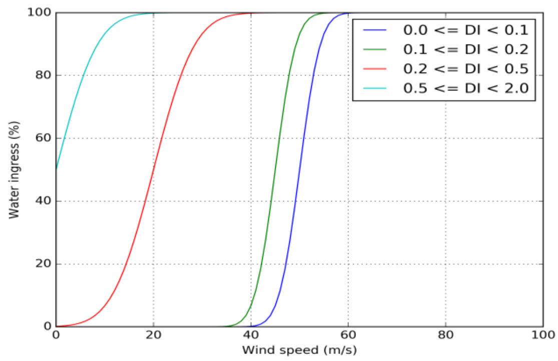

Figure 1. Curves used to determine degree of water ingress from level of envelope damage and gust wind speed. ‘DI’ is the damage index determined considering structural and envelope damage alone

3. Outputs

The primary outputs of VAWS are vulnerability and fragility curves fitted to the numerous data points generated by the Monte Carlo process. However, other outputs are also available. For example, heatmaps of wind speeds at which connections fail can be displayed either as the average failure wind speed across all instances analysed in the Monte Carlo process or for a single instance. These are particularly useful for validating the damage progression and the program logic.

Figure 2 and Figure 3 show output from VAWS for a fictitious hip-ended roof for failure wind speeds for roof sheeting and batten connections respectively. Batten connection 78, shown in Figure 3 was modelled as a weak batten (strength about 75% of other batten connections). All other connections were of uniform strength. External pressure coefficients, $C_{pe,}$ values to the upper and left-hand sections of the roof were modelled as artificially low to limit connection failures to the lower section of the roof. The C_{pe} value for the zone above connection 22 was modelled as double that elsewhere to ensure that failure initiated in both battens and roof sheeting at that location. Roof sheeting connection failure can be seen to commence at the highest loaded connection and cascade up and down roof cladding sheets until reaching the end of a sheet at a ridgeline or eave. Similarly, batten connection failure initiates at the highest loaded connection and cascades along the batten with increasing wind load until reaching the gable end or ridge line.

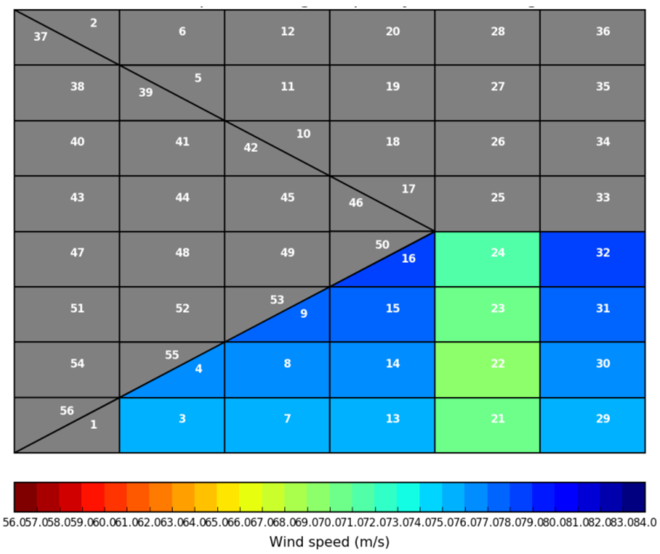

Figure 2. Plan view of a heatmap of failure wind speeds for roof sheeting connections for a hip-ended roof

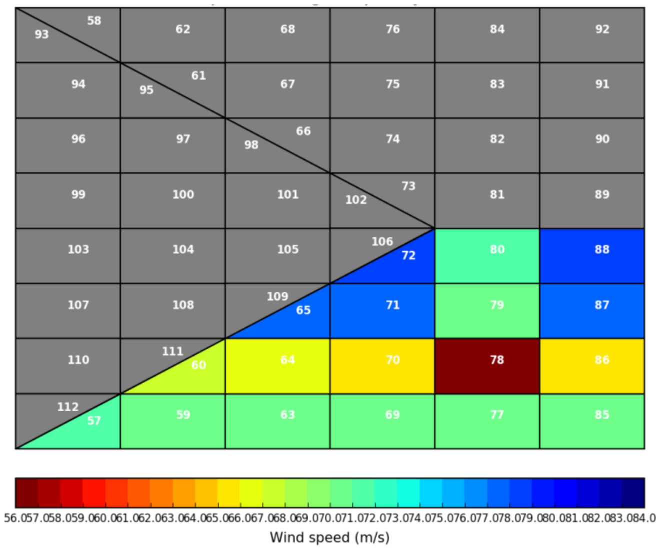

Figure 3. Plan view of a heatmap of failure wind speeds for roof batten connections for a hip-ended roof

4. Estimation of Benefit / Cost of Mitigation Work

The process of assessing the benefit / cost of mitigation work follows the following sequence.

1. A proposed retrofit, or set of retrofits, are identified, as illustrated in Figure 4. Retrofit could consist of installation of cyclone washers, refixing battens to rafters, upgrading door furniture or a complete upgrade of the whole roof structure to be modern code compliant. Once the retrofit work is identified, the work is costed including any necessary access work such as scaffolding, removal and reinstatement of linings, etc. Different timings for carrying out retrofit work can be explored, such as the option to undertake retrofit work whilst the roof sheeting is being replaced for other reasons.

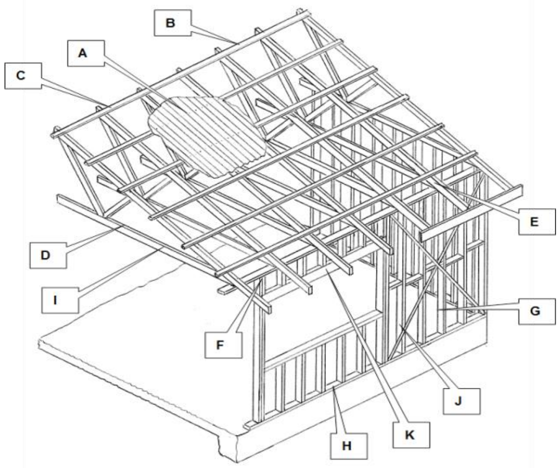

Figure 4. Example of locations of mitigation options in a timber framed house

2. Vulnerability curves are produced using VAWS for the baseline, unmitigated house and for each retrofit scenario. This will produce a family of vulnerability curves such as is representatively in Figure 5.

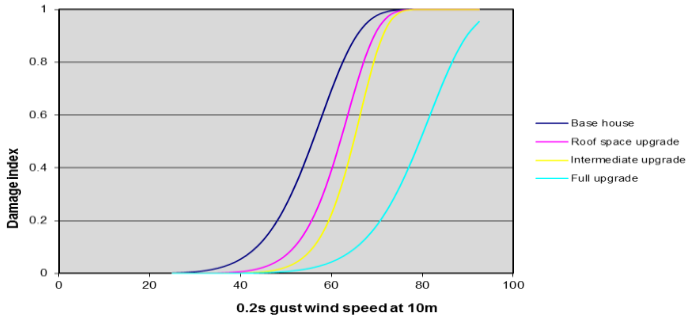

Figure 5. Family of vulnerability curves for a base house and three retrofit options

3. Vulnerability curves are transformed to a Dollar loss – Probability curve.
4. Annualised loss is calculated as the area under the Dollar loss – Probability curve. This is the annualised loss to the physical house fabric.
5. Benefit is calculated as the sum over the house's remaining lifetime of the difference in annualised loss between the unmitigated house and the retrofitted house for each year discounted to current value.
6. Benefits other than savings in repair of damage to the house fabric can be added. These consider avoided costs such as temporary accommodation, medical care and lost productivity arising when people are displaced from their homes due to wind-induced damage.

5. Conclusion

The BNHCRC project "Improving the Resilience of Existing Housing to Severe Wind Events" has developed a software tool to quantitatively model the vulnerability of Australian houses to severe wind. Simultaneously, experimental work and finite element modelling has been undertaken to develop input data for the software tool so that a range of generic house types can be modelled, each with a variety of retrofit options.

Currently the VAWS software is under calibration against existing damage survey results and documentation is being completed. Input data are being assembled for the first of the generic house types planned to be examined by the project.

The outcome will be an evidence base for mitigation investment and an open source software tool that can be further developed by others.

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