

## Research Article

# Typhoon Vulnerability Analysis in South Korea Utilizing Damage Record of Typhoon Maemi

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Received 27 May 2020; Revised 11 September 2020; Accepted 18 September 2020; Published 29 September 2020

Academic Editor: Tiago Ferreira

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The purpose of this research is to identify the indicators of typhoon damage and develop a metric for typhoon vulnerability functions employing the losses associated with Typhoon Maemi. Typhoons cause significant financial damages worldwide every year. Federal and local governments, insurance companies, and construction companies strive to develop typhoon risk assessment models and use them to quantify the risks so that they can avoid, mitigate, or transfer the financial risks. Therefore, typhoon risk assessment modeling is becoming increasingly important, and in order to achieve a sophisticated evaluation, it is also important to reflect more specified and local vulnerabilities. Although several previous studies on economic loss associated with natural catastrophe have identified essential risk indicators, there has been a shortage of more specific research studies focusing on the correlation between vulnerability and economic loss caused by typhoons. In order to fill this gap, this study collected and analyzed the actual loss record of Typhoon Maemi collected and accumulated by a major insurance company in Korea. In order to create the vulnerability functions and to identify the natural hazard indicators and basic building information indicators, information from the insurance record was used in the analysis. The results and metric of this research provide a pragmatic approach that helps create vulnerability functions for abovementioned sectors and like estimating local vulnerabilities and predicting and coping with the possible damage and loss from typhoons.

## 1. Introduction

**1.1. Background.** As the incidence of severe windstorms continues to increase drastically, the resulting losses are also remarkably increasing [1]. For example, in 2005, Hurricane Katrina caused about \$ 108 billion in economic losses, and this loss has been recorded as the most destructive natural disaster in the United States in economic impact wise. Hurricane Sandy and Hurricane Ike have been classified as the hurricanes of the second and third largest financial losses, respectively. That is, Hurricane Sandy in 2012 led to losses of \$71.4 billion, while Hurricane Ike in 2008 led to losses of \$29.5 billion [2, 3]. In December 1999, three sequence of European windstorms, i.e., Anatol, Lothar, and Martin, hit Western Europe and Central Europe with heavy

rains and strong winds. The total economic damages were approximately 13 billion euros [4]. Typhoon Yolanda, a.k.a., Super Typhoon Haiyan passed over several countries in its path in 2013 and recorded as the most extreme typhoon on land. This typhoon severely devastated a wide area covering several southern Asian countries with extreme storm surges, landfall, and winds and led to total losses estimated at \$ 2.88 billion.

To cope with such damages and losses, many industrialized countries have adopted and used insurance as a means to transfer the financial risks caused by typhoons. At this, it is crucial for the insurance industry to be able to accurately estimate and assess the risks. In order to achieve such accurate and reliable assessment, insurance companies use natural catastrophe models and historical loss records to

predict and manage potential economic losses in individual buildings, regions, or countries. Among these, the natural catastrophe model consists of hazard, exposure, finance, and vulnerability modules [5]. The hazard module identifies the frequency and intensity of typhoons and other typhoon information, e.g., storm surge, precipitation, and central pressure, and regenerates typhoons in specific areas and periods according to the prescribed information. The finance module estimates the economic losses based on the policy term, e.g., risk excess of loss, cat excess of loss, and limit of liability. The vulnerability module is a module that uses the vulnerability function to quantify the degree of damage by vulnerability according to the building attributes using the correlation between damage and risk indicators [6]. The vulnerability function can be found by analyzing past storm losses, and it can also be validated by the losses recorded. As can be seen, the precision of the vulnerability function, among many other factors, is substantially affected by the presence and its quality of past damage data.

However, in practice, it is difficult to develop a vulnerability function, since there is a lack of detailed loss records. Meanwhile, claim payout records of insurance companies can provide specific, accurate, and reliable loss data. That is, these claim payout records can be used to assess the vulnerability of individual buildings by taking advantage of the features of building inventory because such data includes the information of engineers' and claim adjusters' objectively inspections and their results and the information of claim payout paid accordingly.

Nonetheless, many insurance companies are tended to be hesitant to record or document the data on detailed building exposures, such as building type, building age, building height, and building materials. The reason for this is that developing a database that includes such information is considered to be inefficient, timewise and moneywise, for not only small- and medium-sized companies but also large corporations [7]. For this reason and many other related reasons, the low data quality does not follow the input level of the sophisticated vendor CAT models to date. And therefore, the current situation is that the risk assessment is relied on the basic and minimum amount of data and information available. Furthermore, in developing countries with emerging economies, in which insurance penetration rates are relatively low, it is strongly required to create vulnerability functions using historical loss records. Similarly, in certain countries, it is particularly difficult to describe the correlation between potential risk and loss, due to incoherent data or a lack of data [8]. In order to reduce the uncertainty of the evaluation model, the demand for and importance of identifying and developing work through proxy measurements of risks is increasing. Therefore, there is an urgent need for metrics and models that can easily and directly estimate and assess the vulnerabilities of the buildings to typhoons in these countries and situations.

In this study, based on the actual record of damages and the consequent financial losses caused by typhoons documented and accumulated by a major insurance company in Korea, it is first aimed to identify the statistically significant risk factors of buildings and of typhoons while relying on the

objectivity and accuracy of the quantitative data. This study also intends to develop and model a local vulnerability function, which assesses the damage of buildings from the results of typhoons by conducting the statistical analysis of the risk factors, in order for many sectors including federal and local governments, insurance companies, and construction companies to utilize in their own damage assessment. Ultimately, this study was designed to provide more methodologically grounded understanding and evidence-based knowledge in minimizing the risks of typhoons to buildings.

*1.2. Natural Catastrophe Model.* As the demand for natural catastrophic risk modeling continues growing, several vendors such as Applied Insurance Research (AIR), EQECAT, and Risk Management Solution (RMS) [9, 10] have developed their own models. These models are also used by insurers and reinsurers around the world to assess the risks of natural disasters such as hurricanes, tsunamis, typhoons, floods, earthquakes, tornadoes, and winter storms, and they are considered to be the standard methodologies for natural disaster risk management. However, such models are hardly applicable for all companies and cases due to their high annual fees and also limitations for specifics. More specifically, it is a problem that models can only be developed and evaluated in a limited number of countries, such as the United States, China, and Japan, which often suffer large losses due to natural disasters and large insurance industries. For small- and medium-sized countries, it is not possible to utilize the models in their own risk evaluations in the same way due to the limitations for specifics. In addition, the modeling firms encourage insurers and reinsurers to create an independent in-house model with which to apprehend and assess portfolios and risks. It is dangerous to conclude the risk solely with the existing standard models alone. One of the reasons for this is that different insurance companies may show results unlike those from the standardized model due to the diverse business preference, portfolio, and capital. They should be able to judge whether the outcome is optimistic, pessimistic, or conservative, depending on their exposure. Therefore, insurers and reinsurers require in-house models that can verify the results of the standard models to their exposure.

Furthermore, many international organizations, e.g., HAZUS Multi-Hazard (MH) in the United States, the Florida Public Hurricane Loss Model (FPHLM) in the state of Florida, the Central American Probability Risk Assessment (CAPRA) in South America, the new Multi-Risk and Multi-Risk Assessment Method (MATRIX) in Europe, and the RiskScape in New Zealand, are investing a lot of resources in developing natural catastrophe models to be able to better predict, respond, and mitigate the risks associated with natural disasters. These models can assess direct and indirect damages at the national or community level due to tropical cyclones, earthquakes, floods, and storm surges. Nonetheless, these models are not designed to be adopted in the insurance industry because there are no finance modules that consider insurance concepts such as layers, deductible,

and so on. For this, this study adopted the various indicators that can be straightforwardly computed and easily accessed, found on Crichton's risk triangle [11].

**1.3. Significance of Analyzing Typhoon Maemi.** After major record-breaking hurricanes, such as hurricanes Katrina, Ike, and Sandy, insurance companies had to shut down, due to unexpected tremendous losses, and the companies that survived had to quickly modify their coverage and rates [12]. For this reason, insurers and reinsurers analyze extreme natural disasters in order to prepare reserves for losses from such extreme natural disasters.

They allocate portfolios to avoid emergencies and worst-case scenarios. They also set up catastrophe zones and limit amounts in order to minimize the damage caused by these extreme disasters. The records of previous extreme disasters are used as essential bases to establish the zone and limit.

Furthermore, the potential risk of natural disaster is the one of the major points used to determine the premium. The premium consists of the pure premium, expense, and profit. The pure premium is a combination of modeled cat risk, nonmodeled cat risk, and noncat risk such as FLEXA (i.e., fire, lighting, explosion, and aircraft). The historical loss records from previous extreme disasters guide the modeled cat risk and nonmodeled cat risk as well. Hence, analyzing extreme disasters makes a significant contribution in assigning risk and determining pricing.

In addition, the maximum amount of loss caused by a catastrophic disaster is a very vital number in the insurance industry. For example, insurers and reinsurers should assess probable maximum loss (PML), excess of loss reinsurance (XOL), liability limit (LOL), and retention. The PML is the amount of maximum loss an insurance company is likely to sustain. It also stands for the amount of loss expected from the worst-case scenario. Probable maximum loss (PML) has to be taken into account by an underwriter when taking risks. Underwriters must consider PML in order to determine whether to take the risk and also to determine the premium [13]. XOL and LOL are meaningful for allocating and limiting financial risk [14]. Retention is the responsibility of the insurer to limit the scope of the risk; it is an important management indicator for an insurance company because it is set as the amount of one's own responsibility, the amount of holding, and the amount of holding limit. The elementary guidelines are based on damage analysis of extreme disasters. Therefore, in order to plan for unanticipated damage and compute maximum losses, it is necessary to analyze extreme disasters.

In the New Oxford American Dictionary, the term typhoon is defined as "a tropical storm in the region of the Indian or western Pacific oceans" [15]. Among the two types of typhoons, straight and recurving, in areas such as Philippines, southern China, and Vietnam, are threatened by straight-moving typhoons, while recurving typhoons are threats to Korea, northern China, and Japan [16].

Typhoon Maemi in 2003 caused the most extreme damages in South Korea, as it was the largest in size and intensity since the record-keeping had begun in the country

in 1904. Typhoon Maemi was generated as 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 its rapid penetration of the southeastern part of the Korean Peninsula, it disappeared on September 14 in the East Sea. Among all the typhoons that have affected the Korean peninsula, it was the most destructive at the time of landing. The typhoon updated the record in various ways; the central pressure was 910 hPa, the maximum wind speed was 54 m/s, and the maximum size was 460 km (radius). The damage was also enormous due to its severe wind speed, storm surge, and precipitation. Ultimately, 135 people died, there were 61,000 victims, and the overall property damage was about \$ 4.3 billion (in 2003 year). In terms of the strength and consequent damage of Typhoon Maemi, the distribution of the loss record indicated the southern part of the Korean Peninsula, such as Busan and Gyeongnam province, was particularly devastated by the typhoon. In particular, the loss distribution shows that in the right side area of the Gyeongnam province, more damage has occurred than in the left side area of the province. The reason for this was that the typhoon landed directly on the midcoast of Gyeongnam province, and the right side of the area had more influence than the left side of the area by the strong wind and rainfall of the typhoon [17, 18]. The World Meteorological Organization decided to remove the name Maemi from circulation and substituted it with Mujigae in 2006 due to the extreme damage and death caused by the typhoon [19].

## 2. Review of Literature

Several previous studies have focused on hurricane/tornado damage, damage assessment, and vulnerability analysis. This section will refer to a few most recent studies that specifically examined hurricane/tornado damage in terms of vulnerability analysis.

Chock looked into hurricane damage on Hawaii residential buildings gathered and georeferenced on the GIS. Data on property tax records, which included construction type attributes and property valuation, were also adopted, in order to specify residential building fragilities in relation to comprehensive reconstruction cost. As a result, this study suggested risk relativity factors and developed loss functions, which contributed to estimating hurricane damage to various Hawaii buildings [20]. Zhang suggested the concept of socioeconomic vulnerability and provided six vulnerability indicators (population density, population of coastline, GDP, primary industry export, annual disposable income of urban residents, and annual disposable income of rural residents) to assess the socioeconomic vulnerability to typhoon surges [21]. Heneka and Ruck focused on German winder storm events in 2000s and the damage from them to residential buildings. Using physical evidence and logical assumptions, this study derived a model that calculates number and financial values of damage, while assessing and simulating the spatial distribution and total damage [22].

In 2014, Zhang et al. examined wind risk of residential buildings in Japan caused by typhoons and developed a

provisional reliability-based vulnerability model to assess the risk. Although provisional, the model this study presents found that it is the resistance of roof tile and the correlation of trajectories of flying debris that takes an important part in the vulnerability [23]. Gautam et al. conducted a vulnerability analysis of damage to residential buildings and infrastructure caused by extreme windstorms in southcentral Nepal in 2019. Based on the field observations and forensic interpretations, this study presents fragility functions obtained from damage statistics for wattle and daub houses [24].

Previous studies on wind speed and precipitation in Korean peninsula have been conducted with similar yet various focuses: typhoon risk assessment wind speed from the GIS (Geographic Information System) [25], natural hazard prediction modeling based on a wind speed of typhoon and precipitation [26], characteristics of the damage scale and risk management system by strong wind speed of typhoon [27], damage analysis of meteorological disasters for each district considering the regional characteristics [28], and measuring typhoon damage by wind speed in the rural area properties [29].

These abovementioned studies have similarities with this study in the sense that most of them relied on the past record of financial information and data in measuring the damage and vulnerability from hurricanes/windstorms/typhoons of residential or industrial buildings in their analyses. In addition, all of these studies aimed to suggest a loss function or a model to adopt in an attempt to estimate and simulate the damage and loss in other areas in the event of future hurricanes/windstorms/typhoons.

Similar to the mentioned studies, this study conducted a vulnerability analysis in order to present the valid risk factors related to building vulnerability based on the accumulated past data and statistics. Although many similarities, however, this study distinguishes itself from other studies especially in terms of the data source it selected. In order to ascertain the actual damage and loss to the commercial, residential, and industrial buildings from Typhoon Maemi, this study made use of the claim payout data accumulated and provided by a major Korean insurance company. This was to achieve the quantification of the damage in numerical, especially in financial values. To be more specific, the monetary data was adopted because of its definiteness and objectivity [30]. This quantification of damage data represented in the insurance claim payout record can be especially helpful because of the detailed and specified information about each case of damage of the buildings, which also enables engineers and insurance underwriters, for logical and accurate, and thus more reliable review estimation of the damage.

### 3. Research Methodology

**3.1. Loss Records.** The purpose of this study is to determine the significant factors, i.e., typhoon loss, natural hazard factors, and basic building information factors in the damage of buildings from the results of typhoons and to identify the relationship among the factors. This study also aims to assess

the loss reflecting the regional vulnerability and to build a systematic method to measure other extreme cases and countries to predict the typhoon loss. In order to reach this goal, this study used Typhoon Maemi loss record from a primary insurance company in South Korea. The research scope is limited to South Korea. The amount of loss is the claim payout based on ground-up loss, which is the pure loss not accounting for insurance. Typhoon Maemi hit the Korean Peninsula on 11th September in 2003, as shown in Figure 1(a). The typhoon landed on the south coast on the Korean peninsula, through the inland, to the east coast, causing extreme economic losses in many cities on the south coast, as shown in Figure 1(b).

Table 1 shows the distribution of loss per province from Typhoon Maemi. In particular, the provinces located in the southern part of the Korean peninsula, Busan and Gyeongnam, were vastly damaged by the typhoon. Gyeongnam was damaged by the typhoon to the dollar amount of loss (48.0%) and the number of losses (35.4%). Busan was also significantly devastated by the typhoon to the dollar amount of damages (43.8%) and the number of losses (45.0%).

**3.2. Data Availability.** This study gathered the loss record from a major insurance company of Construction All Risk (CAR) in South Korea from Typhoon Maemi's damage. The records received include information such as the date of the accident, location, occupancy, structure type, construction period, floor, underground, detail of loss, loss amount, and so on. Yet, due to the nature of the data, although any customer information is hardly included, the public access to the data is not permitted to avoid any possible problems.

### 3.3. Dependent and Independent Variables

**3.3.1. Dependent Variable.** In this study, a regression analysis was first used to determine the significant loss indicators for building vulnerability and then to evaluate the relationship between the indicators and loss ratio. This loss ratio is a concept and a term established in this study; loss ratio is the amount of occurred losses to indemnifying typhoon damages divided by the property value of the damaged building. The property value of the building in this study was measured by the total sum insured. This concept is entered into the following equation (1):

$$\text{Loss ratio} = \frac{\text{Claim} - \text{payout}}{\text{Total sum insured}}. \quad (1)$$

Because in each case, the loss from typhoon damages was relatively small, compared to the total sum insured, most loss ratio were inclined toward zero when presented by equation (1), and for this reason, the dependent variable was converted by log transformation in order to fit the normal distribution. The dependent variable value used in the regression model is shown in equation (2):

$$\text{Transformed loss ratio} = \ln(\text{loss ratio}). \quad (2)$$

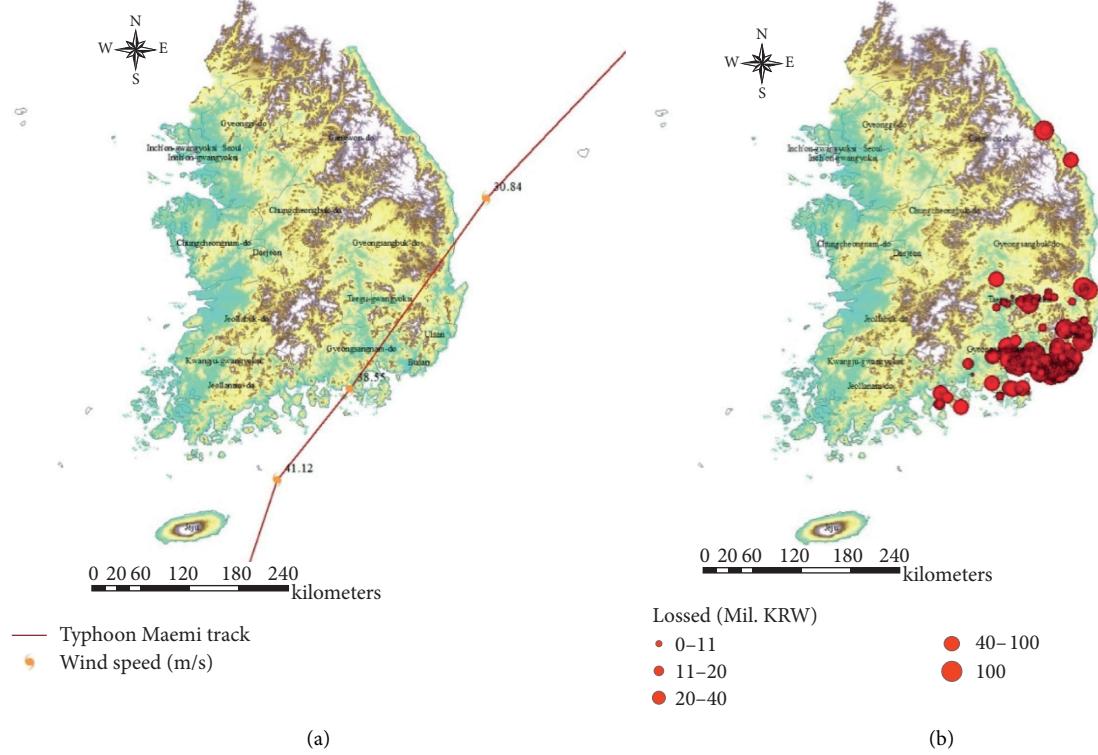


FIGURE 1: Typhoon Maemi: (a) track of typhoon and (b) distribution of losses.

TABLE 1: Loss records per province from Typhoon Maemi.

Province	Total claim payouts (mil. KRW)	No. of claim payouts
Gyeongnam	11,224	110
Busan	10,245	140
Ulsan	928	28
Gyongbuk	530	21
Kangwon	239	4
Jeonnam	135	3
Daegu	91	5

**3.3.2. Independent Variables.** The loss records are consisted of two categories: (1) accident details, e.g., details of the accident, the address, the amount of loss, and the date of the accident, and (2) basic building information, e.g., the total amount of the property, construction type, number of floors, and number of underground floors.

Based on the existing location information, the wind speed and distance from the property centroid to the coastline are estimated. The various properties information of the typhoon directly affects the damage [31]. Wind speed is an important indicator of the intensity of typhoons and causes damage such as floods, storm surge, landslides, and missile impacts [32, 33]. The wind speeds of the individual buildings that suffered damage were collected based on the date of the accident and the address information in the loss records using the Geographic Information System. Wind speed information is collected from the Japan Meteorological Administration's (JMA's) maximum wind speed (10 min sustained) record. The distance from the property

centroid to the coastline is also estimated based on the address information using the Geographic Information System. The distance between the building and coastline also plays an important role in describing a building's vulnerability to windstorms. Highfield et al. estimated the distance from the building to the coastline to identify the relationship between the distance and loss caused by Hurricane Ike on Galveston Island and the Bolivar Peninsula. They indicated that the loss decreased as the distance from the coastline increased [34]. The results reveal that a building farther from the coastline is less vulnerable to windstorms than a building closer to the coastline.

The basic building information, e.g., total amount of the property, construction type, number of floors, and number of underground floors, is used as indicators to reveal the typhoon vulnerability according to the building inventory. The total amount of the property is also substantial in terms of the losses associated with windstorms. Kim et al. indicated that windstorm loss increases as the total amount of the building decreases. The correlation with the total amount of the properties and windstorm loss are negative [7]. The construction type is also an important indicator of the building's typhoon vulnerability. For instance, when construction types can be divided into wood, stone, steel, and reinforced concrete, they are generally vulnerable to typhoons in the following ascending order: reinforced concrete, steel, stone, and wood [6, 35, 36]. The building height is regarded as a vital indicator of vulnerability quantification against windstorms [6, 37]. The reason for this is that the building height is statistically correlated with the degree of financial loss, so it can be used as a vulnerability index to

TABLE 2: Descriptive statistics of the variables.

	N	Mean	Std. deviation	Minimum	Maximum
Dependent variable					
Loss ratio (%)	312	1.68	5.03	0.01	47.14
Independent variables					
Total value of property (mil. KRW)	312	25,677.16	39,814.96	100.00	358,397.00
Construction type (number)†	312	1.32	0.74	0.00	4.00
Floors (number)	312	13.75	9.06	1.00	30.00
Underground floors (number)	312	0.52	0.94	0.00	6.00
Maximum wind speed (m/s)	312	37.58	1.22	31.24	38.56
Distance from coastline (km)	312	33.42	18.80	1.31	117.88

“†” denotes (1) reinforced concrete building, (2) steel structure building, (3) wood, and (4) steel plate roof.

quantify a building’s vulnerability to hurricanes. For instance, the correlation between building height and typhoon loss is negative, which means that as building height increases, typhoon loss decreases [37, 38]. Table 2 defines the loss and data. The central trends in each category are expressed as a mean.

## 4. Results

**4.1. Multiple Regression Analysis.** Table 3 shows the typhoon information and basic building information related to the loss ratio for the line of business (LOB): commercial, residential, and industrial, as assessed through the regression models, correspondingly. The LOB is typically used as a risk indicator to quantify the building vulnerability in the risk assessment model [7, 39]. The LOB is a term that is a commonplace in the insurance industry and denotes a tightly linked product or service that is a business necessity. This terminology from insurance is also stated to relate policies in provision and book-keeping, such as the fact that injury and property policies can be classified as commercial, residential, and industrial. As a result, the LOB category can classify buildings as physical and financial functions. This study adopts this classification to reveal information in a practical manner.

Table 3 displays the typhoon information and basic building information to loss ratios for Typhoon Maemi as assessed through regression analysis. In the regression analysis of the commercial building, the adjusted  $R^2$  value is 0.332, which indicates that 33.2% of the variant of the loss ratio can be described by the regression model. Two significant variables, total value of property and construction type, are branded as meters of the ruthlessness of typhoon loss. By contrast, the other indicators are not associated with the loss ratio of commercial building. The values of the variance inflation coefficient (VIF) ranged from 1.016 to 1.293. These values indicate that there is no substantial multicollinearity between variables. The indicators can be hierarchical in the descending order of their beta coefficients. Following the scale of the coefficient, the indicators are (1) the total value of property (beta coefficient = -0.549) and (2) construction type (beta coefficient = 0.241).

In the regression analysis of the residential building, the Adj- $R^2$  value is 0.587, which indicates that 58.7% of the variant of the loss ratio can be described by the regression

model. Four significant variables, maximum wind speed, distance from coast, total value of property, and floors, are identified as indicators of the severity of typhoon loss. However, the other indicators are not associated with the loss ratio of residential building. The values of the variance inflation coefficient (VIF) ranged from 1.048 to 1.1. The values show that there is no significant multicollinearity between variables. The indicators can be ranked in the descending order of their beta coefficients. According to the number of the coefficient, the indicators are (1) maximum wind speed (beta coefficient = -0.509), (2) total value of property (beta coefficient = 0.328), (3) distance from coast (beta coefficient = -0.248), and (4) floors (beta coefficient = 0.113).

In the regression analysis of the industrial building, the Adj- $R^2$  value is 0.403, which indicates that 40.3% of the variant of the loss ratio can be clarified by the regression model. Three significant variables, distance from coast, total value of property, and construction type, are recognized as indicators of the sternness of typhoon loss. Nevertheless, the other indicators are not related with the dependent variable of residential building. The values of the variance inflation coefficient (VIF) ranged from 1.109 to 2.190. These values show that there is no noteworthy multicollinearity between variables. The indicators can be listed in the descending order of their beta coefficients. Following the scale of the coefficient, the indicators are (1) the total value of property (beta coefficient = -0.622), (2) floors (beta coefficient = 0.227), and (3) distance from coast (beta coefficient = -0.222).

## 5. Discussion

The models are statistically significant because the  $P$  values (0.000) are less than 0.05. This means that there is a significant relationship between the dependent and independent variables. In each regression model, according to the LOB classification, the adjusted  $R^2$  values and the significant indicators were also different. The adjusted  $R^2$  value of the commercial building model was 0.332, indicating that 33.2% of the variance of the dependent variable can be explained by two indicators (total value of property and construction type). However, the remaining 66.8% caused by some unconfirmed indicators was not considered in this study. The adjusted  $R^2$  value of the residential building model is 0.587,

TABLE 3: Results with the regression models.

Variables	Commercial				Residential				Industrial			
	Coefficient	Beta coefficient	$p >  z $	VIF	Coefficient	Beta coefficient	$p >  z $	VIF	Coefficient	Beta coefficient	$p >  z $	VIF
Typhoon information												
Maximum wind speed	0.089	0.060	0.612	1.022	0.484	0.509	0.000	1.101	0.402	0.092	0.338	1.200
Distance from coast	-0.013	-0.107	0.363	1.016	-0.015	-0.248	0.000	1.057	-0.035	-0.222	0.021	1.165
Basic building information												
Total value of property	-3.137E - 005	-0.549	0.000	1.027	-1.413E - 005	-0.328	0.000	1.085	-4.260E - 005	-0.622	0.000	2.190
Construction type	1.094	0.241	0.050	1.073	—	—	—	—	0.214	0.130	0.163	1.109
Floors	0.028	0.083	0.531	1.293	0.033	0.113	0.027	1.048	0.083	0.227	0.080	2.147
Underground floors	0.082	0.055	0.673	1.271	0.024	0.018	0.726	1.055	0.678	0.106	0.267	1.182
Number of observations	51				173				78			
$F$	5.147				47.811				9.785			
Adj- $R^2$	0.332				0.587				0.403			

Coefficient designates the nonstandardized coefficients that reflect the unit scale of the independent variable. Beta coefficient designates standardized coefficients that disregard the unit scale of independent variable, which helps comparisons among the independent variables. The higher value of the beta coefficient means a more significant effect on the dependent variable.

indicating that 58.7% of the change in the dependent variable can be explained by four indicators: maximum wind speed, distance from coast, total value of property, and floors. However, the volatility of 41.3% due to unverified indicators was not considered in this study. The adjusted  $R^2$  value of the industrial building model was 0.403, indicating that 40.3% of the difference of the dependent variable can be described by three indicators (distance from coast, total value of property, and construction type). Nevertheless, the remaining 59.7% caused by some unproven indicators was not considered in this study. The reason why the significant indicators and adjusted  $R^2$  are different among the regression model is that they have different damage vulnerabilities against typhoon damage. It reinforces the previous study indicating that the LOB grouping can categorize buildings as physical and financial functions [7].

Among the key indicators of the variables, the value of property is the significant indicator that is shared among the three models. The value of property is negatively associated with the degree of loss caused by a typhoon. This indicates that the rate of loss increases as the value of property decreases. The lower the property value of a building, the more vulnerable it is to typhoons. This is also consistent with the results of prior studies [20, 24]. Former studies have stated that the value of property affects the degree of loss caused by typhoons and is a valuable factor for loss valuation.

The distance from the coast has also been proven to play a vital role in describing vulnerability to windstorm. The distance from the coast is adversely related with the amount of loss caused by a typhoon. This signifies that the degree of loss rises as a building is closer to the coast. The closer a building is to the coast, the more devastated it is to typhoons [34]. This confirms the results of the initial study and shows that the distance from the coast is an imperative indicator for assessing losses caused by typhoons.

The maximum wind speed and loss due to the typhoon are positively interrelated. This means that the loss increases as the wind speed intensifies. This also supports early research that reported that maximum wind speed is an essential indicator for predicting loss due to typhoons [12, 33, 40].

The construction type also shows a main indicator of the building's typhoon vulnerability. There is a positive correlation between the type of construction and the extent of loss, which suggests that the type of construction affects the magnitude of the loss, which is consistent with the results of previous studies; in the ascending order of construction type, reinforced concrete, steel, stone, and wood, it was found that they are vulnerable to typhoons [6, 36].

The number of floors has a positive relationship with the loss, which suggests that as the number of floors increases, the degree of loss increases. This again confirms that the number of floors is a vital indicator of quantifying typhoon, and it also strengthens the results of previous studies [37, 38].

## 6. Conclusion

This study conducted a statistical analysis on the damages caused by Typhoon Maemi, which was categorized as an

extreme disaster, in order to identify the natural hazard indicators and basic building information indicators and to develop a vulnerability function. The buildings were categorized into three different types, i.e., commercial, residential, and industrial. Variables for natural hazard indicators included maximum wind speed and distance from coast. Variables for basic building information indicators included total value of property, number of floors and underground floors, and construction types.

The statistical analysis found that, in the case of commercial buildings, total value of property and construction type are the two significant vulnerability indicators among the variables of both the natural hazard indicators and the basic building information indicators. For residential buildings, maximum wind speed, distance from coast, total value of property, and number of floors are significant indicators. Last, in the case of industrial buildings, the significant indicators were found to be distance from coast, total value of property, and number of floors.

In this study, the vulnerability function of the typhoon risk assessment models has also been developed and validated based on the statistical analysis of the actual loss claim payout data kept by an insurance company. The models were also developed in specification of various types of buildings including commercial, residential, and industrial, so that the particular and practical application of these models are possible.

Every year, typhoons such as Typhoon Maemi cause serious financial losses worldwide. Therefore, it would be necessary for public and private disaster management agencies to estimate the possible amount of damage by using typhoon risk assessment models. Therefore, findings and results of this research can serve as references and provide vital directions to abovementioned sectors such as federal and local governments, insurance companies, and construction companies in predicting typhoon losses. For example, federal and local governments can refer to this research in an effort to reducing future typhoon damages by predicting financial losses with the models reported in this study and establish mitigation strategies based on expected losses.

Insurance and reinsurance companies can use the model from this research to improve their own business model using the methodologies to measure latent risks. More specifically, they can use modeling to assess risks and make judgments and use the base rate of insurance policies as a percentage of experience with expected losses. Furthermore, they can appraise the event limits and probable maximum loss, delineate premiums, estimate risk accumulation from typhoons, and institute business strategies found on the outcome of the metric. The building construction companies are also able to improve their design guidelines by planning storm-resistant buildings and by assessing building loss based on the predicted total value of property, construction type, and the number of floors of the building.

Furthermore, the frameworks and indicators of this study can also be used for a further similar research, especially in developing countries with few data on loss caused by windstorms and building characteristics to predict windstorms. These countries can assess windstorm losses by

adopting the frameworks and indicators used in this study, although the weight of the indicator should be adjusted by the weight of each province and the coefficient to reflect the local building vulnerability for use in other areas. However, this study solely focused on the one typhoon case, Typhoon Maemi. Therefore, there is a need for a more comprehensive loss data using the damages associated with various categories of typhoons for development of the vulnerability function in future studies, in order to support the results of this study.

In addition, constructing vulnerability curves in further research can make much contribution in the field. That is, based on the data used and the significant factors found in this study, vulnerability curves can be created in a subsequent research. In other words, in catastrophe modeling, vulnerability curves define the degree of vulnerability according to, e.g., types of the buildings, and thus can serve as an important part of the modeling. For example, the vulnerability curve for typhoons describes the link between average damage rate and wind speed and determines the degree of damage, depending on the types of buildings. The average damage rate of the vulnerability curve indicates the building's storm vulnerability. Hence, constructing the vulnerability curves referring to the data and meaning factors from this research can enhance future studies with the similar focus and approach.

Again as to future research, the values of adjusted  $R^2$  were 0.332 for commercial buildings, 0.587 for residential buildings, and 0.403 for industrial buildings, which indicate that the residual variability of the damage is described by some indeterminate indicators. Therefore, in future studies, other possible indicators should be identified and added to the model.

## Data Availability

This study gathered the loss record from a major insurance company of Construction All Risk (CAR) in South Korea from Typhoon Maemi's damage. The records received include information such as the date of the accident, location, occupancy, structure type, construction period, floor, underground, detail of loss, loss amount, and so on. Yet, due to the nature of the data, although any customer information is hardly included, the public access to the data is not permitted to avoid any possible problems.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

## Acknowledgments

This research was funded by the Basic Science Research Program of the National Research Foundation of Korea (NRF-2020R1F1A1048304).

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