

# Nonlinear Analysis of a Reinforced Concrete Containment Building using a 3D Solid Element

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## 1. Introduction

Containment buildings in nuclear power plants are the last barriers to protect the spread of radiation materials to the environment. It is important to evaluate the performance of containment building during its service life. From this point of view, a nonlinear finite element (FE) analysis program NUCAS[1], which can evaluate the ultimate pressure capacity of the prestressed concrete containment building has been developed. In this study, the nonlinear FE analysis for a reinforced concrete containment building is employed to verify the performance of the 8-node solid FE program[2] which is one of the nonlinear modules of the NUCAS code.

## 2. Solid element and material models

### 2.1 Formulation of the solid element

The isoparametric concept is simply for expressing the geometry of an element in terms of its nodal coordinates by means of same set of shape functions  $N$  used in the interpolation of the displacements. The geometry and displacement fields allow the coordinates to be written as, respectively:

$$\mathbf{x} = \sum_{a=1}^8 N_a(\xi_i) x_i^a \quad (1)$$

$$\mathbf{u} = \sum_{a=1}^8 N_a(\xi_i) u_i^a \quad (2)$$

where,  $N_a$  is the shape function of the element.

Analysis of reinforced concrete structures by the finite element method requires a simple but accurate technique of representing the reinforcement. Therefore, a smeared reinforcement layer in an 8-node solid element is adapted. Perfect bond is assumed between the reinforcement and the surrounding concrete. The stiffness and internal forces associated with the reinforcement are integrated and added to those of the concrete to obtain the total stiffness and internal forces of the element.

### 2.2 Material model for concrete

The yield criterion for concrete under a triaxial stress state is generally assumed to be dependent on three invariants[3]. However a dependency of the yield function on the mean normal stress  $I_1$  and the shear stress invariant  $J_2$  has proved to be adequate for most situations. This criterion in the triaxial compression region is formulated in terms of the first two stress invariants and only two material parameters are involved in its definition.

$$f(I_1, J_2) = [\beta(3J_2) + \alpha I_1]^{1/2} = \sigma_0 \quad (3)$$

where,  $\alpha$  and  $\beta$  are the material parameters and  $\sigma_0$  is the equivalent effective stress taken as the compressive stress from a uniaxial test.

From the experimental results, the material parameters are decided as  $\alpha = -0.3799\sigma_0$  and  $\beta = 1.3799$ .

The response of the concrete under a tensile stress is assumed to be linear elastic until the cracking surface is reached. In the triaxial tension zone, the limiting value required to define the onset of a cracking is established as

$$\sigma_{io} = f'_t \quad \text{for } (i=1,2,3).$$

In the tension-compression-compression and tension-tension-compression zones, linearly decreasing tensile strength expressions are used

$$\sigma_{io} = f'_t \left(1 + \sigma_{i+1} / f'_c\right) \left(1 + \sigma_{i+2} / f'_c\right) \quad \text{for } (\sigma_{i+1}, \sigma_{i+2} \leq 0)$$

$$\text{and } \sigma_{io} = f'_t \left(1 + \sigma_{i+1} / f'_c\right) \quad \text{for } (\sigma_{i+1} \leq 0), \text{ respectively.}$$

### 2.3 Material model for reinforcement

The material model for a reinforcement is generally assumed to be identical for the tension and compression regions. For simplicity in a numerical analysis, the reinforcement is idealized by the one-dimensional stress-strain relationship such as an elasto plastic material model with an isotropic hardening rule.

## 3. Numerical example

The test on a 1:6-scale model of a reinforced concrete containment building was conducted by the SNL as a part of the containment integrity programs, which are sponsored by the US-NRC[4]. The schematic of the model is shown in Figure 1. The design pressure of the model was 0.317MPa.

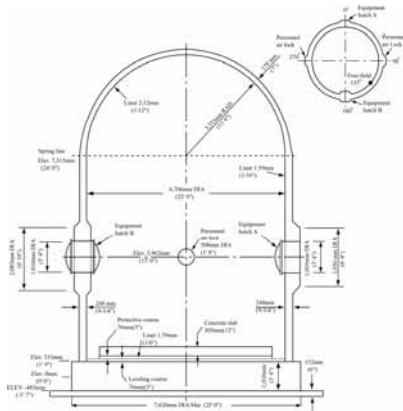


Figure 1. Schematic of 1:6-scale model

The FE model except for the basemat consists of 504 8-node solid elements with normal integration method using a standard strain-displacement matrix. The stiffness matrix of the element was simply incorporated with concrete and reinforcement stiffness matrices by the superposition method. The arc-length control was adapted as a solution algorithm for the material nonlinear analysis of reinforced concrete containment building by representing the strength degradation after a concrete cracking.

Figure 2 and Figure 3 show the pressure-displacement curve of the radial direction at a midheight of the cylinder wall and at the springline, respectively. The figures are compared with experimental results as well as several FE results from the Round Robin Analysis. The analysis codes used were ABAQUS (EPRI, SNL), ADINA (ENEA) and TEMP-STRESS (ANL). The main differences between the analytical models are the failure criteria and material behavior of the concrete.

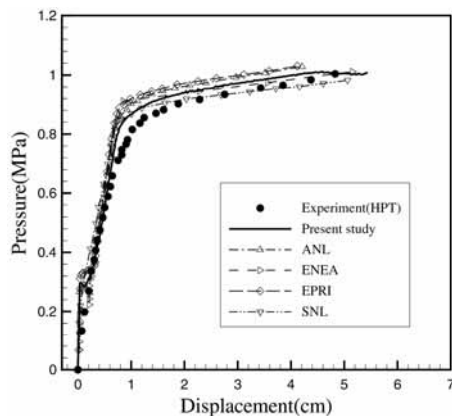


Figure 2. Radial displacement at wall midheight

The initial cracking of the concrete in the cylinder wall due to a hoop stress occurred at 0.29MPa in the cylinder. Cracking pressure level by a finite element analysis is very similar to the experimental results and other FE analysis results shown in Figure 2 and Figure 3. The

cracking of the concrete caused a sudden change in the stiffness of the structure. Beyond this point, the reinforcement steels have to sustain an internal pressure. The first yielding of the reinforcement is initiated at 0.837MPa at the mid-height of the cylinder wall. Finally, the results of the nonlinear FE have to sustain an internal pressure. The first yielding of the hoop analysis shows that a structural failure occurred near the mid-height of the cylinder at 1.01MPa.

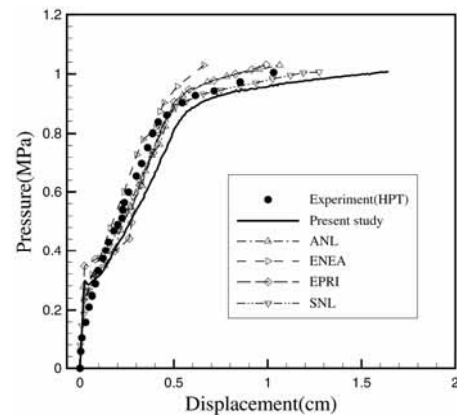


Figure 3. Radial displacement at springline

#### 4. Conclusion

The objective of the present study was to develop nonlinear finite element program using 3 dimensional 8-node solid elements with an elasto-plastic material model for concrete. Initial cracking for the concrete and the yielding for the reinforcement are occurred at 0.29MPa and 0.837MPa, respectively. Finally, the numerical FE results of 1:6-scale RC containment building by using the NUCAS showed a good agreement with experimental data.

#### Acknowledgement

The Research grant from the Ministry of Science and Technology, Korea, for the Nuclear Research & Development Program is gratefully acknowledged.

#### REFERENCES

- [1] S.J. Lee, H.P. Lee and J.M. Seo, The Nonlinear Finite Element Analysis Program for Reinforced Concrete Containment Building NUCAS, KAERI, KAERI/TR-2076/2002, 2002.
- [2] H.P. Lee, Y.S. Choun and J.M. Seo, A Study on the Standard 8-node Finite Element for Nonlinear Analysis of Reinforced Concrete Containment, KAERI, KAERI/TR-2963/2005, 2005.
- [3] W.F. Chen, Plasticity in Reinforced Concrete, McGraw-Hill Book Company, 1982.
- [4] D.S. Horschel, Experimental Results from Pressure Testing a 1:6 Scale Nuclear Power Plant Containment, Sandia National Laboratories, NUREG/CR-5121, 1992.