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Risk Analysis of Three-storey Reinforced Concrete Moment-resisting Frame Structures Using Performance-based Wind Engineering

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Abstract

This paper discusses the application of concepts of performance-based wind engineering used to determine the effects of changing building design elements to the performance of a structure against severe wind hazards in the Greater Metro Manila Area, Philippines. Only three-storey reinforced concrete moment-resisting frame structures were subject to analysis through computational fluid dynamics. Before assessing the performance of structures, severe wind hazards for the study area was characterized by collecting wind speed data from over 50 years and fitting the data using the Gumbel distribution. The building stock was developed by varying roof pitch and floor aspect ratio values in certain set increments. Roof pitches observed were 15, 30, and 45 along with structures with floor aspect ratios of 1:1, 1:2, and 1:3. The damage to roof and windows, as well as the damage index which gives the ratio of the repair cost to the replacement cost of a building, were identified. Damage for each model was classified according to the Hazard-US Damage State Matrix in order to generate a damage probability matrix. From this damage probability matrix, the probability of exceedance of each damage state was compute by taking the cumulative probabilities. Data points for each damage state were then fitted with a lognormal function. Vulnerability curves were developed by multiplying the probability of exceedance of each damage state to cost percentages adopted from the UPD-ICE Report [2]. Damage indices were computed per wind speed by summing the total damage for damage states. Wind speed versus risk density curves were generated by multiplying values for each data point in the vulnerability curves to the probability density function of the hazard. Risk curves were then obtained by plotting wind speeds against values of damage indices that correspond to said wind speeds. One key observation is that damage percentage increased as roof pitch also increased, having as much as around a 15% difference between structures with roof pitches of 15 and 45. Slender structures whose windward sides were also the long sides had the most damage. For all structures, a top-to-bottom progressive damage trend was observed.

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1. Introduction

Recent history has seen the unrelenting effects of natural disasters—earthquakes, storm surges, typhoons—on different structures. Among these structures are schools, government office buildings, and homes. Many have been reinforced, renovated, or rebuilt following these disasters. Most structures, particularly in the Philippines, are designed using the National Structural Code of the Philippines (NSCP), with which a set of minimum requirements (e.g., strength, stiffness, connections, etc.) based on the structural loads expected throughout the building's lifetime. However, with the increasing frequency of natural disasters—particularly typhoons—which are unusually large loads these structures will have to carry; one may not have a clear expectation of the performance of these code-designed buildings. These structures may underperform or be overdesigned. Building back better, more resilient structures requires one to gain insight on what specifically causes them to fail, how likely these specific causes are to happen, and ultimately what the consequences of these failures are. Once this information is available, the weaknesses in these designs may then be better addressed.

Performance-based design or PBD is a process that allows one to examine and quantify the performance of a structure against a particular hazard, while taking into account the inherent uncertainties in both hazard and structural performance. The process begins with the selection of performance objectives, then the development of a preliminary design, and performance assessment. It is an iterative process that terminates once the performance objectives have been met.

This paper begins with the development of a building database based on the scope of this study—three-storey, reinforced concrete moment-resisting frame structures within the context of the Greater Metro Manila Area. At the same time, performance criteria were set based on the Hazard US – Multi-Hazards (HazUS-MH) Hurricane Model and the study made by the University of the Philippines Diliman Institute of Civil Engineering (UPD-ICE). Since the PBD incorporates also the uncertainties in the hazard, maximum wind-speed data in the Greater Metro Manila Area for over fifty years was collected and fitted using a Gumbel distribution. Computational fluid dynamics was then used to assess the interaction between hazard and structure. Risk curves were then obtained from the data gathered.

The objective of this paper is to be able to quantify the performance of the different structures in order to see the relative influence of changes made in the different design variables. Understanding the different factors that affect how a structure performs against a hazard will allow better insight into how to design new structures that are more resilient.

2. Methodology

2.1. Development of Building Database

Severe wind load greatly affects the building envelope. According to different studies made on wind engineering as well as observations made on structures damaged by severe wind load, cladding on the roof and walls, doors, and windows are the most vulnerable to damage [2]. The typical failure sequence of elements of the building envelope are as follows: roof cover → windows → doors → gable ends → roof sheathing →roof framing system → walls, as observed from a case study by Valdez [3]. The Hazard US – Multi-Hazards (HazUS-MH) Hurricane Model presents ways to classify damages states that a structure is categorized under. While the HazUS-MH Hurricane Model covers the effects of debris (missile) impact on structures, the particular study does not. This study focuses only on roof cover and window failure of structures with gable roofs. Roof frame structure and wall failures were not considered as these were the very last components of the building envelope that were damaged, where wall structure had almost no damage.

The applicable table of performance criteria used for this study is presented in Table 1. Since this study was done in line with the research of the University of the Philippines Diliman Institute of Civil Engineering (UPD-ICE), the