A statistical regional typhoon hazard assessment approach based on the area integration of damages

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SUMMARY:

Many studies present extreme wind speeds as the results of typhoon risk assessment. On the other hand, cities under threat of larger extreme wind speed is usually designed with stronger wind resistance. Therefore, for wind hazard assessment or prediction in coastal cities, it will be more meaningful if the assessment could consider the local wind resistance level and the typhoon speed variation in different areas of the city. In this paper, the typhoon hazard index is proposed with the local design wind speed to consider the structural wind resistance ability. Further, the area integration method is adopted with wind field model to consider the typhoon wind speed distribution in target region. Based on the obtained typhoon hazard indexes, the extreme analysis method of “Improved Method of Independent Storms" (XIMIS) is carried out to present local structural loss statistical results with consideration of both typhoon intensity and structural wind resistance ability, which is thought more proper for typhoon hazard assessment.

Keywords: regional typhoon hazard assessment, typhoon damage index, area integration of damages, XIMIS

1. GENERAL INSTRUCTIONS

With the climate change, it is generally agreed that the intensity of typhoons continues to increase. Therefore, the typhoon hazard assessment will be of greater significance to characterize the typhoon impact on buildings and infrastructures in the coastal area threaten by typhoon.

Many studies evaluate typhoon risk by presenting the typhoon extreme wind speed (Li and Hong, 2016), which is more likely to indicate the typhoon impact (or typhoon strength on site), rather than the typhoon induced loss. Ren et al. (2022) proposed a damage index to show the typhoon regional disaster and compared its performance with IWT index from CMA. Wang et al. also used a typhoon hazard index to reflect the losses from typhoon at county level. These studies aim to assess the typhoon hazard from loss assessment perspective.

It will be more comprehensive to assess the typhoon hazard combining with local structure design level. This paper aims to propose the typhoon hazard assessment method with consideration of both typhoon intensity and structural wind resistance.

2. A STATISTICAL METHOD FOR TYPHOON HAZARD ASSESSMENT

2.1. The area integration method for typhoon wind hazard

In order to consider the whole typhoon coverage area and integrate the damage loss in area, the area integration method would be used to assess the regional typhoon hazard with consideration of local structural wind resistance ability, which is similar concept to the Ren (2022), Powell and

Reinhold (2007)

$$D_{area} = \int DdA \tag{1}$$

where D_{area} is the regional typhoon hazard assessment result, D is the typhoon hazard index (with details in the following paragraph) and dA means the area of each grid.

Ren (2022) uses three summarized equations to characterize the degree of structural damage with consideration of lower/medium/upper wind resistance levels, while the HAZUS Hurricane Model uses the normal/lognormal distribution to represent the structural wind resistance. It shall be noted that current structural resistance models for the regional risk assessment are mainly empirical models based on specific assumption or relevant research data. In this paper, typhoon hazard index D is proposed based on cumulative density function value of truncated normal distribution $f(v)$ with mean value $\hat{U}$ and std value $0.1\hat{U}$, where $\hat{U}$ is the local design wind speed，

$$D = \int f(v)dv \tag{2}$$

where $v \in [\hat{U}\text{-}2.5{*}0.1\hat{U},\ \hat{U}{+}2.5{*}0.1\hat{U}]$ is restricted as wind speed boundary when assessing the structural failure loss during typhoon events, i.e., the small wind speed ($<\hat{U}\text{-}0.25\hat{U}$) will result in no structural damage loss and the large wind speed ($>\hat{U}+0.25\hat{U}$) will be definitely cause damage.

2.2. Wind Field Model

Yan Meng model is adopted here to interpret the wind field evolution along the historical typhoon track from database of Joint Typhoon Warning Center (JTWC). And the typhoon intensity parameter (V_{max}) was used from 1949 to 2018. The Yan Meng model (1995) gives gradient height wind field model as following:

$$v_g(r,\beta) = \frac{V_T \sin\beta - rf}{2} + \sqrt{\left(\frac{V_T \sin\beta - rf}{2}\right)^2 + \frac{r}{\rho_a}\frac{\partial p(r)}{\partial r}} \tag{3}$$

$$p(r) = p_c + (p_n - p_c)\cdot exp\left[-\left(\frac{R_{mw}}{r}\right)^B\right] \tag{4}$$

The wind filed model is used for the validation of typhoon in 2018/08/22, which shows good agreement with the field measurement data in Figure 1.

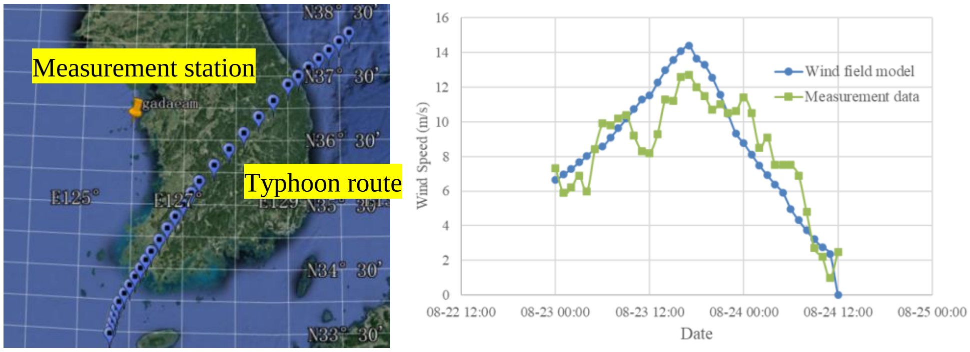

Figure 1. Comparison of simulated wind speed and measured wind speed: typhoon route (left); typhoon speed(right)

2.3. Extreme Value Analysis Method: XIMIS

The XIMIS will be conducted to obtain the statistical extreme value. The average annual rate of occurrence of storms will be denoted by $a = N/R$ with total sample number N and observation period R. From extreme value theory, the appropriate asymptotic form is the Fisher-Tippet distribution when the parent distribution is of the exponential class.

$$\emptyset(q) = \exp[-\exp(-y)] = \exp[-\exp\{-\alpha(q-\gamma)\}] \tag{5}$$

where y is the standard reduced variate and α, γ are the dispersion and location parameters.

In XIMIS, the unbiased mean reduced variate for the largest peak could be expressed as $\bar{y}_1$ with value of ln(R)+0.5772. And then the Poisson process model assumption for independent events is applied for other ranks $\bar{y}_{m+1} = \bar{y}_m - 1/m$. A weighted least-squares method is used to fit the line on the Gumbel ploy and derive the values for the parameters α and $\alpha\gamma$ with sample q,

$$\alpha = \frac{\sum_{m=1}^{N} w_m \bar{y}_m q_m - (\sum_{m=1}^{N} w_m \bar{y}_m)(\sum_{m=1}^{N} w_m q_m)}{\sum_{m=1}^{N} w_m q_m^2 - (\sum_{m=1}^{N} w_m q_m)^2}, \quad \alpha\gamma = \alpha \sum_{m=1}^{N} w_m q_m - \sum_{m=1}^{N} w_m \bar{y}_m \tag{6}$$

where w_m are the m-th storm weight (Harris, 2009).
The extreme value analysis will be conducted on D_{area} introduced in Section 2.1 to give the extreme D_{area} corresponding to a given return period.

2.4. Application of the Regional Wind Hazard Assessment Method

Table 1 presents the extreme typhoon wind speeds of seven selected cities with the ranking Hongkong>Manila≈Xiamen>Shantou≈Busan>Shanghai>Seoul. However, the extreme wind speed does not represent the actual loss from typhoon damage because the city with larger typhoon extreme wind speed is usually coded with the stronger structural wind resistance design. And for the cities with similar extreme wind speed or design wind speed, the typhoon hazard assessment results maybe also vary due to the typhoon frequency and intensity distribution. Therefore, the regional typhoon hazard index D_{area} is used to further assess the local structural reliability to the typhoon effect. In this paper, the region 100km*100km for each selecting city is considered and analysed with grid 10*10 when conducting area distribution integration method.

Table 1. Comparison of extreme wind speed with local code in 10m height with hourly mean speed(m/s)

Location	HK	Manila	Shanghai	Xiamen	Shantou	Busan	Seoul
Extreme wind speed	38.1	34.3	28.1	34.1	32.6	32.9	26.5
Local code	38.7	36.6	27.8	33.5	33.5	35.6	24.4

The results of the non-zero D_{area} of selecting cities are illustrated in Figure 2 and Table 2. It could be seen that most typhoon will result in zero D_{area}, as reflected in Figure 2 and the small n_1/n_2 ratio in table 2, which is reasonable because those typhoon speeds are far below the codified wind speed and therefore not likely to cause damages. However, the percentage of non-zero D_{area} typhoon does not directly give the typhoon induced loss or damages; to address this, two further index the extreme D_{area}, reflecting the damages/loss in an extreme event corresponding to a given return period (e.g. 100 years in this paper), and the accumulated D_{area}, reflecting the accumulated loss in the studied period, are respectively proposed and presented in Table 2 and Figure 3.

As an observation, in spite of higher extreme wind speed in Hongkong than Manila, Manila has higher extreme typhoon hazard index than Hongkong; similarly, in spite of similar codified and extreme wind speeds in Xiamen and Shantou, Shantou has bigger typhoon hazard index than

Xiamen. This may be explained that the extreme damage index, damage in a single extreme storm at a given return period, is mainly controlled by the very limited largest wind storms affecting the city, as shown in Figure 2. On the other hand, the accumulated loss in a city is not only related to the several biggest wind storms but also related to the frequency of strong storms passing the city. For example, the extreme damage index in Busan is very high (in similar orders of Shantou, Hong Kong and Manila) due to a couple of very strong storms affecting the city, but its accumulated damages are much lower because the number of typhoon passing Busan is significantly fewer.

Table 2. The results of hazard assessment for selecting cities

Location	HK	Manila	Shanghai	Xiamen	Shantou	Busan	Seoul
n_1=Total typhoon number	197	238	71	160	171	103	55
n_2=D_{area}>0 number	31	33	18	34	30	12	17
Ratio = n_1/n_2	0.16	0.14	0.25	0.21	0.18	0.12	0.31
Extreme value of D_{area}	68.8	83.5	40.4	63.4	73.2	79.3	58.5
Accumulated D_{area}	436	484	162	362	409	202	163

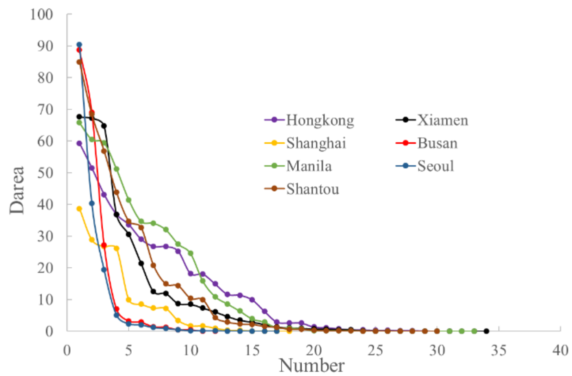

Figure 2. The typhoon hazard index of selecting cities

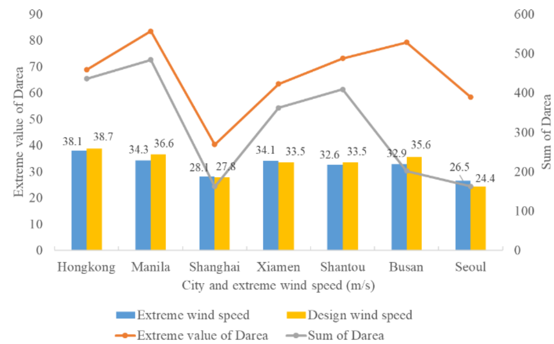

Figure 3. The statistical results of typhoon hazard

3. CONCLUSIONS:

1. A statistical reginal typhoon hazard assessment method is proposed based on best track typhoon data using the area damage integration methods, with a simplified consideration of wind resistance.
2. Two damage evaluation index, the extreme damage index, reflecting damages in a single extreme event at a given return period, and the accumulated damage index, reflecting the accumulated damages in the studied periods, are proposed.
3. The hazards results from case studies are generally consistent with the physical explanations.

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