HURRICANE RISK OF MULTI-FAMILY DWELLINGS IN PUERTO RICO

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Abstract. Hurricanes in the North Atlantic Basin cause widespread damage to the Caribbean islands on a regular basis. Catastrophe risk models are used by insurance and reinsurance companies to estimate the average losses one could expect to buildings and property as a result of natural hazards (e.g., hurricanes, earthquakes, floods, etc.). Catastrophe models contain three major components: (1) a set of possible events for each type of hazard that includes geographic footprints of their intensity (e.g., peak ground acceleration, peak 3-second wind gust); (2) a vulnerability component that links the hazard to expected damage, generally composed of a suite of "vulnerability curves" that account for site-specific building characteristics; and (3) a financial module that estimates the expected monetary losses while accounting for any applicable insurance contracts. The event sets are generated using distributions of the physical parameters of the hazard (including radius to maximum winds, peak wind speeds, minimum central pressure and forward speed for hurricanes), primarily gathered from records of historical events. The vulnerability curves are based partly on past insured losses and judgment based on engineering analysis.

This paper describes the vulnerability of multi-family dwellings in Puerto Rico to hurricane winds. Using information from recent field investigations into local construction practices and from the impacts of Hurricanes Hugo and Georges, an overall risk assessment was performed on multi-family dwellings in Puerto Rico. A basic simulation methodology was developed based on engineering principles to offer guidance in determining the wind vulnerability of these structures. The investigation shows that damage to the building structure is limited due to the reinforced concrete construction and robust building envelope. Damageable components are limited to windows and patio doors, mechanical equipment, fences, and exterior finishes. The structural system, interior and exterior walls, roofs, and floors are not highly damageable due to their solid construction and resistance to water. The methodology for constructing the vulnerability curves is presented as well as an example damage curve for multi-family dwellings in Puerto Rico.

1 INTRODUCTION

Hurricanes in the North Atlantic Basin cause widespread damage to the Caribbean islands on a regular basis. Puerto Rico is highly susceptible to landfalling hurricanes that usually move in an east to west direction across the island. The last two major hurricanes to impact the island are Hurricanes Hugo (1989) and Georges (1998), each causing significant damage (Figure 1). More recently, Hurricane Irene (2011) made landfall as a category 1 hurricane but did not cause significant damage.

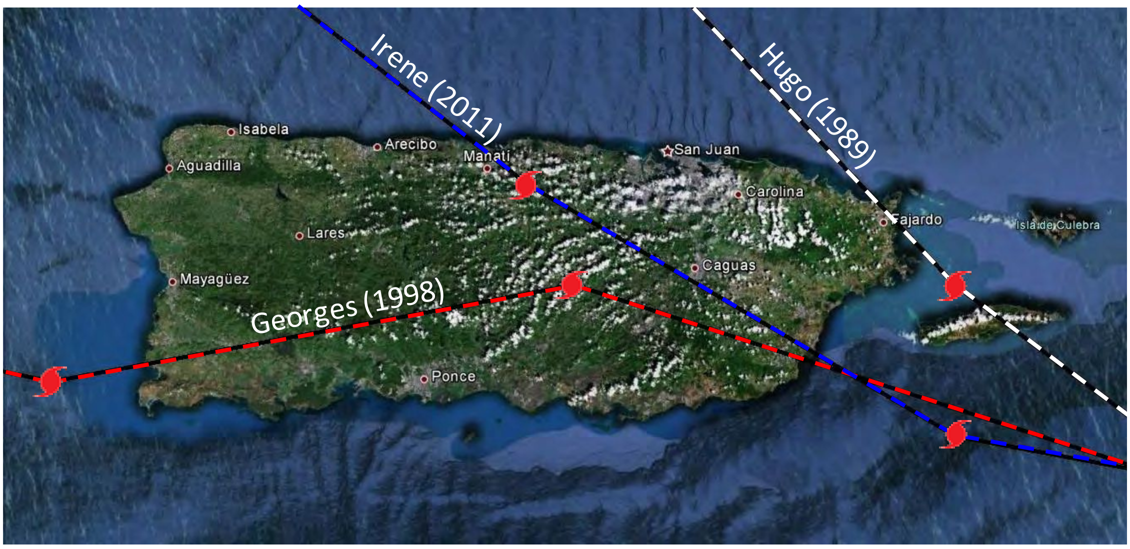

Figure 1: Major hurricanes to impact Puerto Rico

Since natural catastrophes (including hurricanes) occur frequently and cause damage, many people buy property insurance to help alleviate the cost of repair and reconstruction after an event. Since insurance companies need to remain solvent after an event, they need to price insurance premiums appropriately based on the risk. Risk can be defined as a probabilistic view of the frequency and magnitude of future loss and varies by location and natural hazard. Practically, risk is the combination of the probability of a hazard of a given magnitude, the (insured) exposure at a given location, and the damageability of that exposure given the hazard magnitude. In order to better define natural hazard risk, catastrophe risk models have been developed using science and engineering principles along with statistical techniques and financial modeling. These catastrophe risk models are used by insurance and reinsurance companies to estimate the average losses one could expect to buildings and property as a result of natural hazards. Insurance and reinsurance companies license these catastrophe models to provide guidance and to develop strategies to manage the risk in their portfolios. First developed in the 1980s and early 1990s, catastrophe risk models are now used by nearly all property insurance and reinsurance companies. Risk Management Solutions (RMS) provides a suite of catastrophe models for various hazards in over 100 countries.

Catastrophe models contain three major components: (1) a set of possible events for each type of hazard that includes geographic footprints of their intensity (e.g., peak ground acceleration, peak 3-second wind gust); (2) a vulnerability component that links the hazard to expected damage, generally composed of a suite of "vulnerability curves" that account for site-specific building characteristics; and (3) a financial module that estimates the expected monetary losses while accounting for any applicable insurance contracts. The event sets are generated using distributions of the physical parameters of the hazard (including radius to maximum winds, peak wind speeds, minimum central pressure and forward speed for hurricanes), primarily gathered from records of historical events. The vulnerability curves are based on engineering analysis of a structures response to a given hazard and validated using past insured losses. Vulnerability is generally expressed as a mean damage ratio (MDR) defined as the cost to repair a building divided by the total insured value or the replacement cost.

Catastrophe models are updated periodically as new events occur that can be used to calibrate and validate the current state of the art. Additionally, new science is published that can also provide enhancements to the risk models. One such major update was the RMS North Atlantic Hurricane Model Version 11 released in February 2011. Updates were made to the hazard (event set) component as well as the vulnerability of many buildings to extreme winds partially based on advanced hurricane simulation techniques and more than $200 billion (USD) of hurricane claims data.

One area of particular concern after the model release was the change in the vulnerability of multi-family dwellings in Puerto Rico. These buildings, specifically 3-4 story "walk-ups," experienced a large increase in their damageability in the model. Recently, RMS sent a team of engineers to Puerto Rico to investigate the construction and damageability of these buildings to hurricane force winds. The focus of the investigation was to determine the vulnerability of the building coverage as defined in insurance contracts. For multi-family dwellings, the building coverage pertains to the structure and anything attached permanently to the structure including structural framing, windows, flooring, mechanical equipment, kitchen cabinets, etc. Typically, this also includes fences, outdoor fixtures, etc. that are part of common areas to the building and used by multiple tenants.

2 PUERTO RICO "WALK-UP" MULTI-FAMILY DWELLINGS

In Puerto Rico, multi-family dwellings with 2-4 stories are referred to as “walk-ups” because there are no elevators and occupants use stairs to access the upper floors. Figure 2 shows a typical “walk-up” in San Juan, Puerto Rico.

Figure 2: Typical "walk-up" multi-family dwellings in Puerto Rico

2.1 Structural system

Walk-up buildings primarily use reinforced concrete shear walls to resist lateral loads. Moment-resisting frames are almost never used and were not observed in the field. Interior walls are constructed using reinforced concrete masonry blocks (CMU). Gypsum partitions are not used in walk-ups because they are more expensive than masonry and because there is no need for movable partitions, since the apartments do not change their internal configuration.

2.2 Roof system

The roofs are reinforced concrete decks that are generally five to six inches thick. They are essentially flat with a minimal slope for water drainage (Figure 3). Most roofs are covered with either paint or a chemical that combines with the concrete to prevent leakage. When a built-up roof cover is used, the cover is a thermoplastic polyolefin (TPO) membrane or something similar. Gravel is almost never used on the roofs of MFD buildings, even when the roof cover is built-up. Parapets are also common and generally range from a few inches to four feet in height.

Figure 3: Typical reinforced concrete roof deck

2.3 Building envelope

Exterior walls are painted reinforced concrete and are commonly covered with a thin layer of stucco to create a smooth exterior wall surface. Cladding that is traditionally found in the United States such as vinyl, red brick, or wood is not used in Puerto Rico. The prevalence of windows and doors varies widely. Modern buildings have a relatively large number of windows while older buildings typically have a limited number of small windows that are often covered by slats or storm shutters. Many windows use storm shutters that are generally strong enough to withstand indirect hits from small missiles. Ornamentation in the form of clay tiles (as seen in Figure 3 on the window awnings) was occasionally seen on walk-up buildings and is vulnerable to hurricane damage. In some cases, air conditioning units are placed on the sides of the building exteriors rather than on the roofs.

2.4 Building interior

Interior floors are rarely covered by carpets due to susceptibility to mold and mildew from Puerto Rico's high humidity. Ceramic tiles and vinyl are the most popular types of floor covering in walk-ups. Partition walls are constructed of CMU that are then painted.

3 RELATIVE HURRICANE VULNERABILITY OF WALK-UPS

The first points of vulnerability for a walk-up building insurance policy are fences, trees, light fixtures in common areas, light posts, awnings, and other similar structures. However, due to the low relative cost of these components compared to the building as a whole, damage to these components in a light storm would lead to small building loss ratios below 1%.

Windows, sliding glass balcony doors, exterior doors, exterior paint, and rooftop equipment are the next points of vulnerability. Many windows are covered by storm shutters, especially in buildings that are close to the coast, but those that are not protected may be damaged by windborne debris. The paint on a building can be chipped by debris and strong winds, especially for coastal properties where sand can blast the building exterior. Rooftop equipment generally consists of air conditioning units and satellite dishes that will be damaged in strong winds (though air conditioning units are occasionally placed on the sides of buildings in windows or walls rather than on the roofs). Sliding glass doors are occasionally protected by storm shutters, but are often designed to resist missile impacts without the presence of shutters. In a strong storm that damages windows, doors, paint, and rooftop equipment, the building loss ratios should range between 1-10%.

Interior building electrical systems (which generally pass through the walls) and common internal building areas represent the next points of building vulnerability. In a very strong storm that damages internal electrical systems as well as all of the other aforementioned building components, the building loss ratios could climb to 15%.

Components that generally would not be damaged even in very strong storms include the foundation, interior and exterior wall structures (stucco wall cover will likely be damaged by windborne debris), floors (including the floor structure as well as the tile cover), stairs, and roof deck. Because these components contribute the majority of the replacement cost value, the loss ratios to be expected in extreme events should generally remain below approximately 50%.

4 QUANTITATIVE HURRICANE VULNERABILITY OF WALK-UPS

4.1 Quantitative methods for determining building vulnerability

Multiple methods have been proposed for determining the vulnerability or damageability of buildings to wind speeds (e.g., Unanwa, et al., 2000; Khanduri and Morrow, 2003; Pinelli, et al., 2004). Each of these methods has its own strengths and shortcomings. Khanduri and Morrow provide a method of using an aggregate or regional vulnerability curve developed using loss data from previous storms to formulate specific vulnerability curves based on relativities between construction types and building inventory distributions. Unanwa et al. developed a weighting technique using building component cost factors, component fragility functions, and component location parameters to develop upper and lower bounds of building vulnerability. Pinelli et al. use Monte Carlo simulations of resistances of building components combined with wind pressures to probabilistically determine the damage state and the estimated loss. In all three methods, engineering judgment is used when there is a lack of physical laboratory data, post-event damage information, or insurance claims data. The method used for developing the vulnerability curves for the Puerto Rico walk-ups is a combination of these three methods: regionality factors accounting for differences in construction practices between different geographic regions, component fragilities using specified component resistances, and engineering judgment.

4.2 Regional building construction factors

In Puerto Rico, RMS was able to obtain insurance claims data from multiple insurance companies for multiple types of buildings that were damaged during Hurricane Georges in 1998. Of the $628 million (USD) total claims available in Puerto Rico, $8.6 million (USD) was detailed residential claims, and $80.9 million (USD) was detailed commercial claims. There were virtually no claims for walk-up buildings, primarily due to the fact that the majority of walk-ups were constructed after Hurricane Georges. Due to this lack of information on walk-ups, some judgments were made with regards to the construction characteristics. It was assumed that because multi-family dwellings are more similar in size and construction to commercial office buildings that the vulnerability should be more aligned to commercial buildings. The fallacy in Puerto Rico with this argument is that the regional construction practices would actually place multi-family dwellings, and walk-ups in particular, in a similar class as single family dwellings. The major difference being that the walk-ups are essentially several single family dwellings that are attached. Both are constructed of reinforced concrete walls and roofs, have masonry partition walls, and have similar interiors.

4.3 Building component simulation

A building component simulation tool has been developed to aid in determining the vulnerability of various components based on the wind loads and the component resistances. Wind loads are calculated from wind tunnel studies on simple rectangular buildings representative of walk-ups in Puerto Rico. The major components considered in the analysis include windows, wall coverings (i.e. stucco), roof cover, and external ornamentation (i.e., fences, window awnings, etc.). The loads on the windows include both wind pressure and windborne debris. A sample fragility function for a window is shown in Figure 4. From these fragility functions, a mean damage ratio can be determined based on the average cost to repair or replace these components and the probability of failure of each component. This method also accounts for the probability distribution of the wind loads (i.e., pressures) and windborne debris at a given wind speed.

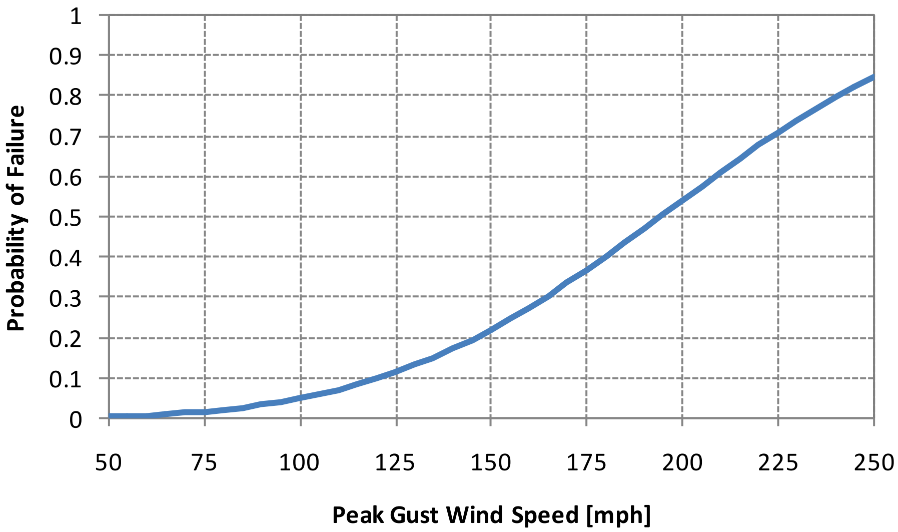

Figure 4: Sample fragility function for windows

4.4 Vulnerability function

By combining the fragility curves for various components with the wind pressure distributions and cost factors that relate the replacement cost of individual components to the total building replacement cost, vulnerability functions can be derived. The original and updated vulnerability functions for a typical Puerto Rico walk-up building are shown in Figure 5. It should be noted that this vulnerability is only for the building itself and anything permanently attached to the building. Individual unit owner's property (or the building contents) is not included in these curves. As can be seen, the updated vulnerability for this specific curve is approximately 40% lower than the original. Due to the "bunker-style" construction of the walk-ups, this new curve seems to be a better representation of the vulnerability of Puerto Rico's walk-ups when taking into account the building characteristics as outlined previously.

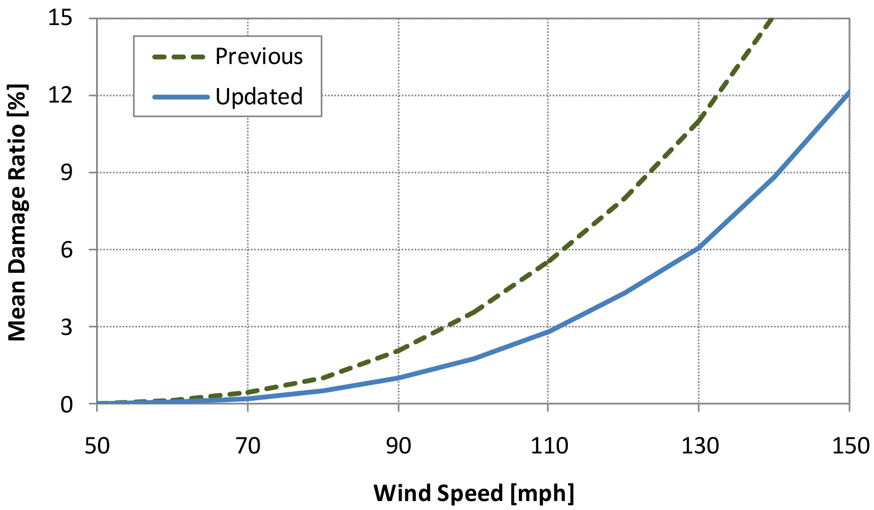

Figure 5: Representative vulnerability curve for Puerto Rico walk-ups

4.5 Vulnerability function calibration and validation

Another important aspect of developing vulnerability functions is calibration and validation. The vulnerability curve needs to be calibrated and validated against any known loss metrics and damage reports from previous storms. Since most walk-ups have been constructed after Hurricane Georges in 1998, there are no insurance claims data on the performance of walk-ups during hurricanes. Damage reports after Hurricanes Hugo and Georges include surveys of reinforced concrete MFD buildings (generally high-rise buildings) that can be used qualitatively to validate the vulnerability curves for walk-ups.

Rodriguez et al. (1992) performed a post-event damage survey of multiple buildings in Puerto Rico following the impact of Hurricane Hugo in 1989. Although they did not survey a walk-up building, they did survey two high-rise MFDs constructed of reinforced concrete. The major damage was to the building facade with the damage focused on the windows and doors; no major structural damage was observed. After Hurricane Georges impacted the entire island in 1998, damage surveys indicated that MFD buildings constructed of concrete performed well structurally (FEMA, 1999). With reported peak gust wind speeds up to 133 mph, the windows and mechanical equipment mounted on the roofs sustained major damage. However, the majority of damage in high-rise MFD buildings was to upper floors, generally above the 7th story. Using these reports, the updated vulnerability curve in Figure 5 seems reasonable for walk-up buildings in Puerto Rico.

5 CONCLUSIONS

Vulnerability curves are developed and used in natural catastrophe risk models to link wind speeds from hurricanes to the expected damage to buildings and property subjected to the storm. The focus of this paper is on the vulnerability of Puerto Rico walk-ups, defined as 2-4 story reinforced concrete multi-family dwellings (MFD). The vulnerability curves are defined and calibrated using a variety of techniques including site visits to understand region specific construction practices, building component damage simulations, post-event disaster reports, and insurance claims data from previous storms. Since claims data are essentially non-existent for Puerto Rico's walk-ups, the vulnerability curve calibration and validation was performed using post-event damage reports from Hurricanes Hugo and Georges. The vulnerability of walk-ups to extreme wind speeds from hurricanes is generally low with the vulnerable components being the windows and doors, rooftop equipment, fences, window awnings, and sometimes exterior wall cladding (i.e., stucco). Having a proper understanding of walk-up construction used in conjunction with a simple building component damage simulation, the vulnerability of walk-ups has decreased from what was originally proposed. The importance of understanding regional differences, especially with respect to using the United States as a baseline, cannot be stressed enough.

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