Probabilistic Flood Assessment of Nuclear Power Plants considering Local Intense Precipitation

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1. Introduction

In recent years, the intensity of precipitation and typhoons' frequency increases due to abnormal climate events [1]. Between August and September 2020, three typhoons Bavi, Maysak, and Haishen hit Korea. As a result, heavy rains fell in Korea, causing flood damage. Also, among these typhoons, the nuclear power plants was automatically shut down as typhoons Maysak and Haishen passed east of Korea [2][3][4].

Therefore, the purpose of this study is to apply the probabilistic concept to the external and internal flood risk assessment of the Nuclear power plants (NPP) site during extreme rainfall events. Also, a fragility assessment is carried out on major facilities of nuclear power plants. And the flood hazard curve and the facility's fragility curve are combined to present the probability of flooding failure of major facilities considering uncertainty.

2. Research Method

2.1. Selected of external boundary condition

Two-dimensional (2D) external flood results of the report "Flood Hazard and Fragility Analysis Resulting from External Event at Nuclear power plants (2020) [5]" were applied as the external boundary conditions for internal flood analysis. The points of the inflow boundary for the internal flood analysis according to the occurrence of an external flood event were selected as shown in Figure 1 and Table 1.

Figure 1. Inflow boundary point for internal analysis (Google map image)

Table 1. Inflow boundary point

Grid No.	Location	Condition
5274	Turbine building of NPP 2	Outside door point
6792	Turbine building of NPP 2	Outside door point
6989	Turbine building of NPP 2	Outside door point
15092	Contorl building of NPP 3	Outside door point
22821	Contorl building of NPP 4	Outside door point

2.2. Decision of flow path

Based on the walkdown, NPP design, and satellite data, the building's internal flood path route was estimated. In the case of power plants, most of them have been replaced with waterproof doors, so other flooded areas were screened out.

2.2. 2D internal flood analysis

Based on the inflow boundary conditions, a grid for 2D internal flood analysis was constructed. For an accurate and detailed analysis in the internal flood analysis, the grid size was 1 m x 1 m. In addition, in order to treat the internal structure in an independent form due to the characteristic of nuclear power plants, the rest of the parts except the door points were composed of walls. Therefore, the 2D structures of NPP 2, 3, and 4 for internal flood analysis were constructed, as shown in Figure 2. And in order to classify the analysis target area into a small flooded area, A ~ B and A ~ D areas were decided.

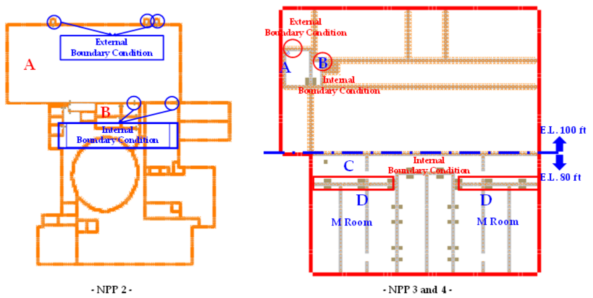

Figure 2. 2D modeling for internal flood analysis

For 2D analysis, flood analysis was performed after modeling the interior of an NPP building through a hydraulic and hydrological model and ArcGIS. Based on the results, the flood hazard curve was estimated. The 2D analysis results are presented as shown in Figures 3.

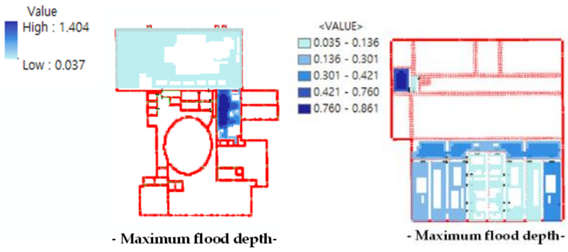

Figure 3. 2D analysis result (NPPs)

2.3. Estimated of fragility assessment for major SSC facilities

The major facilities located in the flood path were calculated. And, the fragility curve was estimated by the fragility assessment for the selected facilities.

For flooding to occur in the MCC room (D) located 80 ft underground the control building, the flood depth must exceed 0.25 m, as shown in Figure 4. Also, the MCC in area D was installed on 80 ft. Therefore, when flooding occurred in area D, it was assumed that the MCC immediately failed. Therefore, the threshold height of 0.25 m between the C and D areas was selected as the critical height, and the fragility curve was estimated through a probabilistic method as shown in Figure 5.

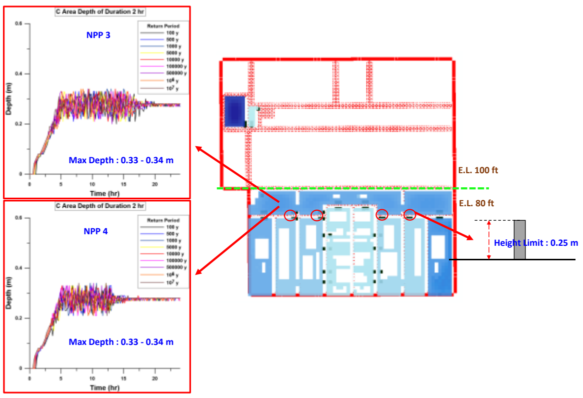

Figure 4. 2D internal flood analysis result (NPP 3 and 4)

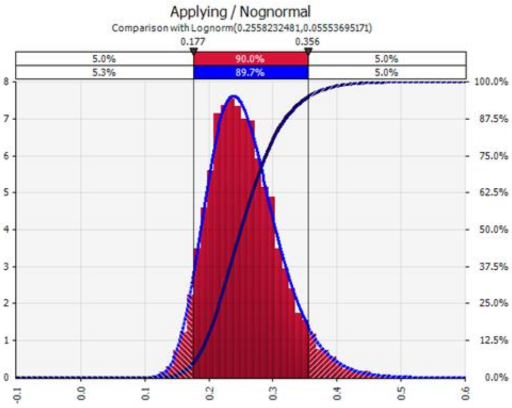

Figure 5. Fragility curve estimated for MCC

2.4. Probabilistic flood assessment by combining the hazard curve and fragility curve

We used the @RISK program [6], which allows various sampling considering uncertainty. Using @RISK, the probability of damage to the failure/non-failure of facilities vulnerable to flooding was presented through a flood assessment technique based on probabilistic analysis that combines the flooded hazard curve and the fragility curve.

As a result of probabilistic flood analysis, the probability that the depth of flooding generated exceeds the critical height was presented. That is, the probability that a flood indicator exceeding 0 in the flood assessment can occur is shown in Figures 6. It was also presented as Table 2.

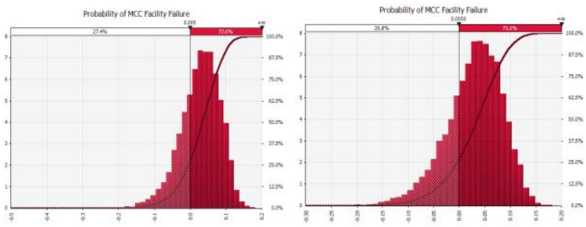

Figure 6. Probabilistic flood assessment result (NPP 3 and 4)

Table 2. Result by probabilistic flood assessment

	MCC Facility for NPP 3 (Under 80 ft)		
Flood assessment	Flood indicator = C < L	Result of flood assessment	Probability of flood
	0.02846	Failure	72.6 %
	MCC Facility for NPP 4 (Under 80 ft)		
	Flood indicator = C < L	Result of flood assessment	Probability of flood
	0.02889	Failure	73.2 %

3. Conclusions

The results of flood assessment by probabilistic flood analysis were as follows. Through the walkdown, the path of the flood propagation to the MCC area located 80 ft underground the control buildings of NPP 3 and 4 by an external flood event was identified. And as a result of 2D internal flood analysis, the inflowed flood into area C has exceeded the threshold height of 0.25 m in area D, where MCC was located. As a result, it was confirmed that the flood from area C propagated to area D, causing the MCC to flood. Then, a probabilistic flood assessment was conducted through statistical analysis by combining the flood hazard curve and the fragility curve. Based on the analyzed results, the general flood assessment and the probabilistic flood assessment were compared. As a result, the probability of MCC failure due to an internal flooding event caused by an external flooding event was analyzed as 72.6% for NPP 3 and 73.2% for NPP 4. Further research on the concept of resistance to increased MCC safety is expected through this study, applying the probabilistic flood assessment method.

4. Acknowledgments

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