Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 20-21, 2022

An Assessment of Ultimate Pressure Capacity of 1/4 Scaled PCCV according to Prestress Loss

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1. Introduction

The reactor containment building is important for safety as a last barrier of the multiple protection systems. Thus, it should not lose its integrity even if the internal pressure increases rapidly due to an accident.

Tendon is arranged in the concrete wall of the containment building to increase its resistance capacity. It is reported that the tendon force decreases gradually over time due to creep and dry shrinkage of the concrete, corrosion, and relaxation of the tendon [1]. Because the safety of containment building decreases as each component is unsuccessful to perform its role, monitoring the prestress loss of tendon is essential.

In the present study, a Finite Element (FE) model of 1/4 scaled Prestressed Concrete Containment Vessel (PCCV) was developed using a commercial software program ABAQUS. With the model, the effect of prestress loss on the containment building's Ultimate Pressure Capacity (UPC) was evaluated.

2. FE Model of the 1/4 Scaled PCCV

2.1 Model description and analysis method

In 1999, Sandia National Laboratories (SNL) conducted an overpressurization test using 1/4 scaled PCCV [2]. The structure consists of a 10.8 m diameter concrete cylinder with a wall thickness of 325 mm, a 3.5 m thick foundation mat, and a 275 mm thick hemispherical dome. 90 horizontal tendons and 108 vertical tendons were embedded in the concrete along with two layers of rebar. Prestress was applied in the hoop and meridional directions of the containment building. The prestressing system was introduced by maintaining the same number and composition of tendons as the actual structure.

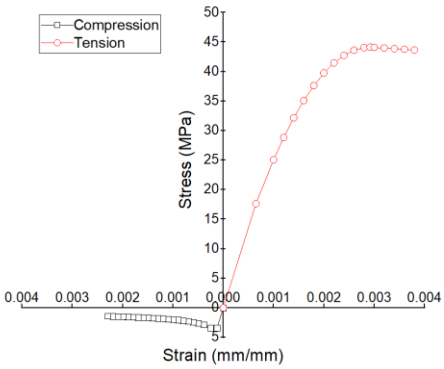

Fig. 1. Concrete response under compression and tension

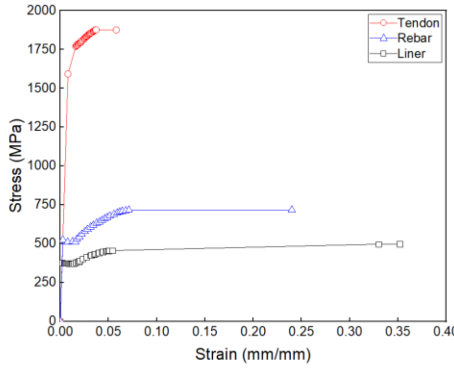

Fig. 2. Stress-strain curves of tendon, rebar, and liner

The body force was considered and the internal pressure corresponding to Structural Failure Mode Test (SFMT) of 3.63 Pd (Design pressure Pd=0.39 MPa) was applied perpendicularly to the inner surface of the liner uniformly. Every node and element of the bottom surface was fixed.

2.2 Constitutive material model

The Concrete Damaged Plasticity (CDP) model provided by ABAQUS was used to consider the nonlinearity of the concrete. The main fracture mechanisms of the model are tensile cracking and compressive crushing [3]. The stress-strain relationship under compression and tension is shown in Figure 1.

The isotropic elasto-plastic model was used for the steel components, and the stress-strain curves of the tendon, rebar, and liner are depicted in Figure 2.

3. Numerical Assessment

3.1 Mesh sensitivity analysis and model verification

Mesh sensitivity analysis was conducted to enhance the accuracy and efficiency of the created FE model. The free field region of the azimuth of 135°, which is far from the discontinuities, and the 6,200 mm height of the cylinder was adopted for the mesh sensitivity analysis. The analysis was performed with mesh sizes of 1,000 mm, 800 mm, 600 mm, 400 mm, and 300 mm. Figure 3 shows the radial displacement of the liner according to the mesh size. Analysis results of the FE model of 400 mm showed an agreement with the denser model. The difference in peak radial displacements between analysis results of 300 mm and 400 mm was under 0.22 mm. Thus, the FE model with a mesh size of 400 mm was adopted.

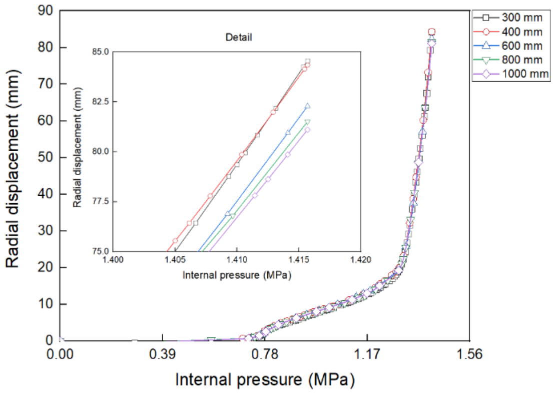

Fig. 3. Mesh sensitivity analysis results

Model verification was performed by comparing the radial displacements of the liner with the test at two major points. Results at the free field and Equipment Hatch (EH), at the azimuth of 324°, and 6,200 mm height were utilized. Figure 4. illustrates the radial displacement contours of the liner. The analysis results matched well with the test because the radial displacement at the free field was 84.19 mm and 87.84 mm at EH which are 0.92% and 0.81% different from the experimental result.

3.2 Effect of prestress loss on radial displacements

Analysis considering prestress loss was conducted using the verified model. The effect of prestress loss on UPC was analyzed by reducing the magnitude of the prestress by 10%, 20%, 30%, 40%, and 50%. The effect of prestress loss on the radial displacement of the liner at the free field is shown in Figure 5. The radial displacements increased at an earlier pressure level and the peak displacement increased as the applied prestress decreased. For the normal operating condition, the radial displacement at the pressure of 3.63 Pd was 83.38 mm. Regarding the figure of 83.38 mm as the criterion for the UPC, the decreased UPCs at each prestress level were investigated and the results are summarized in Table I. The referential radial displacement calculated by the 50% prestress loss model analysis reached UPC at lower internal pressure by 0.024 MPa than the normal operating condition.

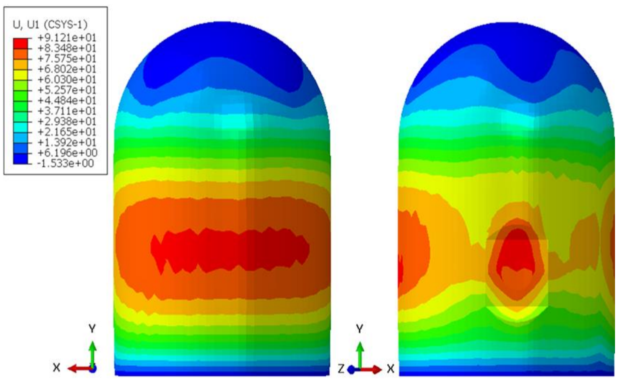

Fig. 4. Radial displacement contours at the free field (left) and EH region (right)

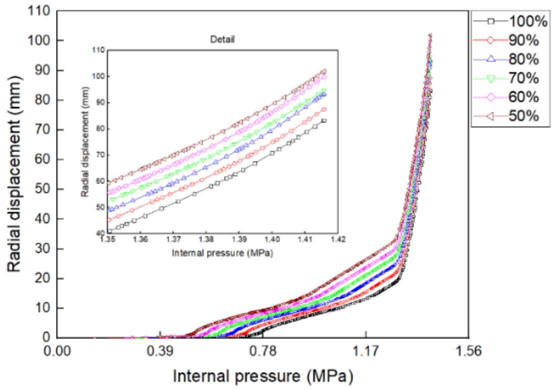

Fig. 5. Effect of prestress loss on the radial displacements

Table I: Reduction of UPC according to prestress loss

Prestress (%)	UPC (MPa)	Reduction (MPa)
100	1.416	0
90	1.411	0.005
80	1.404	0.012
70	1.401	0.015
60	1.396	0.020
50	1.392	0.024

4. Conclusions

In this study, mesh sensitivity analysis and model verification of the 1/4 scaled PCCV model were performed, and the effect of prestress loss on UPC of containment building was evaluated by the FE model with prestressing levels. The conclusions are as follows:

(1) Model verification was performed by comparing the test and the analysis result. The radial displacement at the free field and EH showed a difference of 0.92% and 0.81%, respectively.
(2) The most deformed shape of EH implies that it was the most vulnerable part of the whole containment, followed by the free field.
(3) The UPC of the containment building decreased in accordance with the loss of prestress. For a model with a 50% loss of prestress, the UPC corresponding to the referential radial displacement of 83.38 mm was 1.7% lower than the 100% model, and the radial displacement of the liner at the free field increased by 18.64 mm compared to the normal operating condition.

ACKNOWLEDGMENTS

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KoFONS) using the financial resource granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. 2106034).

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