Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2009

A Tsunami Fragility Assessment for Nuclear Power Plants in Korea

Min Kyu Kim [a*], In-Kil Choi [a] Keum-Seok Kang [b]
[a] *Korea Atomic Energy Research institute, 1045 Daedeok-daero, Youseong, Daejeon, 305-353*
[b] *Korea Electric Power Research Institute, 103-16 Munji-Dong, Yuseong-Gu, Daejeon, 305-380*
[*] *Corresponding author: minkyu@kaeri.re.kr*

1. Introduction

Although Tsunami events were defined as an external event in 'PRA Procedure Guide (NUREG/CR-2300)'after 1982, a Tsunami event was not considered in a design and construction of NPP before the Sumatra earthquake in 2004. But the Madras Atomic Power Station, a commercial nuclear power plant owned and operated by the Nuclear Power Corporation of India Limited (NPCIL), and located near Chennai, India, was affected by the tsunami generated by the 2004 Sumatra earthquake (USNRC 2008). The condenser cooling pumps of Unit 2 of the installation were affected due to flooding of the pump house and subsequent submergence of the seawater pumps by tsunami waves. The turbine was tripped and the reactor shut down. The unit was brought to a cold-shutdown state, and the shutdown-cooling systems were reported as operating safely. After this event, Tsunami hazards were considered as one of the major natural disasters which can affect the safety of Nuclear Power Plants. The IAEA performed an Extrabudgetary project for Tsunami Hazard Assessment and finally an International Seismic Safety Center (ISSC) established in IAEA for protection from natural disasters like earthquake, tsunami etc.

For this reason, a tsunami hazard assessment method determined in this study. At first, a procedure for tsunami hazard assessment method was established, and second target equipments and structures for investigation of Tsunami Hazard assessment were selected. Finally, a sample fragility calculation was performed for one of equipment in Nuclear Power Plant.

2. Overview of Tsunami Fragility

The procedure of tsunami PSA methodology summarized as below figure 1.

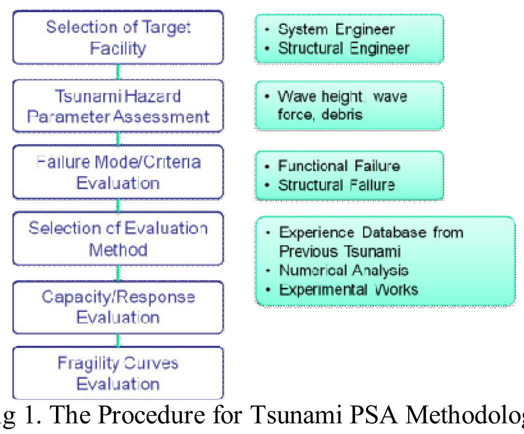

Fig 1. The Procedure for Tsunami PSA Methodology

As shown in the Figure 1, the basic procedure of Tsunami PSA method is almost same as a Seismic PSA method. However a considering parameters for hazard assessment are changed as wave height, wave force and debris.

3. Selection of Target Equipments and Structures

For the performing a Tsunami Hazard assessment, target equipments and structures in NPP are selected and determined failure mode for each equipments and structures. During this work, structural engineer and system engineer also participate. A functional failure and structural failure also considered. For the selection of target facilities, several workdowns performed about target Nuclear Power Plants.

Table 1. Selection of Target Facilities and Failure Modes

Facilities		Failure Mode	Detail	Response Parameter
Out-door	Seawater intake system	Functional failure	Function loss of seawater pump by inundation	Wave height
			Loss of cooling water by backwash	Wave height
			Closed intake by sand moving and fishing net	
		Structural Failure	Damage of intake structure by wave force or debris	Wave force
	Offsite Power	Functional Failure	Loss of transmission function by inundation	Wave height
		Structural Failure	Overturning/sliding failure according to wave force	Wave force
In-door	Core cooling system	Functional failure	Loss of core cooling function and heat removal function by building inundation	Opening height of building

3. Sample Calculation

For the calculation of tsunami-induced fragility, an offsite transformer was selected. Actually, an offsite transformer is not a safety class level equipment but failure of offsite transformer can make loop event of NPP. For a determination of hydrodynamic force, an offsite transformer assumed as vertical wall as show in figure 2. In this case, if the wave height reached h_{max}, hydrodynamic force F_d actuate to a point of $h_{max}/2$. A hydrodynamic force can be determined using equation (1) (FEMA 2008).

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

where,

ρ_s : Fluid density including sediment

C_d : drag coefficient

B : breadth of the structure
hu^2 : momentum flux per unit mass

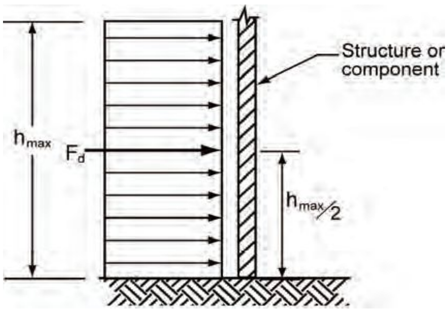

Fig 2. Definition of Hydrodynamic Force

The momentum flux of equation (1) can be estimated using equation (2).

$$(hu^2)_{max} = gR^2\left(0.125 - 0.235\frac{z}{R} + 0.11\left(\frac{z}{R}\right)^2\right) \quad (2)$$

where,
g : acceleration due to gravity
z : ground elevation at the base of the structure
R : design run-up elevation

For the evaluation of Tsunami fragility, functional and structural failure considered. In the case of functional failure, inoperability according to inundation considered. A critical depth for inoperability of transformer assumed as 1m from a foundation level. In the case of structural failure, sliding and overturning of transformer considered. For the evaluation of critical hydrodynamic forces for overturning and sliding, equation (3) and (4) used, relatively.

$$F_d \bullet \frac{H}{2} > \frac{B}{2}W,\ F_{dc} = \left(\frac{B}{H}\right)W \quad (3)$$

$$F_d > F_s = \mu W,\ F_{dc} = \mu W \quad (4)$$

where, H is a inundation height, B is a width of the structure, W is a weight of the structure and F_{dc} is a critical hydrodynamic force according to the overturning and sliding event.

A probability of failure can be determined using an equation (5).

$$P_f = P(failure|PGA = A_i) = \Phi\left[\frac{Ln(\bar{\sigma}_R) - Ln(\bar{\sigma}_U)}{\sqrt{\beta_R^2 + \beta_U^2}}\right] \quad (5)$$

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

As mentioned before, functional failure and two kinds of structural failure were considered for fragility evaluation. For the evaluation of total failure probability, fault tree used as shown in Figure 3. Finally, the fragility results for offsite transformer presented in Figure 4. As shown in Figure 4, a functional failure governed the total failure probability. It can be concluded that a functional failure is the most vulnerable in the case of Tsunami induced fragility for offsite transformer.

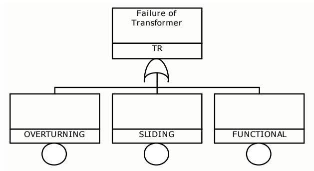

Fig 3. Fault for Evaluation of Failure of Transformer

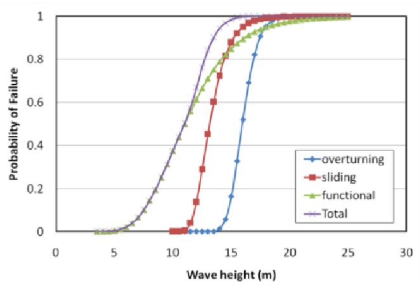

Fig 4. A Fragility Result of Transformer in the case of Tsunami Event

5. Conclusions

A tsunami fragility assessment method for offsite transformer in NPP sites was presented in this study. A procedure for tsunami hazard assessment method established, and target equipments and structures for investigation of Tsunami Hazard assessment were selected including failure modes. Finally, sample fragility calculations performed for one of equipment in Nuclear Power Plant.

ACKNOWLEDGEMENT

This work grant from the Korea hydro & Nuclear Power Co. Ltd., Korea, for the Nuclear Research & Development Program is gratefully acknowledged. This work was also supported by Nuclear Research & Development Program of the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korean government (MEST).

REFERENCES

[1] ANS and IEEE, PRA Procedure Guide-A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants, US NRC, NUREG/CR-2300, 1982.
[2] USNRC, Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America, NUREG/CR-6966, PNNL-17397, 2008.
[3] FEMA P646, Guidelines for Design of Structures for Vertical Evacuation from Tsunami, 2008