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Probabilistic Flood Hazard Assessment at Nuclear Power Plant Sites by Storm Surge

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1. Introduction

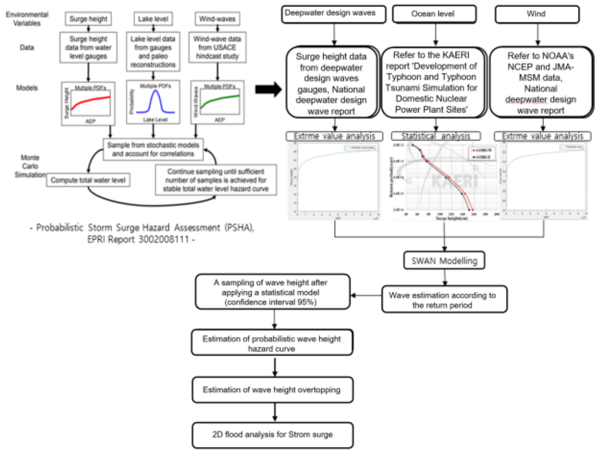
Due to the influence of recent climate change, typhoon invasions of the Korean Peninsula with extreme rainfall frequently occur. Between August and September 2020, three typhoons, Bavi, Maysak, and Haishen, attack the Korean Peninsula, and the resulting heavy rains that fell caused flood damage. As typhoons Maysak and Haishen passed east of Korea, the local nuclear power plants were automatically shut down.

In this study, we tried to apply a probabilistic approach. The probabilistic approach can consider possible uncertainties in the existing deterministic approach. For this methodology, EPRI report 3002008111 "Probabilistic Storm Surge Hazard Assessment" was referred to. Then, the wave overtopping according to the wave height was estimated probabilistically through the EurOtop model. After that, the estimated wave overtopping was selected as the external boundary condition of the nuclear power plant, and a 2D flooding analysis was performed. Finally, a probabilistic hazard curve was calculated according to the flood depth for each return period analyzed.

In order to analyze the wave height, wave period, and wave direction characteristics in the front of the nuclear power plant site, the SWAN model was built in the near sea area through the nesting technique. First, based on the data presented in the deep-water design waves report, wave height, period, and sea wind were estimated according to the return period. Second, the SWAN model was established through SMS and GIS programs based on the sea-depth data around the nuclear power plant site. Third, a probability distribution was applied based on the wave height data, the result of the SWAN model for each return period. Based on the result, the probabilistic wave height hazard assessment of the sea around the nuclear power plant site was estimated. This result was applied to the EurOtop model to estimate the overtopping discharge for the wave height. And, a scenario was constructed by applying the overtopping discharge as a boundary condition for external flooding analysis. After that, the impact of flooding in the target nuclear power plant was evaluated through external flooding analysis according to the return period. Finally, an appropriate probability distribution type was selected based on the results of the 2D flood analysis according to the return period. Then, a probabilistic flood hazard curve was estimated and presented based on the selected probability distribution.

2. Research Method

2.1. Study flow



2.2. Deepwater design wave estimation

Currently, there are 535 designed wave height points in the ocean of the Korean Peninsula. In this study, analysis was conducted based on the ocean of the Gori nuclear power plant. The design wave height point in the Ocean near the Gori nuclear power plant is No. 112-3

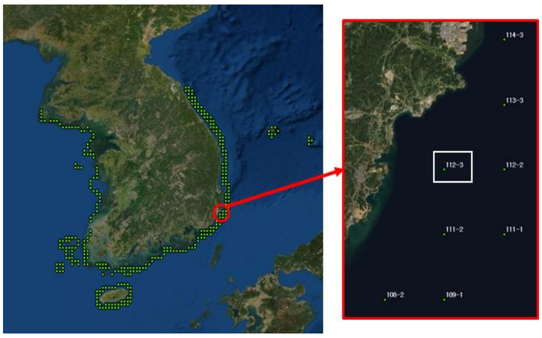


Figure 1. Deepwater design wave height points near Gori NPP

The 'National Deepwater Design Wave Report (2019)' was referred to predict the Gori Nuclear Power Plant waves. In the case of typhoons, 193 typhoons that affected the Korean Peninsula among typhoons that occurred between 1959 and 2017 were selected when calculating the deepwater design wave. Extreme value analysis was performed on the selected typhoon. As a result, the Weibull distribution was selected for the typhoon data.

2.3. Period estimation

The period according to the wave height was calculated by applying the robust regression curve formula.

$$T_p = a(H_s)^b \ (0.2 \le b \le 0.8)$$

Here, a and b are variables, and the parameters are estimated by applying the Solver function according to the range of the variable b.

2.4. Ocean level and wind estimation

The sea level was applied based on the Korea Atomic Energy Research Institute report 'Development of Typhoon and Tsunami Simulation for Domestic Nuclear Power Plant Sites (2017)'.

The sea wind data used the NCEP wind data of NOAA (National Oceanic and Atmospheric Administration) from 1979 to 2017. After that, the same method as the deep-water design wave estimation method was applied.

Table 1. Results of major parameter estimation

Return period (y)	Estimation Hs (m)	Estimation Tp (s)	Estimation Wind (m/ss)	Estimation Sea level (m)
200	12.2328	14.5	25.09	1.1705
500	13.6766	15.2	26.37	1.2220
1000	14.7219	15.6	27.27	1.3010
2000	15.7327	16.1	28.12	
5000	17.0229	16.7	29.19	
10000	17.9684	17.0	29.95	1.6560
20000	18.8904	17.4	30.69	
50000	20.0769	17.9	31.63	
100000	20.9523	18.2	32.31	1.9365
200000	21.8102	18.5	32.97	
500000	22.9199	18.9	33.81	
1000000	23.7422	19.2	34.43	2.0680

2.5. SWAN(Simulation Waves Nearshore) simulation

The nesting function of SWAN is used to analyze the wave height of the Gori nuclear power plant.

A 50 × 50 m grid was constructed in the distant ocean of the nuclear power plant, and a 20 × 20 m grid was constructed in the ocean near the nuclear power plant.

2.6. Probabilistic wave height hazard assessment

Probabilistic wave height hazard assessment (PWHA) is a preliminary step for probabilistic flood risk assessment due to storm surge at the Gori nuclear power plant site.

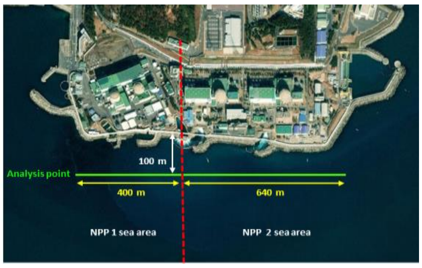


Figure 2. Classified for NPP ocean

The maximum wave height, minimum wave height, mean, and standard deviation were calculated for each return period in the ocean area of each power plant, and the probability distribution was verified through AIC verification by return period.

The @RISK program was used to estimate the hazard curve of the probabilistic wave height caused by the storm surge. Based on the results, wave heights of 5%, Mean, Median, Mode, and 95% were estimated according to the return period of each power plant.

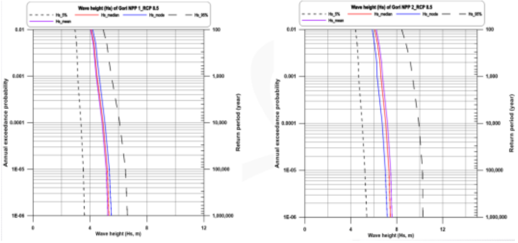


Figure 3. Probabilistic wave height hazard curve.

2.7. Wave overtopping estimation

The probabilistic wave height hazard value was applied to the EurOtop model. The main parameters of the EurOtop model are wave height, period, wave angle, and structures such as coastal barriers.

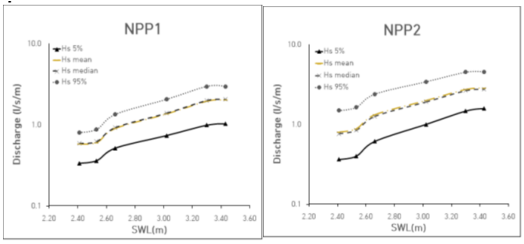


Figure 4. wave overtopping results.

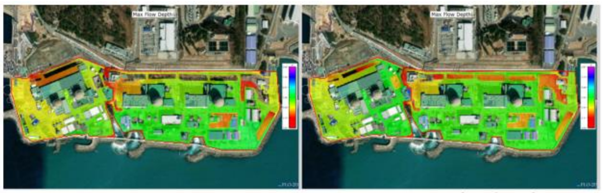
2.8. 2D flood analysis

In this study, the FLO2D model approved by FEMA was applied.

The grid of the nuclear power plant site model was constructed in 3m * 3m. After that, the wave overtopping estimated by the EurOtop model was selected as an external boundary condition.

Finally, a flooding analysis of the nuclear power plant site by overturning waves according to the return period by storm surge conditions was performed.

Figure 5. External flooding boundary condition



< Storm surge duration 1hr > < Storm surge duration 2hr >

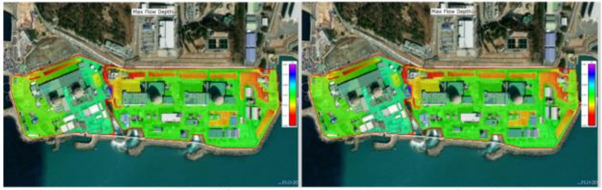


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Figure 6. 2D analysis result by storm surge

2.9. Probabilistic flood hazard assessment

First, the flood depth according to the return period was derived for probabilistic flood hazard assessment. Then, a suitable probability distribution was estimated through statistical analysis by flood depth. Finally, the Monte Carlo method was applied to estimate the probabilistic flood depth according to the return period.

3. Conclusions

This study analyzed the probabilistic wave height caused by the storm surge according to climate change.

A detailed sea bottom topography was constructed for the storm surge simulation. In addition, the parameters were estimated by applying the probability distributions for the deepwater wave height and wind caused by storm surge.

The SWAN model is linked with the nesting technique to analyze the characteristics of wave height, period, and wave direction by frequency in the front ocean of the Gori nuclear power plant.

Based on the results of the SWAN model, statistical analysis was applied to calculate the probability distribution for the possible wave heights in the ocean in front of the nuclear power plant.

A probability distribution model presented the probabilistic wave heights of the ocean in front of the nuclear power plant according to the return period.

Based on the results of this study in the future, it will be used as input data for the EurOtop model, and it is judged that valuable data will be utilized for the analysis of flooding caused by the overtopping of the nuclear power plant site.

The safety assessment for external hazards was performed by 2D flooding analysis of the nuclear power plant site caused by storm surges.

Finally, the probabilistic flood hazard curve was estimated and presented based on the selected probability distribution

Acknowledgments

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