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Measuring Vulnerability of Typhoon in Residential Facilities: Focusing on Typhoon Maemi in South Korea

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Abstract: Typhoons cause severe monetary damage globally. Many global insurance companies and public agencies are currently developing and utilizing windstorm risk estimation models to calculate the level of risk and set up strategies for avoiding, mitigating, and relocating those economic risks. Hence, the usage and accuracy of the windstorm risk estimation model is becoming increasingly significant, and reflecting local vulnerabilities is essential for refined risk assessment. While key risk indicators have been recognized in practical studies of economic losses associated with windstorms, there remains a lack of comprehensive research addressing the relationship between economic losses of residential buildings for South Korea and vulnerability. This research investigates the real damage record of Typhoon Maemi from an insurance company in order to bridge this gap. The aim of this study is to define the damage indicators of typhoons and create a framework for typhoon damage function, using the damage caused by Typhoon Maemi as a representative paradigm. Basic building information and natural disaster indicators are adopted to develop the damage function. The results and metric of this research provide a pragmatic approach that helps create damage functions for insurance companies and contingency planners, reflecting the actual financial losses and local vulnerabilities of buildings. The framework and results of this study will provide a practical way to manage extreme cases of natural disasters, develop a damage function for insurers and public authorities, and reveal the real economic damage and local vulnerability of residential buildings in South Korea.

Keywords: typhoon Maemi; typhoon vulnerability; residential facility; damage function

1. Introduction

The rate of occurrence of extreme windstorms is increasing rapidly, and the associated losses are growing rapidly as well [1]. Hurricane Katrina, which hit the southern US in 2005, generated an economic loss of about $ 81 billion, making it the costliest natural catastrophe in the United States to date [2]. Due to the direct and indirect impacts of Hurricane Katrina, states in the US Gulf Coast suffered for a long period after the hurricane. Hurricane Sandy and Hurricane Ike followed; Hurricane Sandy reached the eastern coast of the US in 2012 and led to losses of $ 71.4 billion, while Hurricane Ike hit the southern coast of the United States in 2008 and led to losses of $ 29.5 billion [2,3]. European windstorms Anatol, Lothar, and Martin, which smashed Central Europe and Western Europe in succession with heavy winds and heavy rain in December 1999, led to losses totaling about 13 billion euros [4]. In 2013, Typhoon Haiyan blasted many countries in its path and was recorded as the most powerful typhoon among those that landed; it was called Super Typhoon Haiyan. The typhoon caused storm surges and strong winds over South Asian countries, and overall losses were valued at $ 2.88 billion [5].

Many developed countries are choosing insurance to actively reduce and transfer the financial losses of these windstorms. Therefore, it is imperative to accurately and objectively predict financial loss. Insurers use natural catastrophe models and chronological damage records to predict the economic losses of various scopes (some individual buildings, provinces, or countries) and to manage cumulative risks. Natural catastrophe models comprise four basic modules, i.e., hazard, exposure, financial, and vulnerability modules. More specifically, these modules consist of Touchstone/Clasic of AIR, RiskLink of RMS, and Risk Quantification & Engineering (RQE) of EQECAT. The hazards regulate typhoon information, e.g., the frequency and intensity of typhoons, the central pressure, precipitation, and storm surges, and the regeneration of typhoons in specific regions and periods. The financial module appraises economic losses based on insurance information, e.g., catastrophic excess loss, excess loss risk, liability limit, etc.). The vulnerability module uses the damage function, which explains the relationship between the vulnerability of the building and risk indicators, in order to calculate damage based on building vulnerability [6]. The damage function is developed or verified based on analysis of past windstorm damages. Consequently, the accuracy of the damage function is substantially affected by the presence and quality of the past damage data.

However, due to the lack of detailed loss records in the real world, it is difficult to generate a damage function. The claim payment record of the insurance company contains detailed and accurate loss information related to the damages. The records are reliable in relation to the damage, since the payment is made according to the results of the objective inspections of the engineer and the claim adjuster. The attributes of the data are used to create a damage function that evaluates the vulnerability of an individual building. Nonetheless, insurance companies hesitate to document detailed building information, e.g., building type, age, height and materials [7]. This is because it takes a lot of effort and time to create a database. It is a burden not only for small businesses, but also for large companies. This phenomenon is more pronounced in developing countries such as South Korea. The low resolution data available for currently-developing countries does not meet the level of the catastrophic model of vendors that requires detailed input information. When a vendor's catastrophic model simulation is performed, over- or under- estimation phenomena may lead to predictions that differ from the actual potential risks, thus failing to demonstrate the model's capacities. Therefore, for a sophisticated evaluation in a developing country, it should be possible to evaluate using minimum information in consideration of the low data quality. Furthermore, in developing countries with low insurance penetration rates, it is principally necessary to produce and validate damage functions through the use of historical loss records. The lack of and low quality of such data make it challenging to label the correlation between the potential risk and loss of the country as a result. Therefore, in these countries and circumstances, indicators and models are needed to easily or directly calculate the vulnerability of a building.

The aim of this research is to provide the development of a damage function for sophisticated damage assessment in cases of insufficient building information. The study also provides damage indicators with which to assess the damage triggered by typhoons.

1.1. Meaning of Extreme Natural Disaster

When a record hurricane, such as Hurricane Ike, Katrina, or Sandy occurs, the resulting unexpected massive losses can cause insurance companies to go bankrupt or change their coverage and charges quickly [8]. Typhoon Maemi was recorded as the typhoon that caused the most damage in South Korea. Typhoon Maemi is the largest typhoon ever in South Korea in terms of size and strength. It is also called Super Typhoon Maemi, due to its strength, and it can be categorized as an extreme disaster. Typhoon Maemi generated a tropical cyclone in the sea near Guam on September 4, 2003 and landed on the southern coast of the Korean peninsula on September 11 after passing through Okinawa Prefecture, Japan. After subsequently landing in the southeastern part of the Korean peninsula, it left the East

Sea on September 12 and faded into the East Sea. When it landed, it was the most robust typhoon among the typhoons that have historically affected the Korean peninsula. For example, the typhoon broke historic typhoons such as a maximum wind speed of 54 m/s, center pressure of 910 hPa, and maximum size of 460 km (radius). The typhoon's extreme precipitation, wind speed, and storm surge led to 61,000 being affected and to 135 deaths. The total cost of the damage was about $ 4.3 billion (Nation Typhoon Center) [9]. The World Meteorological Organization removed the name Maemi from circulation due to the extreme damage caused by the typhoon and replaced it with Mujigae (Nation Typhoon Center) [9].

1.2. Quantification of Natural Disaster Risks

Several state agencies and international organizations are currently investing a lot of resources into developing natural catastrophe models to predict, to react to, and to diminish the risk of natural disasters. For example, the new Multi-Risk and Multi-Risk Assessment Method in Europe, RiskScape in New Zealand, Central American Probability Risk Assessment, HAZUS Multi Hazard (MH) in the Unites States, and the Florida Public Hurricane Loss Model, are representative. These models measure indirect and direct losses on the nationwide or province-wide scale that may arise from flood, windstorm, earthquakes, and storm surges. Even so, since such models measure the vulnerability of the region to natural disasters, it is difficult to assess the risks outside the covered areas where the vulnerabilities differ. Based on Crichton's hazard triangle [10], this research adopts a variety of indicators that everyone could easily calculate and certainly obtain. Consequently, the results and methods of this study will be a worthy guideline for generating a typhoon risk assessment model with which to compute financial risks. Government agencies and the insurance industry will also be able to model their own risk modeling and risk management from the fatal typhoon risk.

2. Methodology of Research

2.1. Damage Records

The goals of this research are to establish a systematic way to determine the relationship between typhoon damage, natural disaster indicators, and basic building information indicators, and to determine the weights of key indicators to compute damages reproducing local vulnerability. In order to achieve these goals, this study incorporates the damage records from Typhoon Maemi from a major insurance company in South Korea. The scope of the research is limited to South Korea. Figure 1 shows the outline of the data collection and analysis process for this study.

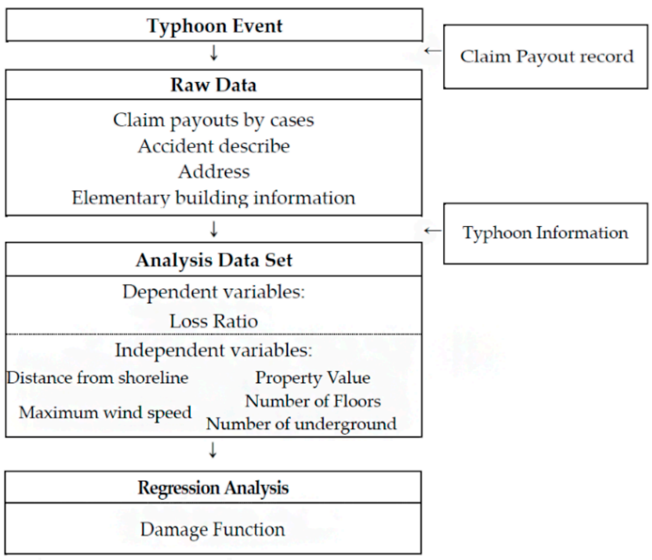

Figure 1. Research procedure.

The amount of damage is the net damage paid by the insurance company on damages caused by Typhoon Maemi without any insurance conditions. As shown in Figure 2, Typhoon Maemi hit the southern coast of South Korea on September 12, 2003, and escaped through the East Sea, causing severe financial losses in its path. Most of the damage occurred on the day of September 12th. The claim payout record collected from the insurance companies included the information as following: accident date, address, occupancy, property value, amount of loss, number of floor, number of underground, and so on. In this study, vulnerability indicator consisted of two factors, building indicators and typhoon indicators. For building factors, the authors collected such information as Property Value, Number of Floors, Number of underground from each claim case. For typhoon factors, such information as the wind speeds of the individual buildings where the damage occurred were collected based on the date of the accident and the address information in the loss records utilizing Geographic Information System (GIS). In addition, the distance from the property centroid to the coastline is also estimated based on the address information using the GIS. After collecting the data, a multiple regression was used to analyze the data, from which the damage function was derived that delineated the relationship between the dependent and independent variables. The collected data were analyzed by a statistical package (SPSS, Statistical Package for the Social Sciences). The following Table 1 includes the details of the adapted variables in this study.

Table 1. Data collection.

Classification	Indicators	Explanation	Measure	Data Source
Typhoon information	Distance from shoreline	Distance from shoreline	Km	Korea Hydrographic and Oceanographic Agency
	Maximum wind speed	Sustained maximum wind speed over 10 min	m/s	Japan Meteorological Agency
Building Information	Property Value	Total value of property	$	Claim payout record
	Number of Floors	Total number of buildings' floors	Number	
	Number of underground	Total number of buildings' underground	Number	

In this study, the dependent variable representing the quantitative damage in the model is expressed as the ratio of the compensation amount to the property value as shown in Equation (1), which is referred to as Damage Ratio.

$$\text{Damage Ratio} = \frac{Claim\ payout}{Property\ Value} \quad (1)$$

Table 2 displays the regional loss distributions collected from the insurance claim records from Typhoon Maemi. In particular, the southern part of the Korean Peninsula, Gyeongnam and Busan specifically, was devastated by the typhoon. Due to the typhoon, Busan represented as much as 47.0% of total claim payouts and 38.6% of number of claim payouts. Gyeongnam also suffered inordinate damage, accounting for 43.0% of total claim payouts and 22.2% of number of claim payouts. Both provinces were located in the typhoon landing area, and more damage occurred in areas located to the east of the typhoon path.

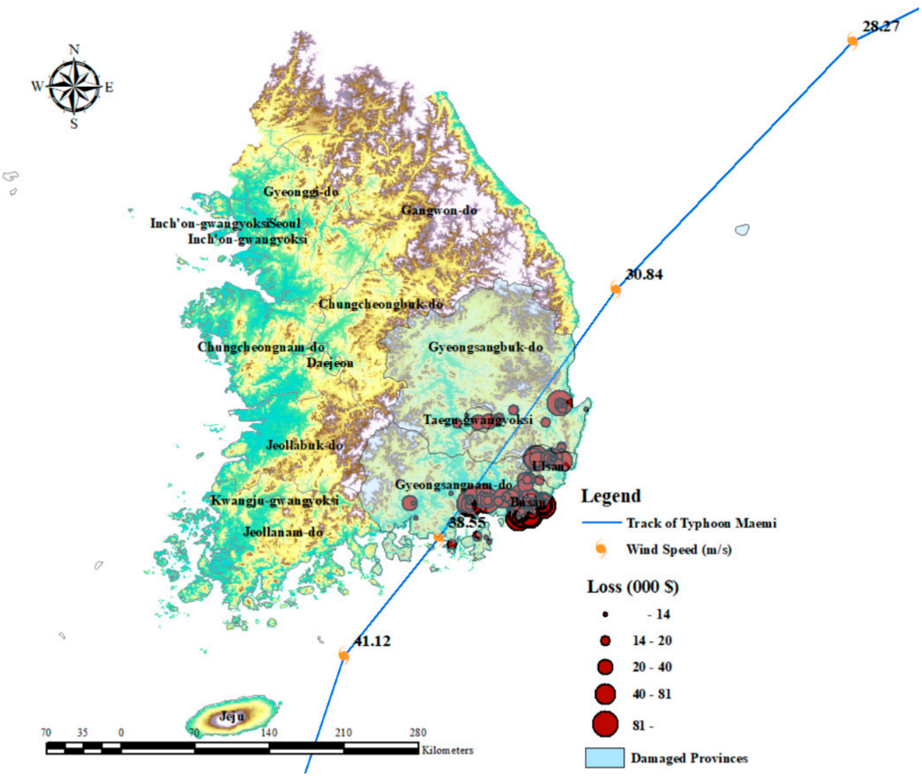

Figure 2. Damage distribution.

Table 2. Damage record of Typhoon Maemi by province.

Province Name	Number of Claim Payouts	Total Claim Payouts (1000 USD)
Busan	127	4,643,478
Gyongnam	73	4,256,039
Gyongbuk	48	414,493
Ulsan	46	495,652
Daegu	35	78,261
Sum	329	9,887,923

2.2. The Section of Variables

The damage record comprises two categories: the first is the damage detail, including the amount, date and description of the damage, and the location where the damage occurred; the second is basic building information, which includes the building value and classification, number of floors, and number of basement floors. The records did not include detailed building inventory information.

Various characteristics of the indicators directly or indirectly affect the typhoon damage [11]. Using the recorded location information, the indicators for each damage were gathered and calculated using the Geographic Information System. The distance between the building and shoreline is also a main factor for the vulnerability of the building to typhoons. Highfield et al. (2010) [12] demonstrated the relationship between the distance to the shoreline and the vulnerability of the building by analyzing the damage caused by Hurricane Ike in Bolivar Peninsula and Galveston Island. They reported that as the distance from the shoreline rises, the damage is reduced. This indicates that buildings near the shoreline are more exposed to typhoons than buildings far from the shoreline. Wind speed is an essential meter of the typhoon's strength and triggers several damages e.g., missile impact, storm surge, and flood [13–15]. The wind speed of the damaged building was measured using the Geographic Information System based on the maximum wind speed of the accident date. The wind speed information consisted of the

10 minutes' maximum sustained wind speed of the Japan Meteorological Administration, which are the Regional Specialized Meteorology Centers (RSMC) for Northwest Pacific region.

The basic features of the building are well-known indicators of typhoon vulnerability depending on building inventory. The property value of the building has a statistically significant relationship with the damage of the typhoon. Kim et al. (2017) proved that the correlation between the property value and damage is negative [7]. This means that typhoon damage increases as the building value decreases. Building heights are also a vital indicator of vulnerability to storms [6,16]. This is attributed to the fact that the building height has a statistically significant relationship with the degree of financial damage and can be used as a vulnerability indicator to compute a building's vulnerability to typhoons. For example, building height and hurricane damage are positively correlated. This indicates that typhoon damage increases as building height increases [17,18]. Table 3 presents the descriptive statistics of the dependent variable and independent variables.

Table 3. Descriptive statistics.

	N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable					
Damage ratio (%)	329	0.0	0.2	0.0	0.0
Independent Variables					
Distance from shoreline (km)	329	1.3	117.9	27.1	19.8
Wind speed (m/s)	329	31.2	38.2	37.2	1.3
Property Value (1000 USD)	329	96	152,044	30,117	27,306
Number of Floor (number)	329	1.0	28.0	20.4	4.1
Number of Underground (number)	329	-	5.0	0.6	0.9

3. Results

Statistical Analysis

Table 4 displays the results of the multiple regression model analysis of damage in residential buildings and variables, i.e., the basic features of building and typhoon information, caused by Typhoon Maemi. The adjusted R^2 value is 0.534, which indicates that 53.4% of the variation of the damage ratio can be described by the regression model. Five significant variables, i.e., property value, number of floors, number of underground floors, distance from the coast, and wind speed, are defined as indicators of the severity of typhoon loss. The values of the variance inflation coefficient (VIF) ranged from 1.034 to 1.098. This range explains that there is no considerable multicollinearity between variables. Therefore, through the VIF test results, it can be said that there is no significant relationship between the variables. The significant variables can be ranked in descendant order of their beta coefficients. According to the number of the coefficient, the indicators are (1) wind speed (beta coefficient = −0.509), (2) property value (beta coefficient = −0.317), (3) distance from shoreline (beta coefficient = −0.248), (4) number of underground floors (beta coefficient = 0.113), and (5) number of floors (beta coefficient = 0.093).

Table 4. Regression analyses results.

Variables	Coef.	Beta Coef.	p >|z|	VIF
Basic Features of Building				
Property Value	−1.422E-005	−0.317	0.000	1.034
Number of Floor	0.039	0.093	0.015	1.051
Number of Underground	0.029	0.113	0.023	1.044
Typhoon Information				
Distance from shoreline	−0.013	−0.248	0.000	1.059
Wind speed	0.479	0.509	0.000	1.098
Number of Observations		329		
F		46.789		
Adj-R^2		0.534		

"Coef." labels the non-standardized coefficients that reproduce the unit scale of the independent variable. "Beta Coef." describes standardized coefficients that neglect the unit scale of independent variable, which aids to contrasts among the independent variables. The higher value of the Beta Coef stands for the more substantial influence on the dependent variable.

4. Discussion

Due to the demand for sophisticated natural disaster risk modeling raises, numerous vendors are conducting professional modeling, such as Risk Management Solution, EQECAT, and Applied Insurance Research [19,20]. These companies have developed models to quantify the risks of natural disasters, e.g., European windstorm, earthquake, flood, tornado, typhoon, hurricane, and tsunami that are used by insurance and reinsurance companies around the world. This is now used as a standard method for analyzing natural hazards. Nevertheless, high annual fees are an obstacle for any company or organization to practice. Moreover, there are limited countries in which evaluation is possible. For example, the United States, Japan and China have large insurance industries and are often hit by natural disasters, so many vendor companies are currently developing models and doing business. On the other hand, small and medium-sized companies or organizations that cannot afford the elevated annual fees of aforementioned countries cannot be evaluated using the vendor model. There will be a problem if an insurer attempts to assess the risk of an area not covered by a vendor's model. Further, the modeling firms also recommend that insurers and reinsurers use independent models to identify and assess their portfolios and risks. The reason for this is that it is risky to determine the risk by using only the existing standard models. This is because insurance companies may differ from the results of standardized models due to different capital, business preferences, and portfolio. They should be able to judge whether the results of the vendor model are optimistic or conservative in their circumstances. Therefore, the insurers and reinsurers should have their own models or standards that can verify the results of the standard model. Therefore, in order to satisfy the demand of the models, this study statistically analyzed the damages of residential facilities caused by typhoon Maemi and identified the features of typhoon damage according to the path of the typhoon by statistically analyzing the damage caused by the typhoon.

Typhoon Maemi was considered the worst-case scenario, with the strongest intensity and causing the most damage from a typhoon in South Korea, especially in the southern part of the Korean peninsula, i.e., Busan and Gyeongnam. For these reasons, the typhoon has been referred to as Super Typhoon Maemi and classified as an extreme disaster. Most damage occurred in Gyeongnam and Busan, which are located on the right side of the typhoon path. The cause for this is that the typhoon landed on the coast of Gyeongnam, causing direct damage to the area and, in particular, to the area to the right side of the typhoon path due to the extremely strong winds and heavy rainfall [21]. In the right-sided area of the expected path of the typhoon, more efforts are needed to mitigate typhoon damage.

This study used insurance claim payouts, typhoon information, and building information to analyze Typhoon Maemi damage and to assess the risks. As the relationship between damage ratio and the valid variables were identified as statistically significant in this study, this study confirms that the damage function model is statistically significant. This finding reinforces the hypothesis of previous studies, i.e., that the significant variables are worthy parameters to explain the damage of natural disaster and are also important to quantify the damage amount. In addition, this study also revealed that there is a significant relationship between the amounts of insurance loss caused by natural disasters and adopted variables. This finding can make contributions to a variety of relevant sectors, including government agencies, insurance and reinsurance companies, building construction companies and homeowners.

First of all, government agencies and disaster officials in the public sector alike can utilize the damage function model suggested in this study and predict the possible economic damages, which can contribute to moderating the damages associated with a typhoon and to creating mitigation plans for estimated damages in advance. In so doing, there is a need for the weight of each variable to be adjusted through the use of a coefficient that replicates the vulnerability of the local buildings in each region.

Second, the metrics set in this study can be applied to forecast economic damages in insurance and reinsurance companies. That is, an insurance or reinsurance company can use the metric from this study to reconstruct a business model along with the risk attitude. They can use this model to estimate the maximum loss of an individual building or a group of buildings, to set an event limit, and then to estimate the appropriate premium. Furthermore, the maximum losses can be used as a basis for managing the cumulative risk of typhoons in specific regions. For example, an insurance company could calculate the amount of damage that could be caused by typhoons whose scale and intensity were similar to those of Typhoon Maemi by putting the damage function of this model and the insurance policy currently held in vendor's typhoon model. The result will be used to estimate the maximum amount of loss that can be incurred from the insurance policy currently in operation and for the accumulative risk management of the typhoon. Moreover, this model can be used to set the appropriate premium. The risk of catastrophe is an important factor in determining premiums. Premiums, in insurance business, are a combination of specific risks, uncertain risks, administrative prices and catastrophe risks. The catastrophe risk is calculated on the basis of extreme disasters. By using this model, it is possible to set a proper premium by estimating the amount of loss caused by typhoons.

Third, building construction companies are able to improve design guidelines by designing storm-resistant buildings and by assessing the building loss based on the predicted total value of property, construction type, and the number of floors of the building. As such, of this study can contribute to designing buildings that can withstand typhoons. By estimating the expected loss of the building based on the expected value of the building, number of buildings, and number of basements, damage to the typhoon in the future can be reflected in the life cycle cost of the building.

Furthermore, homeowners can use it as a decision for insurance and retrofit. Retrofitting and insurance are methods for managing natural disaster risks for residential buildings. Insurance is a risk management method that distributes risk, which is how the homeowner reduces the damage by transferring the risk to the insurance company. Retrofitting, on the other hand, is a risk management method that reduces physical damage to buildings. For example, an additional anchor can be added to the roof sheath to reduce wind damage, or a brace can be installed on the opening shutter to prevent hurricane damage. In particular, retrofitting is considered a way to effectively reduce risks and costs for un-insured homeowners [22]. For homeowners, it is necessary to select insurance and retrofitting by judging the economic feasibility according to the risk of the baseline, e.g., the insurance policy, building inventory, location, and risk attitude [22–24]. For these questions, it is essential to quantify the exact risks of natural disasters. Therefore, the results and framework of this study will help to make this judgment.

Various studies have used real scenarios for disaster management and strategic foresight [25–27]. However, the scenario approach tends to be somewhat time-consuming, in the sense that data and information from various sources need to be collected and analyzed over time [28]. The study is novel because it can add an alternative option, as it provides realistic and quantified values in the analysis; these provide a better understanding of the facts for more timely effective decision making [29]. Risk cost has been considered the most common scale in risk analysis; various studies have used it [30–33]. Therefore, the use of actual cost, such as insurance claim payout, as an assessment scale will not only improve the accuracy and validity of the analysis and decision making, but will also provide valuable insight for public policy and the insurance industry

5. Conclusions

Typhoons are instigating noteworthy financial losses worldwide, and in response insurance companies, municipalities, and governments are adopting typhoon risk assessment models to assess levels of damage. The damage functions of the typhoon catastrophic models are produced and confirmed based on the analysis of real damage, such as statistical records from governments and insurance companies.

Nonetheless, shortages in comprehensive damage records are among the most common problems in the development of the damage function, which are more of an issue in developing countries such as South Korea. Hence, this study proposes a method with which to develop a damage function based on damage records from Typhoon Maemi in South Korean insurance company. The results and methodology of this study could be used as a guideline for the development of a damage function that reflects the local vulnerability of typhoons in areas where data are rare.

However, this study only considers residential buildings in Korea that were damaged by Typhoon Maemi; the results for commercial and industrial buildings may vary. The damage function in this study is to find the mean damage ratio, resulted from Typhoon Maemi. However, by showing the statistical significance of the function, this case study also lends credence to the possibility for the function to be adopted and generalized to some cases of other typhoons in other regions. Yet, admittedly, there is a degree of concern to use and adopt the damage function in this study for all the typhoon cases, regardless of possible distinctiveness of each case. Future studies should include commercial and industrial buildings in order to strengthen the results. The value of adjusted R^2 is 0.534, which designates that the remaining variability of the damage is described by the indefinite predictor. Therefore, it is necessary to determine other potential predictive variables and add them to the model. The data used in this study are only made up of the damage caused by Typhoon Maemi. For this reason, we call for supplementary studies, especially dealing with various categories of typhoons and the local vulnerability of the buildings.

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