Development of Tsunami PSA method for Korean NPP site

Min Kyu Kim [a*], In-Kil Choi [a] Jin-Hee Park [a]
[a] *Korea Atomic Energy Research institute, 1045 Daedeok-daero, Youseong, Daejeon, 305-353*
[*] *Corresponding author: minkyu@kaeri.re.kr*

1. Introduction

A methodology of tsunami PSA was developed in this study. A tsunami PSA consists of tsunami hazard analysis, tsunami fragility analysis and system analysis. In the case of tsunami hazard analysis, evaluation of tsunami return period is major task. For the evaluation of tsunami return period, numerical analysis and empirical method can be applied. The application of this method was applied to a nuclear power plant, Ulchin 56 NPP, which is located in the east coast of Korean peninsula. Through this study, whole tsunami PSA working procedure was established and example calculation was performed for one of real nuclear power plant in Korea.

2. Tsunami Hazard Analysis

In this study an empirical method was applied for an evaluation of tsunami hazard curve. For the regression for return period of tsunami in the east coast of Korea, power law, upper-truncated power law and exponential function were considered but, at the end, power law and general exponential function were used. The equations for power law and upper-truncated power law are shown in equation (1) and (2), respectively.

$$\dot{N}(r) = Cr^{-\alpha} \quad (1)$$
$$\dot{N}_T(r) = C(r^{-\alpha} - r_T^{-\alpha}) \quad (2)$$

For the development of tsunami catalogue, instrumental records after 1900 were considered. After 1940, there were 4 times that a tsunami occurred on the east coast of Korea. In the case of historical event, "The annals of the Chosun dynasty" referred to the evaluation of the tsunami catalogue. Through the historical records assessment, 5 tsunami events in the east coast of Korea were found. Finally, the tsunami catalogue was developed using a combination of historical and instrumental record as shown in Figure 1. This catalogue covers from 1392 to 2009, for 618 years.

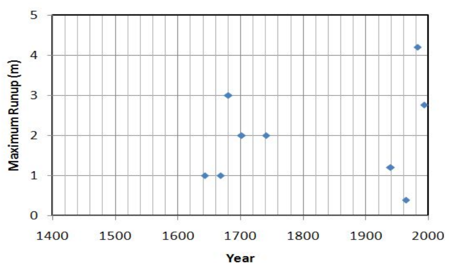
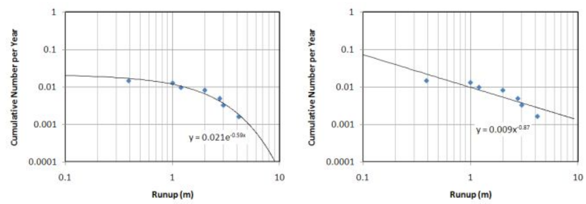


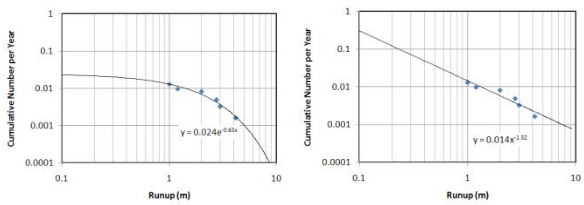
Figure 1. A tsunami catalogue of the east coast of Korea

The return period of tsunami events was determined using a power law and exponential function as shown in Figure 2. As shown in Figure 2, an exponential function matches the tsunami return period better and moreover the power law over estimated a tsunami return period overestimated. The exponential function was more appropriate for the estimation of tsunami return period.

However, as shown in the figure 2, there was only one tsunami event where maximum wave height was below 1 meter. For the decreasing of uncertainty of tsunami return period, a 1940 tsunami event where maximum wave height was recorded as 0.39m was deleted. Through this method, the tsunami return period was re-evaluated as shown in Figure 3. As shown in figure 3, the tsunami return period was decreased compared to the figure 2.



(a) Exponential function (b) Power law
Figure 2. Tsunamis return period evaluation by using empirical method



(a) Exponential function (b) Power law
Figure 3. Tsunamis return period evaluation by using empirical method in the case of exclude on 0.39m event

3. Tsunami Fragility Analysis

For a determination of hydrodynamic force, an offsite transformer assumed as a vertical wall. In this case, if the wave height reaches h_{max}, hydrodynamic force F_d actuates to a point of $h_{max}/2$. A hydrodynamic force can be determined by using equation (1) [FEMA 2008], as follows:

$$F_d = \frac{1}{2}\rho_s C_d B (hu^2)_{max} \quad (3)$$

where, ρ_s : Fluid density including sediment
C_d : drag coefficient
B : breadth of the structure
hu^2: momentum flux per unit mass

For the evaluation of tsunami fragility, functional and structural failures were considered. In the case of a functional failure, inoperability according to inundation was considered. A critical depth for inoperability of a transformer was assumed as 1m, 3m and 5m from the foundation level. In the case of a structural failure, sliding and overturning of a transformer were considered. For the evaluation of critical hydrodynamic forces for overturning and sliding, equations (4) and (5) were used, as follows:

$$F_d \cdot \frac{h_{max}}{2} > \frac{B}{2}W,\ F_{dc,overturning} = \left(\frac{B}{h_{max}}\right)W \quad (4)$$

$$F_d > F_s = \mu W,\quad F_{dc,sliding} = \mu W \quad (5)$$

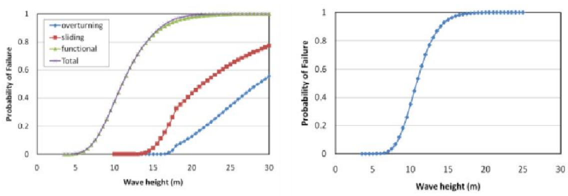
where, h_{max} is the inundation height, B is the width of the structure, μ is a friction coefficient between structure and foundation, W is the weight of the structure and, F_{dc} is the critical hydrodynamic force according to the overturning and sliding event. A probability of failure can be determined by using equation (6), as follows:

$$P_f = \Phi\left[\frac{Ln(\bar{\sigma}_R) - Ln(\bar{\sigma}_U)}{\sqrt{\beta_R^2 + \beta_U^2}}\right] \quad (6)$$

where,

$\bar{\sigma}_R$: average of response
$\bar{\sigma}_C$: average of capacity
β_R : uncertainty of response
β_U : uncertainty of capacity

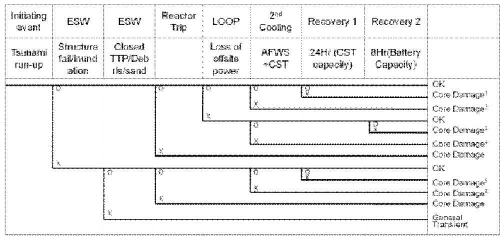
A functional failure and two kinds of structural failure were considered for fragility evaluation. For the evaluation of a total failure probability, a fault tree was used. Finally, the fragility results for an offsite transformer are presented in Figure 4 according to the failure criteria of functional failure. As shown in Figure 4, a functional failure governed the total failure probability. The failure probability of the ESWS system is shown in Figure 10. A functional failure caused by debris was not considered in this study.



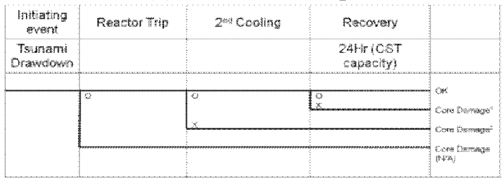
(a) (b)
Fig. 4 Fragility result in the case of a tsunami event
(a) a transformer (functional failure criteria : 1m)
(b) ESW system

4. System analysis and CDF assessment

The accident scenarios were considered as a tsunami run-up and a tsunami draw-down. The accident scenarios caused by a tsunami run-up and draw down are summarized in Figure 5 according to the initiating events.



(a) Tsunami run-up



(b) Tsunami drawdown
Fig. 5. Accident scenario in an NPP in the case of tsunami event

Using tsunami hazard analysis results, tsunami fragility analysis results and accident scenario analysis, core damage frequency for Ulchin 56 NPP site was evaluated. But this core damage frequency analysis results does not have much meaningfulness because of there are many assumptions during this research. But core damage frequency assessment in this study means showing an applicability of tsunami PSA. For the calculation of tsunami induced CDF, the PRASSE code was used [Choi, et al., 2010]. A total tsunami induced CDF was calculated as 3.92E-05.

5. Conclusions

For the safety evaluation of an NPP in anticipation of a tsunami event, a probabilistic safety assessment (PSA) method was applied. A tsunami hazard analysis for determining a return period of tsunami run-up height was performed by using an empirical method. A procedure for a tsunami fragility methodology was established, and target equipment and structures for the investigation of tsunami fragility assessment were selected. Accident scenarios of a tsunami run-up and drawdown were presented and finally core damage frequency (CDF) caused by tsunami event was determined.

ACKNOWLEDGEMENT

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