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Synthetic Typhoon Simulation-Based Estimation of the 100-Year Return-Period Wind Speed at the Shin-Kori Site under the SSP5-8.5 Scenario

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1. Introduction

Climate change alters the environmental conditions governing the development of tropical cyclones (TCs) through mechanisms such as rising sea surface temperatures and increased atmospheric moisture, and changes in the probability of major TC occurrence and the characteristics of rapid intensification have been reported [1, 2]. In addition, studies have suggested that under warming conditions, the maximum sustained winds of typhoons affecting the Korean Peninsula may increase [3]. At present, the design and assessment wind intensities used for structures and facilities have generally been determined based on historical observational statistics [4]. However, if the occurrence, tracks, and intensity characteristics of TCs change under future climate change, historical statistics alone may not adequately represent wind intensities under future conditions. Accordingly, this study simulated synthetic typhoons for the Shin-Kori Nuclear Power Plant using the environmental fields from the UKESM1-0-LL climate model and estimated return-period wind speeds (return-level wind speeds) at the site of interest. These return-level wind speeds can serve as indicators of future wind intensity applicable not only to structural design but also to safety assessment.

2. Methodology for Synthetic Typhoon Simulation

The synthetic typhoon simulation was conducted based on the methodology of NUREG/CR-7005, which was originally developed from historical observations and records, while incorporating the effects of climate change [5, 6]. First, seeds were randomly generated and their tracks were modeled to reflect climate change conditions. Next, the maximum potential intensity (MPI) was estimated, and intensity was evolved using a logistic intensity change model. Quantile Delta Mapping (QDM) was then applied to historical and future datasets to correct intensity bias. Wind speeds at the site of interest were calculated using the Holland (1980) wind field model, and return-level wind speeds for 100year return period was estimated through extreme value analysis [7].

2.1 Seed Generation and Track Modeling Considering Steering Flow

To reflect climate change conditions, seeds were randomly generated and then screened using the sea surface temperature (SST) conditions from the climate model. For the selected seeds, steering flow was estimated from the climate model winds at different altitudes, and hourly movement was simulated to construct typhoon tracks.

2.2 Typhoon Intensity Modeling

The maximum potential intensity (MPI) along each track was estimated using the environmental fields from the climate model and TCpyPI. Based on the estimated MPI, a logistic-type intensity change model was applied to evolve the central pressure (i.e., storm intensity). Quantile Delta Mapping (QDM) was applied to correct biases in the climate model. Subsequently, the maximum intensity within the radius of influence of the site of interest was selected and used in the next step for wind speed estimation and extreme value analysis.

2.3 Wind Speed Estimation and Extreme Value Analysis

In the Holland model, the wind field is derived from the central pressure deficit, the radius to maximum wind (RMW), and the pressure profile parameter (B). In this study, wind speeds at the site of interest were calculated using the Holland (1980) wind field model with the radius to maximum wind and the pressure profile parameter (B) [7]. The surface wind reduction relationship of Vickery and Twisdale was then applied to convert the results to 10-m, 10-minute mean wind speed at the surface [8]. Extreme value analysis was performed on the derived wind speeds to estimate the 100-year return-level wind speed.

3. Results and Discussion of the 100-Year Return-Period Wind Speed at the Shin-Kori Site

3.1 Results of the 100-Year Return-Period Wind Speed at the Shin-Kori Site

The Shin-Kori Nuclear Power Plant was selected as the site of interest, and synthetic typhoons were simulated using the environmental fields for 2070–2100 under the SSP5-8.5 scenario from the CMIP6 UKESM1-0-LL model. A total of 30,000 seeds were generated, and those satisfying the tropical cyclone genesis condition of SST ≥ 26.5°C were selected. For the selected seeds, steering-flow-based track modeling and MPI-based intensity estimation were performed to calculate the 10-m, 10-minute mean wind speed at the site of interest. To account for uncertainty in the wind-field input parameters, six combinations of RMW and Holland B (Cases 1–6) were considered. The weights of the logic tree were adopted from those used by Kim et al. for the Kori site, and the constructed logic tree is shown in Fig. 1. Cases 1–6 were defined by branching RMW into $\mu-2\sigma$, μ, and $\mu+2\sigma$, and Holland B into Holland and Powell, applying the six model combinations and weights used by Kim et al. [9]. Table 1 presents the 100-year return-period wind speed for each case. The logic-tree-weighted wind speed was estimated to be 38.108 m/s for the 100-year return period.

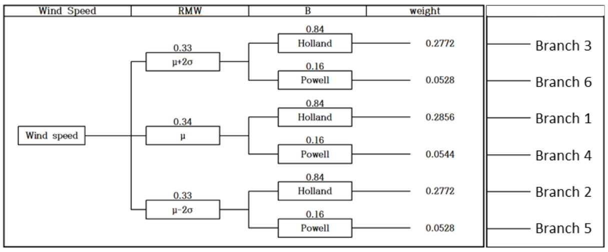

Fig. 1. Constructed logic tree [9]

Table I: 100-year return-period wind speed at the Shin-Kori site for Cases 1–6 (10 m, 10-minute mean, m/s)

Return Period	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
100	37.97	38.85	32.92	48.12	51.66	38.32

3.2 Discussion of the 100-Year Return-Period Wind Speed at the Shin-Kori Site

Based on the methodology of NUREG/CR-7005, typhoon simulations were performed while incorporating future climate change scenarios. In the present study, 30,000 simulations were conducted; however, a larger number of simulation runs is needed to more thoroughly verify the stability and convergence of the estimates. In future work, it will be necessary to expand the simulation size in order to further assess the convergence behavior of the results and the reliability of the estimates.

4. Conclusions

As climate change increases the likelihood of changes in tropical cyclone genesis regions, track patterns, intensity, and extreme-value distributions, wind hazard maps and return-level wind speeds based solely on historical observational statistics may not adequately represent future conditions. In particular, for critical facilities such as nuclear power plants, which are long-lived structures, future external hazards such as strong winds need to be conservatively considered in long-term safety assessments. Therefore, estimation of return-level wind speeds based on environmental fields from future climate scenarios is required. In this study, future return-period wind speeds (10-m, 10-minute mean) at the Shin-Kori Nuclear Power Plant site were estimated using the 2070–2100 environmental fields from CMIP6 SSP5-8.5 (UKESM1-0-LL). The return-period wind speeds at the Shin-Kori site were finally presented. These results can be used as quantitative indicators that incorporate future climate conditions in the design and assessment of structures and facilities against strong winds.

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