Sensitivity analysis of structural characteristic parameters for the spent fuel storage pool seismic analysis

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1. Introduction

Since the Fukushima accident, the importance of the evaluation of spent fuel assembly (FA) stored in the spent fuel storage rack (SFSR) has been increasing. For this reason, the evaluation of FA stored in SFSR under seismic loading condition is required by U. S. Nuclear Regulatory Commission (U.S. NRC) Standard Review Plan (SRP) 3.8.4 Other Seismic Category I Structures, Appendix D Rev. 4[1] which was revised in 2013. According to revision of regulatory document, the structural integrity assessment of FA and SFSR under Safety Shutdown Earthquake (SSE) should be performed. Also, the effect of the-end-of-life (EOL) condition on the evaluation of the fuel assembly for the SFSR should be considered.

To determine the impact of the major parameters on the evaluation results, sensitivity analysis of structural characteristic parameters was performed in this paper. In order to improve computational efficiency and numerical stability, Whole-Pool-Multi-Rack Model (WPMR) was used in the FE analysis. WPMR model consists of simplified FA and simplified SFSR model as beam element. Also, WPMR model can take into effect of contact between storage rack and nearby storage rack, hydrodynamic mass, buoyancy and friction. The parameters considered in the sensitivity analysis are fuel gap size, fuel one-sided stiffness effect and fuel assemble EI.

2. FE model

Figure 1(a) shows the simplified SFSR model. As mentioned before, the simplified model is composed of 3-D elastic beam element (ANSYS BEAM4) and lumped mass element (ANSYS MASS4) with properties derived from the dynamic characteristics (natural frequency and mode shapes) of the detailed SFSR model as described in Fig. 1(b). To consider the interaction among the multiple SFSRs, the WPMR model which is composed of a simplified model for individual SFSRs was used, as shown in Fig. 2. Figure 1 (a) represents five nodes representing masses of fuel and rack cells and contact elements, Contact elements are used to simulate the rack sliding and impact. Detail structural properties for fuel racks are obtained from Ref. [2].

Artificial acceleration time history for three orthogonal directions developed while carrying out APR1400 NRC-DC project [3] was used in this study.

To analyze the effect on the sensitivity variable, FE analysis were performed for the value corresponding the ±20% of the reference value. Analysis of gap size effect is important as the size of the FA cell increases under the EOL condition.

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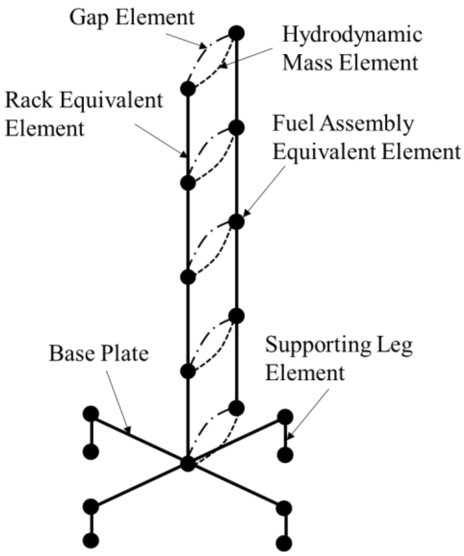
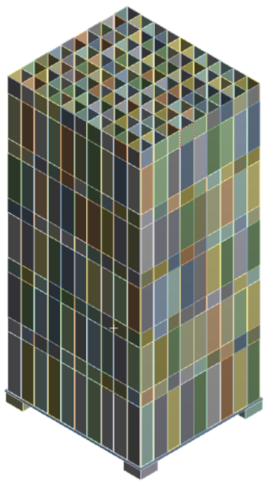


(a)



(b)

Fig.1 FE model of spent fuel storage rack
(a) Simplified model (b) Detailed model

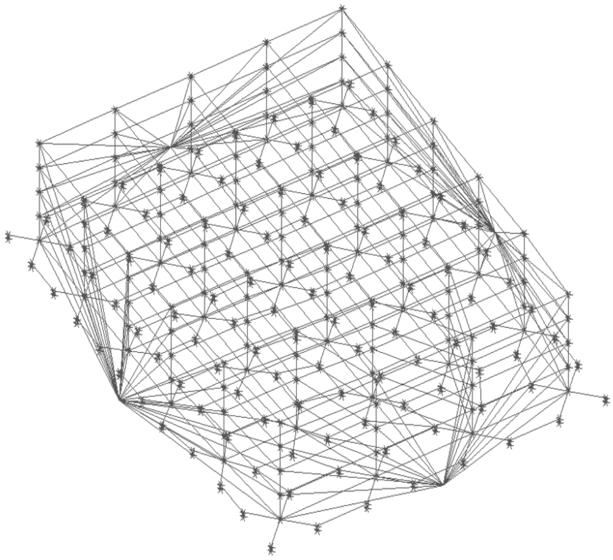


Fig.2 FE model for Whole-Pool-Multi-Rack

Table 1 Assessment results for gap size effect (Normalized results)

	-20%	Base	20%
Damage of fuel rod	0.879	1.000	1.103
Cooling performance degradation	0.883	1.000	1.112

3. Structural integrity assessment

Stress evaluation of the FA and SFSR was performed under the Level D based on the ASME Sec. III Div. 1, Subsection NF-3300 [4] as described in the SRP 3.8.4 Rev 4. The stress assessment was carried out for male, female, cell section and thread of SFSR. In the addition, the fuel rod damage assessment, cooling function assessment and dynamic evaluation (such as sliding, overturning and buckling) of the SFSR were calculated. The detailed evaluation process is described in the Ref. [5].

4. Results

According to the assessment results, all three variables have no significant impact on several evaluation items, such as stress evaluation, weld evaluation, sliding, overturning and buckling. In addition, increased fuel one-sided stiffness is shown to degrade cooling performance. When the gap size increased, the fuel rod damage and cooling performance is degraded. The related results are shown in Table 1.

5. Conclusion

In this paper, the effects of three structural parameters on seismic analysis of the spent fuel pool was analyzed. According to the analysis results, the gap size effect among the parameters has significant impact on structural integrity assessment. So, it can be seen that seismic evaluation under EOL conditions with the large gap size should be considered important.

References

[1] U.S. Nuclear Regulatory Commission, Standard Review Plane, Sections 3.8.4, Rev. 4, 2013.

[2] KHNP, Methodology for the Development a Model for the Fuel Storage Rack Seismic Analysis, 2018-50003339-0540TM, 2018.

[3] KHNP, Mechanical Analysis for New and Spent Fuel Storage Racks", APR1400-H-N-NR -14012-P, Rev. 3, 2017.

[4] ASME Boiler and Pressure Vessel Code Section III, Division 1, Subsection NF Component Support, 2013 edition.

[5] KHNP, Method to Evaluate the Structural Integrity of a Spent Fuel Rack and a Fuel Assembly under the Seismic Load, 2018-50003339-0541TM, 2018.