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Estimation of Typhoon Wind Hazard for the Yeonggwang Nuclear Site

Young-Sun Choun*, Min-Kyu Kim
Structural and Seismic Safety Research Team, Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Daejeon, 34057, Republic of Korea
**Corresponding author: sunchun@kaeri.re.kr*

1. Introduction

The intensity of typhoons that can influence the Korean Peninsula have recently been on an increasing trend owing to a rapid change of climate of the Northwest Pacific Ocean. Currently, the U.S. Nuclear Regulatory Commission requires that a new nuclear power plant be designed to endure the design-basis hurricane wind speeds corresponding to an annual exceedance frequency of 10^{-7} [1].

The prediction of typhoon wind speeds for long return periods includes an unavoidable epistemic uncertainty owing to limited observations. Using a logic-tree framework and a Monte Carlo simulation, the typhoon wind hazard for the Yeonggwang nuclear site is estimated.

2. Typhoon Wind Profile Model

Holland [2] developed a physical model of typhoon wind using climatological parameters, and Georgiou [3] suggested an advanced model to represent the asymmetric structures in a land-falling hurricane. The gradient wind V_g can be expressed in the following form:

$$V_g(r,\alpha)=\frac{V_T\sin\alpha-rf}{2}+\sqrt{\frac{(V_T\sin\alpha-rf)^2}{4}+\frac{B\Delta p}{\rho}\left(\frac{r_{mw}}{r}\right)^B\exp\left[-\left(\frac{r_{mw}}{r}\right)^B\right]} \quad (1)$$

where r is the radius from the storm center, α is the angle from the direction of the hurricane movement, V_T is the hurricane translation speed, f is the Coriolis parameter, B is Holland's pressure profile parameter, Δp is the pressure difference between the center and periphery of the storm, r_{mw} is the radius to the maximum winds, and ρ is the air density.

The maximum wind speed can be approximated by

$$V_{g,\max}\approx\frac{1}{2}(V_T-fr_{mw})+0.61\sqrt{\frac{B\Delta p}{\rho}} \ . \quad (2)$$

3. Wind Hazard Estimation

3.1 Typhoon Wind Data

The sources of the typhoon observation data are datasets for severe tropical storms (STS) and typhoons (TY) during the period of 1951-2014 from RSMC, the Japan Meteorological Agency. Fifty-three typhoons available within 300 km from the Yeonggwang nuclear site were used in this estimation.

3.2 Probability Distribution Functions and Models

Probability distribution functions (PDFs) were selected for the typhoon parameters, and goodness of fit tests were used to determine the probability distributions. The PDFs and models adopted for the typhoon parameters are shown in Table I.

Table I: Probability Distribution Functions and Models used in the Hazard Estimation

Parameter	PDF or Model
Occurrence frequency	Poisson process
Central pressure difference, Δp	Weibull and Lognormal distributions
Radius to maximum wind, r_{mw}	Kawai et al. [4], Powell et al. [5], Vickery and Wadhera [6]
Pressure profile parameter, B	Powell et al. [5], Vickery et al. [7], Vickery and Wadhera [6], B=0.5
Translation speed, V_T	Lognormal distribution
Radial distance, r	Uniform distribution
Heading angle, α	Linear step function

r_{mw} models used in this estimation are as follows.
Kawai et al. [4]:

$$R_{mw}=94.89\exp\left(\frac{p_c-967}{61.5}\right), \quad (3)$$

Powell et al. [5]:

$$\ln R_{mw}=2.0633+0.0182\Delta p-0.00019008\Delta p^2+0.0007336\psi^2, \quad (4)$$

Vickery and Wadhera [6]:

$$\ln R_{mw}=3.015-0.00006291\Delta p^2+0.0337\psi, \quad (5)$$

where p_c is the central pressure in hPa, Δp is the central pressure difference in hPa and ψ is the latitude in degrees.
B models used in this estimation are as follows.
Powell et al. [5]:

$$B=1.881093-0.005567r_{mw}-0.010917\psi \quad (6)$$

Vickery et al. [7]:

$$B=1.38+0.00184\Delta p-0.00309r_{mw}, \quad (7)$$

where r_{mw} is in km, ψ is the latitude expressed as degrees North, and Δp is the central pressure difference in hPa.

Vickery and Wadhera [6]:

$$A = \frac{r_{mw} \cdot f}{\sqrt{2R_d T_S \cdot \ln\left(1 + \frac{\Delta p}{p_c \cdot e}\right)}} \quad (8)$$

$$B = 1.732 - 2.237\sqrt{A}\,. \quad (9)$$

where r_{mw} is in m, and f represents the contribution to angular velocity associated with the Coriolis force. In addition, R_d is the gas constant for dry air, T_S the sea surface temperature in K, Δp is the central pressure difference in hPa, and p_c is the central pressure in hPa.

3.3 Logic Tree

The logic trees are constructed using three key parameters of the typhoon wind field model: the central pressure difference (Δp), pressure profile parameter (B), and radius to the maximum wind (r_{mw}). The weights for Δp are assigned based on the result of a Chi-square goodness of fit test. The weights for B and r_{mw} are determined using the observation values.

3.4 Typhoon Wind Hazard Curves

A typhoon wind hazard assessment was conducted using a Monte Carlo simulation. To obtain the wind speeds for return periods of up to 10,000,000 years, the simulation was applied for 10,000,000 iterations. Fig. 1 shows the mean hazard curves for the simulated winds, which were generated from a simulation by a random sampling of the typhoon parameters, and for the probable maximum winds (PMWs), which are occurring at $r = r_{mw}$ and estimated using Eq. (2). The predicted mean values of 10-min wind speeds at the 10-meter level for the simulated winds and the PMWs are presented in Table II.

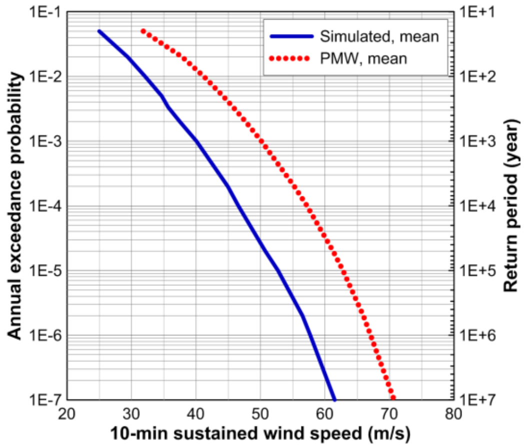

Fig. 1. Wind hazard curves at the Yeonggwang site.

Table II: Predicted 10-min mean wind speeds at 10 m-level for the Yeonggwang site

Return period (year)	Annual exceedance probability	Simulated wind speed (m/s)	PMW speed (m/s)
50	2E-2	29	38
100	1E-2	32	41
500	2E-3	37	48
1,000	1E-3	40	50
10,000	1E-4	47	57
100,000	1E-5	53	63
1,000,000	1E-6	58	67
10,000,000	1E-7	61	71

4. Conclusions

Typhoon wind hazard curves were predicted for different return periods through a Monte-Carlo simulation and a logic-tree framework using the typhoon observation data for the Yeonggwang nuclear site. The mean hazard curves for the simulated and probable maximum winds were proposed.

The mean hazard curves for the simulated and probable maximum winds can be used for the estimation of storm surge from typhoon winds at the site, and for the design and risk assessment of the Hanbit nuclear power plants.

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REFERENCES

[1] USNRC, Design-Basis Hurricane and Hurricane Missiles for Nuclear Power Plants, Regulatory Guide 1.221, U.S. Nuclear Regulatory Commission, Washington, D.C., 2011.

[2] G. J. Holland, An Analytic Model of the Wind and Pressure Profiles in Hurricanes, Monthly Weather Review, Vol.108, pp.1212-1218, 1980.

[3] P. Georgiou, Design Wind Speeds in Tropical Cyclone Prone Regions, Ph.D. Thesis, University of Western Ontario, 1985.

[4] H. Kawai, K. Honda, T. Tomita, T. Kakinuma, Characteristic of Typhoons in 2004 and Forecasting and Hindcasting of their Storm Surges, Technical Note of the Port and Airport Research Institute, No. 1103, 2005.

[5] M. Powell, G. Soukup, S. Cocke, S. Gulati, N. Morisseau-Leroy, S. Hamid, N. Dorst, L. Axe, State of Florida Hurricane Loss Projection Model: Atmospheric Science Component. Journal of Wind Engineering and Industrial Aerodynamics, Vol. 93, pp. 651-674, 2005.

[6] P. J. Vickery, D. Wadhera, Statistical Models of Holland Pressure Profile Parameter and Radius to Maximum Winds of Hurricanes from Flight-Level Pressure and H*Wind Data, Journal of Applied Meteorology and Climatology, Vol. 47, pp. 2497-2517, 2008.

[7] P. J. Vickery, P. F. Skerlj, L. A. Twisdale, Simulation of Hurricane Risk in the U.S. Using Empirical Track Model, Journal of Structural Engineering, Vol. 126, pp. 1222-1237, 2000.