Assessment of Structural Safety in Local Elements using Internal Pressure Analysis Results of Nuclear Containment Building

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1. Introduction

The containment building serves as the final shield against radioactive material leakage in severe accident. Therefore, maintaining the structural integrity of the containment building has a significant impact on the scale of accident damage. Existing severe accident analysis codes use a simple pressure boundary condition to assume leakage, which limits the ability to quantitatively evaluate the cracks that occur in the walls of the containment building and the leakage through them. The final goal of this study is to develop a model that can evaluate wall cracks with stress distribution through internal pressure analysis of the containment building, and to evaluate the vulnerability of ultimate pressure capacity and leakage of the containment building in connection with a severe accident scenario in the future.[1] This paper introduces a method for selecting vulnerable wall parts of containment buildings through pressure analysis and calculating stress-based boundary conditions to evaluate their capacity at the local member level prior to crack and leakage assessment.

2. Limit state criteria for the containment

Severe accident is one in which the nuclear fuel core is severely damaged. As nuclear fuel damage and melting progresses, radioactive materials are generated through reactions with surrounding structures, and cracks in the containment building due to increased pressure can lead to leakage. Therefore, it is very important to evaluate the limit state and failure mode of the containment building. The limit state strain criteria for the containment building presented in Regulatory Guide 1.216.[2] The guide defines the limit state as a strain of 0.4% for reinforcement, 0.4% for liner plates, and 0.8% for tendons, and it can be expected that tensile cracking has already occurred in the concrete located at the back.

3. Internal pressure analysis

3.1 Finite element model

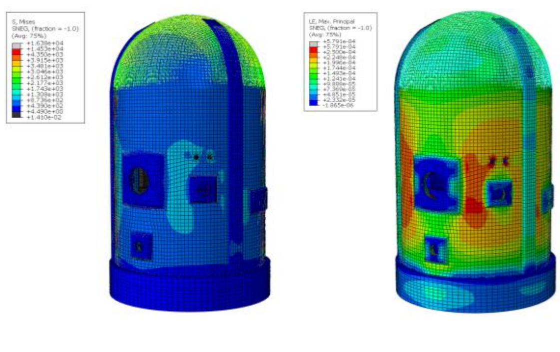
The ABAQUS model for the pressure capacity evaluation of the APR1400 type containment building was constructed as shown in Fig. 1.[3] The containment building consists of a cylindrical wall, an upper dome, three side walls, a foundation slab, and an liner steel plate. The containment is modeled in consideration of large-scale penetrations such as equipment hatch and several mechanical penetrations. The penetrations are expected to be susceptible to cracking due to their discontinuous geometry, which can lead to localized stress concentrations. Concrete was modeled with solid elements and Concrete Damaged Plasticity(CDP) material, while rebar and tendons were modeled with truss elements and Plasticity material. The internal pressure was simulated by applying the same pressure load to the wall elements inside the containment building.

(a) containment (b) rebar (c) tendon

Fig. 1. Modeling of APR1400

3.2 Pressure analysis results

Fig. 2 is the result of analyzing about 0.4 MPa as a pressure load considering the APR1400 design pressure load(60psig). Von Mises stress and strain distribution in the direction of the maximum principal stress were shown, and the strain around equipment hatch was relatively large, so it was selected as a vulnerable wall.



(a) stress (b) strain

Fig. 2. Stress and Stain results under design pressure load

3.3 Section force of local element

A post-processing code was developed to calculate the sectional force for the boundary condition calculation for the equipment hatch part, which is a vulnerable wall. Fig. 3 shows the stress result of the equipment hatch, which consists of 2,609 elements and 3,543 nodes, considering only concrete material. Using the stress values, the nodal forces are obtained from the pressure analysis by Eqs. 1 and 2. Then, by calculating the combined forces of the elements that share a point of contact, the force equilibrium is achieved at the point of contact located inside the wall, and the sum of the nodal forces at the end is calculated as the section force. To perform many iterative calculations, the necessary information such as the coordinates of the nodal points, element numbers, and stress values from the ABAQUS analysis results were processed with Python. Fig. 4 shows the result of the combined force acting on the top of the equipment hatch, and the section force acting on all sections and materials is calculated in the same way to be used as a boundary condition for the crack and leakage evaluation of the detailed model in the future.

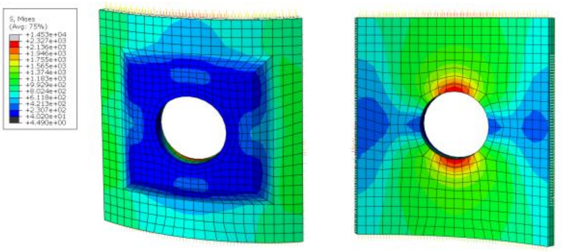


Fig. 3. Stress distribution of Equipment hatch part

$$N_i = \frac{1}{8}(1+ss_i)(1+tt_i)(1+z'z'_i) \quad \text{Eq. (1)}$$

$$[f_n] = \int_V [B]^T \sigma |J| \mathrm{dv} \quad \text{Eq. (2)}$$

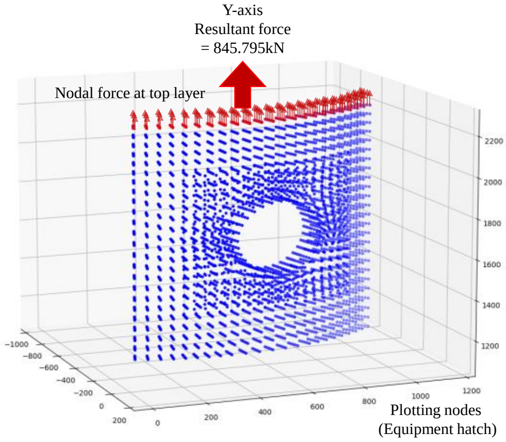


Fig. 4. Section force of Equipment hatch part

4. Conclusions

Conventional pressure capacity evaluation of containment buildings is performed with many assumptions, such as strain-based deterministic evaluation procedures and probabilistic evaluation. This study developed a process to calculate the local elements' nodal force and section force based on the stress analysis results after the pressure analysis using finite element model of the containment building. This method enables the calculation of boundary conditions for detailed analysis of vulnerable walls and will be used in future crack propagation and leakage analysis of containment building walls.

REFERENCES

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