Development of a software tool for quantitative assessment of the vulnerability of Australian residential building stock to severe wind

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1 INTRODUCTION

Knowledge of the degree of damage to residential buildings caused by severe wind can be used to study the benefits from adaptation strategies developed in response to expected changes in wind severity due to climate change and inform government, the insurance industry and emergency services of estimates of expected damage. Geoscience Australia, together with its collaborators the Cyclone Testing Station at James Cook University and JDH Consulting, have commenced development of a software tool, called WindSim, to quantitatively model the vulnerability of residential buildings to severe wind. The hazard parameter is taken as the 3 second gust wind speed at 10m height at the location of the building ($V_{10m,3sec}$). This paper describes the overall logic of the tool and presents typical results that the tool can generate.

2 SIMULATION TOOL LOGIC

2.1 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 with values for component/connection strengths, external and internal pressure coefficients, shielding coefficients, wind speed profile, building orientation, debris damage parameters, and component weights randomly sampled from predetermined probability distributions. Then, for successively increasing 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. Finally it evaluates the damage scenario repair costs and thus 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 revise 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 (i.e. batten) is modelled by a hierarchical approach to assessing component failures at each wind speed. Roof sheeting connections are assessed first, and any necessary distribution from failed roof sheeting connections is undertaken before loads are calculated on batten connections, which are then assessed and redistributed before loads on roof structure connections are calculated, and the connections assessed. Hence if an area of roof sheeting were to fail (lift off), the underlying battens and rafters would not receive any load from that area. 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 relates 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 section calculates the damage from windborne debris [1, 2].

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, intact, house is generated with new randomly selected parameters and the process repeated.

At the completion of the simulation 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 (Figs 1 and 2).

2.2 Probability distributions for an example residential building

Various types of probability distributions are used in the tool to generate wind loading and house component strength parameters.

2.2.1 *Wind speed profiles.*

Variation in the profile of wind speed with height is captured by the random selection of a profile from a choice of 10 profiles for a given terrain category [3]. The wind speed used for vulnerability curves is the 3 second gust at 10m height, however calculation of wind loads requires the wind speed at mid-roof height. The appropriate factor to account for the change in wind speed from 10m to the house's mid-roof height is selected from the sampled profile.

2.2.2 *Shielding coefficients.*

Variability in shielding to a house within its surroundings is accounted for by modifying the incident wind speed. The modifying factor is randomly chosen from a population of shielding coefficients for suburban houses developed from suburban wind speed field observations [4]. Variability in the degree of shielding applied to different house surfaces is accounted for, modifying the external pressures using factors obtained from wind tunnel experiments [4].

2.2.3 External and internal pressure coefficients.

Pressure coefficients for different zones of the house surfaces are randomly chosen from a Type III extreme value distribution with specified mean values for different zones of the house envelope, and specified coefficients of variation for different load effects: cladding, structural member, internal pressure (no openings), and internal pressure (with openings) [5]. The tool samples pressure coefficients for every zone of each house surface for each wind direction and each load effect; approximately 6,500 coefficients.

2.2.4 Building orientation.

For each simulated house, its orientation with respect to the wind is chosen from the eight cardinal directions either randomly, or as specified by the user.

2.2.5 *Connection strengths.*

Connection strengths for generated houses are randomly sampled from log-normal probability distributions for each type of connection. The mean and coefficient of variation values have been developed from testing and damage survey work [6].

3 RESULTS AND CALIBRATION

Examples of the simulation tool output are given in Figs 1 and 2 for a Queensland high-set, fibro clad type house with corrugated steel roof cladding, timber battens at 900mm centres and timber framed roof structure consisting of timber rafter pairs at 900mm centres with collar ties to every second pair. The roof structure connections modelled are rafter to top plate, rafter to ridge board and collar tie to rafter. The outputs are given in two parts:

- A graphical view of results of Damage Index (DI) versus wind speed with a fitted vulnerability curve. Results from simulations on 20 houses (simulations at each wind speed increment approaching from a single direction) are shown in Figure 1. The curve is described by Eq. (1) fitted to the mean DI values.

$$DI = 1 - \exp\left[- \left(\frac{V_{10m,3\,\sec}}{e^{\beta}} \right)^{\frac{1}{\alpha}} \right] \tag{1}$$

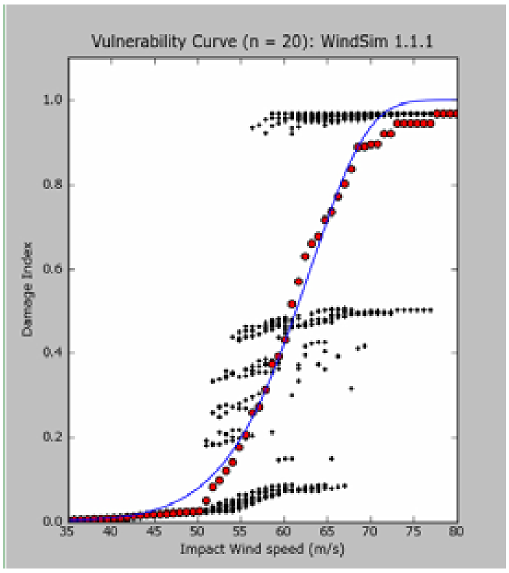

Fig 1. Output of simulation tool showing the DI versus $V_{10m,3sec}$ (m/s) vulnerability curve. The small black dots are individual simulation - wind speed increment results. The large red dots are mean DI at each wind speed increment. The large gap in results between DI of about 0.5 and 0.9 is due to collapse of walls and lower storey structure.

- A graphical view of calculated Fragility Curves for slight, medium and total damage is shown in Figure 2.

The simulation tool is calibrated by comparing the results of the Queensland high-set house type to damage outcomes observed following cyclones. Post disaster damage investigations describing the performance of the high-set house type are predominantly limited to Cyclone Althea, which hit Townsville in 1971 [7] and Cyclone Tracy which made landfall in Darwin in 1974 [8]. The calibrations are conducted by comparing damage extent on a given house as well as the overall percentage of failure for the housing stock [9].

4 CONCLUSIONS

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. Current and future work will involve extending the scope of the tool to include damage to wall structure, as well as calibrating results against damage observed during post-storm surveys.

Data has been developed for a single house type: a high-set, fibro clad type house dominant in residential building structures in the 1960's and early 1970's from north Queensland to Darwin. Current and future work will involve assembling data sets for two further building types: a portal frame industrial shed typical of north Queensland and a two-storey tiled-roof brick veneer house typical of western Sydney.

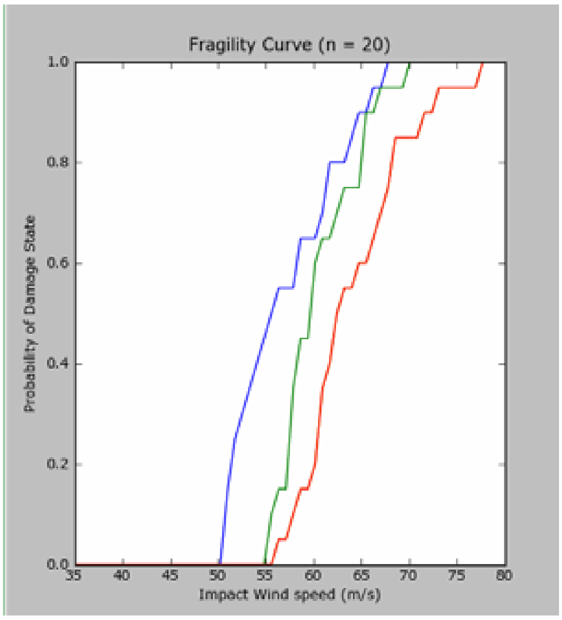

Fig 2. Output of simulation tool showing fragility curves calculated from the results shown in Figure 1. The curves capture the spread of results about the mean vulnerability curve and show the proportion of houses expected to suffer no damage, slight damage, medium damage, and total damage at each wind speed. The stepped nature of the curves results from the low number of simulations (20 in this case). The DI defining each level of damage is arbitrarily set.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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