Evaluation of weak area in reinforcement concrete walls of containment building by over-pressure analysis

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1. Introduction

In Korean nuclear power plants, the design pressure of containment buildings is determined based on the internal pressure that occurred during a Loss-of-Coolant Accident (LOCA), and prestress is applied through the tendon system to maintain the structural integrity of the containment buildings in the event of an accident. Recent inspections of operational containment building walls in South Korea have uncovered issues such as corrosion of liner plates and the formation of concrete voids, which could serve as leakage pathways in the event of a severe accident. The simultaneous increase in pressure and temperature inside the containment building can cause cylindrical containment buildings to bulge, resulting in radial displacement and tensile stress. If the internal pressure increases uncontrollably, it can cause cracks in the concrete. These cracks can lead to stress concentration at the weak points in the stress field, ultimately resulting in the liner plates' yielding and tearing[1]. Therefore, a realistic evaluation of the containment building's wall damage, actual structural performance, destruction mechanisms, vulnerable areas, destruction criteria, and leakage is necessary. This requires predicting cracks in concrete walls due to internal pressure and evaluating the resulting leakage of radioactive materials. When the steel's strain reaches the limit state criteria presented in RG 1.216, extensive tensile cracks in the concrete located behind can be anticipated.

However, analyzing cracks for the entire wall surface is physically time-consuming, and performing a crack analysis for the entire large-scale containment building is impossible. Therefore, to reduce the time and errors in the analysis process, it is necessary to develop post-processing that can evaluate cracks in particular walls by deriving the cross-sectional force of the wall, which requires a crack review first using the existing internal pressure analysis results. Additionally, localized modeling that reflects the detailed connection design between concrete and liner plates of vulnerable walls is required.

In this study, a three-dimensional finite element analysis model was constructed to evaluate the overall behavior and limit state of the APR1400 containment building under design-exceeding internal pressure. Utilizing the internal pressure analysis results, vulnerable areas within the containment building were identified, and localized modeling was conducted for crack analysis and leakage evaluation of the wall concrete. Subsequently, a method was presented to determine the boundary conditions of the local model and evaluate the localized response using the FEA results of the Global model.

2. Evaluation of weak area in PCCV

2.1 Internal Pressure Analysis of Global FEM

A nonlinear finite element analysis model was developed for the APR1400 containment building. Concrete was modeled using solid elements, while reinforcement and tendons were represented as truss elements. The Concrete Damaged Plasticity (CDP) model examined concrete damage. The performance evaluation for the design overpressure was conducted by applying uniform pressure loads to the interior wall elements of the containment building. Figure 1 presents the analysis results, showing the strain in the liner plates at five locations within the containment building under increasing internal pressure. A rapid increase in strain was observed in the liner plate surrounding the equipment hatch (red line).

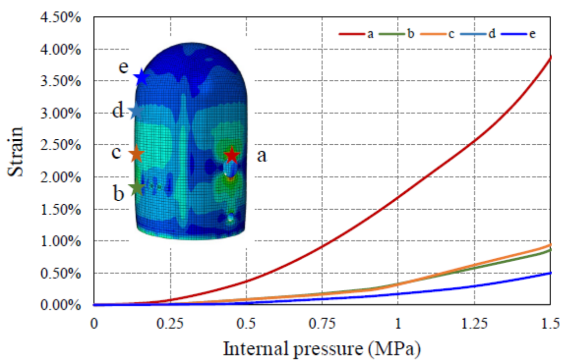

Fig. 1. Liner plate strain value under internal pressure

2.2 Determination of Weak Wall

The KINS/RG-N04.32 standard[2] specifies that the strain limit state criteria for the design overpressure of containment buildings cannot be applied to large bolted closures. Consequently, the ultimate internal pressure capacity of penetrations, such as equipment and personnel entry points, must be assessed separately. Based on this guidance, this study has selected vulnerable walls within the APR1400 containment building's finite element analysis model, following the analysis results of design over-pressure. It then calculates the sectional forces acting on the vulnerable wall's local model based on the global model stress values to conduct a detailed structural analysis.

2.3 Local Modeling of Equipment Hatch

In this study, the walls surrounding equipment access points were identified as vulnerable walls, and it is proposed to perform localized modeling based on the stress distribution obtained from the internal pressure analysis results of the Global model, allowing for a detailed evaluation of parts of the wall. Figure 2 represents the local model of an equipment hatch part. While the Global containment structure model considered only concrete, rebar, and tendons for the internal pressure analysis, the Local model incorporated additional elements such as liners, backside angles, and penetration covers for enhanced detailed modeling and structural analysis.

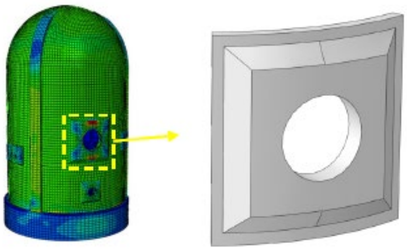

Fig. 2. Local modeling of E/H

3. Conclusions

In response to a severe accident causing internal pressures exceeding the design pressure within the containment building, an analysis using finite element models and evaluating vulnerable wall behavior due to cracking was conducted. The analysis identified walls surrounding equipment access points as critical areas for localized modeling due to maximum stress. This approach involved calculating the loads occurring on the cross-sections of these vulnerable walls from the overall stress distribution in the containment building and inputting them as boundary conditions for detailed structural analysis of specific wall sections. Future research aims to utilize the results from the analysis of these vulnerable walls to simulate crack formation and progression, assess leakage quantities, and propose criteria for the ultimate pressure capacity of the containment building, considering structural damage.

REFERENCES

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