https://doi.org/10.20965/jdr.2020.p0822



Paper:

# Statistical Analysis of Building Damage from the 2013 Super Typhoon Haiyan and its Storm Surge in the Philippines

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[Received May 18, 2020; accepted July 14, 2020]

**In November 2013, Super Typhoon Haiyan (Yolanda) hit the Philippines. It caused heavy loss of lives and extensive damages to buildings and infrastructure. When collapsed buildings are focused on, it is interesting to find that these buildings did not collapse for the same reasons after the landfall of the typhoon and storm surge. The objective of this study is to develop a statistical model for building damage due to Super Typhoon Haiyan and its storm surge. The data were collected in collaboration with Tanauan Municipality, the Philippines. The data for the inundation map were obtained by field surveys conducted on-site to determine the cause of the damages inferred from satellite data. The maximum wind speed was derived from the Holland parametric hurricane model based on the Japan Meteorological Agency (JMA) typhoon track data and the inundation depth of storm surge was calculated using the MIKE model. Multinomial logistic regression was used to develop a model to identify the significant factors influencing the damage to buildings. The result of this work is expected to be used to prepare urban plans for preventing damage from future storms.**

**Keywords:** building damage, statistical analysis, storm surge, Super Typhoon Haiyan

## 1. Introduction

The Philippines is the most storm-exposed country on earth [1]. The average number of tropical storms in the Philippines that make landfall is 8 or 9 storms per year [1]. Super Typhoon Haiyan-local "Yolanda" was one of the strongest typhoons on record in the Philippines [2, 3]. It formed in the low-pressure region in the West Pacific Ocean on November 2, 2013, and it was equivalent to a Category 5 on the Saffir-Simpson hurricane scale assessed by the Joint Typhoon Warning Center (JTWC) [4]. On November 8, 2013, Super Typhoon Haiyan hit the eastern part of the Philippines consisting of Tacloban, Palo, and Tanauan [5, 6].

Moreover, its wind blew seawater onto the shore. A storm surge was generated due to Super Typhoon Haiyan's strong winds. Tacloban City had the highest storm surge, about 6 meters tall. In total, 220,000 people became homeless [7]. More than 16 million people were affected, and 6,300 people died [8]. Around 1.14 million buildings were damaged [8]. In addition, the total financial loss of infrastructure, fisheries, and agriculture was valued at more than 39.8 billion PHP, approximately 0.77 billion USD [8]. The super typhoon and storm surge caused massive impacts to both lives and property. Consequently, many researchers have studied this typhoon and storm surge in order to reduce future storms' impacts.

The purpose of this research is to develop a statistical model for predicting damage levels of buildings due to a super typhoon and its storm surge. This study focuses on Super Typhoon Haiyan and its storm surge event in November 2013 in the Philippines. The study areas include Tacloban, Palo, Basey, Dulag, Marabut, Tanauan, and Tolosa.

Accordingly, understanding the factors that have a significant effect on collapsed buildings has many advantages. For instance, the proposed model is expected to assess the risk of building in each zone. There will then be ways to prepare buildings during super typhoons and storm surges. Moreover, the model can indicate whether the major damage to buildings occurred from wind or a storm surge. This work is expected to be used to develop urban planning for preventing damage in buildings located in typhoon and storm surgeprone areas.

## 2. Background

### 2.1. Wind vs. Storm Surge Damage

Many researchers have studied the differences between wind and water damage. Baradaranshoraka et al. [9] applied a statistical analysis to estimate the loss model from a hurricane in Florida, US, together with engineering judgment and hazard information (e.g., intensity and timing). The interaction of wind, storm surge, flood, and waves with low-rise structures was studied by Amoroso and Gurley [10]. They conducted a field study and found that wind-only damage is generally characterized as top-down while storm surge, flood, and wave damages are characterized as bottom-up [10]. Li et al. [11] used the non-stationary Poisson process to develop a probabilistic framework for hurricane damage assessment. They found that changes in wind speed and occurrence rate have significant impacts on hurricane damage [11]. They also found that hurricane wind speeds did not affect the expected hurricane damage [11].

### 2.2. Building Damage Studies Using Statistical Analysis

Ham et al. [12] developed a typhoon fragility measure for industrial buildings in Korea. They used the Monte Carlo simulation and compared the damage prediction with the post-disaster survey. Pita et al. [13] developed a novel approach to estimate the interior building damage caused by hurricanes using the study area of Florida based on a simulation of the co-occurrence of wind, rain, and damage. Statistical analysis was applied to the typhoon landing and failure mechanism of coastal low-rise buildings in China [14]. Their findings showed that most damaged houses were restricted to the exterior of the building and the roof was more likely to be damaged than the wall [14]. Another statistical analysis was conducted by Padgett et al. [15]. They identified significant parameters including surge elevation, number of spans, and relative surge [15]. By using the stepwise process and Monte Carlo simulation, Pinelli et al. [16] developed a probabilistic model to estimate the expected annual damage induced by hurricane winds in residential structures. They found that a sudden roof collapse results in immediate damage to the walls [16].

This study also reviewed other related research. Nishijima et al. [17] studied the preliminary impact assessment of typhoons using AGCM simulation and a probabilistic typhoon model and predicted the expected decreasing number of damaged residential buildings in Japan. A review of Duy et al. [18] found that the technical solutions recommended for existing and new buildings in cyclonic areas in Vietnam include planning, architectural, and structural solutions such as avoiding building long, thin houses.

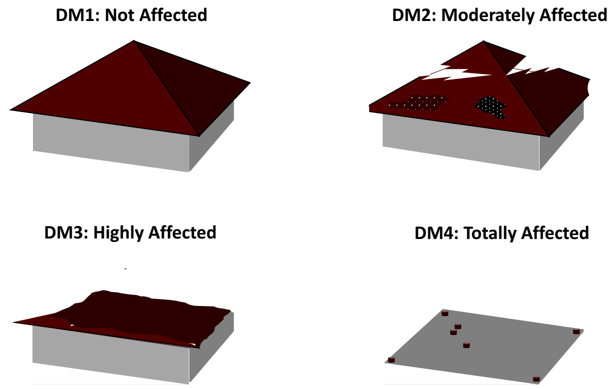


**Fig. 1.** Damage levels.

Moreover, statistical analyses on building damage from natural disasters have been studied by many researchers [19, 20]. Ordinal logistic regression was used to assess the building damage from the 2011 tsunami disaster in Japan [21]. Multinomial logistic regression was used to analyze the building damage from the 2011 tsunami in Japan [22, 23] and the 2004 Indian Ocean tsunami in Sri Lanka [24]. In addition, linear and non-linear logistic regression approaches were used to estimate the fatality ratios from the 2011 tsunami in Japan [25, 26].

## 3. Research Design and Methodology

### 3.1. Dependent Variable

In this study, the dependent variable is the damage levels of buildings, which can be categorized into four levels that are defined by the Japan International Cooperation Agency (JICA): "DM1" Not Affected, "DM2" Moderately Affected (roof is damaged), "DM3" Highly Affected (roof is gone/"no roof"), and "DM4" Totally Affected. The damage levels are illustrated in **Fig. 1**.

### 3.2. Independent Variable

The potential independent variables assumed to be used in this study were chosen based on previous studies: wind speed and inundation depth of storm surge [15, 16]. When the super typhoon occurs, a storm surge will be induced. The depth of the storm surge inundation was obtained using two models: DHI-MIKE21 and Delft3D, which are hydraulic models. These models have been evaluated as high quality and technically sound [27]. Therefore, these two models were chosen to compute the depth of the storm surge inundation.

In addition, due to the diversity in the affected areas, a location characteristic was expected to be a criterion for categorizing. As a result, it was planned that the data would be grouped based on location characteristics before data analysis.

## 3.3. Assumption

Since people in the same location quite often have a similar lifestyle, residences are built in the same way (e.g., number of floors). Thus, the assumption is that buildings in the same general location have the same characteristics.

## 3.4. Research Design

### 3.4.1. Descriptive Statistics

Each independent variable was analyzed using Minitab 17 in order to observe the descriptive profile.

### 3.4.2. Correlated Predictor Testing

It was confirmed that all independent variables were independent; in other words, they are not correlated according to Pearson Momentum Correlation Analysis in IBM SPSS Statistics 22. It is necessary to check this assumption before performing regression analysis because of the possibility of multi-collinearity, which occurs when there is a high level of correlation between independent variables. It affects the coefficient estimations of the regression model.

### 3.4.3. Statistical Methods

Linear regression analysis is simpler than other regression techniques. However, it has many important assumptions: The variables should have normal distributions and the variance of errors should be constant. Moreover, the mean of errors should be equal to zero and be independent [26]. The fundamental descriptive data analysis found that this assumption was violated as the variables do not have a normal distribution. Therefore, linear regression analysis was not applied.

In fact, in addition to the normal distribution assumption being violated, the dependent variable is categorical. Thus, logistic regression is considered suitable. There are three types of logistic regression: (1) binary logistic regression, (2) ordinal logistic regression, (3) multinomial logistic regression.

From the above, the data were analyzed using IBM SPSS Statistics 22. Multinomial logistic regression is suitable for analyzing the data in this study because the dependent variable can be categorized which has more than two categories. Moreover, ordinal logistic regression is expected to be suitable since the dependent variable is likely to have a natural order.

### 3.4.4. Statistical Model Development

The data were analyzed to develop a statistical model using the dependent variable: damage levels of buildings (DM) and independent variables: wind speed and storm surge inundation depth. However, the nature of the building damage from the storm differs from that of the storm surge. Therefore, the separately developed statistical models are expected to be suitable.

As a result, in each location, three models were developed: (1) damage models using the "entire" dataset; (2) damage models using the datasets "without" storm surge inundation (i.e., the data whose storm surge $=$ 0.000; these were buildings damaged by storm winds alone); and (3) damage models using the datasets "with" storm surge inundation (i.e., the data whose storm surge $\neq$ 0.000; these were the buildings damaged by both storm winds and the storm surge).

### 3.4.5. Accuracy Testing

The data were separated into training (80%) and testing (20%) datasets. The models were checked for their accuracy by fitting them with another dataset that was collected and kept separately for checking the accuracy of each model.

## 3.5. Data Collection

The field survey was conducted in 2013–2014 to collect detailed data immediately after the disaster. However, the data collected via field survey were not adequate. Therefore, in this study decided to combine satellite data and other sources [27]. The parameters were collected and computed: (1) maximum wind speed, derived from the Holland parametric hurricane model based on the Japan Meteorological Agency (JMA) typhoon track data; and (2) storm surge inundation depth, Delft3D models run with 25 m resolution over high-resolution topographic data and MIKE21 models run with 100 m resolution over high-resolution topographic data. The setup of the parametric hurricane and hydrodynamic/wave models was the same as described in Bricker et al. [30] and Watanabe et al. [31].

## 3.6. Data Analysis and Results

During data preprocessing from all collected data, the data using the MIKE21 model to generate the depth of storm surge inundation was selected to develop statistical models because the data using the MIKE21 model was more complete. There were originally 86,890 pieces of data; once the missing data were cleaned, 66,651 piece were left. The remaining data were then separated into two sets with an equal proportion across all levels. The first dataset (20%) was used for checking the accuracy of the model, while the second dataset (80%) was used for developing the models. The second dataset was then divided into three locations due to the fact that seven locations are not on the same island, which can lead to differences in topography. As shown in **Fig. 2**, Basey and Marabut are located on Samar Island while Tacloban, Palo, Tanauan, Tolosa, and Dulag are located on Leyte Island. Thus, Basey and Marabut were named "Location 1," Tacloban was named "Location 2" because Tacloban is an urban city while other locations are municipalities. Since Palo, Tanauan, Tolosa, and Dulag are located in remote


Note. Location 1: Basey and Marabut; Location 2: Tacloban; Location 3: Palo, Tanauan, Tolosa, and Dulag.

**Fig. 2.** Study area.

areas, they were called "Location 3." In addition, the difference in density of each location was used to differentiate these locations into three groups as well. The density of each location was approximately equal. Location 1 ranged from 93.09 to 123.9 people per km$^2$ with an average of 108.5 people per km$^2$. Location 2 has 2,284 people per km$^2$. Location 3 ranges from 605.3 to 928.2 people per km$^2$ and the average is 804.4 people per km$^2$. Finally, Location 1 (Basey and Marabut) is 733 km$^2$ (596 km$^2$ for Basey and 137 km$^2$ for Marabut) [32]. Location 2 (Tacloban) is 106 km$^2$ [33]. Location 3 is 248.8 km$^2$ (81 km$^2$ for Palo, 67.1 km$^2$ for Tanauan, 22.6 km$^2$ for Tolosa, and 78.1 km$^2$ for Dulag) [33].

### 3.6.1. Descriptive Statistics

After grouping the data into the three locations, the data were preliminarily analyzed. **Table 1** shows the descriptive statistics of the wind speed and storm surge inundation depth of Location 1, Location 2, and Location 3.

The minimum depth of storm surge inundation in every location is zero. This refers to the fact that not all buildings were inundated. The buildings with zero storm surge inundation depth suffered only from the power of the wind (storm). It is interesting to separate the dataset at each location further into two subsets: (1) those buildings with storm surge inundation, and (2) those without storm surge inundation.

**Table 1.** Descriptive statistics of wind speed and storm surge inundation depth.

| Location-Variable | *N* | Min | Max | Mean (SD) |
|---|---|---|---|---|
| Location 1 (Basey and Marabut) | | | | |
| Wind speed [m/s] | 1,051 | 76.913 | 83.435 | 77.935 (0.973) |
| Storm surge inundation depth [m] | 1,051 | 0.000 | 7.109 | 1.0249 (1.830) |
| Location 2 (Tacloban) | | | | |
| Wind speed [m/s] | 46,422 | 72.544 | 83.503 | 82.409 (1.563) |
| Storm surge inundation depth [m] | 46,422 | 0.000 | 5.731 | 0.798 (1.011) |
| Location 3 (Tanauan, Tolosa, and Dulag) | | | | |
| Wind speed [m/s] | 19,178 | 79.899 | 83.487 | 82.040 (0.994) |
| Storm surge inundation depth [m] | 19,178 | 0.000 | 9.196 | 0.499 (0.661) |

### 3.6.2. Correlation Analysis

The data were tested for correlation using the Pearson Product-Moment Correlation coefficient to measure the strength of the relationship between the two independent variables [33], wind speed and the depth of the storm surge inundation.

The relationship between the two independent variables of Location 1, Location 2, and Location 3 for the damage model are 0.559, 0.148, and $-0.088$, respectively. According to the rule of thumb for interpreting the size of a correlation coefficient, 0.7 to 0.9 is a high or strong correlation [34]. The results showed that there are no strong correlations between variables.

### 3.6.3. Damage Models Using the "Entire" Dataset

First, the data from each location were analyzed using ordinal regression, but the test of parallel lines (i.e., testing whether the coefficient estimates for each variable across categories are the same) was significant at $p < 0.01$.

Therefore, the data of each location were analyzed using multinomial logistic regression. The results show that each location has a significant fit for the damage models ($p < 0.01$).

**Table 2** presents the results of multinomial logistic regressions for the three different locations (see **Fig. 2**). For each location, the model for each damage level $i$ follows Eq. (1), where $\mathrm{DM}_i$ is damage level $i$, $B_{speed,i}$ is a coefficient of wind speed, and $B_{depth,i}$ is a coefficient of storm surge inundation depth.

$$\ln\left[\frac{Pr(\mathrm{DM}_i)}{Pr(\mathrm{DM}_{Base})}\right] = B_{speed,i} \times Speed + B_{depth,i} \times Depth + c \quad . . (1)$$

- Location 1. The results showed that there were nine pieces of DM1 data (1.1% of all data), 540 pieces of DM2 data (64.3%, the largest group), 0 pieces of DM3 data, and 291 pieces of DM4 data (34.6%). Pseudo $R^2$ was computed. Three methods were used to estimate pseudo $R^2$ [35–37]. The results are as follows: $R^2_{Cox\ and\ Snell}$ is 0.096; $R^2_{Nagelkerke}$ is 0.127; and $R^2_{McFadden}$ is 0.072. On average, this model has a 67.5% prediction accuracy.

- Location 2. There were 6,636 pieces of DM1 data (17.9%), 17,991 pieces of DM2 data (48.4%), 113 pieces of DM3 data (0.3%), and 12,398 pieces of DM4 data (33.4%). $R^2_{Cox\ and\ Snell}$ is 0.072; $R^2_{Nagelkerke}$ is 0.082; and $R^2_{McFadden}$ is 0.036. On average, this model has a 54.1% correct prediction rate.

- Location 3. There were 164 pieces of DM1 data (1.1%), 6,304 pieces of DM2 data (41.1%), 241 pieces of DM3 data (1.6%), and 8,634 pieces of DM4 data (56.3%). $R^2_{Cox\ and\ Snell}$ is 0.035; $R^2_{Nagelkerke}$ is 0.044; and $R^2_{McFadden}$ is 0.022. On average, this model has a 60.4% correct prediction rate.

**Table 2.** Coefficients of independent variables in damage model using entire data set.

| DM | Parameter | B | | |
|---|---|---|---|---|
| | | Location 1 | Location 2 | Location 3 |
| 2 | Intercept | 159.849*** | −0.334 | 82.055*** |
| | Wind speed [m/s] | −1.990*** | 0.017** | −0.952*** |
| | Storm surge inundation depth [m] | −0.057 | −0.112*** | 1.302*** |
| 3 | Intercept | n/a | −8.479* | 81.133*** |
| | Wind speed [m/s] | n/a | 0.055 | −0.985*** |
| | Storm surge inundation depth [m] | n/a | −0.197* | 1.900*** |
| 4 | Intercept | 66.756*** | 2.821*** | 105.190*** |
| | Wind speed [m/s] | −0.802*** | −0.033*** | −1.231*** |
| | Storm surge inundation depth [m] | −0.035 | 0.471*** | 1.444*** |

*Significant at level $p < 0.1$ (2-tailed).
**Significant at level $p < 0.05$ (2-tailed).
***Significant at level $p < 0.01$ (2-tailed).

### 3.6.4. Damage Models Using the Datasets "Without" Storm Surge Inundation

**Table 3** presents the results of multinomial logistic regression using only the data without storm surge inundation at each location.

**Table 3.** Coefficients of independent variables in damage model using datasets "without" storm surge inundation.

| DM | Parameter | *B* | | |
|---|---|---|---|---|
| | | Location 1 | Location 2 | Location 3 |
| 2 | Intercept | 2,346.171*** | 2.617*** | 316.885*** |
| | Wind speed [m/s] | −30.129*** | −0.019* | −3.778*** |
| 3 | Intercept | n/a | 2.207 | 324.083*** |
| | Wind speed [m/s] | n/a | −0.077 | −3.909*** |
| 4 | Intercept | 196.474*** | 0.728 | 362.910*** |
| | Wind speed [m/s] | −2.460*** | −0.004 | −4.332*** |

*Significant at level $p < 0.1$ (2-tailed).
**Significant at level $p < 0.05$ (2-tailed).
***Significant at level $p < 0.01$ (2-tailed).

- Location 1. There were two pieces of DM1 data (0.3%), 458 pieces of DM2 data (69.1%), no pieces of DM3 data, and 203 pieces of DM4 data (30.6%). $R^2_{Cox\ and\ Snell}$ is 0.158; $R^2_{Nagelkerke}$ is 0.220; and $R^2_{McFadden}$ is 0.136. On average, this model has a 76.3 correct prediction rate.

- Location 2. There were 3,048 pieces of DM1 data (18.7%), 8,746 pieces of DM2 data (53.6%), 53 pieces of DM3 data (0.3%), and 4,474 pieces of DM4 data (27.4%). The model did not have a significant fit. As a result, all values of pseudo $R^2$ are 0.000.

- Location 3. There were 131 pieces of DM1 data (1.9%), 2,798 pieces of DM2 data (40.2%), 74 pieces of DM3 data (1.1%), and 3,961 pieces of DM4 data (56.9%). $R^2_{Cox\ and\ Snell}$ is 0.088; $R^2_{Nagelkerke}$ is 0.110; and $R^2_{McFadden}$ is 0.057. On average, this model has a 61.2% correct prediction rate.

### 3.6.5. Damage Models Using the Datasets "with" Storm Surge Inundation

**Table 4** presents the results of multinomial logistic regression using only the data with storm surge inundation at each location.

- Location 1. There were seven pieces of DM1 data (4.0%), 82 pieces of DM2 data (46.3%), no DM3,

**Table 4.** Coefficients of independent variables in damage models "with" storm surge inundation.

| DM | Parameter | B | | |
|---|---|---|---|---|
| | | Location 1 | Location 2 | Location 3 |
| 2 | Intercept | 102.978*** | −9.596*** | −2.490 |
| | Wind speed [m/s] | −1.293*** | 0.131*** | 0.081 |
| | Storm surge inundation depth [m] | 0.466 | −0.175*** | 0.785* |
| 3 | Intercept | n/a | −66.232*** | −8.536 |
| | Wind speed [m/s] | n/a | 0.758*** | 0.108 |
| | Storm surge inundation depth [m] | n/a | −0.454** | 1.588*** |
| 4 | Intercept | 54.595*** | −1.074 | 5.939 |
| | Wind speed [m/s] | −0.686*** | 0.006 | −0.023 |
| | Storm surge inundation depth [m] | 0.692 | 0.786*** | 1.219*** |

*Significant at level $p < 0.1$ (2-tailed).
**Significant at level $p < 0.05$ (2-tailed).
***Significant at level $p < 0.01$ (2-tailed).

and 88 pieces of DM4 data (49.7%). $R^2_{Cox\ and\ Snell}$ is 0.140; $R^2_{Nagelkerke}$ is 0.173; and $R^2_{McFadden}$ is 0.091. On average, this model has a 53.7 correct prediction rate.

- Location 2. There were 3,588 pieces of DM1 data (17.2%), 9,245 pieces of DM2 data (44.4%), 60 pieces of DM3 data (0.3%), and 7,924 pieces of DM4 data (38.1%). $R^2_{Cox\ and\ Snell}$ is 0.138; $R^2_{Nagelkerke}$ is 0.158; and $R^2_{McFadden}$ is 0.071. On average, this model has a 56.2% correct prediction rate.
- Location 3. There were 33 pieces of DM1 data (0.4%), 3,506 pieces of DM2 data (41.8%), 167 pieces of DM3 data (2.0%), and 4,673 pieces of DM4 data (55.8%). $R^2_{Cox\ and\ Snell}$ is 0.023; $R^2_{Nagelkerke}$ is 0.029; and $R^2_{McFadden}$ is 0.015. On average, this model has a 54.6% correct prediction rate.

## 4. Discussion and Conclusions

The result of correlation testing showed that there are no strong correlations between wind speed and the depth of the storm surge inundation variable. This means that there was no multicollinearity between the variables. Therefore, the regression model can be developed using only one or both variables. In this study, the regression models of each location were developed using multinomial logistic regression. Although the damage levels are likely to have a natural order, the results of parallel line testing show that they are not suitable for analysis using ordinal regression. Since the damage levels of buildings are determined by humans, they might not have an actual natural order.

### 4.1. Models of Location 1

The results show that the storm surge inundation depth did not have a significant effect at every damage level. Moreover, based on the damage models using the datasets "without" storm surge inundation show that wind speed significantly affected every damage level. Thus, only the wind speed variable affected the probability of the occurrence of different damage levels. Based on expert consultation, this seems to be because Basey and Marabut are located mainly in a mountainous area. Thus, the buildings may not have been damaged by the storm surge since the storm surge might not reach the buildings.

### 4.2. Models of Location 2

According to the damage models using the "entire" dataset, both wind speed and the storm surge inundation depth had a partial significant effect on damage levels. However, the wind speed variable at DM3 did not have a significant effect. The damage models using the datasets "with" storm surge inundation show that all variables had a partial significant effect on the damage levels. However, the wind speed variable did not have a significant effect at DM4. Since Tacloban is located in an urban area, there might be other potential factors that affect the probability of the occurrence of different damage levels. Based on expert consultation, in this case, it was hypothesized that debris floating along with the storm surge is another significant factor that causes damage to buildings.

### 4.3. Models of Location 3

According to the damage models using the "entire" dataset and the damage models using the datasets "without" storm surge inundation, the results show that all variables significantly affected the damage levels at every damage level. This means that both wind speed and the storm surge inundation depth variable affected the probability of the occurrence of different damage levels. Based on expert consultation, Tolosa, Tanauan, Palo, and Dulag are located in the plains area. Thus, buildings may be damaged from a storm surge since a storm surge can easily reach into buildings. However, the damage models using the datasets "with" storm surge inundation show that the wind speed variable did not have a significant effect at every damage level while the depth of the storm surge inundation had a significant effect at every damage level. This may be because the buildings that the storm surge can reach incur more major damage from the storm surge than storm winds.

### 4.4. Conclusion

The Philippines was the country most strongly affected by Super Typhoon Haiyan, with extreme losses of lives

**Table 5.** Summary of findings.

| No. | Location characteristics | Findings |
|---|---|---|
| 1 | Mountainous area | Only typhoon wind speed significantly affected all damage levels. It is possible to use wind speed as the main parameter to predict damage levels. |
| 2 | Urban plain area | Wind speed significantly affected all damage levels. When looking at both wind speed and storm surge, they partially affected the damage levels. Thus, it is possible to use wind speed as the main parameter to predict damage levels. It seems there are more parameters required for further investigating. |
| 3 | Coastal plain area | Wind speed significantly affected all damage levels. In addition, using both wind speed and storm surge inundation depth also significantly affected damage levels. Thus, it is possible to use only wind speed or use both wind and storm surge inundation depth to predict damage levels. |

and damage to buildings. When buildings are analyzed, it is interesting to note that all of the buildings did not collapse for the same reason after the impact of the typhoon and the storm surge. The purpose of this paper is to develop statistical models for building damage due to Super Typhoon Haiyan and its storm surge. In this work, following the assumption of the natural order, statistical analysis using ordinal regression was selected to identify the significant factors influencing the damage to buildings and develop statistical models. However, the results of parallel line testing showed that this situation is not suitable for using ordinal regression. Thus, statistical analysis using multinomial regression was selected instead. The models were conducted for three locations (seven cities) on the same island. This can lead to differences in topography, as shown in **Table 5**.

Results from Location 1 showed that only the storm wind speed variable was significant at every damage level. The results from Location 2 showed that the developed models do not fit because there might be additional factors because Tacloban is an urban city with unique characteristics. The results from Location 3 showed that both wind speed and the depth of storm surge inundation variables were significant at every damage level. These results showed that the wind speed variable was a significant factor in every location. According to other research, the wind speed parameter was always a significant factor in the models. However, Location 3 had another significant factor: the storm surge inundation depth. Therefore, risk reduction studies in the area of Location 3 should consider both wind speed and the depth of storm surge inundation. The different topography can lead to the different significant factors for predicting the damage of buildings.

This study is expected to help authorities in the area understand disaster risk and invest in disaster risk reduction for resilience according to the Sendai Framework for Disaster Risk Reduction 2015–2030 [38]. The results of this work are also expected to be used to develop urban planning for preventing damage to buildings located in a typhoon- and storm surge-prone area.

Although the models in this work were expected to be general models for risk analysis in other areas, the models were developed using the data in specific areas; therefore, the models might not be generalized for use in other areas. Still, the developed models are hardly able to predict the probability of DM1 and DM3 occurrences since the data that were used to develop models were inadequate and the categorization of damage levels might not be suitable. Moreover, the factors influencing the damage to buildings for developing the models were limited. Nevertheless, developing an urban city's model for predicting the probability of damage level occurrence is necessary because there are many people living there.

Further studies might consider more potential parameters influencing the damage to buildings for developing statistical models such as debris floating with storm surge, construction of buildings, and the number of floors and age of buildings. In addition, big data from locations can be used to developing other models with a higher prediction accuracy.

**Acknowledgements**

This research is supported by the Radchadapisek Sompoch Endowment Fund (2020), Chulalongkorn University (763014 Climate Change and Disaster Management Cluster); JSPS Grant-in-Aid for Young Scientists (B) "Applying Developed Fragility Functions for the Global Tsunami Model (GTM)" (grant no. 16K16371); a JSPS-NRCT Bilateral Research Grant, the Core Research Cluster of Disaster Science in Tohoku University (Designated National University); Tokio Marine & Nichido Fire Insurance Co., Ltd.; Willis Research Network (WRN; and EU Marie Curie project: GOLF (reference no. GOLF-777742). Volker Roeber acknowledges financial support from the Isite program Energy Environment Solutions (E2S), the Communauté d'Agglomération Pays Basque (CAPB) and the Communauté Région Nouvelle Aquitaine (CRNA) for the chair position HPC-Waves.

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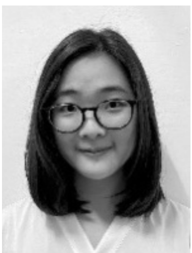

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