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Assessment of the Internal Pressure Fragility of the Hanul NPP Units 3&4 Containment Building Using a Nonlinear Finite Element Analysis

Hyung-Kui Park [a*] , Deagi Hahm [a] , In-Kil Choi [a]
[a]*Integrated Safety Assessment Division, Korea Atomic Energy Research Institute, 989-111 Deadeok-daero, Deajeon,305-353, Republic of Korea*
[*]*Corresponding author: hyungkui@kaeri.re.kr*

1. Introduction

As can be seen from the Fukushima nuclear power plant accident, the containment building is the final protecting shield to prevent radiation leakage. Thus, a structural soundness evaluation for the containment pressure loads owing to a severe accident is very important. Recently, a probabilistic safety assessment has been commonly used to take into account the possible factors of uncertainty in a structural system. An assessment of the internal pressure fragility of the CANDU type containment buildings considering the correlation of structural material variables [1], and an assessment of the internal pressure fragility of the CANDU type containment buildings using a nonlinear finite element analysis, were also performed [2]. However, for PWR type containment buildings, a fragility assessment has not been performed yet using a nonlinear finite element model (FEM) analysis.

In this study, for the Hanul NPP units 3 & 4 containment building, the internal pressure fragility assessment was established using an FEM analysis. To do this, a three-dimensional finite element model, material property values, and a sensitive analysis were developed.

2. Finite Element Model of Containment Building

The Hanul NPP units 3 & 4 containment building is composed of a foundation slab, cylindrical wall, and an upper dome. It is a pre-stressed concrete structure. The vertical and horizontal tendons were placed in a cylindrical wall and the upper dome. Three buttresses are located in a cylindrical wall for the horizontal tendons to settle. Figure 1 shows the whole finite element modeling of the containment building.

Fig. 1. Whole finite element modeling of the containment building.

Figure 2 shows the tendon arrangement of the containment building.

Fig. 2. Tendon arrangement of the containment building.

The material properties of the containment building are organized in Tables 1.

Table 1. Material Properties of the containment building (psi)

Category	Foundation slab	Wall, dome
Compressive strength	4000	5500
Tensile strength	474	556
Modulus of elasticity	4230000	
Density (lb/in^3)	0.00022	
Poisson ratio(%)	0.17	

3. Ultimate Pressure Capacity Assessment

The compressive strength of concrete and the strength of steel were selected for the random variable volatility because the two design variables had the greatest impact on the internal pressure resistance of the containment building in a preliminary analysis. Figure 3 shows the variability in the ultimate pressure load of the design parameters.

■ Concrete Strength

Category	Interal Pressure(psi)/ $\left\|\frac{Nomal-(\pm)}{Nomal}\right\| \times 100(\%)$	
	+30%	-30%
Concrete	141.8 / 6.9	124.1 / 6.5
Liner	126.1 / 8.6	105.6 / 9.0
Rebar	205.2 / 4.4	187.9 / 4.4
Tendon	150.5 / 7.1	130.5 / 7.1

■ Pre-Stress(Tendon)

Category	Interal Pressure(psi)/ $\left\|\frac{Nomal-(\pm)}{Nomal}\right\| \times 100(\%)$	
	+10%	-10%
Concrete	133.6 / 0.7	131.7 / 0.8
Liner	117.1 / 0.9	115.2 / 0.8
Rebar	197.4 / 0.5	195.6 / 0.5
Tendon	142.1 / 1.1	139.6 / 0.6

■ Liner Thickness

Category	Interal Pressure(psi)/ $\left\|\frac{Nomal-(\pm)}{Nomal}\right\| \times 100(\%)$	
	+10%	-10%
Concrete	134.1 / 1.0	131.3 / 1.1
Liner	117.5 / 1.2	115.5 / 0.5
Rebar	197.9 / 0.7	195.0 / 0.8
Tendon	141.9 / 1.0	139.7 / 0.6

■ Steel Strength

Category	Interal Pressure(psi)/ $\left\|\frac{Nomal-(\pm)}{Nomal}\right\| \times 100(\%)$	
	+10%	-10%
Concrete	136.4 / 2.8	128.8 / 2.9
Liner	120.0 / 3.4	112.0 / 3.5
Rebar	202.8 / 3.2	188.7 / 4.0
Tendon	145.1 / 3.3	136.3 / 3.0

Fig. 3. Ultimate pressure load of the design parameters variability

4. Sensitivity Analysis and Fragility Assessment

The results at the point of maximum response were analyzed. Figure 4 shows the changes in the compressive strength of concrete based on the results of a sensitivity analysis. Based on 3Pd(171 psi), a ±10.2% difference in response occurred.

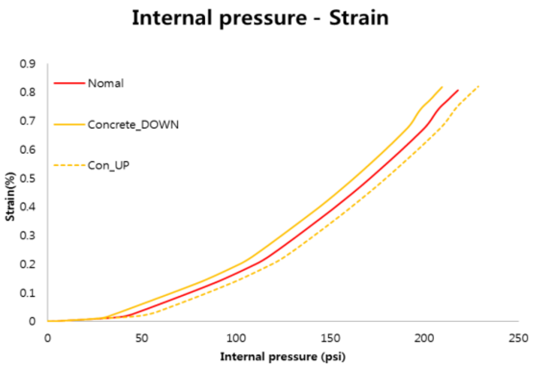

Fig. 4. Results of sensitivity analyses according to the variation of the concrete strength.

Figure 5 shows the changes in the steel strength based on the results of the sensitivity analysis. Based on 3Pd(171 psi), a ±6.7% difference in response occurred. The changes in the pressure response were considered to have occurred owing to changes in the material strength.

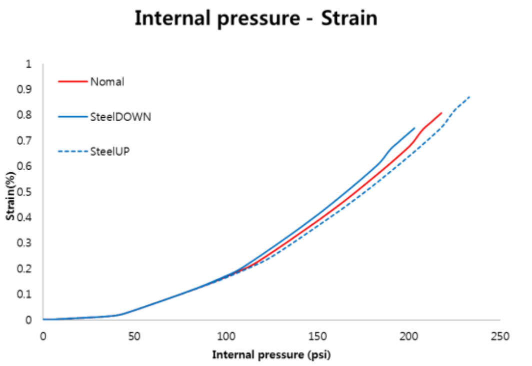

Fig. 5. Pressure-strain relationship according to variations in the steel strength.

For the internal pressure fragility assessment, 30 sets of an FE model considering the material uncertainty of concrete and steel were established. With this input FE model, we performed an UPC analysis, and assessed the internal pressure fragility capacity. For the target containment building, i.e., Hanul NPP units 3 & 4, the median capacity of the liner leakage is estimated as 116 psi. The median capacity of the rebar and tendon rupture is about 196 psi and 141 psi, respectively.

5. Conclusions

A nonlinear finite element analysis of the Hanul NPP units 3 & 4 containment building was performed for a material sensitivity analysis and internal pressure fragility assessment. The sensitivity of the concrete strength is relatively higher compared to that of the steel strength. According to changes in the structure of the material, about 6-10% ultimate internal pressure differences occurred. Thirty sets of an FE model considering the material uncertainty of concrete and steel were composed for the internal pressure fragility assessment. From the internal pressure fragility assessment of the target containment building, the median capacity of liner leakage is estimated to be 116 psi.

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