Ultimate Pressure Capacity Assessment of Containment Structure considering Localized Corrosion of Liner Plate and Long-term Prestress Losses of Tendon

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1. Introduction

There have been reports of localized corrosion of Containment Liner Plate (CLP) at a few domestic and overseas nuclear power plants [1]. The CLP is a crucial functional component that serves as a sealing, preventing the external leakage of radioactive materials in the event of an accident involving internal pressure within the containment structure, such as LOCA or severe accident. Localized corrosion of CLP may result in strain concentration in some areas instead of uniform tensile strain under accidental internal pressure, and this phenomenon can prematurely reach the failure strain criterion specified in Standard Review Plan (SRP) 3.8.1[2].

Additionally, if the operational lifespan of NPP extends beyond its original licensed term, the tendon prestress deteriorates below the effective prestressing force. Therefore, it is necessary to analyze the impact of this on the ultimate pressure capacity of the containment structure.

In this study, two parameters that could affect the ultimate pressure capacity of an operating containment structure are considered and their respective impacts were analytically evaluated. And the two factors are considered simultaneously to analytically evaluate their impact on the ultimate pressure capacity of the containment structure. In this case, the strength and peak strain at a 50% corrosion rate decreased by approximately 20% compared to the uncorroded state.

2. Numerical Analysis Model

The three-dimensional finite element model of the APR1400 containment structure used for the analysis consists of concrete solid elements, steel and tendon truss elements, and CLP membrane elements.

The local corrosion ratio of CLP considered in the finite element analysis was assumed to be 0% and 50% with reference to the research results of Li et al.[3]. In the analysis model, the local corrosion phenomenon of CLP is considered as a decrease in strength and fracture strain based on the material model proposed by Li et al. instead of the thinning of the cross-section.

The loss rate of tendon prestress is calculated by considering short-term and long-term loss factors, and loss beyond the NPP's lifespan is estimated by extending the loss curve.

Comparison of analysis results considering influencing variables is performed at the location where the maximum membrane strain occurs at the free surface of the cylinder wall, as defined in SRP 3.8.1.

3. Analysis Results

2.1 Corrosion of CLP

Figure 1 compares the strain changes of CLP in non-corrosion(C0T60), overall corrosion(C50T60), and local corrosion(LC50T60) states with increasing pressure. In this analysis, the effective prestress of the tendon is introduced as the initial load.

In the case of an overall corrosion rate of 50% (C50T60) of CLP, the strain tended to increase after yielding compared to the strain in the non-corroded state. In other words, when the overall corrosion of 50% occurs in CLP, the pressure at 0.4%, which is the failure strain criterion of SRP 3.8.1, is found to be reduced by 7% compared to the non-corrosion state. Additionally, it is found that when local corrosion occurs near the location where the maximum strain occurs (LC50T60), the ultimate pressure capacity is slightly reduced compared to the case of overall corrosion.

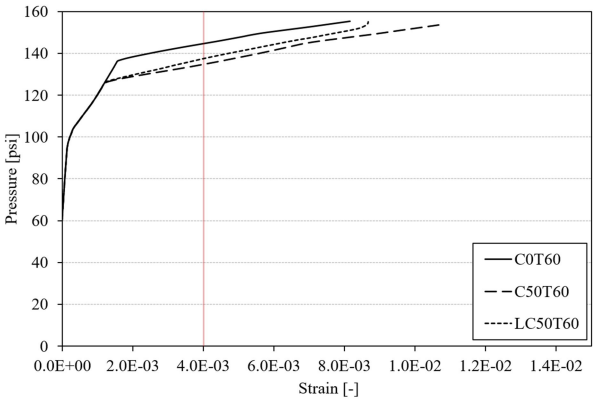

Fig. 1. Comparisons of internal pressure-strain relationships for overall corrosion and local corrosion of CLP

Table 1 summarizes the internal pressure levels for each analysis case when the CLP reaches the failure strain criterion of 0.4% according to SRP 3.8.1. The table also summarizes the strain of the reinforcing steel under the same pressure conditions.

Table 1. Summary of CLP corrosion consideration analysis results

Model name	CLP		Horizontal rebar
	Pressure	Strain	Strain
C0T60	144.70 (1.00)	0.004	0.0017 (1.00)
C50T60	134.80 (0.93)		0.0014 (0.85)
LC50T60	137.46 (0.95)		0.0014 (0.85)
C50T80	129.18 (0.89)		0.0013 (0.76)

2.2 Long-Term Loss of Tendon Prestress

Figure 2 shows a comparison of the analysis results considering the long-term loss of tendon prestress when the design life of the NPP extends 20 years and the analysis results considering the effective prestress of the tendon. In this analysis, the overall corrosion rate of 50% is considered simultaneously. Figure 3 shows the long-term losses and uncertainty range of tendon prestress over time calculated based on Regulatory Guide (RG) 1.35.1[4].

C50T60 and C50T80 represent analysis cases considering the effective prestress of the tendon and analysis cases considering the tendon prestress when the power plant life is extended by 20 years, respectively.

It is found that according to the tendon prestress is decreased due to long-term loss, the strain of the CLP increases at the same internal pressure level. However, the 20-year loss of tendon prestress is assessed to have only a minor effect, reducing the ultimate pressure capacity of the containment structure by less than 5%.

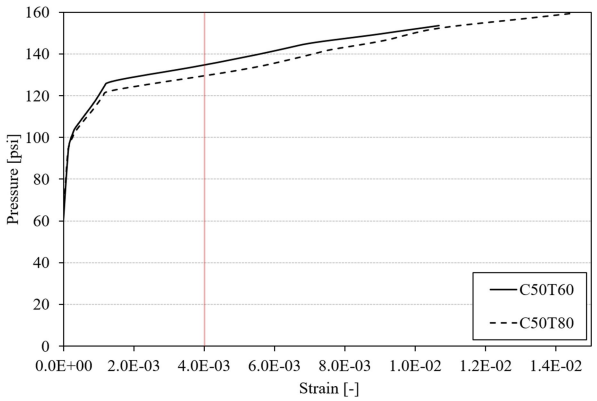

Fig. 2 Comparisons of internal pressure-strain relationships for effective prestress and additional prestress loss of tendon

4. Summary and Conclusions

This study assesses the effects of CLP corrosion and tendon prestress losses on the ultimate pressure capacity of APR1400 containment structure. The analysis results shows that overall and local corrosion of CLP reduce the ultimate pressure capacity required to reach the limit strain by approximately 7%. Additionally, under the same corrosion conditions of CLP, the additional loss of tendon prestress The additional loss of tendon prestress has only a minor effect of less than 5% on the ultimate pressure capacity of the containment structure.

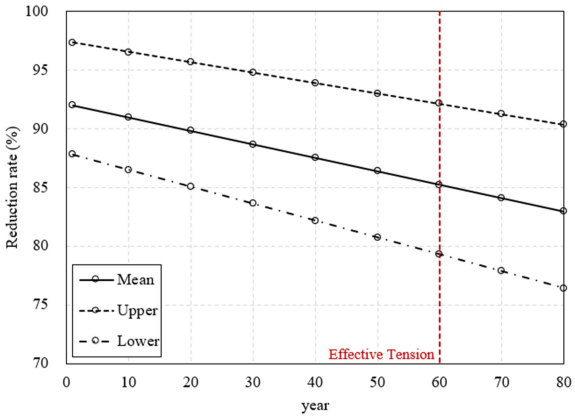

Fig. 3. Tendon prestress losses

In the next study, we plan to present a material model using the results of our own tests that reflect local corrosion of CLP. And we will evaluate the ultimate pressure capacity of the containment structure considering the material model.

REFERENCES

[1] D. S. Dunn, A. L. Pulvirenti and M. A. Hiser, "Containment Liner Corrosion Operating Experience Summary," Washington DC: Nuclear Regulatory Commission, 2011.

[2] U.S. Nuclear regulatory commission, " Standard Review Plan 3.8.1: Concrete Containment", September 2013.

[3] X. B. Li, X. Y. Wu and J. X. Gong, "Steel liner corrosion and its effects on the leak-tightness of the nuclear containment structure.", Annals of Nuclear Energy, Vol. 180, 2023, 109487.

[4] U.S. Nuclear regulatory commission, " Regulatory Guide 1. 35. 1: Determining Prestressing Forces for Inspection of prestressed concrete containments", July. 1990.

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