International Journal of Disaster Risk Reduction xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

How much should be invested in hazard mitigation? Development of a streamlined hazard mitigation cost assessment framework

Mehdi Noori[a,*], Reed Miller[b], Randolph Kirchain[c], Jeremy Gregory[d]

[a] Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, United States
[b] Yale School of Engineering and Applied Science, New Haven, CT 06511, United States
[c] Materials Processing Center, Massachusetts Institute of Technology, Cambridge, MA 02139, United States
[d] Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, United States

A R T I C L E I N F O

Keywords:
Windstorms
Buildings
Resilience
Hazard mitigation mechanisms
Break-Even Point

A B S T R A C T

Even though it is in society's interest to mitigate hazard damage, investments in hazard resilience are often not made, in part due to uncertainty around the potential costs and their benefits. The goal of this paper is to introduce a new resilience metric for buildings that captures the maximum investment that can be made in hazard mitigation while still breaking even on hazard repair savings over the lifetime of the building: the break-even mitigation percent (BEMP). We couple this with a streamlined approach to assess hazard mitigation costs for windstorms and demonstrate it by calculating the BEMP for forty hazard mitigation scenarios for multi-family buildings in all zip codes in the eighteen states that border the Atlantic Ocean and the Gulf of Mexico. The preliminary results of the analysis indicate that the BEMP is higher in areas near the coasts, but some communities inland would also benefit from the windstorm mitigation mechanisms. For instance, assuming a 7% discount rate over a 50-year time period, in Miami Dade county, FL the BEMP of switching from a baseline wood frame structure to an enhanced concrete structure was found to be 17.3%, meaning $1470,500 could be spent on mitigating a $8.5 M midrise multi-family building, and break even over the building life.

1. Introduction

With more than 75% of catastrophic losses in the United States in the period of 1993–2012 caused by windstorms [1], the U.S. faces wind vulnerability in many of its states, including the 18 coastal states on the Atlantic Ocean and Gulf of Mexico, which almost accounts for 45% of the value of built environment in the U.S [2]. Windstorms are geographically pervasive and cause considerable fatalities. Societal actions in recent decades have focused on increasing emergency capacity, rather than investing in resilience capacity. Hurricane resilience is claimed to be non-cost effective, because its probability of occurrence is low [2]. In addition, FEMA states the catastrophic losses of these low probability events are hard to cover by insurance companies [3]. This paper aims to investigate the cost-effectiveness of hazard mitigation mechanism against windstorms for new construction.

Investments in hazard mitigation are often not made, in part due to uncertainty around the potential costs of such investments and their benefits [4]. Studies have shown that hazard mitigation in residential buildings has not been pursued voluntarily [5]. This is partly because homeowners assume government preventive actions make people safe [6]. The National Association of Home Builders (NAHB) indicates that the average homeowner stays around 13 years in a home, meaning that the homeowners do not tend to consider the long term benefits of hazard mitigation mechanisms [7]. Homes with enhanced resistance features have shown a higher resale value, only if buyers can discern and care about the design, location, and construction features [8]. Therefore, quantifying the long term cost-effectiveness of hazard mitigation mechanisms and conveying such information to homeowners can help them make the right decision.

There have been efforts in reviewing the cost-effectiveness of disaster risk reduction in the literature including [9] that compared case studies that performed Benefit-Cost Analysis (BCA). Moreover, there are approaches for tornado loss assessment [10,11] and a few tools and models available that evaluate the cost-effectiveness of hazard mitigation techniques against windstorms. Cole at al. compared the existing hurricane loss models and investigated the factors contributing to the differences in the modeled average annual losses and found that there is correlation among the modeled loss costs [12]. Stewart et al. assessed the damage risks and cost-effectiveness of climate change mitigation strategies in residential buildings and increasing the wind speed design will create net benefits [13]. Researchers at the firm Applied Research Associates (ARA) developed a suite of hurricane wind modeling tools,

* Corresponding author.
E-mail address: noori@mit.edu (M. Noori).

https://doi.org/10.1016/j.ijdrr.2018.01.007
Received 6 October 2017; Received in revised form 7 January 2018; Accepted 8 January 2018
2212-4209/

including HurLoss® [14], which underlie Federal Emergency Management Association (FEMA) tools and the ASCE 7–10 Wind Loads [15]. Vickery et al. provided a detailed overview of the damage and loss modeling components of FEMA's HAZUS Hurricane Model [16]. The BCA Toolkit developed by FEMA is aligned with HAZUS, and is a required screening step for FEMA Hazard Mitigation Grant applicants in identifying the hazard mitigation costs [17]. AIR Worldwide has also developed a hurricane model for the U.S. that quantifies the risk from hurricanes and storm surge, which uses a fully probabilistic approach and is relatively complex [18]. Rose et al. investigated to what extent hazard mitigation mechanisms pass the benefit cost analysis and summarized their results for a sample of FEMA-funded mitigation programs across the U.S., and concluded that every dollar spent on hazard mitigation produced four dollars benefit [19].

However, these tools are not designed as tools to aid stakeholders in weighing options and do not provide an easily understandable measure of windstorm mitigation cost-effectiveness for the stakeholders, including homeowners. Fragility curves characterize the cumulative probability of reaching a certain damage state as a function of a specific hazard intensity and are widely used for assessing the vulnerability of structures against natural hazards [20]. The FEMA BCA toolkit is intended to assess the cost-effectiveness of hazard mitigation mechanisms for single buildings in a given location using pre-defined fragility curves. Extracting the fragility curves from FEMA BCA is challenging and these curves do not directly allow for comparison between different structures with different mitigation features in a large geographic area. Thus, there is an opportunity to explore the trends of hazard mitigation cost-effectiveness across a wide range of scenarios.

This paper introduces a streamlined hazard mitigation cost assessment framework that is coupled with a new metric for buildings that captures the maximum investment that can be made in hazard mitigation while still breaking even on hazard repair savings over the lifetime of the building: the break-even mitigation percent (BEMP). The information is intended to provide a bound on the maximum hazard mitigation costs that can be considered cost effective, thereby helping to inform early-stage design decisions about hazard mitigation mechanisms. The framework uses currently available tools and approaches in the literature and is implemented to estimate the potential benefits of hazard mitigation mechanisms across many contexts, including different regions and different designs, and expresses the results in a simple metric.

First, we introduce the BEMP. Second, we describe the derivation of a meta-model for hurricane wind that is the core of the streamlined hazard mitigation cost assessment framework. Finally, we demonstrate the utility of the BEMP and the framework across a few case studies with wide range of design variables and geographic regions.

2. Methods

2.1. Break-Even mitigation percent

The break-even mitigation percent captures the maximum investment that can be made in hazard mitigation while still breaking even on hazard repair savings over the lifetime of a building. It quantifies the investment in mitigation in an enhanced design (EN) expressed as a percentage of the initial cost (assumed to be equivalent to building replacement cost) of the baseline design (BL). It considers the expected hazard damage-loss ratio (the ratio of expected hazard damage cost to the initial investment of the building – Please refer to Eq. (2)) of the baseline design (H_{BL}), and the reduced damage-loss ratio of the enhanced design (H_{EN}). The BEMP is calculated according to Eq. (1), which is derived in the supporting material (SM).

$$\mathrm{BEMP} = \frac{\text{Mitigation Investment}_{EN}}{\text{Initial Cost}_{BL}} = \frac{1+H_{BL}}{1+H_{EN}} - 1 \tag{1}$$

Note that this metric does not take the perspective of a particular stakeholder that may be financially responsible for hazard damage incurred. Rather, it looks at costs incurred and prevented across stakeholders. These costs are generally allocated across property owners, insurance companies, and government agencies. Factors influencing the allocation depend on terms of insurance policies, acceptance of insurance claims, and willingness of government agencies to provide emergency funding. Some states require insurance hazard deductibles and/or insurance mitigation incentives [21]. Eq. (1) can be modified to consider the insurer's or property owner's perspective; government funding would apply to eligible property owners who are not able to afford out-of-pocket hazard damage costs. It is worth mentioning that FEMA BCA estimates the hazard damage costs from a stakeholder neutral perspective as well.

It is also important to note that the metric represents an upper bound for mitigation investments since the break-even point time period is over the building's lifetime. A different time period could be used to evaluate shorter break-even, or payback, periods.

This measure can be applied to any building design and different hazard types for which data is available on hazard damage-loss ratios. The focus of this paper is only the hazard mitigation mechanisms against windstorms.

2.2. Streamlined hazard mitigation cost assessment framework

Fig. 1 shows the general framework of the proposed streamlined hazard mitigation cost assessment framework. A probabilistic meta-model of FEMA's BCA Toolkit V5.2.1 [17] for hurricane hazard damage cost estimation is developed and can then be applied to specific case studies for particular building types and mitigation mechanisms. The development of the framework is described here and specific case studies are defined in the following section.

2.3. BCA inputs and outputs

The BCA toolkit hurricane wind mitigation module requires definition of the type of building, consistent with those in FEMA's HAZUS-MH database [22]. Combinations of building properties pertaining to windstorm mitigation baseline scenarios and enhancements in the structure are selected for each run. A set of locations identified from ASCE 7–10 wind contour maps are selected and iteratively run to represent a wide range of expected wind loads. The project useful life and discount rate need to be defined as well.

Only structural damage is considered here. Post-hazard costs associated with displacement, rebuilding volunteers, mental stress and anxiety, lost productivity are not incorporated but could be in future iterations with sufficient estimates of such costs. Total building replacement value (V_{BCA}) is the only monetary input. The V input is recorded, but is arbitrary since the expected hazard damage-loss ratio H is the variable of interest, calculated by comparing the present value of expected hazard damage (D_{BCA}) determined by the BCA toolkit to the V_{BCA}, as shown in Eq. (2).

$$H = D_{BCA}/V_{BCA} \tag{2}$$

2.4. Meta-model fitting and application

A meta-model is created for each building configuration using a two-step model fitting process with linear regression, demonstrated in Fig. 2. The hazard curve data for step one are included in the BCA Toolkit run output. Nine sample locations were selected across the studied region and for each of these locations, the 3-second gust wind speed in mph, W, is regressed against the natural logarithm of mean recurrence interval (MRI) in years, X_1. MRI is defined as the average or mean time in years between the expected occurrences of events of specified intensity. Since we are making a meta-model of a well characterized phenomenon, we would expect and do find that regressions