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Long-term Durability of the Safety-related Concrete Structures in Kori Unit 1 Nuclear Power Plant

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1. Introduction

Material properties and structural performance of nuclear power plant(NPP) concrete structures, subjected to physical and environmental stressors, degrade during life time due to continuous degradation such as steel corrosion, frost attack, chemical attack, leaching, and alkali aggregation reaction. Significant progress of the degradation causes degradations of structural safety, durability and functional performance and could have a serious effect on structural integrity[1,2]. To cope with the problems, the structure life management system (SLMS) involving the inspection of aging, the evaluation of the remaining service life and preserving the sustenance of the structural integrity as well as the repair of the NPP structures was established in 1997 by the utility[3]. And maintaining activities have been performed according to the SLMS data. The aging data of the structures provided by the SLMS are also utilized for periodic safety review and life extension.

Kori Unit 1 NPP has recently reached its design lifetime. Therefore, in order to extend its service life, the assessment of structural integrity and durability of the concrete structure was performed for the purpose of safety cinfirmation. Especially, the evaluation of the durability was focused on long-term durability against salt attack and carbonation which are the major aging factors to the seashore structures like Kori Unit 1 NPP. This paper presents detail observations obtained through this study.

2. Durability Evaluation Methods

2.1 Carbonation

The carbonation depth of concrete, the carbonation speed, is in proportion to the square root of time and can be generally expressed by means of the following equation [4].

$$C = A\sqrt{t} \qquad (1)$$

where, C is the carbonation depth, t is time, and A is the carbonation coefficient.

Furthermore, the service life under carbonation is assumed to correspond to the time in which carbonation reaches the outermost rebar. The remaining service life is calculated by subtracting the age at measurement from the service life.

2.2 Salt Attack

The assessment of degradation of concrete structures due to chloride aggression has been calculated with chloride diffusion equation (2) derived from Fick's Second Law[4].

$$C_{(x,t)} - C_i = (C_0 - C_i)\left[1 - erf\left(\frac{x}{2\sqrt{D_e t}}\right)\right] \qquad (2)$$

where, C(x,t) is the chloride concentration (kg/m^3) at the age of t(years) and at the depth of x(cm), C_i is the initial chloride concentration (kg/m^3) assumed to be 0 here. C_0 is the external chloride concentration(kg/m^3) at the age of t and at the surface. The relative salinity is obtained from the analysis of the salinity data measured for 2 years through the salinity sampling device installed in Kori Unit 1 NPP. Thereafter, the salinity is obtained by means of the relationship between the salinity and concentration of chloride on the surface as expressed in equation (3) and proposed by KICT[5].

$$C_0 = 0.0944C_a + 0.7645 \qquad (3)$$

where, C_a is the flying salinity contents.

D_e is the diffusion coefficient of chloride in concrete (cm^2/year) estimated on the basis of the measured data for Kori Unit 1 NPP. t is elapsed time(sec) after construction, x is depth(cm) from the concrete surface, and erf is the error function.

$$erf\ (x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-\mu^2}du \qquad (4)$$

Besides, the lifetime with respect to chloride is assumed to be the initiation of the corrosion of steel, which corresponds to 0.03% of critical chlorides in the concrete around the rebar as proposed by various researcher[6] for the limit at which initial corrosion due to chloride may occur.

3. Results and Discussion

3.1 Carbonation

The carbonation coefficient A in Kori Unit 1 NPP structures was obtained through the relationship between the carbonation depth C actually measured on site and the age t at measurement. Table 1 shows the evaluation results for the remaining service life. Though the computed remaining service life exhibits slight differences according to the structures, the minimum remaining service life were assessed to be 57 years.

Moreover, the rebar cover depth of the ESWIS being significantly larger than those of the other structures, degradation appears to be induced by chloride rather than carbonation, which may explain the overestimation of the remaining service life.

Table 1. Evaluate the Carbonation of Kori #1 Structures

Designation of Structure	Cover Depth (mm)	Carbonation Depth at 30 years (mm)	Carbonation Coefficient *A*	Carbonation Depth at 40 years (mm)	Residual Lifetime (year)
ACB	41.4	22.6	4.1	26.1	70
FHB	49.8	21.3	3.9	24.6	> 100
CCWB	53.0	29.5	5.4	34.1	67
DGB	34.8	20.42	3.7	23.6	57
ESWIS	68.8	21.6	3.9	24.9	> 100

[Note] ACB : Auxiliary & Control Building, FHB : Fuel Handling Building, CCWB : Component Cooling Water Building, DGB : Diesel Generator Building, ESWIS : Essential Service Water Intake Structure

3.2 Salt Attack

The Kori Unit 1 NPP structure was exposed to marine environment. Accordingly, the external concentration of chlorides C_0 is naturally depending on the ambient salinity. The flying salinity content of Kori Unit 1 NPP structure was analyzed to be 1.35(NaCl, mg/100cm^2/day) based on the salinity data measured for 2 years(Dec. 2004-Dec. 2006) by means of a salinity sampling device installed in the structure.

In addition, the result obtained by conversion of the chloride contents at the surface from the relationship between the flying salinity content and the chloride contents at the surface of concrete in equation (3) revealed that the external concentration of chlorides C_0 is 0.89 kg/㎥.

Table 2 shows the evaluation results of the residual life and chlorides in the concrete around the rebar of safety-related structures at 40 years in Kori Unit 1 with respect to the chloride diffusion coefficient measured in Kori Unit 1. It can be seen that the quantity of chlorides in steel at 40 years ranges between 0.016 % and 0.027%, which corresponds to the degraded state class 2 with respect to the chloride ingress assessment criteria of KHNP's inspection procedure[3]. Moreover, in view of the degradation prediction resulting from equation (2), the occurrence of steel corrosion exhibits minimum 36 years from now. However, as the data obtained during the inspection for the durability evaluation of structures are limited and the variation of the data is large with the locations, it is necessary to develop more enhanced inspection method to ensure the reliability of the inspection data. Also, the deterioration evaluation of a structure through consistent observation and periodic monitoring is required.

Table 2. Evaluate the Salt Attack of Kori #1 Structures

Designation of Structure	Chlorides in Concrete around the Rebar at 30 years (%)*	Chloride Diffusion Coefficient D_e (㎠/year)	Chlorides in Concrete around the Rebar at 40 years (%)	Residual life (year)	Class
RSB	0.016	0.431	0.018	> 100	2
ACB	0.016	0.431	0.018	> 100	2
FHB	0.015	0.384	0.017	> 100	2
CCWB	0.013	0.309	0.016	> 100	2
DGB	0.024	1.277	0.026	64	2
ESWIS	0.026	1.817	0.027	36	2

[Note] RSB : Reactor Shild Building

4. Conclusions

As a result of this study, the residual life of safety-related concrete structures in Kori Unit 1 NPP is predicted as minimum 57 and 36 years, respectively for carbonation and chloride ingress. However, as the obtained inspection data for the durability evaluation of structures are limited and the variation of the data is large with the locations, it is necessary to develop more enhanced inspection method to ensure the reliability of the inspection data. Also, the aging assessment of a structure through consistent observation and periodic monitoring is required.

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