Prediction of Typhoon Wind Speeds under Global Warming Conditions

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1. Introduction

The formation and intensity of typhoons depend significantly upon the sea surface temperature (SST). The maximum possible intensity of a typhoon increases with an increase of SST. The continuous increase of SST by global warming conditions in the western North Pacific Ocean results in an increased occurrence of supertyphoons in East Asia and the Korean Peninsula. Recent numerical experiments [1] have found that the central pressures of two historical typhoons, Maemi (2003) and Rusa (2002), which recorded the highest storm surges along the coasts of the Korean Peninsula, dropped about 19 and 17 hPa, respectively, when considering the future SST (a warming of 3.9℃ for 100 years) over the East China Sea.

The increase in typhoon intensity strongly influences the safety-related systems, structures, and components (SSCs) in nuclear power plants (NPPs). Under future global warming conditions, a prediction of the maximum possible wind speeds in NPP sites is necessary for the safe operation of NPPs.

2. Typhoon Wind Profile Model

The climatological characteristics of typhoons include the (1) rate of typhoon occurrence in any given region, (2) difference between atmosphere pressures at the center and periphery of the storm, (3) radius of the maximum wind speeds, (4) speed of storm translation, (5) direction of storm motion, and (6) crossing point coordinate on a line normal to the coast [2]. The physical model of the typhoon wind has been developed using climatological parameters. Holland [3] described the radial distribution of surface pressure in a hurricane in the following form:

$$p(r) = p_0 + \Delta p \, \exp\left[-\left(\frac{r_{mw}}{r}\right)^B\right] \quad (1)$$

where $p(r)$ is the surface pressure at distance r from the storm center, p_0 is the central pressure, Δp is the pressure difference between the center and periphery of the storm, r_{mw} is the radius of the maximum winds, and B is Holland's pressure profile parameter. The wind profile for a stationary storm is

$$V_g(r) = \sqrt{\frac{r^2 f^2}{4} + \frac{B\Delta p}{\rho}\left(\frac{r_{mw}}{r}\right)^B \exp\left[-\left(\frac{r_{mw}}{r}\right)^B\right]} - \frac{rf}{2} \quad (2)$$

where $V_g(r)$ is the gradient wind at radius r, ρ is the air density, and f is the Coriolis parameter. The maximum wind intensity is independent of the radius of the maximum winds, but the shape of the pressure profile is required through parameter B.

The Holland model is an axisymmetric model, which cannot represent the asymmetric structures of a hurricane. To overcome this limitation, Georgiou [4] introduced an advanced model to represent the asymmetric structures in a land-falling hurricane:

$$V_g(r,\alpha) = \frac{V_T \sin\alpha - rf}{2} + \sqrt{\frac{(V_T \sin\alpha - rf)^2}{4} + \frac{B\Delta p}{\rho}\left(\frac{r_{mw}}{r}\right)^B \exp\left[-\left(\frac{r_{mw}}{r}\right)^B\right]} \quad (3)$$

where α is the angle from the direction of the hurricane movement and V_T is the hurricane translation speed. The model proposed by Georgiou can be effectively used to forecast the storm surge in land-falling typhoons.

3. Typhoon Wind Speed Simulation

The direct wind-speed measurements are insufficient to determine the typhoon wind speeds as a function of the return period. This study determines the typhoon wind speeds using the Monte-Carlo simulation technique.

3.1 Probability Distributions for Typhoon Parameters

Probability distribution functions were selected for typhoon parameters and four goodness of fit (GOF) tests, i.e., Chi-square (χ^2) test, Kolmogorov-Smirnov (K-S) test, Cramer-von Mises (CVM) test, and probability plot correlation coefficient (PPCC) test, were used to determine the probability distributions, as shown in Table 1.

Table I: Probability Distribution Functions and GOF tests

Parameter	Probability distribution function	Goodness and fit test			
		χ^2	K-S	CVM	PPCC
Frequency	Uniform Poisson				
Pressure difference	Weibull	5.59(○)	0.12(○)	0.10(○)	0.98(○)
Translation speed	Linear Step Function	2.29(○)	0.10(○)	0.07(○)	0.98(○)
Distance	Uniform	3.00(○)	0.10(○)	0.08(○)	0.98(○)
Angle	Linear Step Function	1.84(○)	0.08(○)	0.04(○)	0.98(○)

3.2 Recurrence Interval of Wind Speeds

The climatological data for each typhoon that hit the site of interest were determined from the respective probability distributions through random sampling. For each typhoon, a set of wind speeds at the site was calculated. A large number of wind speeds were calculated and the largest speed represents the maximum wind speed caused by the typhoon at the site. The wind speeds are ranked by magnitude, and the mean recurrence interval, T_{v_i}, of the i-th ranking wind speed, v_i, in a set of m wind speeds are estimated by [2]

$$T_{v_i} = \frac{1}{1-\exp\left[-\mu\left(1-\frac{i}{m+1}\right)\right]}, \qquad (4)$$

where μ, the Poisson parameter, is the annual rate of occurrence of typhoons at the site of interest.

3.3 Typhoon Wind Speeds

Estimates of typhoon wind speeds at the Younggwang site were made using the historical typhoon data of the Regional Specialized Meteorological Center (RSMC), Japan Meteorological Agency for the years 1951 to 2014. The simulated typhoons, which represent the highest wind speed recorded in 1904 near the site, were included in the typhoon data sets. Wind speeds were obtained from the Monte-Carlo simulation considering the effects of global warming. Figs. 1 and 2 show the maximum possible wind speeds for different return periods at the Younggwang site.

3. Conclusions

Typhoon wind speeds were estimated for different return periods by the Monte-Carlo simulation using the typhoon data, which include historical observed typhoons and simulated typhoons. The maximum wind speeds increase under global warming conditions. The probability of occurrence of super-typhoons increases in the future. The estimated return period for super-typhoons affecting the Younggwang site is about 1,000,000 years.

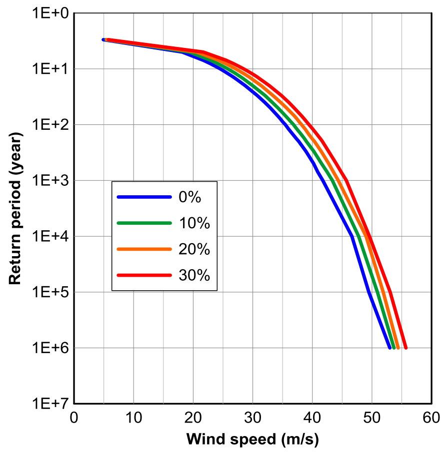

Fig. 1. Changes in the maximum wind speeds at the Younggwang site due to decrease in the central pressures at the storm.

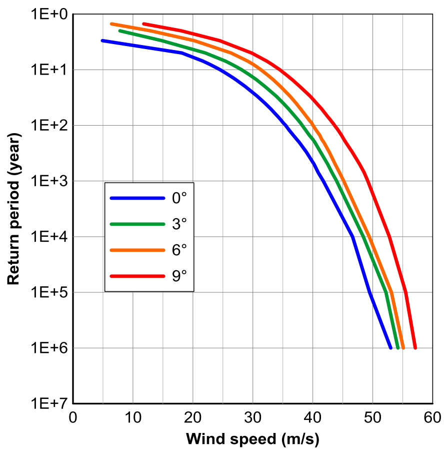

Fig. 2. Changes in the maximum wind speeds at the Younggwang site for northward moving typhoons.

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