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Using the principles of wind engineering to estimate the resilience of existing strata buildings

Dr Geoff Boughton[1], Dr Saira Viqar[2], Debbie Falck[3], Dr Geeth Bodhinayake[4]
Cyclone Testing Station, College of Science, Technology and Engineering,
James cook University, Townsville, QLD 4811.
[1] geoffrey.boughton@jcu.edu.au; [2] saira.viqar@jcu.edu.au;
[3] debbie.falck@jcu.edu.au [4] geeth.bodhinayake@jcu.edu.au;

ABSTRACT

In 2016, the Australian Government committed funding for research and other projects to improve the resilience of buildings in tropical cyclone-prone communities, and to develop opportunities to make insurance for strata buildings more affordable. The Cyclone Testing Station has developed models that estimate the resilience of strata buildings to damage from wind, wind-driven rain, and storm tide in future tropical cyclones. The paper discusses these models in the context of resilience.

1. Introduction

Over the last 15 years, tropical cyclones in North Queensland have caused damage to residential buildings that have resulted in a large number of insurance claims. The cost of insuring residential strata buildings in North Queensland has increased significantly. The Cyclone Testing Station (CTS) at James Cook University has developed a structural engineering model that can estimate the likely performance and resilience of properties in future tropical cyclones. The model is based on the knowledge of the performance of building products and systems gained from detailed damage investigations by CTS teams following previous tropical cyclones, research, and commercial testing programs. (Henderson *et al* (2006), Boughton *et al* (2011), Boughton *et al* (2017)) Typical damage to strata properties in previous tropical cyclones has included wind damage to the roof, windows and glass sliding doors, glass balustrades; extensive damage to ceiling and wall linings from wind-driven rain entering the building; and damage from storm surge or vegetation to swimming pools, fences, and other items within the grounds.

The outcome of the project is a tool to assess the likely resilience of properties to a future tropical cyclone and provide owners with a report that includes resilience scores and mitigation options tailored to reduce the risk of damage to any vulnerable items in the property in a future event. (James Cook University (2021)). Each type of building on a property is evaluated separately. Building types include multi-storey apartment complexes; single-storey units; townhouses; large garages, carports, and sheds.

1.1 Resilience and resilience categories

'Resilience' in the context of the model developed for this project is related to functionality, strength and robustness; resilience is the extent to which a building can remain mostly undamaged and functional during and after a tropical cyclone. Buildings that are resilient will require minimal repairs to return them to service. Five categories are used to assess the resilience of a property: grounds, wind, rainwater, storm tide, and ancillaries, as described below.

Grounds resilience

Grounds resilience refers to the ability of different structures on the property (not the main building/s) to withstand the wind and storm tide forces generated during a tropical cyclone. It includes items such as free-standing carports, sheds, large trees, fences, and swimming pools. The grounds resilience is mostly affected by the number and condition of items on the property.

Wind resilience of a building

Wind resilience refers to how well the components of a building can resist wind loads and impact from wind-borne debris and remain mostly undamaged during a tropical cyclone; i.e. parts of the building do not break or detach. Elements assessed for wind resilience include roof and wall cladding, flashings, gutters, windows, doors, and garage doors. The resilience of a building to wind is most affected by the selection of robust building materials and the effectiveness of connections.

Rain resilience of a building

Rain resilience refers to how well the building can continue to function if water gets in, or alternatively, how well building elements can prevent wind-driven rain entering. Wind-driven rain can enter a building through windows, under doors, through the roof or the wall cladding, or around flashings. It can damage ceilings, wall linings, floors, and building contents. A building that sustains water damage may require expensive repairs even though in some cases there may be little or no structural damage. Features assessed for rain resilience include material, type, and condition of: roof and wall cladding; gutters; flashings; windows and seals; doors and seals; ceilings; and soffits.

Resilience of building ancillary items

Ancillary items are attached to the building (wall and roof-mounted), and include photovoltaic panels, communication aerials, signs, and air conditioning units. They may cause damage to the building as they detach, or they can become wind-borne debris that can break windows, doors, or roof and wall cladding. The number, type, and condition of items attached to the roof or external walls are assessed.

1.2 North Queensland Strata Title Inspection Program

The program is funded by the Australian government and offers fully subsidized inspections of strata residential properties. Bodies corporate can request an assessment of their property by appropriately trained building inspectors. Inspectors record the answers to around 90 questions in a mobile or tablet-based App, which are used as input to the resilience model presented in this paper. Bodies corporate receive a report that indicates the estimated resilience of their properties to future tropical cyclones. Mitigation options are suggested when the estimated resilience of the property is low, and the report also indicates the improvement to the resilience scores if the mitigation options are undertaken.

2. Development of the model

Over the past 40 years, the CTS has investigated damage caused to buildings during tropical cyclones, tested the performance of many different building materials and systems, and evaluated aggregated insurance data. This information, data, and experience were used to inform the development of the model.

In order to make the resilience reports based on the model widely available for qualifying properties, the CTS has developed a system consisting of different software components. An online portal is used for outreach and information dissemination. It allows interested parties to register for the program online. The first component of the assessment is the Survey App which is used to capture and store data from the property inspection. The Survey App component uses commercially available mobile and tablet-based form-builder software. Once the data from an assessment has been collected, it is retrieved, checked and provided as input to the Excel-based resilience model. The outputs from the model are then used to produce a resilience report with appropriate scores and recommendations. The modular aspect of the system makes it easy to progressively refine the model and release new versions. Figure 1 shows the inputs and outputs of the model.

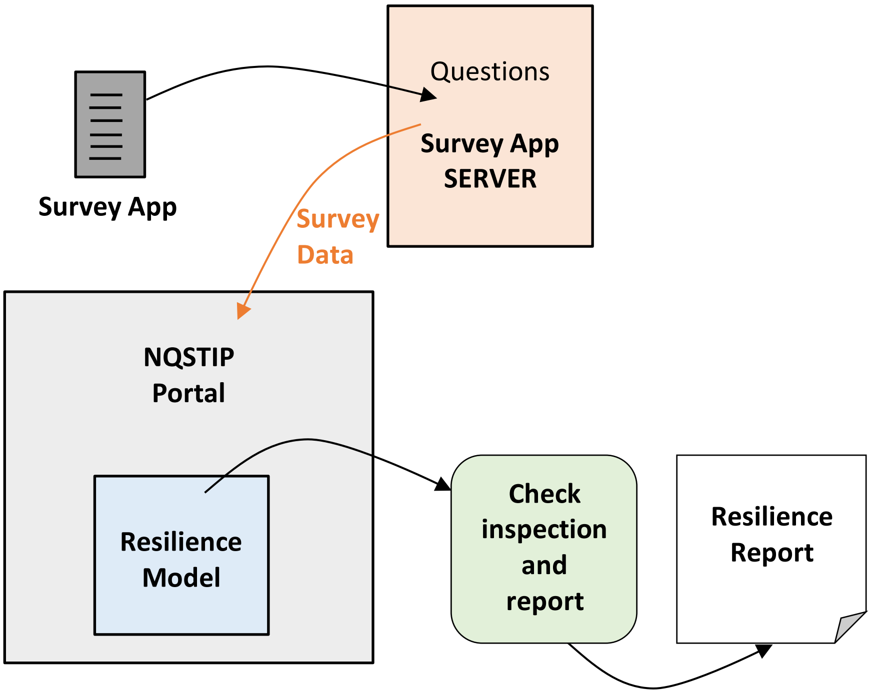

Figure 1 Information flow to evaluate resilience

2.1 *Inferred resilience*

The assessment of the strata property involves trained building inspectors answering the questions using on-line resources and maps, and an on-site, non-invasive, visual inspection. Ideally, a detailed structural assessment is required to accurately evaluate the likely performance of a building. However, it is not possible for this program due to limitations in accessing all elements in a completed building, and lack of availability of the structural drawings or design criteria. Instead, the questions used in the model represent the best way of obtaining an indication of the likely condition and features of the critical elements that often lead to damage in a tropical cyclone. Resilience is inferred from the answers rather than measured. For example, a question requiring the inspector to estimate the distance from salt water can be used to infer that a building very close to salt water has a high potential for corrosion, possible impact from waves in a storm tide event, and a higher exposure to winds. Similarly, a question that asks about the best view from the building is used as an indication of the exposure to winds – buildings with great views have higher levels of aerodynamic exposure.

The model uses a number of steps to evaluate a resilience score:

- The answers are used to give resilience rankings in each resilience category to the item addressed in the question (e.g., fixing type and spacing on roof flashings);
- The probability of survival with respect to specific issues (e.g., wind damage to flashings) is estimated;
- A number of different issues are combined to evaluate the likely performance of features (e.g., combinations of roof issues such as damage to cladding, fasteners, flashings, etc. are used to estimate the likely performance of the roof as a single feature of the building;
- The output resilience score is evaluated by combining all of the features within a resilience category. The combination is weighted according to the building geometry.

2.2 Inputs to the model

Between 20 and 75 questions contribute to the estimation of the building's resilience in each category, and many questions contribute to more than one resilience category. For example, whether flashings are fixed to manufacturer's specifications is used to calculate both wind and rain resilience.

To illustrate the range of questions included for a resilience category, wind resilience is estimated from a number of questions that relate to:

- The magnitude of wind pressures: e.g., Wind Region; approximate distance to salt water; roof shape; roof cladding material and condition; height of building; roof area; number of roof-mounted ventilators, or vents in eaves or gables; fire protection details between SOUs; and porosity of garage doors.
- Vulnerable materials used in the building: e.g., number of roof-mounted items such as photovoltaic panels, communication aerials, air conditioners, and ventilators; material used for ceilings immediately under the roof; material used for eaves linings; exterior wall material; number and type of window awnings; outdoor ceiling material over balconies, verandas, and entrances; number of outdoor ceiling fans; number of air conditioners mounted on external walls; and percentage of glazed openings.
- Condition of elements that resist wind actions: e.g., the condition of roof fastenings and flashings and whether they are installed to manufacturers' specifications; condition of timber and steel in the roof space; condition of gutters; condition of eaves linings; and condition of exterior wall material.
- The likelihood of dominant openings being created: e.g., the number of large trees (> 6 m tall) within 5 or 6 m of building; the number, type and condition of garage doors, whether they have wind ratings or other effective wind locks complying with AS/NZS 4505; type of windows; type of debris protection on windows and external glass doors; condition of seals on windows and doors; number of inward opening swinging doors; whether there are loose items in the grounds or neighbouring properties; and condition of other structures such as patios, and lightweight sheds in the grounds.
- Design to resist wind loads: e.g., year building constructed and year of the most recent structural upgrade; and approximate distance to salt water.

2.3 Resilience rankings

Within the model, each answer option is assigned a ranking between 1 and 5 (1 = lowest resilience option and 5 = highest resilience option). The ranking indicates the answer's relative effect on the resilience of the building for each resilience category. Table 1 shows an example of the answer options and the rankings for each resilience category for the question 'What type of debris protection is on the windows?' This question contributes to scores for wind, rain, and storm tide resilience and to wind-borne debris, but is not used to estimate the resilience of ancillary items. The rankings for this question also illustrate how two options involving strong screens are very resilient to wind damage (ranking near 5), but will do little to prevent ingress of water into the building (ranking = 1 for rain resilience).

Within each resilience category, relevant questions are also assigned a correlation factor that represents the extent to which that question contributes to that resilience category. Questions that have a larger influence on the resilience of a building during a tropical cyclone have a higher correlation factor. A correlation factor of 1 indicates the question has a significant influence on the resilience category, while a correlation factor of 0.2 indicates that the question only has a minor influence. For example, the correlation factor for the question 'Condition of roofing and fasteners' is 1 for rain resilience, and 1 for wind resilience, indicating that the answer to the question is a significant contributor to both resilience categories. Conversely, the correlation factor for the question 'Condition of gutters and drainage systems – free from detritis' is 1 for rain resilience, and 0.2 for wind resilience, indicating that the answer to the question contributes significantly to the score for rain resilience, but only contributes a little to the score for wind resilience.

Table 1. Example of answer options and resilience rankings for debris protection of windows

		Ranking for each resilience category				
Option No.	**Option**	**Wind**	**Rain**	**Surge**	**Ancil**	**Debris source**
1	No windows	5	5	5	NA	5
2	No debris protection	1	1	1	NA	5
3	Temporary debris shutters on < 50% of window area	2	2	1	NA	2
4	Temporary debris shutters on > 50% of window area	4	4	2	NA	2
5	Lightweight screens, debris-rated glass or security film on < 50% of window area	2	1	1	NA	4
6	Lightweight screens, debris-rated glass or security film on > 50% of window area	3	1	1	NA	4
7	Strong screens (heavy gauge steel, masonry or concrete) on < 50% of window area	4	1	1	NA	5
8	Strong screens (heavy gauge steel, masonry or concrete) on > 50% of window area	5	1	1	NA	5

The combination of the rankings and the correlation factors are used to estimate the probability of survival of features of the building. These probabilities can be aggregated across all of the features of a building type, and then used to estimate the resilience score (1 to 5 where 1 = low and 5 = high) for each resilience category. Boughton *et al* (2019).

Table 2 Interpretation of resilience scores

		Likelihood of significant insurance claim at the	
Score	**Estimated resilience**	**1/500 AEP event**	**1/25 AEP event**
0 to 1.5	Very low	Almost certain	Likely
1.6 to 2.5	Low	Likely	Possible
2.6 to 3.5	Medium	Possible	Not likely
3.6 to 4.5	High	Not likely	Very unlikely
4.6 to 5	Very high	Very unlikely	Very unlikely

For most strata buildings, the ultimate design event is a 1/500 AEP event, so this column in Table 2 relates to a property's expected performance in a design tropical cyclone. Investigations of damage caused by previous tropical cyclones indicate that, on average, existing strata buildings have a score of around 2.5. Therefore, for this program, properties with building scores of 2.5 or higher are considered to have better than average resilience. Mitigation options are recommended for buildings with resilience scores less than 3.5. Some examples of recommendations include: the roof structure of older buildings is checked and upgraded if necessary; worn or damaged seals on windows are replaced; and flashing fastenings meet the requirements of AS/NZS 1562.1. The model can recalculate the resilience scores for each category to indicate revised scores if all recommendations are implemented.

2.4 Calibration

Answers to the inspection questions for more than twenty different strata properties were manually generated to include a range of different types of buildings, construction materials and condition of elements. All of the scores for each feature and for each resilience category were analysed to adjust and refine the correlations, interactions and rankings for each question to ensure that the scores for the grounds and the resilience categories for the simulated properties were consistent with the observed performance of each type of building in past tropical cyclones.

An algorithm was subsequently developed to randomly select appropriate options within defined parameters for each of the questions to generate hundreds of different properties and buildings. This process checked whether there were any combinations of attributes that would produce erroneous results. The resilience scores were assessed to ensure they were consistent with those expected from experience in previous damage investigations following tropical cyclones in Queensland. Some of the correlation factors, interactions and rankings for some questions were further refined, and a few minor changes to individual element scores for some resilience categories were required.

The model has been further refined as the program has been implemented to appropriately represent the performance of different features on the disparate strata building types covered in the program.

2.5 Other applications

The model developed for the NQSTIP could also be used to assess drawings or building and property plans at the design stage so specifications of potentially vulnerable features or elements could be replaced. Several different design scenarios could be quickly and easily trialed using the model, and alternatives discussed with the developer or owners before construction commenced.

3. Conclusions

The model has demonstrated that wind engineering, combined with experience and knowledge from damage investigations, research and commercial testing programs can be used to estimate the resilience of strata properties in future tropical cyclone events. It is anticipated that the model will be further refined as more data from inspections and evidence of the performance of inspected properties during future tropical cyclones becomes available. Participation in the North Queensland Strata Title Inspection Program is increasing as Bodies Corporate recognize the value of the assessments, and it is likely that the program will be extended.

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