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Measured Prestress Loss of over 20-Year-Old Prestressed Concrete Containment Vessels

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1. Introduction

Most nuclear reactors, both in Korea and worldwide, are enclosed by a prestressed concrete containment vessels(PCCVs). The containment wall is approximately 1 m thick and is prestressed in two directions by large prestressing tendons. The main purpose of the containment is to maintain the structural integrity of the containment in the event of a major internal accident. The main accidental scenario, which the containment is designed to withstand, is a so-called loss of coolant accident (LOCA). A LOCA is initiated by a pipe rupture in the cooling system, discharging hot steam into the containment. The escape of steam increases both the temperature and pressure inside the containment. The increased internal pressure arising from a LOCA is referred to as the design pressure. The prestressing system is designed to counterbalance the tensile forces arising from the design pressure. The status of the containment is gradually changed due to environmental factors and by alterations in the micro structure of the material. The prestress will be reduced due to shrinkage and creep in the concrete and relaxation in the tendons.

The corrosion protection of tendons are for Korean containments arranged in two different ways, either by cement grouting (bonded tendons) or e.g. by grease injection (unbonded tendons). The major advantage using unbonded tendons is the possibilities of assessing their status (e.g. prestress losses or corrosion damages) which is not possible using bonded tendons. Both bonded and unbonded tendons are used worldwide. For example in the U.S. almost all tendons are unbonded, whereas in France almost all tendons are bonded.

For Korean reactor containments with unbonded tendons (14 containments) the tendon force is monitored at regular in-service inspections. The power plant Wolsung in Korea has bonded tendons and several prestressed concrete beams were constructed with the single purpose to follow up the prestress losses. The remaining tendon forces in some of these beams have recently been tested. Results from the beam tests and from the in-service-inspections for Korean containments are presented in this paper. The measured loss of tendon force has been estimated by using different models for predicting creep and shrinkage of the concrete and relaxation in the prestressing steel.

2. Methods and Results

2.1 Test on Beams with Bonded Tendons

When the nuclear power plant Wolsung was built in Korea several prestressed concrete test beams were fabricated. The beams were cast simultaneously and with the same concrete that was used for the containment walls. The test program was such that one beam was planned to be tested approximately every five year. The tests included e.g. determining the remaining tendon forces, the concretes compressive strength and modulus of elasticity. The main purpose of the tests was to roughly estimate the condition of the containment, e.g. regarding prestress losses.

The prestress losses of these beams have recently been tested and the degradation of ultimate pressure capacity of containment building has been evaluated with prestress losses estimated using finite element analysis. In total sixteen beams were tested, each of four beams from unit 1 to unit 4. In each beam there is one tendon placed in the center of the cross-section. For the PCCVs, two different post-tensioning systems have been used, BBR type 85 Ø 0.276 in for unit 1 and VSL type 37 Ø 0.500 in for unit 2 to 4, respectively. After the tensioning, each duct was injected with cement grout. The difference between the beams with the two different post-tensioning systems is the prestressing force and dimensions of bearing plates & ducts. The remaining tendon forces in the beams were determined by using jack rods, surveillance ram, and feeler gauge.

Fig.1 shows the normalized post-tensioning force of each test beam with respect to their service life when the tests were performed. Dotted line represents the 95% reliability post-tensioning force. From the graph, we can find that the prestressing force reduction rate is about 0.5% per year. We can also expect that the post-tensioning force will be degraded about 23% in thirty year service life. It can be noted that the value of prestressing loss of bonded tendons is relatively low especially compared to the test results of the Olkiluoto nuclear power plant built in Finland[1]. Anderson et al. reported that the prestressing force of test beams were reduced about 37 to 61% in thirty years of service time.

2.2 Tensioning Force Inspection of Unbonded Tendons

Korean reactor containments with unbonded tendons are located at three different power plants, four PCCVs at Kori, six at Youngkwang and Ulchin, respectively. The type of the entire reactors is pressurized water reactor (PWR).

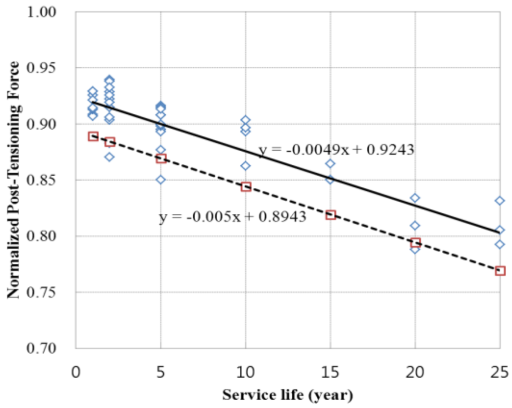


Fig. 1. Normalized post-tensioning force of bonded tendons.

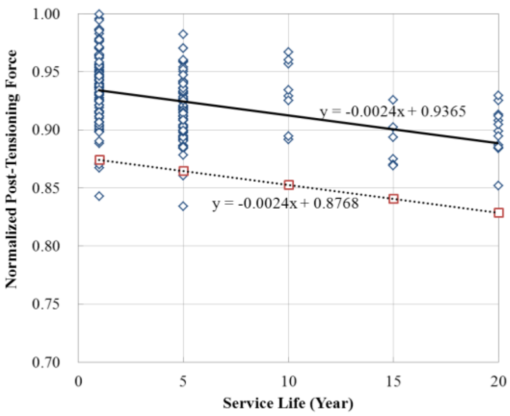
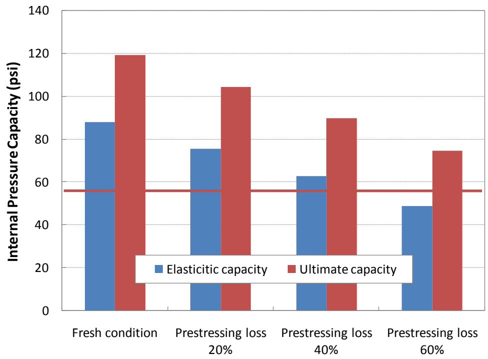


Fig. 2. Normalized post-tensioning force of unbonded tendons.

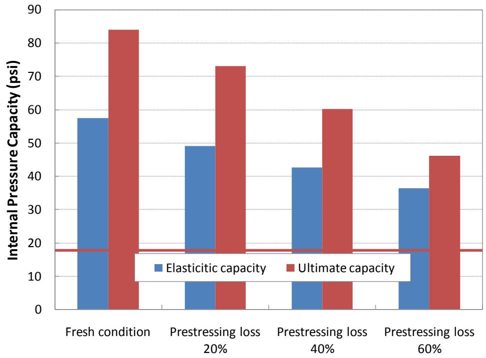
The inspections were performed 1 and 5 years after the structural integrity test and thereafter every 5th year. Lift-off technique is used for measuring tendon forces. Fig.2 shows the normalized post-tensioning force of each test tendons with respect to their service life when the tests were performed. Dotted line represents the 95% reliability post-tensioning force. It can be figured out that the prestressing force reduction rate is about 0.24% per year which is about a half of that of the bonded tendons. It can be also expected that the post-tensioning force will be degraded about 13% after thirty years of the construction.

2.3 Effect on the Pressure Capacity of PCCVs

Hahm et al., by using the 3-D finite element analysis, reported the elastic and ultimate pressure capacity of PWR type and CANDU type PCCVs with respect to the loss of prestressing force[2]. From the results (Fig. 3), the PCCV wall losses their elasticity at 75.5psi(14.3% reduction) of internal pressure load for PWR type reactor and 49.1psi(14.6% reduction) for CANDU type reactor when the prestressing force is reduced 20%. That capacity is quite above of the design pressure, 57psi for PWR type and 18psi for CANDU type PCCVs. Hence, we can conclude that the PCCVs have an enough safety margin in the viewpoint of resisting the design pressure load.



(a) PWR type PCCVs (unbonded tendons)



(b) CANDU type PCCVs (bonded tendons)

Fig. 3. Pressure Capacity of PCCVs with respect to Prestressing Loss

3. Conclusions

Measured prestress loss of over 20-Year-Old Korean PCCVs are reported. From the results, after thirty-year service life, it is expected that the post-tensioning force will be degraded about 23% for bonded tendons and about 13% for unbounded tendons. The degradation rate is about 0.5% per year for bonded tendons and 0.24% per year for unbounded tendons. From the finite element UPC analysis result, we can find that the pressure capacity is quite above of the design pressure, even though the PCCVs experienced the prestressing loss during thirty-year of service life.

ACKNOWLEDGMENT

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[2] D. Hahm, I.-K. Choi, H.-P. Lee, Internal Pressure Capacity Estimation of Prestressed Concrete Containment Buildings with considering Structural Performance Degradations, Transaction of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 22, 2009.