# Nonlinear FE Analysis for PCCV 1/4 Model using NUCAS Code

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## 1. Introduction

During the several years, ultimate pressure analysis as well as failure mode evaluations of containment building in nuclear power plant have been carried out in KAERI. In this point of view, the program NUCAS (NUclear Containment Analysis System) code[1], which is FE (Finite Element) program with the sole purpose of evaluating ultimate pressure capacity of PSC containment building, was developed to predict nonlinear behavior. The main objective of this paper is to verify the performance of the program's solid element[2].

## 2. 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:

$$\mathbf{x} = \sum_{a=1}^{8} N_a\left(\xi_i\right) x_i^a,\ \left(i = 1,2,3\right) \tag{1}$$

$$\mathbf{u} = \sum_{a=1}^{8} N_a\left(\xi_i\right) u_i^a,\ \left(i = 1,2,3\right) \tag{2}$$

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

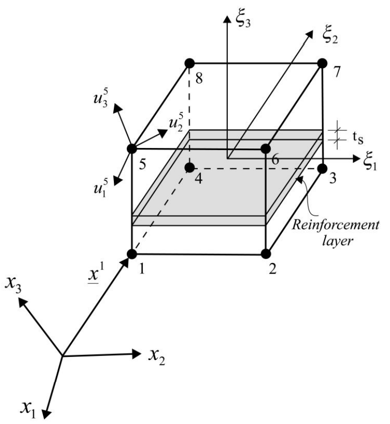


Figure 1. Solid element

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(figure 1) 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.

## 3. Material model

The yield criterion for concrete under a tri-axial 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.

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

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 $\sigma_{io} = f_t'$ for (i=1,2,3). In the tension-compression-compression and tension-tension-compression zones, linearly decreasing tensile strength expressions are used $\sigma_{io} = f_t'\left(1+\sigma_{i+1}/f_c'\right)\left(1+\sigma_{i+2}/f_c'\right)$ for $\left(\sigma_{i+1}, \sigma_{i+2} \le 0\right)$ and $\sigma_{io} = f_t'\left(1+\sigma_{i+1}/f_c'\right)$ for $\left(\sigma_{i+1} \le 0\right)$, respectively.

The material model for 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. The figure 2 shows reinforced concrete material model.

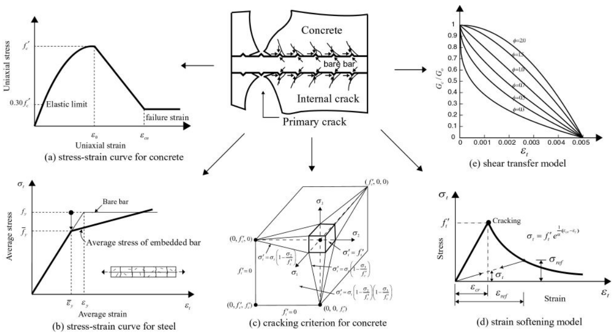

Figure 2. Material model

## 4. Numerical example

The test on a 1:4-scale model of a prestressed concrete containment vessel(PCCV)[4] was conducted by the SNL as a part of the containment integrity programs, which are sponsored by the NUPEC and US-NRC. The schematic of the model is shown in Figure 3. The design pressure of the model was 0.39MPa.

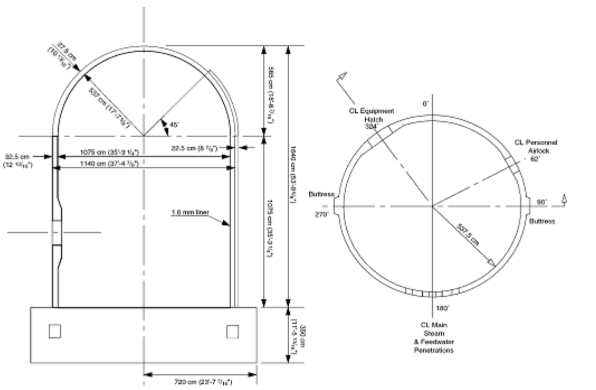

Figure 3. Schematic of 1:4-scale model

The FE model without the basemat consists of 540 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 4, which is compared with experimental results from the Round Robin Test, shows the internal pressure-displacement curve of the radial direction at a mid-height of the cylinder wall.

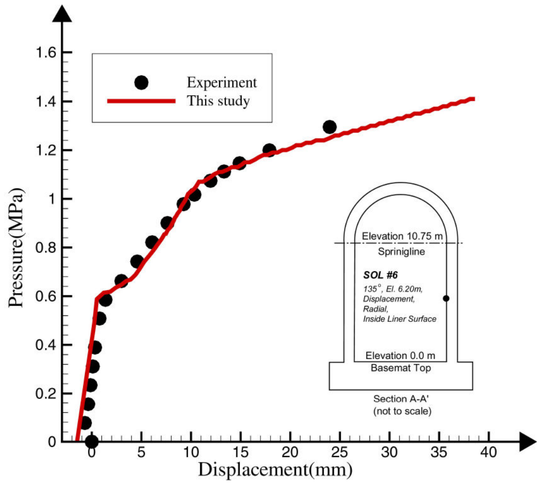

Figure 4. Load-displacement relationship at mid-height

The initial crack of concrete in the cylinder wall and yielding of rebar for the FE analysis results is occurred at 0.58MPa and 1.05, respectively. It is very similar to the experimental results showed at Figure 4. The figure shows that using this method gave very good simulation of overall behavior for the PCCV 1/4 model.

## 5. Conclusion

This paper describes the FE analysis results of NUCAS solid element which is mainly focused to evaluate nonlinear behavior and ultimate pressure capacity of nuclear containment building, for PCCV 1/4 model. From the analysis results, the FE analysis techniques using this paper are useful to predict nonlinear behavior of the pre-stressed concrete containment building.

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## 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 Solid 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] M.F. Hessheimer, Pretest round robin analysis of a prestressed concrete vessel model, NUREG/CR-6678, Sandia National Labs, Albuquerque, 2000.