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Internal pressure capacity estimation of prestressed concrete containment buildings with considering structural performance degradations

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1. Introduction

Since the accident at Three Mile Island nuclear plant in 1979, it has become necessary to evaluate the internal pressure capacity of the containment buildings for the assessment of the safety of nuclear power plants [1-3]. According to this necessity, many researchers including Yonezawa et al. [4] and Hu & Lin [5] analyzed the ultimate capacity of prestressed concrete containments subjected to internal pressure. In these studies, the ultimate capacity analyses are performed for the containments under a fresh condition. However, most of nuclear power plants are exposed to the severe environments such as costal area and ambiance irradiation. Hence, the aging effects on a structural system caused by these environmental conditions should be considered for the estimation of internal pressure capacity in a quantitative manner. Especially in Korea, some containment structures were built in the late 1970 or early 1980, so that the degradation of their structural performance must also be explained in the procedure of the internal pressure capacity evaluation.

Therefore, in this study, we developed the degradation models for the structural components of prestressed concrete containment buildings, and evaluated the internal pressure capacity with considering aging and degradation factors. The target containment building types were PWR (Pressurized Water Reactor) and CANDU (CANada Deuterium Uranium) type containments which are the most typical reactor buildings in Korea.

2. Methods and Results

There exist many degradation and aging factors in the prestressed concrete structures. For the concrete material, the most of degradation factors can be classified into physical processes such as cracking, freezing & thawing, irradiation, fatigue, settlement, and chemical processes such as sulfate & biological attack, acids, aggressive water, etc. In general, these degradation factors finally cause a loss of section and tensile /compression strength of containment wall. We modeled such aging effect and considered for the internal pressure capacity estimation. In the prestressed concrete containment building, the loss of prestressing force is recognized another important aging factor. Hence, we also estimated the amount of prestressing loss for the evaluation.

For the modeling of containment buildings, there exists a burdening process on the modeling of tendons at the hatch area since their geometry is somewhat complicated. In this study, we developed a program which can automatically generate the coordination of the tendon components around the hatch areas. The FE-based general-purpose structural analysis program, ABAQUS [6], was adopted as an analysis tool and developed models were implemented into the input files. We modeled PWR and CANDU type containments as 3D FE models. For the modeling of the containment wall, dome, buttress and slab, solid elements were used. The reinforcement bars and tendons were modeled using embedded surface and truss elements, respectively. The material nonlinearity of the concrete was implemented by introducing the concrete damaged plasticity model [6]. The tri-linear plasticity model and piecewise linear stress-strain model were used for the material nonlinearity of steel rebars and tendons, respectively. In the preliminary analysis, the critical points under an internal pressure load were the top of the hatch and the middle of the containment wall areas.

Figures 1 and 2 show the results for the ultimate internal pressure capacity evaluation for the PWR type containment. The elastic capacity almost decreased linearly as the prestressing loss increased, while it does not vary during the degradation of the concrete strength. It can also be found that the loss of the concrete strength only effects the elastic stiffness of containment walls. The elastic internal pressure capacity decreased about 45% while the prestressing force was lost 60%. When the internal pressure reached the elastic capacity, the displacement response increased about 114% during the elastic modulus of concrete decreased 60%. For the PWR type containment, the internal pressure capacity will become smaller than the design internal pressure, about 57psi, if the loss of prestressing force exceeds about 50%.

Figures 3 and 4 show the results for the ultimate internal pressure capacity evaluation for the CANDU type containment. The overall tendency is almost same with that of PWR type containment. The elastic internal pressure capacity decreased about 37% while the prestressing force reduced to 40% of the original condition. When the internal pressure reached the elastic capacity, the displacement response increased about 122% during the elastic modulus of concrete decreased 60%. From the viewpoint of the degradation of the prestressing force, the CANDU type containment shows a sustainable performance compared to the PWR type because the internal pressure capacity is larger by two times that of the design internal pressure, about 18psi, even though the prestressing force remains just 40% of the fresh condition.

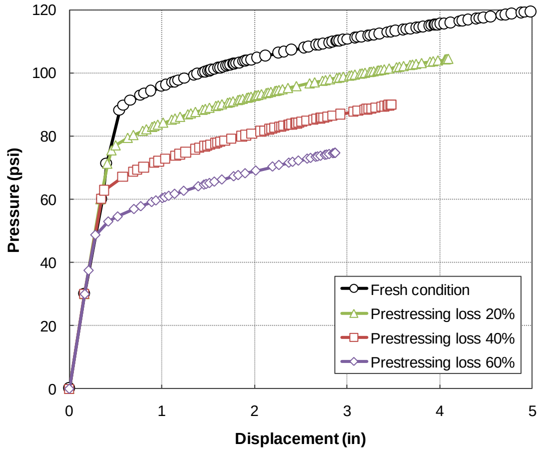

Fig. 1. Internal pressure capacity evaluation results considering the prestressing loss (PWR type, center of wall).

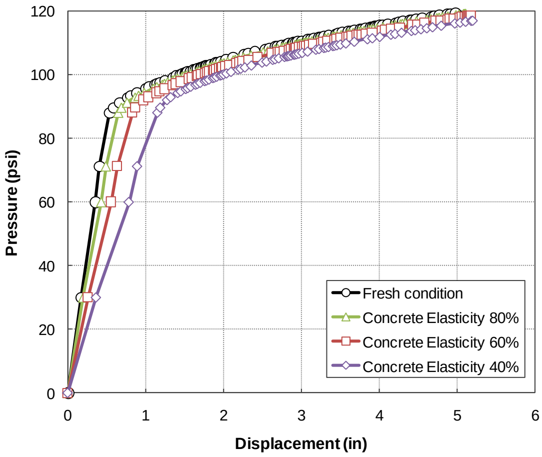

Fig. 2. Internal pressure capacity evaluation results considering the degradation of the concrete strength (PWR type, center of wall).

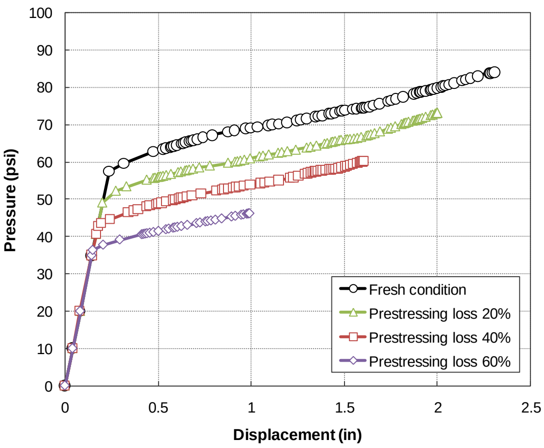

Fig. 3. Internal pressure capacity evaluation results considering the prestressing loss (CANDU type, center of wall).

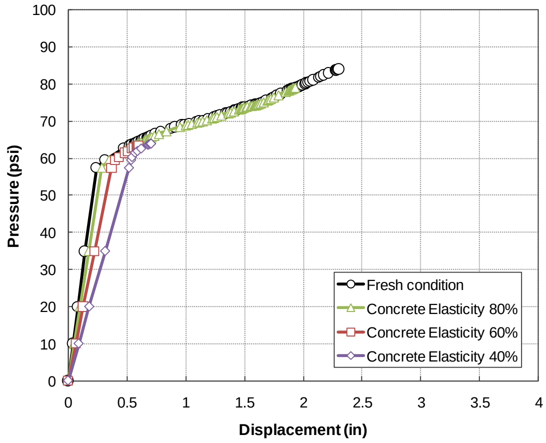

Fig. 4. Internal pressure capacity evaluation results considering the degradation of the concrete strength (CANDU type, center of wall).

3. Conclusions

We developed the degradation models for the structural components of prestressed concrete containment buildings, and evaluated the internal pressure capacity with considering aging and degradation factors. The FE-based general-purpose structural analysis program, ABAQUS was adopted as an analysis tool and developed full-3D nonlinear FE models were implemented. The results show that the elastic capacity almost decreased linearly as the prestressing loss increased, while it does not vary during the degradation of the concrete strength.

ACKNOWLEDGEMENT

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