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Estimation of Typhoon Wind Hazard Curves for Nuclear Sites

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1. Introduction

High winds from typhoons can cause dynamic wind loads, large differential pressures, or wind-driven missiles, and can result in damage to the structures, systems, and components of a nuclear power plant (NPP). The intensity of such typhoons, which can influence the Korean Peninsula, is on an increasing trend owing to a rapid change of climate of the Northwest Pacific Ocean. Therefore, nuclear facilities should be prepared against future super-typhoons. Currently, the U.S. Nuclear Regulatory Commission requires that a new NPP should be designed to endure the design-basis hurricane wind speeds corresponding to an annual exceedance frequency of 10^{-7} (return period of 10 million years) [1].

A typical technique used to estimate typhoon wind speeds is based on a sampling of the key parameters of typhoon wind models from the distribution functions fitting statistical distributions to the observation data. Thus, the estimated wind speeds for long return periods include an unavoidable uncertainty owing to a limited observation. This study estimates the typhoon wind speeds for nuclear sites using a Monte Carlo simulation, and derives wind hazard curves using a logic-tree framework to reduce the epistemic uncertainty.

2. Typhoon Wind Profile Model

The climatological characteristics of typhoons include (1) the rate of typhoon occurrence in any given region, (2) the difference between atmosphere pressures at the center and periphery of the storm, (3) the radius to the maximum wind speeds, (4) the speed of the storm translation, (5) the direction of the storm motion, and (6) the crossing point coordinate on a line normal to the coast [2].

Holland [3] developed a physical model of the typhoon wind using climatological parameters, and Georgiou [4] 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. Estimation of Wind Hazard Curves

A Monte-Carlo simulation is used to estimate the typhoon wind speeds because the direct wind-speed measurements are insufficient to determine the typhoon wind speeds as a function of the return period. A logic-tree is used to obtain the wind hazard curves available for nuclear sites.

3.1 Probability Distribution Functions and Models

Probability distribution functions (PDFs) were selected for typhoon parameters and four goodness of fit tests, i.e., a Chi-square test, Kolmogorov-Smirnov test, Cramer-von Mises test, and probability plot correlation coefficient test 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
Translation speed, V_T	Lognormal distribution
Radial distance, r	Uniform distribution
Heading angle, α	Linear step function
Pressure profile, B	Harper and Holland [5], Hubbert et al. [6], Powell et al. [7], Vickery et al. [8]
Radius to maximum wind, r_{mw}	Powell et al. [7], Vickery and Wadhera [9], Willoughby et al. [10]

3.2 Logic Tree

The logic trees are constructed with three key parameters of the typhoon wind field model: central pressure difference (Δp), pressure profile model (B), and radius to the maximum wind (r_{mw}).

3.3 Typhoon Wind Hazard Curves

Estimates of the typhoon wind speeds were made using historical typhoon data of the Regional Specialized Meteorological Center (RSMC), Japan Meteorological Agency, for the years 1951 to 2014. To obtain the wind speeds for return periods of up to 10,000,000 years, the simulation was run for 10,000,000 iterations.

Figs. 1, 2, and 3 present the mean hazard curves for the simulated winds and the possible maximum winds (PMWs) in Younggwang, Kori, and Ulchin sites, respectively.

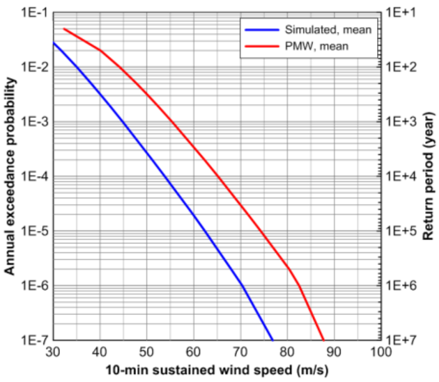

Fig. 1. Wind hazard curves at the Younggwang site.

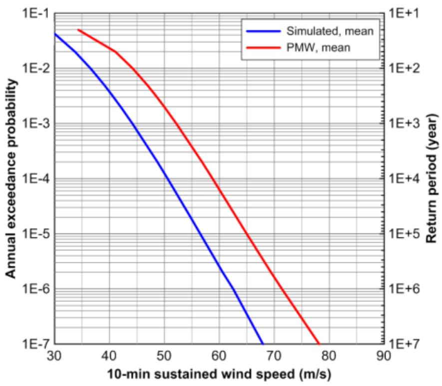

Fig. 2. Wind hazard curves at the Kori site.

4. Conclusions

Typhoon wind speeds were estimated for different return periods through a Monte-Carlo simulation using the typhoon observation data, and the wind hazard curves were derived using a logic-tree framework for three nuclear sites. The hazard curves for the simulated and probable maximum winds were obtained.

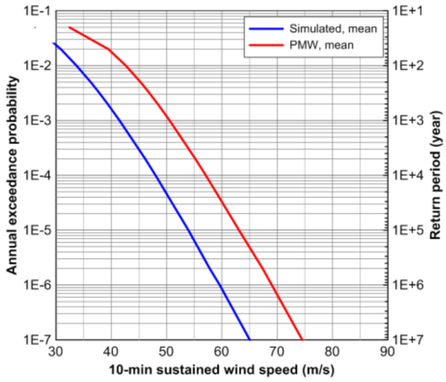

Fig. 3. Wind hazard curves at the Ulchin site.

The mean hazard curves for the simulated and probable maximum winds can be used for the design and risk assessment of an NPP. The hazard curve for the simulated winds can be used for the design of an NPP, and the hazard curve for the probable maximum winds can be used for the assessment of an NPP.

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