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Stress Tensor-Based Evaluation of Internal Pressure Effects on Containment Structure Wall Integrity

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1. Introduction

During a severe accident, pressure and temperature simultaneously increase inside the containment building, causing the cylindrical containment to bulge, resulting in radial displacement and tensile stress. If pressure continues to rise uncontrolled, cracks may form in the concrete, and stress may concentrate at liner plate discontinuities, leading to yielding and tearing. Therefore, a realistic assessment of containment failure mechanisms, vulnerable areas, failure criteria, and leakage as internal pressure increases is necessary. Specific evaluations of concrete wall crack prediction and radioactive material leakage due to increasing internal pressure must be performed, and the use of local models is required to overcome the difficulties of time-consuming crack analysis for the entire wall. In this paper, stress values obtained from existing internal pressure analysis of the containment building were used to derive the section forces of vulnerable walls that require priority damage assessment, and the load changes for each material composing the containment building were examined as internal pressure increased. The section forces for each material can be used as boundary conditions for detailed crack analysis and leakage evaluation of local models.

2. Stress-based wall integrity assessment

2.1 Calculation procedure

A technical code was developed to calculate nodal forces for 8-node hexahedral elements and 2-node truss elements used in modeling containment building walls in a three-dimensional finite element analysis model. This process calculates nodal forces using stress tensors obtained after performing internal pressure analysis. In finite element analysis, structures are divided into small elements to calculate stress, deformation, and displacement, and the stress in each element is converted into forces concentrated at nodes. In an 8-node element, the nodal force vector f_{node} can be defined as shown in equation (1).

$$f_{node} = \int_V B^T \sigma \, dV \tag{1}$$

Here, B is the matrix defining the transformation between deformation and displacement, sigma is the stress vector acting within the element, and V is the volume of the element. Nodal forces can be calculated by inputting nodal coordinates, element stress tensors, and connection member information from the global containment building model.

2.2 Internal Pressure Analysis Result

In this study, using a 3D analysis model of the APR1400 containment building, vulnerable walls were identified based on increasing internal pressure, and the stress and load characteristics acting on the concrete, reinforcement, and tendons comprising the walls were examined. According to the beyond design basis pressure analysis results, the equipment hatch wall's strain increased rapidly after approximately 80psi, and exceeded the RG 1.216 tendon strain limit state of 0.8% at an internal pressure of about 140psi (Fig.1).

Therefore, based on the analysis results, the equipment hatch was selected as the vulnerable wall, and this study aims to analyze the load changes in different materials of the equipment hatch as internal pressure increases.

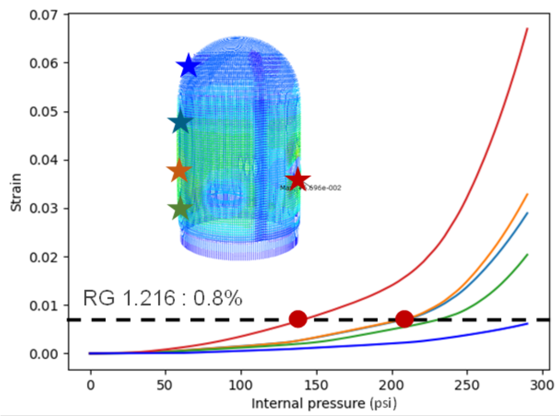
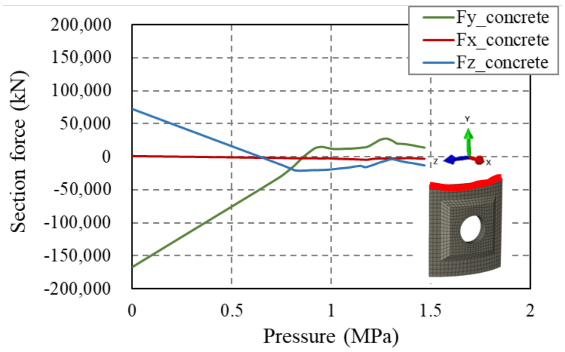


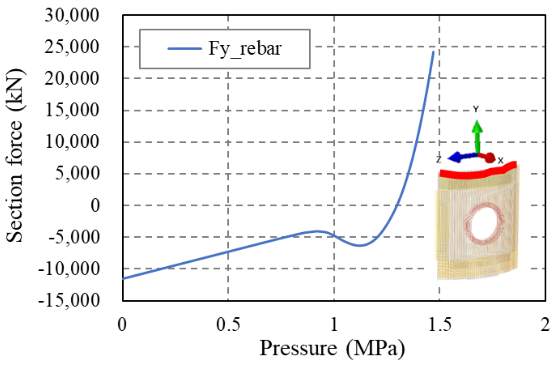
Fig. 1. Tendon strain

2.3 Wall section force

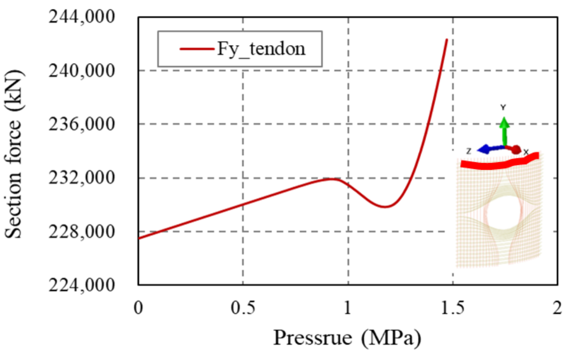
Figure 2 shows the section forces for each material in the upper section (red part) of the equipment hatch as internal pressure increases, calculated using the wall nodal force estimation process. From an internal pressure of about 1 MPa, which is 2.5 times the design pressure, the concrete yields with its load sharing converging to 0, while the loads on vertical reinforcement and vertical tendons increase rapidly. In the 0.9-1.2 MPa range, the section forces of vertical reinforcement/tendons decrease and then increase again, which is believed to be due to stress concentrating in horizontal members because of rapidly increasing hoop stress, causing a momentary decrease in stress in vertical members.



(a) Concrete element



(b) Rebar element



(c) Tendon material

Fig. 2. Section force change in the upper section of the equipment hatch

3. Conclusions

In this study, based on the results of beyond design basis internal pressure analysis of the containment building, the development and application of element technology for damage assessment of local walls was performed. Using the developed technology, the load effects on different materials of the wall were analyzed as internal pressure increased, and this will be utilized in future evaluations of local wall crack propagation and subsequent leakage characteristics due to rising internal pressure.

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