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A survey of wind and storm surge damage following Tropical Cyclone Yasi

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Abstract

Tropical Cyclone (TC) Yasi crossed Queensland's Cassowary Coast during the night of the 2nd and 3rd of February, 2011. The cyclone was forecast by BoM (2011) to be a severe storm with wind gusts forecast to exceed the design gust wind speeds for houses set out in AS4055. Following the passage of the cyclone, it was evident that the severe wind and large coastal storm surge had caused significant damage to the region's building stock. Geoscience Australia (GA), together with collaborators from the National Institute of Water and Atmospheric Research, New Zealand (NIWA), Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) and Maddocks & Associates, undertook a survey of damage to the region's buildings caused by severe wind and storm surge. This paper reports on the objectives, the methodologies, the outcomes and the preliminary findings of the survey.

Introduction and Aims

Vulnerability is a measure of the expected damage caused to a particular type of building due to a level of hazard exposure. It is usually described by a vulnerability curve that relates a non-dimensional *damage index* (repair cost divided by replacement cost) to hazard magnitude. The measure of hazard for severe wind is the maximum gust at 10m height at the building location in question. The measure of hazard for storm surge is inundation depth $\times$ water velocity. Knowledge of the vulnerability of the built environment is a key element of the risk assessment process, which is a convolution of hazard, exposure and vulnerability; see for example, Schneider et al (2009).

Vulnerability relationships have been developed by various authors for severe wind effects on a variety of Australian housing types; see for example, Wehner et al (2010a). The curves are usually developed by heuristic methods that are informed by available survey data. More recently attempts have been made to develop vulnerability curves by analytical methods; e.g. Wehner et al (2010b). The reliability of such curves is improved through calibration using survey data.

An event such as TC Yasi provides an excellent opportunity to gather empirical data on the vulnerability of buildings to severe wind. TC Yasi has provided the best opportunity to gather data on the damage caused by severe wind since TC Larry in March 2006. Furthermore, the storm surge that accompanied the cyclone provided an opportunity to gather data on the damage caused by storm surge. To the authors' knowledge, this was the first time a systematic survey of storm surge damage for vulnerability knowledge development has been undertaken in Australia.

GA's damage survey post-TC Yasi was designed to provide data at a sufficient level of detail that the damage index for each surveyed building could be calculated and used to calibrate existing vulnerability curves. Thus detailed information about a building's location, size, construction and sustained damage was recorded. The aim was to survey all buildings in urban areas from Kurrimine Beach south to Cardwell and as far inland as the Bruce Highway thus including towns such as Tully, El Arish and Silkwood.

Survey Methodology

The survey methodology adopted reflected the available resources and the type of data required. Field work was carried out during three sequential week-long deployments during the period 18 February, 2011 to 15 March, 2011. Each of the three teams consisted of between 9 and 12 personnel comprising a team leader, a GIS specialist and a mix of engineers and non-engineers.

Each of the three trips had a different focus: the first trip aimed to capture damage to residential buildings, the second trip aimed to survey all properties affected by storm surge and the final trip focussed on non-residential buildings and any residential buildings missed during the first two trips. A variety of survey methods were adopted.

To ensure that data on overall storm surge damage was collected quickly and in view of the vagaries of tropical weather and speed of cleanup GA's Rapid Inventory Collection System (RICS) was deployed during the first trip to photograph all buildings affected within the storm surge area. RICS is a vehicle borne camera system developed by GA that takes geo-located images from a moving vehicle and is available as open source software; Habili et al (2010). The equipment is shown in figure 1. Images taken by RICS are automatically attached to survey database entries by post-survey processing that selects the nearest RICS image to each building location.

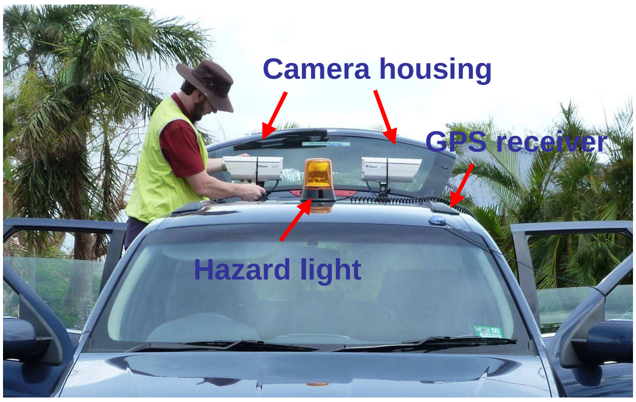

Figure 1. The RICS system mounted on a car. Images from the two cameras and positional data from the GPS receiver are automatically recorded on a laptop computer within the vehicle.

Data on the extent and depth of storm surge inundation were obtained by a Real Time Kinematic (RTK) survey conducted by NIWA personnel during the second trip. Height and positional consistency was achieved by using Queensland Government Department of Environment and Resource Management permanent survey marks as control points. An example of the equipment is shown in figure 2.

Figure 2. RTK survey equipment postioned over a permanent survey mark.

The largest component of the survey work was directed at door to door surveying on foot where data was recorded onto hand-held computers (PDAs) pre-programmed with a survey template. The template contained fields to record details about the building's location, size and construction and also the nature and extent of any damage suffered. Building location details were obtained prior to the survey from GA's National Exposure Information System (NEXIS) and loaded onto the PDAs together with aerial imagery and cadastral information. The PDAs had an in-built camera enabling surveyors to record up to 9 images for each building. The PDAs also contain a GPS facility. Thus the surveyor could see where they were at all times on the screen. Figure 3 shows a survey team of two recording data in front of a house damaged by storm surge.

Figure 3. Survey team recording data at a storm surge damaged house. Usually surveyors worked singly however when inexperienced surveyors were introduced to the equipment they were paired with an experienced surveyor.

Recording data began with the surveyor identifying the relevant building on the PDA screen. The PDA recorded the latitude and longitude of the building, retrieved the street address from the NEXIS database and opened the survey template. Figure 4 is an image of the PDA as normally seen by a surveyor showing a small segment of the survey area. Figure 5 is an image of the PDA with a page of the survey template displayed. Note that most data entry is by selection from drop-down lists to speed data entry and improve consistency of responses between surveyors.

Figure 4. Image of PDA unit showing background image consisting of aerial photo, cadastral information, street layout and NEXIS points.

Figure 5. Image of PDA showing a single page of the survey template with the *Height to Eaves* field being entered from a drop-down list.

The survey template contained 54 fields of which 5 related to location and were automatically filled by the PDA unit, 23 related to the size and construction of the building, 15 related to damage due to wind and 11 related to damage due to storm surge. Where a building had not been affected by storm surge, those fields were left blank.

Completion of the survey template by an experienced surveyor took approximately 20 minutes. Survey teams consisted of both experienced and inexperienced staff and despite the first half day of each trip being used as training, in practice a longer period of time was required for the surveyor to become fully familiar with damage identification and the use of the PDA tool.

Results

Post-cyclone survey and analysis has indicated that the peak gust wind speeds experienced by the region's buildings were less than those forecast; Boughton et al (2011). Nevertheless significant damage due to severe wind was observed for residential and industrial building types. Damage from storm surge was typically severe to most building types often resulting in partial or full removal of the building. Reinforced masonry structures showed increased resilience often only losing their ground floor windows.

The survey covered approximately 1800 buildings of all types in urban areas from Kurrimine Beach to Cardwell. Almost all buildings within urban areas were surveyed with the exception of some houses in Cardwell that were not accessible due to riverine flooding at the time of the third trip. Figure 6 shows an extract of an aerial image of the town of Tully showing surveyed buildings as an example of the coverage of the survey.

Figure 6. Aerial image of part of Tully showing surveyed buildings. The different colours denote different usages as recorded in the NEXIS database.

Similarly to previous post-cyclone damage surveys, the assessment of damage due to water ingress proved problematic. The presence of such damage can often be inferred by piles of wet linings and contents on nature strips such as is shown in figure 7. However, the extent of water ingress damage can only be surveyed if access to the building's interior is possible. This is significant as water ingress can yield a damage index up to 0.3 with little or no structural damage.

Figure 7. A house with little exterior damage. The pile of water damaged contents and linings on the nature strip is indicative of significant water ingress damage that would not be detected if the materials and goods had been removed.

The survey activity also providing a valuable opportunity for staff from the Philippine Atmospheric, Geophysical and Astronomical Service Administration (PAGASA) to observe and comment on the survey tools and techniques employed in this post-cyclone activity. PAGASA, with support from AusAID, is leading a research effort to better understand climate related natural hazard risk in the Philippines and to identify the best strategies for risk reduction. Through AusAID funding four PAGASA staff were able to travel to participate in two separate survey phases and obtain first-hand experience on the survey damage capture processes used which may inform the augmentation of current survey techniques used by PAGASA in their Typhoon survey responses. This augmentation will enable PAGASA and their collaborators to develop representative wind vulnerability models for Philippine construction.

Future Work

Future work can be categorised into three stages:

1. Post-processing of survey data to provide a usable set of survey data. This includes cleaning the data by checking every survey template field for each building against aerial photos and photos taken during the survey. Additionally, building footprint areas and dimensions are measured from aerial photography using GIS software and added to the database.
2. Identification of hazard severity at each building location. For severe wind hazard this will be achieved by modelling the cyclone using GA's Tropical Cyclone Risk Model (TCRM) calibrated to available meteorological observations and field observations of damage to road signs immediately after the cyclone by James Cook University in Boughton et al (2011). For each building location the maximum wind gust obtained from TCRM will be modified to account for local topography, surface roughness and shielding. For storm surge hazard it is anticipated that the hazard magnitude will be computed by numerical modelling of the storm surge undertaken by NIWA.
3. Computation of damage indices. Finally the damage index for each building will be calculated using the costing modules in Turner and Townsend Rawlinsons (2006) and plotted against the peak gust wind speed determined as described above to enable calibration of vulnerability curves for groups of structurally similar buildings.

The capture of data via door to door foot survey is a slow, labour intensive process. GA has commenced development of a software tool, called Field data Analysis Tool (FiDAT), that will enable desk-top completion of survey templates by reference to a number of data sources. Many data sources could potentially be accessible but would include as a minimum: aerial imagery, footprint data, RICS imagery and street-view type imagery. The user would view all data sources relevant to a particular building and from these complete the template fields on screen. If a foot survey had been carried out, FiDAT would automatically populate the template with the surveyed attributes for subsequent checking by the FiDAT user. An image of the preliminary interface is shown in figure 8.

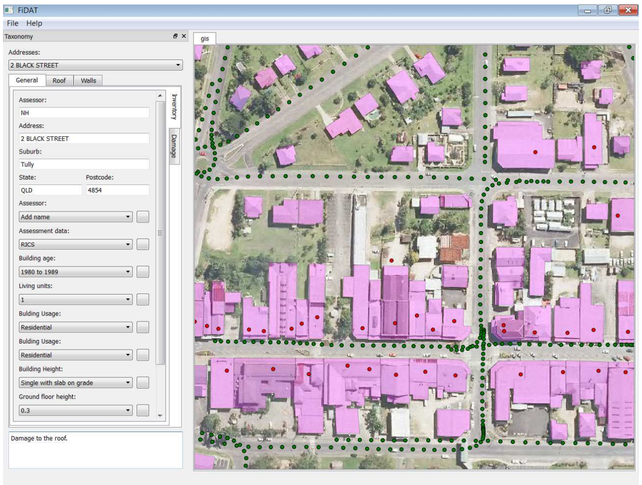

Figure 8. Image of the preliminary interface for GA's desk-top survey data processing tool. The main pane shows an aerial image with building footprint outlines and locations of available RICS imagery. The left hand pane shows the survey template. When the user selects a building the software tool will display relevant data for that asset derived from a variety of sources.

Summary

A large sample of buildings exposed to severe wind and storm surge hazards during Tropical Cyclone Yasi has been surveyed at a sufficient level of detail to enable their repair and replacement costs to be calculated. Hence damage indices can be calculated at the individual building scale and the results used to calibrate vulnerability curves. The dataset of damage due to storm surge is the best known Australian record of such damage.

Future cleaning and analysis of the data will enable the calculation of damage indices for each surveyed building and hence provide empirical data for the calibration of vulnerability relationships.

Acknowledgments

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