Ultimate Pressure Capacity Evaluation of Pressurized Heavy Water Reactor (PHWR) Containment Building

Il Hwan Moon, Tae Young Kim, Seong-Moon Ahn
Korea Power Engineering Company, Morning Plaza Building, 351-1 Gugal-dong, Giheung-gu, Yongin-si, Gyeonggi-do, Korea, Tel: 82-31-899-2251, Fax: 82-31-899-2091, E-mail: youmoon@kopec.co.kr

1. Introduction

The purpose of this study is to evaluate ultimate pressure capacity of test model which is 1:4 scale structure of a 540 MWe pressurized heavy water reactor containment building.

PHWR containment building is pre-stressed concrete structure with bonded tendon system, and inside surface of the structure is coated with epoxy. Two steam generator openings in dome along with main airlock, fuelling machine airlock and emergency airlock barrel openings in cylindrical wall are included in this structure, and that is designed for an internal pressure of 0.142 MPa.

In this study, PHWR containment building is idealized as three-dimensional finite element model, and a nonlinearity of the materials is considered for estimation of structural failure. Concrete structure is modeled using 4-node tetra solid elements, and damaged plasticity concrete model is applied for material behavior of concrete. Bonded tendon and reinforcement are modeled as truss elements, and they are embedded in concrete model. Therefore, the tendons are completely bonded with concrete without friction behavior, and compressive stresses also are directly induced to the concrete through pre-stressing forces in tendon.

This paper represents structural failure modes of the containment structure under high pressure, and summarizes the analysis result.

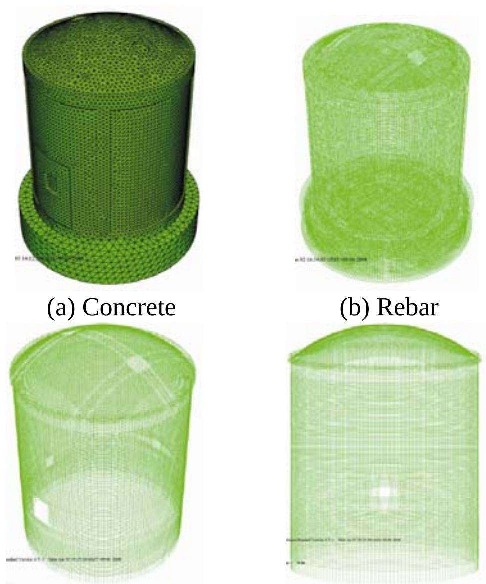
2. Finite Element (FE) Model Description

Three-dimensional finite element model which is utilized to calculate the overall response of the PHWR containment building under internal pressurization, is shown in Fig. 1. This model consists of tetra solid elements for concrete, tension non-active soil springs between basemat and soil foundation, and truss elements for bonded tendons and reinforcements. The truss element is embedded in solid element, and formed the rigid link between two elements. Main openings are considered for estimation of actual behavior of the containment building.

Characteristic compressive strength of concrete is 45 MPa, and tensile strength is 2.78 MPa. Concrete material has the nonlinear deformation behavior, because it may crack under tension stresses and will be elastic under compression stresses. Damaged plasticity concrete model with non-associated plastic flow is adopted for the analysis [1, 2].

Compression stresses on reinforcement are generally negligible, rebar deformation and yielding usually are not caused by pressure stresses. According to Hsu's study result, the stress-strain curves of a bare steel bar and of a steel bar embedded in concrete are quite different [3]. This study, therefore, applies the stress-strain relationship of a rebar embedded in concrete.

Stress-strain curve of tendon consists of two straight lines jointed by curve. The first part is a straight-line part up to 0.7 f_{pu}, where f_{pu} is the ultimate strength of the tendon and the value is 1,848 MPa. The second part is expressed by Ramberg-Osgood equation that meets the first part at the stress level of 0.7 f_{pu} [3]. Pre-stressing force, 189.3 kN/cable, is induced along the length of the tendon in concrete as initial stress.



(a) Concrete (b) Rebar

(c) Tendon

Fig. 1 Finite Element Model

3. Finite Element Analysis

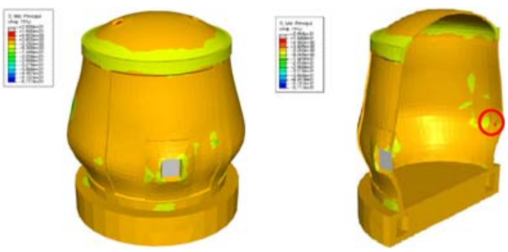
Because of the elastic support under basemat, the effect of the weight of the structure had to be acted first. This is accomplished by specifying as mass proportional load for each material included in the 1:4 scale PHWR containment building model prior to initiating the internal pressure. The weights of each material are considered in the numerical model as gravity dead loads.

Internal pressure load is specified to act as a uniformly-distributed force, remaining normal to the interior element surface of the containment shell & dome and basemat.

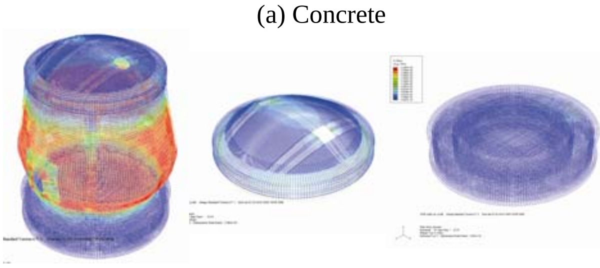
The pressure levels corresponding to structural failure mode are summarized in Table 1, and stress contours of the materials are shown in Fig. 2. Structural failure due to tendon breaking is expected to occur at about the mid-height of the cylinder shown in figure 2. The height where the maximum radial displacement is obtained by the analysis also is at the same location shown in Fig. 3. Concrete cracking is initiated at pressure of 0.43 MPa, and tendon is yielded at pressure of 0.53 MPa. Tendon breaking is expected to occur at pressure of 0.54 MPa. As a result, ultimate pressure capacity of the PHWR containment building is 0.54 MPa.

Table 1. Comparisons of Pressure Levels

Events	Pressure (MPa)
Initial concrete crack in cylindrical wall	0.43
Initial concrete crack in dome	0.46
First yield of hoop rebar in cylindrical wall	0.52
First yield of meridional rebar at wall-basemat junction	0.54
Hoop tendon yielding (1% strain)	0.53
Hoop tendon strain (2% strain)	0.54

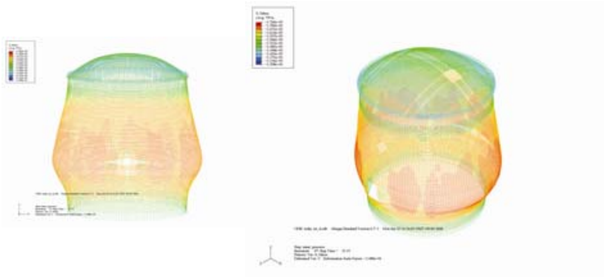


(a) Concrete



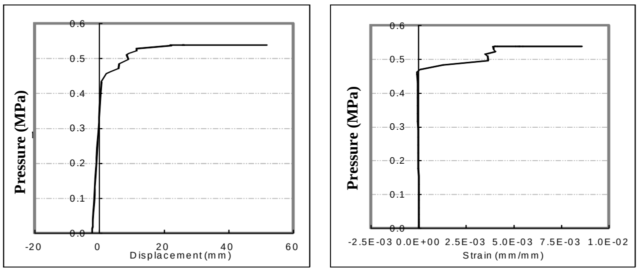
(b) Reinforcement

Fig. 2 Stress Contour for Containment Structure

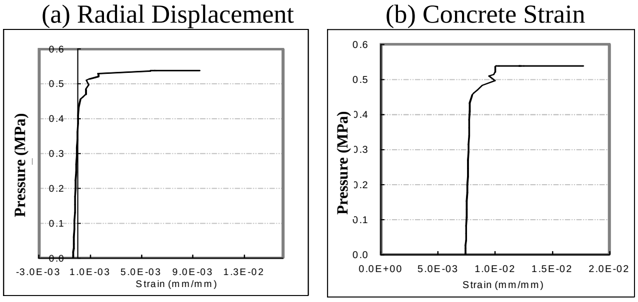


(c) Pre-stressing Tendon

Fig. 2 Stress Contour for Containment Structure (cont'd)



(a) Radial Displacement (b) Concrete Strain



(c) Rebar Strain (b) Tendon Strain

Fig. 3 Displacement or Strain-Pressure Relationship

4. Conclusions

The nonlinear analyses of PHWR containment structure under internal pressure loading are carried out in this paper. According to analysis results, the ultimate pressure capacity of the PHWR containment structure is remarkably smaller than that of PWR containment structure.

REFERENCES

[1] Lee, J., and G. L. Fenves, "Plastic-Damage Model for Cyclic Loading of Concrete Structures", Journal of Engineering Mechanics, Vol. 124, No. 8, 1998, pp. 892–900

[2] Lubliner, J., J. Oliver, S. Oller, and E. Oñate, "A Plastic-Damage Model for Concrete", International Journal of Solids and Structures, Vol. 25, No. 3, 1989, pp. 229–326

[3] Thomas T.C. Hsu, "Unified Theory of Reinforced Concrete", CRC Press, 1993