The Final Seismic PSA for Post-Irradiation Examination Facility (PIEF)

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1. Introduction

According to the requirements of the Citizen Verification Team (2018.3 ~ 2019.4), a research project was launched in 2019 to prove that the operating research facilities are fully satisfied with the domestic nuclear safety goals (e.g., less than 0.1% of individual risks) through the risk profile assessment of the research site. Generally speaking, a seismic event is the most important contributor for the site risk assessment.

This study focuses on the final seismic probabilistic safety assessment (PSA) for Post Irradiation Examination Facility (PIEF) in the research site, which is the only research facility for inspections and examination of the commercial spent fuels in the country.

2. Model and Quantification for PIEF Seismic PSA

According to EPRI procedure [1], a seismic PSA consists of four steps; 1) seismic hazard analysis, 2) seismic fragility analysis, 3) system analysis (event tree and fault tree analysis), and 4) core damage frequency (CDF) quantification.

2.1 Seismic Hazard Analysis

The seismic event frequency for a specific peak ground acceleration(PGA) are obtained from a seismic hazard curve, which presents the annual exceedance frequency for a selected PGA value. A site-specific seismic hazard curve was developed for KAERI site as shown in Fig. 1 [2].

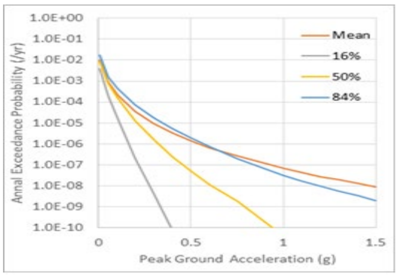

Fig. 1. Seismic hazard curve for KAERI site

As the results of the sensitivity study on the number of bins, the most appropriate number of bins is determined to be three for the PIEF seismic PSA. The final binning information and the corresponding seismic event frequencies are summarized in Table 1.

Table 1. Seismic event frequency for each bin

Case	Range (PGA)	Representative PGA	IE. Freq
Bin 1	0.1-0.3	0.173	2.20E-04
Bin 2	0.3-0.5	0.387	8.20E-06
Bin 3	0.5-1.0	0.707	1.36E-06

2.2 PIEF Seismic Fragility Analysis

The seismic fragility analysis for PIEF is conducted by a hybrid approach (Fig. 2) due to the limitations of the detailed structure design information. Hybrid approach is based on a conservative deterministic failure margin (CDFM) method.

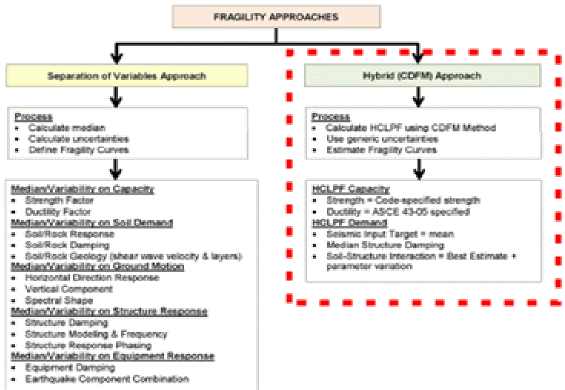

Fig. 2. Seismic hazard curve for KAERI site

The structure elements that can affect the spent fuel storage pool (SFP; #9402) by a seismic event are slabs and walls as shown in the Fig. 3 & 4.

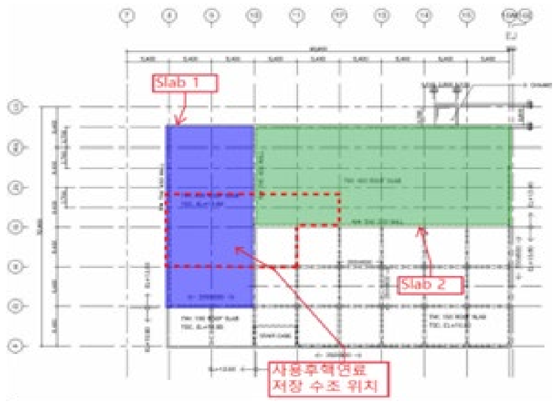

Fig. 3. Structure elements to affect SFP (Slabs)

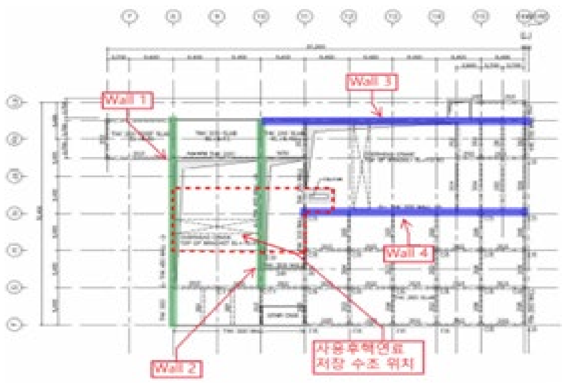

Fig. 4. Structure elements to affect SFP (Walls)

Fragility is defined as conditional failure probabilities for a given PGA level, that is expressed as the formula below, where ф is the standard Gaussian cumulative distribution function.

$$f' = P(A < a) \quad , (\text{Capacity} < \text{Response})$$
$$f' = \phi\left(\frac{\ln\left(\frac{a}{A_m}\right)+\beta_U \phi^{-1}(Q)}{\beta_R}\right) \text{ with Q uncertainty level, or}$$
$$f' = \phi\left(\frac{\ln\left(\frac{a}{A_m}\right)}{\beta_C}\right), \text{ with composite uncertainty } \beta_C = (\beta_R{}^2 + \beta_U{}^2)^{1/2} \qquad (1)$$

The seismic fragility of the PIEF structure elements are evaluated as shown in Table 2 [3, 4, 5]. The most vulnerable structural elements for wall and slab are found be Wall 3 and Slab 2, respectively. Wall 3 is selected as the structural element with the greatest impact in the spent fuel storage (#9402), considering on the location and strength of the structure.

Table 2: Results for PIEF fragility analysis

Element	Am	Br	Bu	HCLPF
Wall 1(western-side)	0.695g	0.24	0.26	0.304g
Wall 3(north-side)	0.53g	0.24	0.26	0.23g
Slab 2	1.26g	0.24	0.26	0.55g

Note that the results of fragility analysis are estimated conservatively due to use of generic ground response spectrum with even more conservatism (NH84.1 in Fig. 5), instead of site-specific uniform hazard response spectrum (UHRS) as shown in Fig. 5.

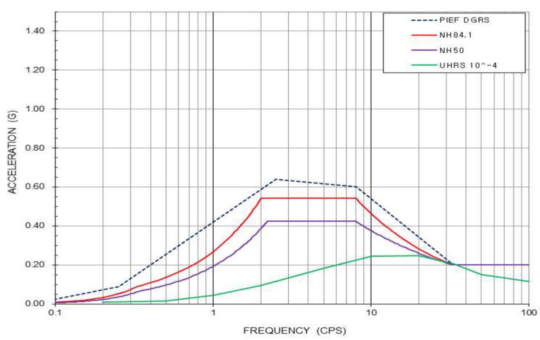

Fig.5. Comparison on GRS and site-specific UHRS

2.3 System Analysis

The key assumptions and rules (KAG) for seismic event tree (Fig. 6) are as follows.

- ✓ Basic accident scenario: earthquake occurrence → structural collapse → physical damage to spent fuel in SFP #9402 due to falling objects.
- ✓ Assume a building collapse due to the collapse of the western outer wall (Wall 1) (North-side wall (Wall 3) is identified as the most vulnerable structural element, is excluded due to its less impact on the SFP #9402).
- ✓ Exclude the possibility of damage to the SFP #9402 due to structural collapse or significant leakage from SFP (because SFP #9402 id installed on a rock bed, is a triple concrete structure (at least 1m thick) and sufficiently meets the protection requirements (~ 46cm) for the effects of tornado missiles defined by the standard review plan (SRP))

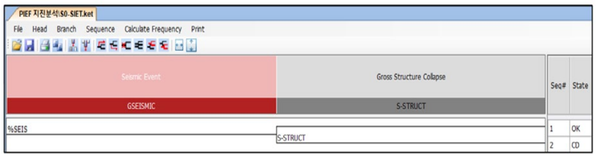

Fig.6. Seismic event tree for PIEF

The conservatism of the seismic PSA model is sufficient guaranteed for the following reasons.

- ✓ If spent fuel in the SFP is exposed to the air despite excluding the possibility of damage to the SFP or leakage from SFP due to structural collapse, air temperature will remain at a certain level after structural collapse by earthquake, so cladding oxidation(565℃) of spent fuel exposed to the air will not occur for the spent fuel cooled for more than 15 months, because of the low decay heat [6, 7, 8].
- ✓ The failure mode of spent fuel in the storage rack (4m x 1m; 2rows of 10 each) installed in the SFP #9402 (3m x 6.5m x 10m) is one-way fall above the design earthquake, but a complete fall is impossible due to the structure of the SFP and there is little displacement due to the drag for the SFP water
- ✓ The size of structural debris that can enter the SFP #9402 is limited and the kinetic energy of the drop objects is likely not to cause physical damage to spent fuel stored in the storage rack due to the drag force of the SFP water.

2.4 Quantification

As shown in seismic event tree (Fig.6), a seismic PSA for PIEF is conservatively quantified with an assumption that PIEF building collapse due to an earthquake leads to spent fuel damage in the pool of PIEF directly. In other words, the spent fuel damage frequency (FDF) in the pool of PIEF due to seismic event is simply quantified by the multiplication of the seismic event frequency and the corresponding PIEF building collapse probability. The seismic FDF is estimated as 1.12e-6/year. As mentioned before, note that it is the result based on the very conservative assumptions and ground-rules.

Table 3. Results of seismic FDF quantification

Case	Range (PGA)	IE. Frequency	Failure Probability	Damage Frequency (/yr)
Bin 1	0.1-0.3	2.20E-04	4.24E-05	9.33E-09
Bin 2	0.3-0.5	8.20E-06	4.90E-02	4.02E-07
Bin 3	0.5-1.0	1.36E-06	5.19E-01	7.06E-07
Total				1.12E-06

3. Summary and Conclusion

The seismic level 1 PSA was performed on Post Irradiation Examination Facility (PIEF). In the study, the damage frequency of spent fuels in the pool of PIEF due to seismic event is simply evaluated as 1.12e-6/year by the multiplication of the seismic event frequency and the corresponding PIEF building collapse probability. However, note that it is close to the bounding analysis for PIEF seismic PSA due to very conservative assumptions and ground-rules.

Acknowledgements

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