Long-Term Behaviors of the OPC Concrete with Fly-ash and Type V Concrete Applied on Reactor Containment Building

Yoon, Eui-Sik,*a* Park, Young-Soo,*b* Lee, Hee-Taik,*a* Paek, Yong-Lak,*c*
a Department of Structural System and Site Evaluation, Korea Institute of Nuclear Safety, Daejeon, 305-338, Korea
k319yes@kins.re.kr
b Civil Engineering Team, Shin-Kori 1&2 Construction Office, Korea Hydro & Nuclear Power Co. Ltd., Busan, 619-711, Korea
c Division of Nuclear Regulation, Korea Institute of Nuclear Safety, Daejeon, 305-338, Korea

1. Introduction

The prestressed concrete has been used extensively in the construction of Reactor Containment Buildings (RCBs) in Korea in order to strengthen the RCBs and at the same time, prevent the release of radiation due to the Design Basis Accident and Design Basis Earthquake. It is well known that the prestressed concrete loses its prestressing force over the age, and the shrinkage and creep of the concrete significantly contributes to these long term prestressing losses.

In this study, an evaluations of long term behaviors of the concrete such as creep and shrinkage have been performed for two types of concretes : Ordinary Portland Cement containing fly-ash used for the Shin-Kori 1&2 NPP and Type V cement used for the Ul-Chin 5&6 NPP.

2. Experimental Investigation

2.1 Material

2.1.1 Cement

For RCB concrete, Type V portland cement(low-heat and high sulfate resistant type) and ordinary portland cement(OPC) are used for the Ul-Chin(UCN) 5&6 NPP and the Shin-Kori(SKN) 1&2 NPP, respectively.

2.1.2 Aggregate

Fine & coarse aggregates used for the UCN 5&6 NPP are natural sands and gravels from the Gagok stream in Sam-Chok. In the SKN 1&2 NPP, natural sands from Naksan in Gumi and crushed stone from the NPP construction site are used.

2.1.3 Fly Ash

Fly-ash for the SKN 1&2 NPP concrete was manufactured at Samchunpo Thermal Power Plant in accordance with ASTM C 618 Class F.

2.2 Mix proportion

Mix proportions for concrete used in RCBs of UCN 5&6 and SKN 1&2 were determined through test mix proportions. The procedures of test mix proportions are based on ACI 211.1 to meet the criteria of ACI 349, ACI 211.1 and design compressive strength (5500psi at 91 days). Table 1 shows the mix proportions.

Table 1. Mix Proportions of Concrete for Reactor Containment Building of the UCN 5&6 and the SKN 1&2

NPP Units	Specified Strength (psi)	W/B	S/a (%)	Air (%)	Slump (in)	Unit Weight (lb/yd^3)					Chemical Agent (oz)	
						Cement Material		Water	Aggregate			
						Cement	Fly Ash		Fine	Coarse	WRA	AEA
UCN 5&6	5,500	0.45	0.43	3.5~6.5	3±1	632	-	276.3	1250	1682	40.46	0.46
SKN 1&2	5,500	0.45	0.44	3.5~6.5	4±1	493	123	277	1274	1635	39.42	1.48

2.3 Test Method

2.3.1 Drying Shrinkage

According to ASTM C 157, specimens of 10×10 ×28.5cm prisms were made and the specimens were de-molded at an age of 24 hours. The specimens, then, had been stored in water at a constant temperature of 23±1.7℃ for 28 days and 91 days respectively. After 28 days and 91 days, the length of the specimen had been measured periodically by using Whitmore strain gauges at the constant temperature of 23±1.7℃ and humidity of 50±4%RH during 64 weeks.

2.3.2 Creep

Cylindrical specimens of 15×30cm was tested according to ASTM C 512. Firstly, the circumferential surfaces of the specimens were sealed by paraffin to prevent loss of moisture, after moist-cured at a constant temperature of 20±2℃ for 7 days. Then, all specimens had been moist-cured at a constant temperature of 23±1.7℃ and humidity of 50±4%RH for 28, 91, 180 days and 365 days correspondingly. After cured for certain periods of times, the amount of creep under a 30% sustained loading of the specified compressive strength for one year had been measured. Drying creeps of the specimens were also evaluated by approximately measuring the amount of shrinkage after sealing the circumferential surface of cylindrical specimens of 15×30 cm using paraffin.

3. Results and Discussion

3.1 Drying Shrinkage

Fig. 1 shows the drying shrinkage of concrete used in UCN 5&6 and SKN 1&2 RCBs.

The shrinkage of the OPC concrete containing fly-ash is higher than that of the Type V concrete at early age. However, as time passes, shrinkage of the OPC concrete containing fly-ash is less than that of the Type V concrete.

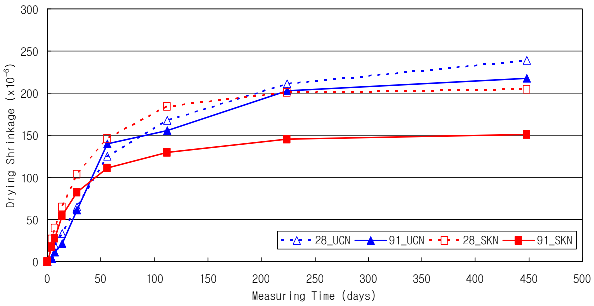

Fig. 1 Drying Shrinkage of Concrete used in the UCN 5&6 and the SKN 1&2

Once shrinkages of specimens at a curing age of 91 days are measured after 64 weeks, drying shrinkage are 151×10^{-6} in/in for the OPC concrete containing fly-ash and 218×10^{-6} in/in for the Type V concrete. Note that the results exceed the design shrinkage strain of 100×10^{-6} in/in. These results, nevertheless, have slight influence on the structural integrity of NPPs, since not only does the accumulated loss of prestressing force due to elastic shortening, shrinkage, creep of concrete and relaxation of tendon fall short of the design values, but post-tensioning is also introduced after required curing(91 days) has been fulfilled.

3.2 Creep

Table 2 and Fig. 2 shows the creep for concrete used in UCN 5&6 and SKN 1&2 RCBs. The results show that all creeps such as total creep, drying creep and basic creep of the OPC concrete containing fly ash were less than those of the Type V concrete at any age of loading. In addition, specific creep of the OPC concrete containing fly-ash was markedly less than that of the Type V concrete. This trend becomes apparent as the length of loading time decrease.

Also, the estimations of specific creep over 40 years according to both the prediction formula in ACI 209R and Hansen's formula in Reg. Guide 1.35.1 are performed.

Table 2. Creep of Concrete used in UCN 5&6 and SKN 1&2 at the 365 Days after Loading

NPP Units	Loading Ages (day)	Total Creep ($\times10^{-6}$)	Drying Creep ($\times10^{-6}$)	Elastic Strains ($\times10^{-6}$)	Basic Creep ($\times10^{-6}$)	Specific Creep ($\times10^{-6}$/psi)	Creep Coefficient φ	
							Total	Basic
UCN 5&6	28	1919	513	489	917	0.5558	2.8753	1.8753
	91	1498	324	464	710	0.4303	2.5302	1.5302
	182	1162	203	428	531	0.3218	2.2407	1.2407
	365	775	76	382	317	0.1921	1.8298	0.8298
SKN 1&2	28	1129	356	362	411	0.2491	2.1354	1.1354
	91	1030	293	355	382	0.2315	2.0761	1.0761
	182	831	165	341	325	0.1970	1.9531	0.9531
	365	649	71	315	263	0.1594	1.8349	0.8349

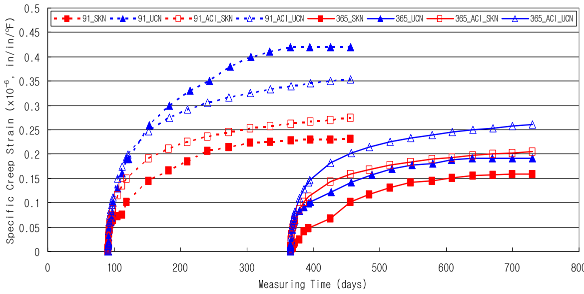

Fig. 2 Creep of Concrete used in the UCN 5&6 and the SKN 1&2

In case of loading after 365 cured, the specific creeps predicted by the formula in ACI 209R are 0.26×10^{-6} in/in/psi for the SKN 1&2 and 0.32×10^{-6} in/in/psi for the UCN 5&6. The predictions by Reg. Guide 1.35.1 are 0.33×10^{-6} in/in/psi for the SKN 1&2 and 0.34×10^{-6} in/in/psi for the UCN 5&6. Note that all of these values satisfy the design criterion of 0.50×10^{-6} in/in/psi.

4. Conclusion

The test results can be summarized as :

(1) At early age, the shrinkage of the OPC concrete containing fly-ash is slightly higher than that of the Type V concrete. As time passes, however shrinkage of the OPC concrete containing fly-ash becomes less than that of the Type V concrete. Although shrinkage strains of the concrete cured for 91 days measured after 64 weeks exceed the design shrinkage strain regardless of cement types, the accumulated loss of prestressing force considering long-term characteristics of concrete and tendon is less than the design accumulated loss of presstressing force.

(2) Both creep strain and specific creep of the OPC concrete containing fly-ash are significantly less than those of the Type V concrete. This trend becomes apparent as the length of loading time decreases. In addition, the design creep predicted by the Hansen's formula in Reg. guide 1.35.1 is slightly higher than that by the formula in ACI 209R. Types of cement do little influence on creep behaviors and all the prediction values fall within design criteria of 0.5×10^{-6} in/in/psi.

References

[1] ACI 209R, "Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures", ACI 209 Committee, 1992
[2] Reg. Guide 1.35.1, "Determining Prestressed Forces for Inspection of Prestressed Concrete Containments", US NRC, 1990.7
[3] ASTM C 512, "Standard Test Method for Creep of Concrete in Compression"