The Ultimate Pressure Capacity of a Prestressed Concrete Containment Building According to the Concrete Models

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1. Introduction

The research on the ultimate capacity and integrity of containment buildings has been performed all over the world since the late 1980's, because the containment building has a role of a radiation shield when a severe accident occurs. The containment building is constructed with a complex material such as concrete, reinforcement, liner plates, and tendons. Therefore it is difficult to predict the response of containment structures with numerical methods because of the complex behaviors after a cracking of the concrete, and the uncertainties in the properties of the concrete. The purpose of this paper is to compare the ultimate pressures of a prestressed concrete containment according to the concrete models in the computer code ABAQUS.

2. Analytical Methods

2.1 Finite Element Analysis Models

In this study, a nonlinear analysis is carried out to predict the ultimate pressure of a prestressed concrete containment building using the commercial code ABAQUS. The generally used 2D analysis is simple, but there is a limitation in the estimation of the nonlinear response of a containment because it cannot consider penetrations which are structurally weak. Therefore in this research a 3D FE analysis by considering a discontinuity was performed to estimate the response of a containment with a 2D FE analysis together. In addition, a 3D FE analysis without considering that which hasn't any discontinuity such as an equipment hatch and air lock was performed.

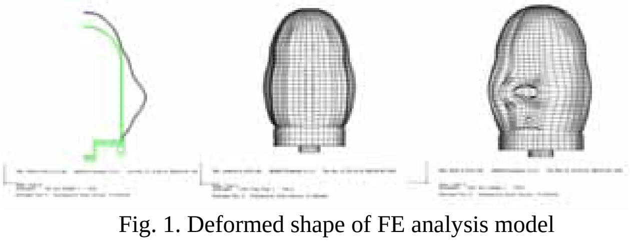

Fig. 1. Deformed shape of FE analysis model at the ultimate pressure state

As shown in Fig. 1, in the case of the 2D model, the mid-height of a cylinder wall is the vulnerable region. And, in the case of the 3D model, the deformation is very irregular around the penetrations, due to a geometric discontinuity. This geometric discontinuity may affect the overall behavior and the ultimate pressure capacity of the containment.

2.2 Concrete Models

An analysis is carried out using three concrete material models which are the Drucker-Prager model, the damaged plasticity model and the Chen-Chen model for the ABAQUS concrete material [1].

In the Drucker-Prager's model [2], three different yield criteria based on the shape of the yield surface in the meridional plane are provided in ABAQUS. These yield surfaces are a linear form, a hyperbolic form, and a general exponent form. In the present analysis, a yield surface with a linear form is adopted, and the friction angle and the dilation angle are adopted as 71.56 degrees and 56.97 degrees, respectively.

In the damaged plasticity model [3], two main failure mechanisms, a tensile cracking and a compressive crushing of the concrete material, are considered. The evolution of the yield (or failure) surface is controlled by two hardening variables related to a failure mechanism, $\bar{\varepsilon}_t^{pl}$ and $\bar{\varepsilon}_c^{pl}$, which are the tensile and compressive equivalent plastic strains, respectively.

In the Chen-Chen model [4], the failure surface is defined in the stress space such that once the stress state reaches this surface the material will completely rupture and cannot resist any further loading. In other words, the stresses in the failure zone of the material will drop to zero.

3. Ultimate Pressure Capacity

3.1 Results of the Axi-symmetric Analysis

Analysis results according to concrete material models show a different behavior after an initial cracking. As shown in Table 1, in the damaged model, an initial crack of the containment occurred at 87.4psig, then, the pre-stress force was offset and the cracks speared all over the cylinder wall of the containment at 121.5psig.

Table 1. Maximum pressure and displacement according to the concrete models at the mid-height of cylinder wall.

Models	First Cracking of Concrete (psig)	Max. Pressure (psig)	Max. Displacement (cm)
Damaged Plasticity	87.4	230	10.5
Drucker-Prager	101	158	3.75
Chen-Chen	88.5	153	3.12

In this model, the pressure occurred at the initial crack in the upper internal pressure state (about 12psig) as compare with other concrete material models, which are the Drucker-Prager model, and the Chen-Chen model. But it is the probable error according to the analytical increment. This error can be neglected.

As shown in Fig. 2, the damaged plasticity model has a good astringency after an initial cracking occurs, therefore the final internal pressure state of this model is observed at the upper internal pressure state of about 1.45times as compared with other concrete material models. The results show that the displacement difference of the Drucker-Prager model and the Chen-Chen model at the final pressure (153psig) is about 0.526~0.551cm (within 17%) when compare with the damaged plasticity model.

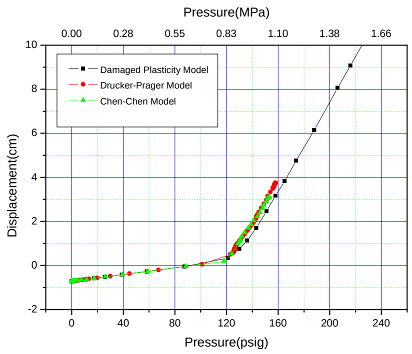

Fig. 2. 2D -Radial displacement
at the mid-height of the cylinder

3.2 Results of the 3-dimensional Analysis

The initial cracking of the cylinder wall occurred at 87.3psig in the damaged plasticity model, as shown in Fig. 3. Pre-stress force was offset at 123.7psig. These are similar pressure values for the cracking pressure obtained from the results of the axi-symmetric model. The first yielding of the hoop rebar is initiated at 247psig at the mid-height of the cylinder wall, but a yielding of the tendon does not occur. The 3D FE analysis results were likewise axi-symmetric results where the damaged model obtained an upper initial cracking pressure for the concrete models. 3D FE analysis by considering a discontinuity obtained a lager displacement (about 0.9cm, within 15%) than the 3D FE analysis which is not consider any discontinuity such as an equipment hatch and air lock, at the same pressure, 243psig.

Table 2. Pressure level of 3D damaged Plasticity models with considering penetrations at the mid-height of cylinder (psig)

Item	Pressure
First cracking of concrete	87.3
First yield of hoop rebar	247
First yield of meridional rebar	247
Ultimate internal pressures	276

When the concrete cracks begin to spread all over the FE model, the FE analysis is terminated since the Chen-Chen concrete model does not reflected thoroughly the inelastic behavior of concrete. The Drucker-Prager model was similar to the final pressure state of the Chen-Chen concrete model. On the contrary, the damaged plasticity model produced a higher internal pressure than the Chen-Chen model and the Drucker-Prager model.

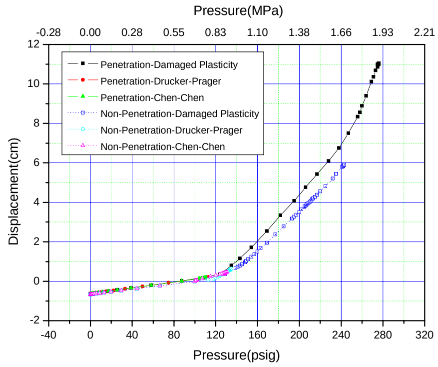

Fig. 3. 3D -Radial displacement
at the mid-height of the cylinder

4. Conclusion

In this study, a nonlinear finite analysis of a prestressed concrete containment building was conducted to predict the ultimate internal pressure capacity according to the concrete material models.

Location of the maximum displacement is at the mid-height of the cylinder wall, which is the critical section of the containment. Especially, the deformed shape of the 3-domensional model is very irregular around the penetrations for a geometric discontinuity. So, an axi-symmetric result cannot be achieved. A geometric discontinuity may affect the overall behavior and the ultimate pressure capacity of the containment.

Initial concrete cracking occur at 87.4 psig (axi-symmetric model) and 87.3psig (3D model) in the cylinder wall. It is a similar behavior before the initial cracking, while the behavior after the initial cracking is different according to the concrete material models. Results of the analysis show that the damaged model has a good astringency in the inelastic section, but the astringency significantly decrease in the Drucker-Prager model and the Chen-Chen model. At that time, the damaged model revealed at a pressure about 1.45 (axi-symmetric model) ~2.44 (3D model) times higher than the Chen-Chen model and the Drucker-Prager model.

ACKNOWLEDGEMENT

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