Non-Linear Structural Analysis of Reactor Cavity Permanent Pool Seal Assembly

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1. Introduction

The Reactor Cavity Permanent Pool Seal Assembly (PPSA) is the structure to seal the annulus gap between the reactor vessel flange and the refueling pool floor for refueling water. It is classified as non-nuclear safety and seismic category II. The PPSA for Shin-kori Nuclear Power Plant Units 1 and 2 (SKN 1 & 2) consists of a seal plate, flexible seal plates, supports, plug hole covers and access hole covers. Each flexible seal plate, L-shaped and the C-shaped, is welded to the refueling pool embedment and the seal ledge of the reactor vessel flange, respectively. Therefore, the thermal load from the reactor vessel flange during plant power operation and the seismic load are applied to the PPSA. The supports of the PPSA withstand the loads resulting from the water head that is the full depth of the refueling cavity from the elevation of operating floor. In this paper, non-linear properties of the PPSA, which were considered in the structural analysis, are presented and the results of the non-linear structural analyses are discussed.

2. Non-linear properties and Analysis

In this section, some of the non-linear properties of the PPSA and the brief descriptions of the analysis model were presented, and the structural analysis results were also described.

2.1 Non-linear properties

The PPSA undergoes thermal load due to the temperature difference between the reactor vessel flange and the refueling pool, and the loads due to the displacement of the reactor vessel flange relative to the refueling pool floor in the vertical, the radial and the translational directions in the case of the heat-up and cool-down of the reactor vessel. The seismic loads were also considered in the analysis. It was shown that the stress level under those loads exceeded material yield stress of the PPSA[1, 2]. To calculate actual stress level and deformed shape, elasto-plastic analysis using the material properties (stress-strain curve) was performed. The non-linear elements (contact elements) for the flexible seal plates and the supports were also used in structural analysis model.

2.2 Analysis Model

The shape of the installed PPSA for SKN 1 & 2 is shown in Fig. 1.

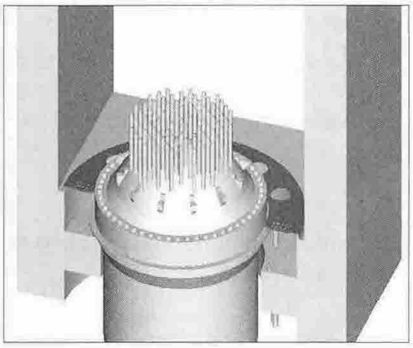

Fig. 1 Installed PPSA

The thermal and the hydro-pressure loads are axisymmetric, but the seismic load is line symmetric. Therefore, the 3-D finite element model for the half of the PPSA was developed for the structural analysis by using ANSYS code[3]. The plastic shell element was used for modeling the PPSA as shown in Fig.2.

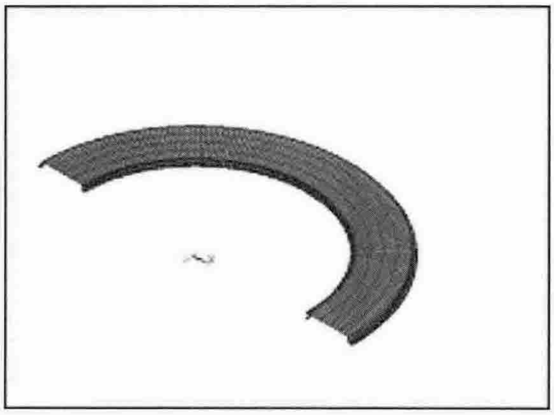

Fig. 2 FE Model of the PPSA

The edges of the flexible seal plates were connected to the seal plate, the reactor vessel seal ledge and the embedment. The top of the support was also connected to the seal plate. All degrees of freedom of nodes, which correspond to the points connected to the reactor vessel seal ledge and the embedment, were constrained. The symmetric boundary conditions were applied to the nodes on the symmetric face. The stress-strain curve, which was gained from experimental test results, and contact elements were incorporated in the analysis model.

2.3 Analysis Results

The non-linear structural analyses were preformed for the thermal load, the hydro-pressure load and the safe shutdown earthquake (SSE) load. As a result of the analyses, the maximum equivalent stress, which was shown in Fig. 3, was happened at the flexible seal plate under the load combination of deadweight plus hydro-pressure plus SSE. This stress was lower than the ultimate tensile strength for the PPSA material [4]. Therefore, no failure for the PPSA was anticipated. Table 1 shows the ratios of the maximum equivalent stress to the ultimate tensile strength for each load combination.

Table 1. The ratios of the maximum equivalent stress to the ultimate tensile strength

Operating Condition	Load Combination	Ratio (%)
Power Operation	DW + Thermal Load	45
Refueling	DW + Hydro-pressure	35
	DW + Hydro-pressure + SSE	48

For the seismic load case, which was applied at the x-direction in Fig. 2, the high stresses were occurred at the elements which were placed at the perpendicular to the applied seismic input direction. That means that the seismic load is mainly applied to the PPSA as shear force and high stress occurs by shear stress.

3. Conclusion

The finite element model considering the non-linear properties of the PPSA for SKN 1 & 2 were developed, and structural analyses were performed by using ANSYS code. From the analysis results, the structural integrity of the PPSA was verified by checking the maximum equivalent stress and the highest stress points. The model developed considering the non-linear properties in this paper can be useful for analyzing the PPSA.

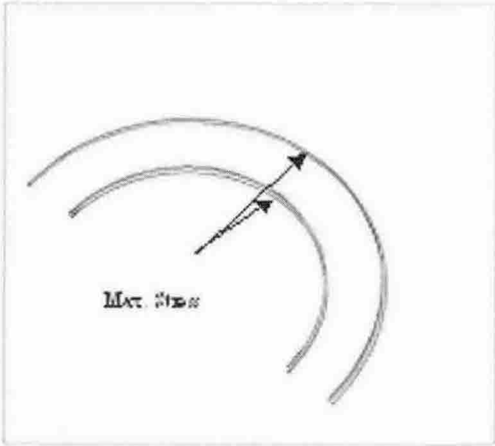

Fig. 3 Maximum Equivalent Stress Points of the PPSA

REFERENCES

[1] M. G. Kim, I. Y. Kim, B. S. Kim, "Development of Permanent Reactor Cavity Pool Seal Using Optimal Design Technique", Transactions of the 15th International Conference on SMiRT, 1999.

[2] M. G. Kim, C. S. Maeng, B. S. Kim, J. K. Hwang, I. Y. Kim, "Development of Improved Reactor Cavity Permanent Pool Seal Assembly", Proceedings of the Korea Nuclear Society Meeting, Seoul, Korea, October 2001.

[3] ANSYS User's Manual for Revision 7.1, ANSYS, Inc., 2003.

[4] ASME Boiler and Pressure Vessel Code, Section II, Materials, Part D, 1998 Edition.