

# Probabilistic life-cycle cost-benefit analysis of portfolios of buildings under flood hazard



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## ABSTRACT

Nowadays, the number of residential buildings in flood prone zones is increasing significantly. Therefore, for these buildings, it is of vital importance to apply hazard risk mitigation strategies. In this paper, probabilistic cost-benefit analysis of flood risk mitigation strategies for portfolios of residential buildings is performed in a life-cycle context. Additionally, an efficient methodology is proposed to aid decision-makers on whether or not to retrofit portfolios of structures considering both expected and standard deviation of life-cycle cost. The vulnerability model of buildings under flood hazard is introduced considering serviceability and ultimate limit states. Probabilistic cost-benefit analysis is performed by comparing the effectiveness of different retrofit actions. Additionally, uncertainty and correlation effects are considered in the probabilistic loss and cost-benefit analysis procedures. The proposed approach is applied to a portfolio of residential buildings located in Florida to illustrate its capability and application. However, the proposed approach is general and can be applied to buildings located in other regions.

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## 1. Introduction

Typically, flood causes include long-lasting rainfall, snowmelt, dam break, and temporary sea-level rise [1]. Flood accounts for almost 30% of the global losses associated with natural hazards [2,3]. Due to the catastrophic losses to the people and assets, flood is considered as one of the major natural hazards for the society and economy in the United States and many other countries. Due to the effects of global warming and climate change, the frequency, intensity, and magnitude of flood are increasing. Buildings play an important role in the economy and their damages resulting from a flood event contribute significantly to the total community loss. Furthermore, due to the rapid urbanization and population growth, buildings have an increasing exposure to flood in the urban areas. Thus, an effective probabilistic assessment and hazard mitigation approach for building portfolios is needed to estimate and optimize the performance of buildings under floods at a large scale in a life-cycle perspective. This paper aims to propose a novel approach to aid the flood hazard mitigation of portfolios of residential buildings considering the uncertainty and correlation effects.

Nowadays, performance-based engineering (PBE) is developing rapidly and is applied to investigate the performance of infrastructure under hazard effects [4–7]. Relevant studies to incorporate PBE within structural design code are still needed. In this paper, the PBE approach is adopted within performance assessment and mitigation of building portfolios imposed to flood hazard. Generally, the performance-based assessment can be divided into three parts: (a) hazard scenarios analysis, (b) structural performance and damage assessment, and (c) consequence and loss evaluation associated with decision variables (e.g., repair loss, downtime, and fatalities). In this study, PBE is adopted to investigate the performance of portfolios of buildings under flood effects.

The performance of a building under a flood event depends on many parameters, such as wall thickness, height of the building, presence of barriers, dimensions and configuration of doors and windows, and height of the raised foundation [8]. The damage mechanisms of buildings under flood effects include physical and chemical deterioration, structural failure of walls or windows, and scour of foundation. The building performance also depends on the characteristics of floods (e.g., duration, frequency, and magnitude). Most vulnerability analyses under a flood event consider the flood depth as the main factor [9,10]. Although flood depth is the most common factor considered in the damage assessment, the flood velocity also has a significant effect on the structural failure [11]. In this work, both flood depth and velocity are considered

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in the structural vulnerability analysis. Roos [12] developed damage curves of residential buildings considering the failure of walls and scour of the foundation under the hydrostatic and hydrodynamic pressures, wave actions, and pounding debris. Both the flood depth and velocity were considered within the damage assessment procedure. Kelman [13] presented an approach for the vulnerability assessment of residential buildings at a component level (e.g., wall and window) considering both flood rise and water infiltration processes; Mazzorana et al. [14] developed a method to quantify vulnerability of buildings by modeling the process intensity, the impact on the element, and the physical response of the building envelope; and Custer and Nishijima [15] proposed a vulnerability model considering relevant hazard and building characteristics at both component and system levels. All these studies investigated the performance of a single building under flood effects. To the best knowledge of the authors, there are no studies available focused on the performance and loss assessment of portfolios of buildings in a systematic manner; thus, relevant studies are needed. This paper aims to provide an approach to aid the assessment of portfolios of buildings under flood effects by considering both the correlation and uncertainty effects.

There are uncertainties associated with hazard intensity, structural performance, and consequences of structural systems under flood effects. Accordingly, a probabilistic approach is needed to account for different types of uncertainties. Under a given flood event, there are uncertainties with respect to the hazard intensity in terms of depth and velocity at the locations of buildings. In this paper, a probabilistic risk assessment and mitigation approach is developed to compute the loss of portfolios of buildings in a life-cycle context. As the flood is a low-probability high-consequence event during the service life of infrastructure, it is reasonable to investigate the flood effects on buildings within a large time interval, such as the life-cycle. Therefore, the life-cycle concept should be incorporated within decision making process of retrofit actions of portfolios of residential buildings under the flood. Additionally, since the buildings within a portfolio may be constructed by the same company using similar materials and specifications, there exist correlations among these buildings. The hazard intensities at the locations of the buildings are also correlated as they all arise from the same investigated flood event. Probabilistic loss of portfolios of buildings under flood effects at a large scale considering uncertainties and correlation effects has not been considered in previous studies. Herein, in order to quantify the probabilistic regional loss of portfolios of buildings, the uncertainties and correlation effects are incorporated within the evaluation procedure. Both mean and standard deviation are computed in the assessment process considering uncertainty and correlation effects.

Cost-benefit analysis should be incorporated into the hazard mitigation process in a probabilistic manner. The majority of the previous studies emphasized the expected value of benefit and did not consider the uncertainty related to benefit analysis, which may lead to inappropriate decisions. As there are large uncertainties associated with the hazard occurrence and intensity, these uncertainties should be incorporated within the benefit-cost anal-

ysis. Thus, the benefit-cost ratio should be treated as a random variable instead of a deterministic value. The benefit associated with a specific retrofit plan depends on the intensity and frequency of the investigated hazard, time interval considered, and the structural performance under retrofit actions. To the best knowledge of the authors, there are no studies available incorporating all relevant uncertainties within the benefit-cost analysis of infrastructure at a large scale. Herein, the uncertainties associated with benefit are considered in the hazard risk mitigation procedure at a community level. Furthermore, the life-cycle concept is adopted to investigate buildings' performance and benefit-cost ratio of retrofit actions.

Overall, this paper aims to provide an efficient probabilistic framework to aid the flood hazard risk mitigation of portfolios of residential buildings considering the probabilistic flood scenarios, building's performance, and benefit-cost analysis. The proposed probabilistic framework is general and can be applied to any portfolios of buildings. In this study, it is applied to unreinforced masonry buildings, one of the most common low-rise residential building types.

## 2. Building damage assessment under flood

In order to assess the structural performance of buildings under flood effects, a framework that considers hazard intensity and occurrence frequency, structural vulnerability under hazard, and consequence evaluation should be established. The flowchart regarding the performance-based hazard loss assessment is shown in Fig. 1.

### 2.1. Flood scenarios

The first step is to identify the magnitude and intensity of the flood. The performance-based assessment of buildings under a flood event involves many parameters. The most critical parameters are the flood factors (e.g., depth and velocity) and the building properties. Thus, in order to compute the structural performance, the flood depth and velocity should be identified first. The peak flow associated with different return periods of the flood can be determined based on the historical data. Given the flood scenario model, together with the topographic map of the investigated region of interest, the hazard intensity associated with the water height and velocity for a given return period can be obtained and incorporated within the structural performance assessment and hazard management process. This information, together with the detailed cartography of the investigated area and a digital elevation model, is used as input into the hydraulic model. The characteristics of the flood can be used for the flood load and structural performance analysis. In this paper, the load effects of the flood on residential buildings are related with flood depth, velocity, and debris considering different limit states. The Poisson process, which has been applied widely in the modeling the number of occurrence of floods within a specific time or space interval

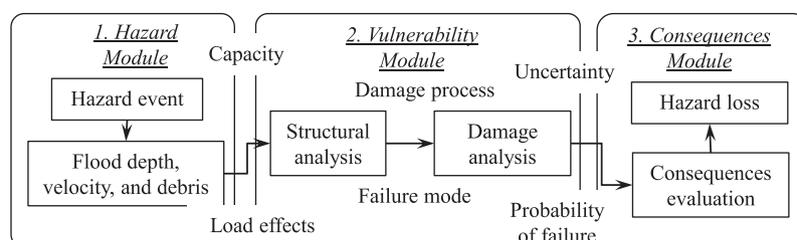


Fig. 1. Flowchart for the performance-based assessment of residential buildings under flood.

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