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Wind-borne Missile Fragility Assessment for Nuclear Power Plant Equipment to External Hazard due to High-wind

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1. Introduction

The Fukushima nuclear power plant accident that occurred in 2011 was an accident caused by an extreme/combined external hazard caused by the Tohoku earthquake and tsunami. After this accident, ensuring the safety of nuclear power plants against extreme external and combined hazards became an issue around the world, and one of the representative hazards is external hazard caused by strong winds. Because it is not possible to screen out all high wind events using the screening criteria included in ASME/AND PRA std. [1], a probabilistic high wind safety assessment may need to be performed for specific power plants structure, system, and component (SSC) [2]. Unlike seismic events, where probabilistic safety evaluation procedures for nuclear power plants are relatively well established, such procedures have not yet been systematically established for other external hazards such as high winds. In this study, we discuss the fragility assessment of nuclear power plant equipment against wind-borne missile caused by strong winds as part of the high-wind probabilistic risk assessment (HW PRA) procedure.

2. Methods and Results

HW PRA has a fundamentally similar procedure to seismic probabilistic risk assessment (SPRA), and the basic elements to perform them are as follows [2].

- High wind hazard analysis
- High wind fragility analysis
- High wind plant response model

HW PRA includes high wind hazard analysis to determine annual exceedance probability and frequency for various wind speeds, high wind fragility assessment to determine failure probability for high winds and wind-borne missile, and development of a PRA model that includes the combination of hazard and fragility.

2.1 High-wind Fragility Model

The high-wind fragility can be defined as the conditional probability of failure of a target SSC with respect to a damage parameter (such as wind speed) in a procedure similar to seismic PRA. The high-wind fragility curve of SSC can be defined as a lognormal distribution function as follows.

$$f = \Phi\left(\frac{ln\left(\frac{v}{v_m}\right) + \beta_u \Phi^{-1}(Q)}{\beta_r}\right)$$

where, Φ is the Gaussian cumulative distribution function, v is the variable related to the high wind, v_m is the median capacity against high, β_r is the randomness, β_u is the uncertainty, and Q is the confidence level. It can be defined in the same form as the seismic fragility curve, as shown in Fig. 1.

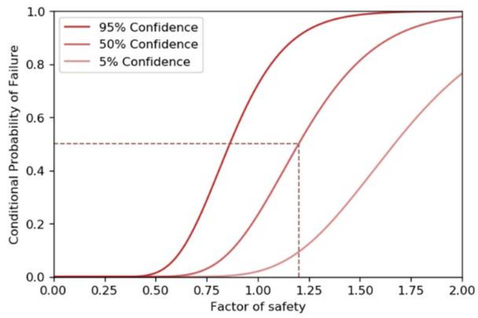

Fig. 1. Example of high wind fragility curve

2.2 Missile Impact Hazard

In order to perform a fragility assessment against wind-borne missile collisions, a missile impact hazard assessment need to be conducted separately from the high wind hazard assessment. Even if a hazard analysis has been performed to determine the annual exceedance frequency for various wind velocity, the probability of missile hitting the target SSC at a specific wind speed may vary for each NPP, structure, and equipment. Even under the same wind velocity conditions, the probability of missiles colliding can be evaluated differently depending on the location of the NPP, surrounding terrain and features, geometry and layout of internal structures, exposed area, etc. This probability is derived through a missile impact hazard analysis.

Therefore, the probability of a wind-borne missile impact on an SSC is determined by the wind velocity, the surface area of the target, and the quantity and type of missiles. The final wind-borne missile fragility can be derived by assessing the conditional probability of failure of the target after missile impact. The U.S. EPRI provides an expression for the probability of collision as follows [3].

$$\text{Target hit probability} = \Psi \times SA_T \times N$$

where Ψ is the normalized impact probability, SA_T is the exposed area of the target, and N is the number of missiles.

2.3 Wind-borne Missile Fragility

Wind-borne missile collision fragility analysis evaluates the conditional probability of failure after the missile collide with the target SSC. From a conservative perspective, equipment exposed to the outside or vulnerable structures not designed to resist high-wind can be assumed to be damaged with a conditional probability of 1.0 [3]. However, for robust tanks made of steel plates, for example, it may be necessary to evaluate the conditional probability of damage following a collision.

In this study, a condensate storage tank (CST) located outside the structure is selected for the fragility assessment to high wind induced missile, and the 6-inch pipe is determined as potential missile by referring to the Shin Kori Units 1 and 2 Final Safety Analysis Report (for public use) [3]. The equipment response to missile impact is derived by evaluating the impact load using LS-DYNA, a commercial finite element software.

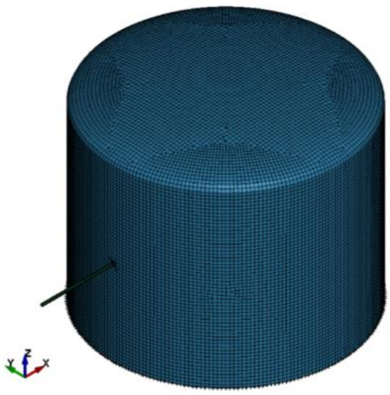

Fig. 2. Numerical model of CST for wind-borne missile impact

Penetration caused by flying objects was selected as the main failure mode, and impact analysis is performed to derive the limit state and safety factor based on the effective stress at the impact location and the strength of the material. CST, the target of wind-borne missile collision, is composed of shell elements, and the Plastic_kinematic material model is used. It is conservatively assumed that the wind-borne missile is composed of solid elements and had no deformation with rigid material model.

Variability for deriving fragility curve is divided into randomness and uncertainty. Randomness is derived through parameter analysis according to collision angle and collision location. Material strength and modeling uncertainty are based on values used for the seismic fragility assessment [4].

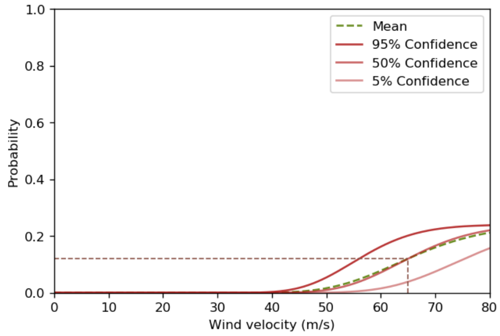

Fig. 3. Fragility curve of CST against wind-borne missile

The fragility curve of wind-borne missile for the CST is shown in Fig 3. The missile impact frequency is determined to be 0.24 under conservative assumptions, with a median capacity against missile (v_m) of 64.98 m/s, randomness (β_r) of 0.15, and uncertainty (β_u) of 0.09.

3. Conclusions

In this study, as one of the elements for HW PRA, fragility assessment of CST to wind-borne missile is performed. The variability of the fragility curve is derived by parametric analysis using numerical simulation and referring the values utilized in existing seismic fragility assessments. In addition, the safety factor is evaluated through numerical analysis to derive the median capacity of CST. The results are evaluated under conservative assumptions and found to have sufficient performance against wind-borne missile. The results of this study can be applied to the HW PRA of NPPs in combination with the results of hazard assessments.

ACKNOWLEDGEMENT

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REFERENCES

[1] ASME/ANS, 2009. Addenda to ASME/ANS RA-S-2008 – Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications. ASME/ANS RA-Sa-2009.
[2] EPRI, 2015, High Wind Risk Assessment Guidelines, TR-3002003107, Electric Power Research Institute.
[3] KHNP, 2018, Shin Kori Units 1 and 2 Final Safety Analysis Report (for public use).