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Prediction Method for Building Damage Areas due to Tornadoes in Japan

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Abstract

Tornado damage has occurred frequently in urban areas in recent times. It is important to predict the risk of damage in an area resulting from gusty winds so that the local governments can implement the necessary disaster management measures and the rate of non-life insurance premium can be calculated. In this work, we investigated the path of the tornado that occurred in Nobeoka, Miyazaki in 2006. We tried to predict the extent of damages caused to buildings using building densities and the “high wind damage scale” [5] by the tornado. We then compared the actual and predicted building damages. Since there were many non-damaged buildings in the areas where the winds had a lower speed, the actual rate of occurrence of building damage did not coincide with the probability density used to predict the damage. Therefore, large damaged areas were predicted in an area where building damage had hardly occurred in reality. However, the predicted building damage and the actual damage values coincided in an area with stronger winds.

Introduction

Many cases of tornado damage have been reported in urban areas in Japan in recent times [1, 6]. It is important to predict the tornado damage risks in order for the local governments to implement the necessary disaster prevention measures and to calculate non-life insurance premium.

In an earlier study, we identified the path of a tornado using GIS, and proposed a method for predicting tornado damage using the building densities in an area [2, 3]. In the present study, we predicted areas with building damage due to the tornado that occurred in Nobeoka City, Miyazaki Prefecture, Japan in 2006. We then compared these predicted damages with the actual damage.

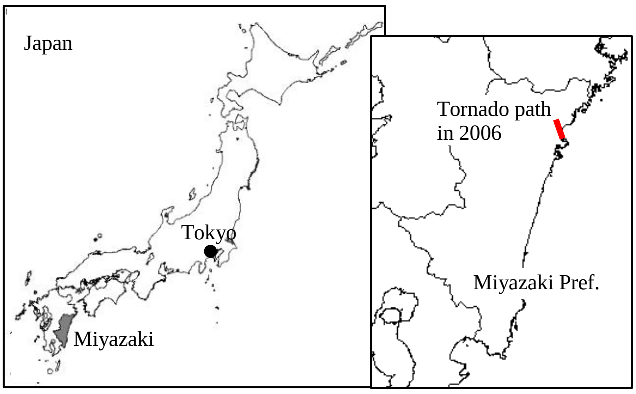

Figure 1. Path of the tornado that occurred in Nobeoka City, Miyazaki Prefecture, Japan on September 17, 2006.

Outline of the Tornado Damage in Nobeoka, Japan in 2006

A tornado occurred at around 2 p.m. on September 17, 2006 in Nobeoka City, Miyazaki Prefecture, Japan [4]. Figure 1 indicates the location and the path of the tornado. The area damaged by the tornado was reported to be around 7.5 km long and around 200 m wide by the Japan Meteorological Agency (JMA). The strength of the tornado was recorded as F2 on the Fujita scale.

Table 1 shows the extent of damage with examples and the number of damaged buildings for different ranks on the "High wind damage scale" [5]. Figure 2 represents the distribution of damaged buildings.

Rank	Damage	Examples of damage	Number of damaged buildings
1	Light	Some damage to houses.	241
2	Moderate	Roof tiles slide. Roof surface peels off partially (less than 30% of roof area).	283
3	Considerable	Most of the roof tiles are blown off (30% or more of roof area). Some glass windows break.	310
4	Severe	Frame of the roof and many windows break.	75
5	Devastating	Houses collapse.	29

Table 1. The extent of damage with examples and number of damaged buildings for different ranks on the "High wind damage scale" due to the tornado in Nobeoka in 2006.

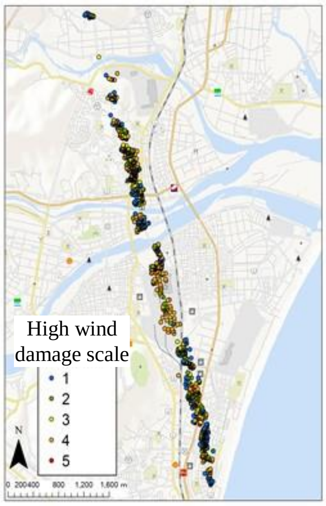

Figure 2. Distribution of the damaged buildings due to the tornado in Nobeoka City, Miyazaki Prefecture in Japan on September 17, 2006.

Prediction of Structural Damage by the Tornado

Determining the Path of the Tornado

JMA provides the rough latitude-longitude information regarding the generation and disappearance points of tornadoes in Japan. However, the information related to the exact location of the center of the tornado that occurred at Nobeoka in 2006 is not enough. We estimated the tornado path from the locations of the damaged buildings and the estimated wind speeds based on earlier studies [3]. The procedure is roughly as follows:

1) A temporary path of the tornado center was set based on the distribution map of the damaged structures. We decided that the path was along the center of the building damage distribution.

2) We measured the distance from the tornado center to a damaged building. Then we counted the number of damaged buildings at the same distance from the tornado center.

3) The wind speed at the damaged structure was determined based on the estimated wind speed. Figure 3 indicates the estimated wind speeds of the tornado in Nobeoka using Rankine vortex model. Then we counted the number of damaged buildings at each estimated wind speed.

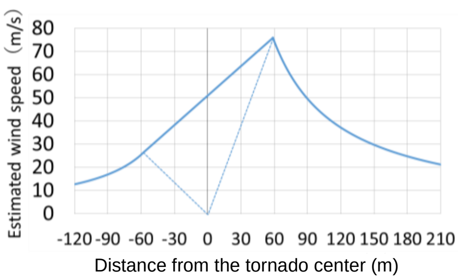

Figure 3. Estimated wind speeds of the tornado in Nobeoka using Rankine vortex model.

4) The distances from the tornado center to the damaged buildings were adjusted in such a way that the number of damaged buildings increases rapidly when the estimated wind speed exceeds 30 m/s. Figure 4 shows the number of damaged buildings at each estimated wind speed after the adjustment.

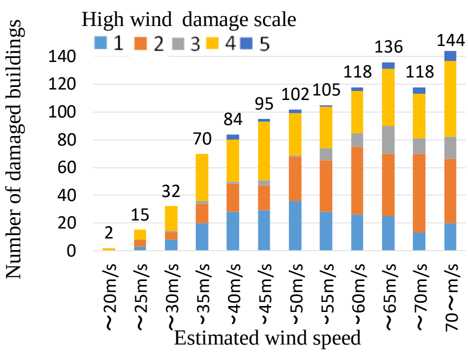

Figure 4. Number of damaged buildings at each estimated wind speed after the adjustment.

Estimation of Building Damage Areas

Figure 5 shows the estimation procedure of building damage areas. The damaged area, due to the tornado, was divided into 30 × 30 m grids based on the path of the tornado that was determined earlier. The grid width was set to divide the core radius of the tornado (about 59 m) almost in half. Next, the wind speeds were estimated for each grid based on the distribution of wind speed using Rankine vortex. The grids were categorized into three wind speed groups, low (30 m/s or less), middle (30-50m/s) and high (50 m/s or more). The grid area divided by the sum of all the building areas inside the grid is defined as building area density. We multiply the area of a damaged building by the coefficient as shown Table 2, based on the "High wind damage scale" [5], and add the products obtained in each grid. The sum total of all the grids is defined as the area of damaged buildings. Coefficients according to "High wind damage scale" are shown in Table 2. The coefficient of non-damaged buildings is zero.

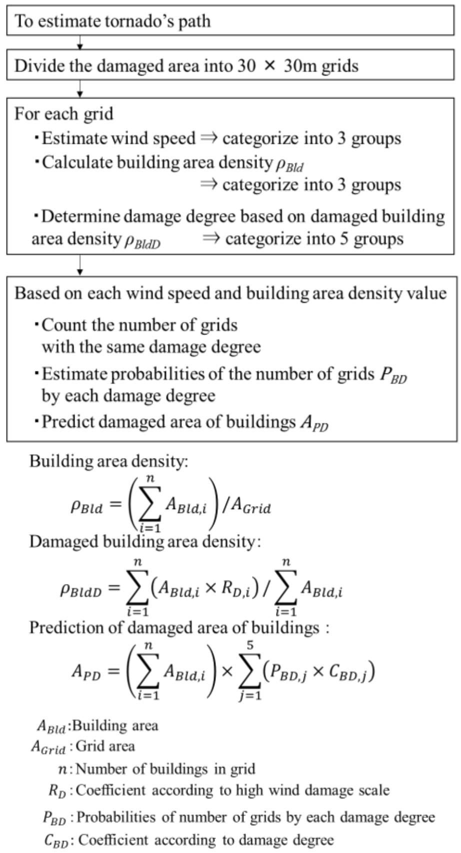

Figure 5. Estimation procedure for damaged building areas.

High wind damage scale Rank	Damage	Coefficient
-	No damage	0
1	Light	0.1
2	Moderate	0.3
3	Considerable	0.5
4	Severe	0.7
5	Devastating	1.0

Table 2. Coefficients according to "High wind damage scale".

Figure 6 indicates the relationship between the building area density and damaged building area density. Figure 6a shows the relationship at low wind speeds, figure 6b at middle wind speeds and figure 6c at strong wind speeds. Damaged building area density is the area of damaged buildings divided by the sum of building area in the grid. As the building area densities increase, the damaged building area densities seem to decrease. The building area densities are categorized into three groups, 20% or less, 20-40%, and 40% and more. Then the damaged building area densities are categorized into five groups. Table 3 shows the damaged building area density and the coefficients for different degrees of damage. The first group, with 10% or less of damaged building area density and a coefficient of 0.1, is defined as damage degree I. Similarly, four more groups are presented. Each grid, thus, represents a particular wind speed, a building area density, and a damage degree. We count the number of grids with the same damage degree at each wind speed and building area density.

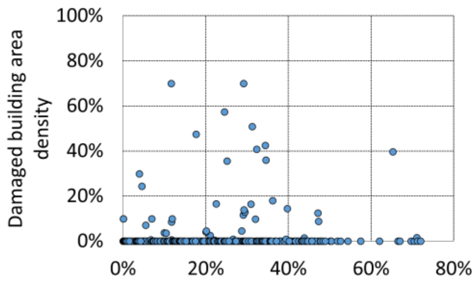

Figure 6a. Relationship between the building area density and damaged building area density at 30 m/s or less wind speeds.

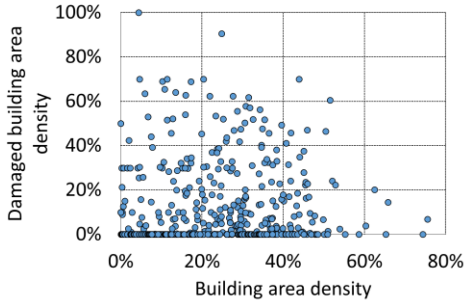

Figure 6b. Relationship between the building area density and damaged building area density at 30-50 m/s wind speeds.

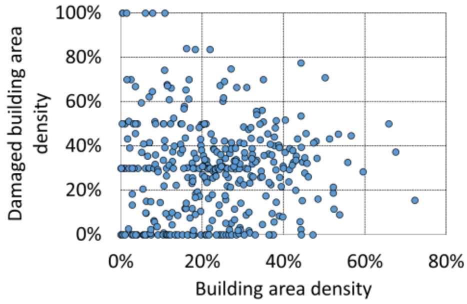

Figure 6c. Relationship between the building area density and damaged building area density at more than 50 m/s wind speeds.

Damage degree	Damaged building area density	Coefficient
I	10% or less	0.1
II	10-30%	0.3
III	30-50%	0.5
IV	50-70%	0.7
V	70% and more	1.0

Table 3. Damaged building area density and the coefficients for each damage degree.

Figure 7 shows the number of grids and their frequency distribution at different building area densities and estimated wind speeds. In this study, we focused just on building damage in the residential areas. The probabilities of the number of the grids were estimated using the normal distribution based on this frequency. As shown in figures 7a-7f, the actual number of grids and the estimated values, based on the damage degrees I and II, differ when the wind speeds are low or middle. On the other hand, the actual number of the grids almost coincides with the estimated probabilities when wind speed is high, as shown in figures 7g-7i. Though our prediction of damage suffers from certain drawbacks, based on the low damage degree and low wind speeds, these probabilities are used to predict the areas of building damage in this paper. As shown in Figure 3, the building area density and the wind speed for each grid are defined first. Next, the probability is multiplied by the coefficient according to the damage degree, and then these values are summed up. This is how the area of building damage in the grid is estimated.

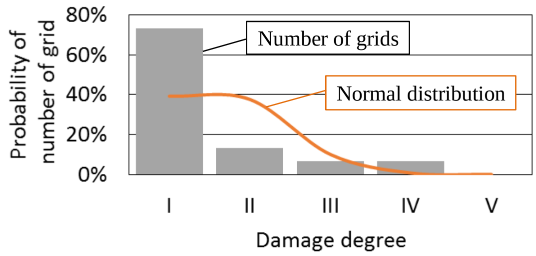

Figure 7a. Number of grids and their frequency distribution at less than 20% of building area density and less than 30 m/s of estimated wind speed.

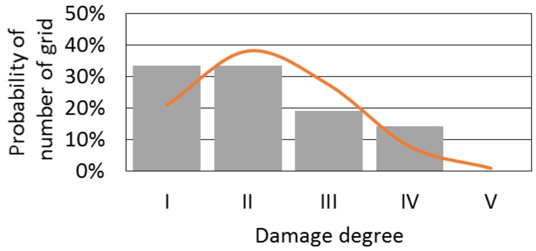

Figure 7b. Number of grids and their frequency distribution at 20-40% of building area density and less than 30 m/s of estimated wind speed.

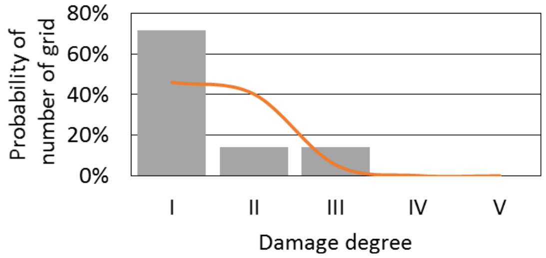

Figure 7c. Number of grids and their frequency distribution at more than 40% of building area density and less than 30 m/s of estimated wind speed.

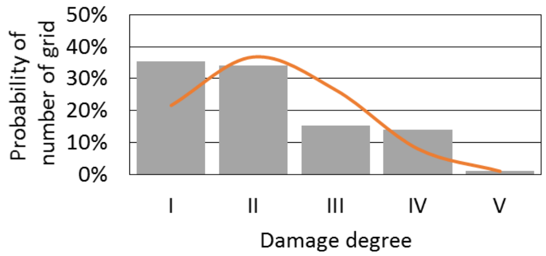

Figure 7d. Number of grids and their frequency distribution at less than 20% of building area density and at 30-50 m/s of estimated wind speed.

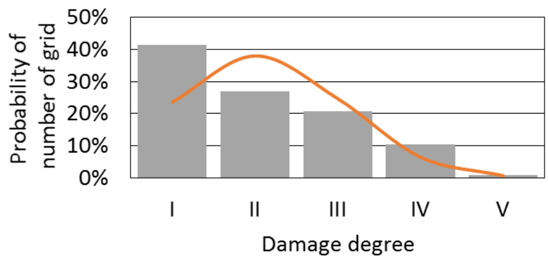

Figure 7e. Number of grids and their frequency distribution at 20-40% of building area density and at 30-50 m/s of estimated wind speed.

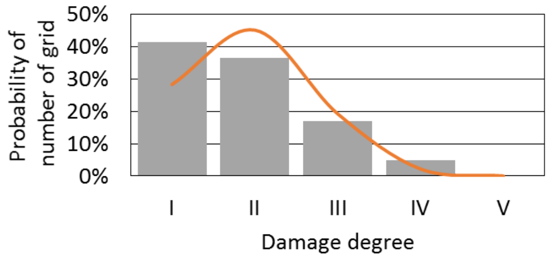

Figure 7f. Number of grids and their frequency distribution at more than 40% of building area density and at 30-50 m/s of estimated wind speed.

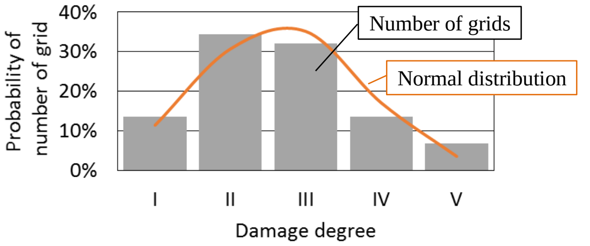

Figure 7g. Number of grids and its frequency distribution at less than 20% of building area density and more than 50 m/s of estimated wind speed.

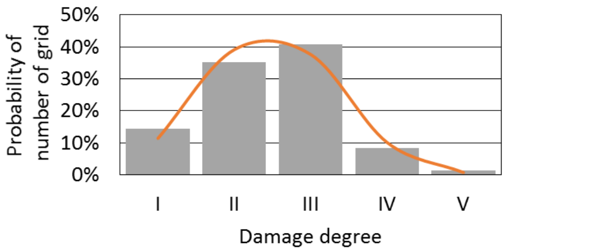

Figure 7h. Number of grids and its frequency distribution at 20-40% of building area density and more than 50 m/s of estimated wind speed.

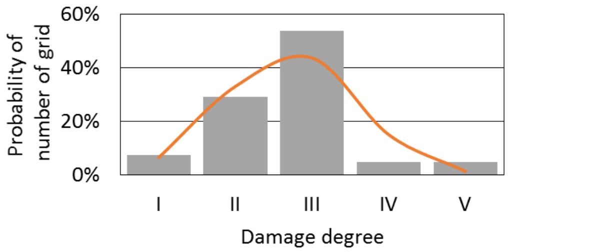

Figure 7i. Number of grids and its frequency distribution at more than 40% of building area density and more than 50 m/s of estimated wind speed.

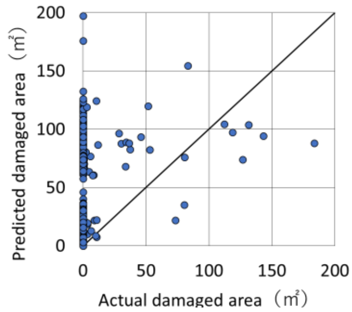

Figure 8a. Comparison between the predicted and actual building damage areas at less than 30 m/s of estimated wind speed.

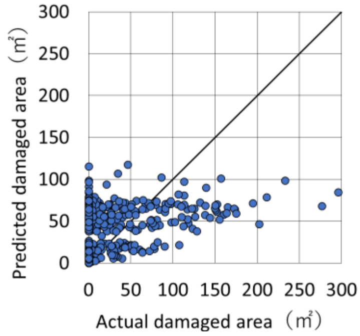

Figure 8b. Comparison between the predicted and actual building damage areas at 30-50 m/s of estimated wind speed.

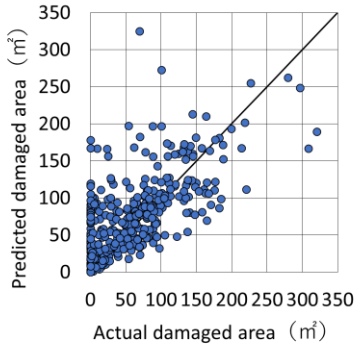

Figure 8c. Comparison between the predicted and actual building damage areas at more than 50 m/s of estimated wind speed.

Comparison between the estimated and actual building damage area

Figure 8 shows the comparison between the predicted damaged area and the actual damaged area. The predicted damaged area is larger than the actual damaged area, when the wind speed is low or medium. On the other hand, the predicted values corresponded to the actual values, when the wind speed is high. The predictive accuracy of tornado damage will surely improve with better estimates of the probability of number of grids at low wind speeds.

Conclusions

We estimated the areas of damaged building due to the tornado in Nobeoka City, Japan on September 17, 2006, and we compared these estimated values with the actual ones. Although the predicted damaged area was larger than the actual damaged area at low wind speeds, the predicted values agreed with the actual values at high wind speeds. The damage prediction during low wind speeds needs to be investigated further.

Acknowledgments

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