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Creep Characteristics of Concrete for Reactor Containment Structure

H.-W. Song [1], K.-J. Byun[1], Y.-C. Song[2] and W.-S. Jeoung[2]

1) Yonsei University, Korea
2) Korea Electric Power Research Institute, Korea

ABSTRACT

Since the biggest time-dependent prestress loss of reactor containment concrete structure is due to creep of concrete, the creep is one of important structural factors to be considered for the safety in the reactor containment structure during design, construction and maintenance. In this paper, the creep characteristics of concrete of the reactor containment structure made of type V cement are obtained from creep test. Then, in order to evaluate the applicability of major creep prediction equations by the AASHTO LRFD Design Specification, the Japanese Standard Specification for Concrete Structure, the ACI Committee 209 and the CEB/FIP Model Code, the creep test results are compared with prediction results using the prediction equations. From the comparisons, the applicability of the equations is discussed.

INTRODUCTION

Most of the reactor containment structures of nuclear power plants are prestressed concrete structures. The creep and shrinkage of concrete and the relaxation of steel tendon are the main causes of pre-stressing loss in the reactor containment structures and these are related to the safety of the reactor structures. Among them, the creep of concrete is the biggest source of the time-dependent prestress losses. So, it is very important to consider the concrete creep effect for design, construction and maintenance of the reactor structures[1]. Especially, in initial design phase, the loss of pre-stressing force due to the creep is predicted by using reliable creep prediction equations because the creep test is very much time consuming. Since the first paper on the creep was presented in ACI report about ninety-five years ago, a number of prediction equations for concrete creep have been proposed. Since the concrete for the reactor containment structures is made of the type V cement, it is important to investigate creep characteristics of the concrete from creep tests and applicability of creep prediction equations.

In this paper, creep tests are performed by using concrete specimens made of type V cement according to the procedure of ASTM C512[2]. Test results are compared with prediction results by the major creep prediction equations by the ACI committee 209 (ACI, 1982)[3], the CEB/FIP (1990)[4], the JSCE (1996)[5] and the AASHTO (1994)[6]. The creep prediction equation of the LRFD bridge design specification of the AASHTO was adopted to the Korean Standard Specification for Concrete Structure of KSCE (1996)[7]. Then, in this paper, the applicability of the prediction equations for the creep of the concrete made of type V of reactor containment structures are evaluated from the comparison.

CREEP TEST FOR CONCRETE OF REACTOR STRUCTURE

Test Procedure

Creep test is carried out according to standard test method of the ASTM C512[2] under the condition shown in Table 1. In order to represent the same property of on-site concrete of the reactor containment, all components of concrete used in mix design are same as used for concrete at the construction for a concrete reactor containment structure in Korea. Table 2 summarizes the mix design for the concrete. The properties of constituent materials of the concrete are presented in Table 3. The compressive strength of the concrete at age of 28 days is 5,000 psi (352 kgf/cm^2).

Table 1 Creep test condition

Temp. in Curing	Humidity	Temp.	Age at Loading (Day)	Cycle of Measurement (Day)	Correction of Loading
23±2℃	50±4℃	23±2℃	2, 7, 28, 180, 365	before loading, after loading (2~6 time) 1, 2, 3, 4, 5, 6, 7, 2 weeks, 3 weeks, 4 weeks, every month ·······1 year	when it changes over 2%

Table 2 Mix design

Max. Aggregate Size	Slump (cm)	Air Content (%)	W/C (%)	S/A (%)	Quantities (kg)				Admixtures (ml)	
					W	C	S	G	AE Agents	Water-reducing admixture
20	10	5.5	42	43.7	165	393	762	983	40	1572

Table 3 Properties of constituent materials for concrete

Division	Cement	Coarse Aggregate	Fine Aggregate	Admixture (ml)	
				AE Agents	Water-reducing admixture
Rel. Density (SSD)	3.15	2.62	2.55	1.03	1.15
FM	-	-	2.83	-	-
Water Absorption Rate	-	1.80	2.35	-	-
Unit Weight	-	1.663	1.639	-	-

Modulus of elasticity and Poisson's ratio are measured from tests according to standard method of the ASTM C469[8] for three 15 cm by 30 cm cylindrical concrete specimens, at ages of 7, 28, 90, 180 and 365 days. For determining the modulus of elasticity, the compressometer is used. The compressive strength of concrete is measured at ages of 7, 28, 90, 180 and 365 days and creep tests are also performed by loading at the moist curing ages of 7, 28, 90, 180 and 365 days for the period of one year. For each ages, total seven 15cm by 30cm cylindrical concrete specimens are prepared and tested, i.e., three specimens are tested for the compressive strength, two are loaded and observed for total deformations, and two are remained unloaded for the measurements of drying shrinkage deformations. Since creep of concrete is proportional to the stress about up to 40% of concrete compressive strength, creep test specimens are loaded with compressive strength below 40% of the compressive strength at each age of loading. Strains are measured immediately before and after loading, 2 to 6 hours after loading, then daily for a week, weekly until the end of one month, and monthly until the end of one year. The concrete specimens for these test items are summarized in Table 4.

Table 4 Test specimens

Test Item	SPEC	Size	No.	Equipment	Plan & Time
Modulus of Elasticity & Poisson's Ratio	ASTM C469	$\phi 15 \times 30$cm	$6 \times 5=30$	- Compressive Strength Tester - Compressometer - Extensometer	◦ Preparation : 1 day ◦ Molding : day/time: #30 : 1 day ◦ Unmolding : 1 day ◦ Measurement : 5 days ◦ Total required time : 8 days
Creep	ASTM C512	$\phi 15 \times 30$cm	$7 \times 5=35$	- Creep Tester #5	◦ Preparation : 1 day ◦ Molding : 1 day ◦ Unmolding : 1 day ◦ Measurement : after setting : 1 day, 7 days (day interval), 4 days (week interval) 12 days (month interval) ◦ Total required time for measuring : 24 days$\times$5 (age) = 120 days ◦ Total required time : 123 days

Test Results

The compressive strength σ_{ck} , modulus of elasticity E and Poisson's ratio μ averaged with tested three specimens are summarized in Table 5. As shown in Table 5, the compressive strength of concrete increases with ages and, after 90 days, it reaches constant value near about 500 kgf/cm^2. The 28-day compressive strength is 470 kgf/cm^2 which is far larger than the specified compressive strength 352 kgf/cm^2. The modulus of elasticity increases with ages, but it tends to become gradually constant with time. All measured values for every ages exceed the design modulus of elasticity 290,000 kgf/cm^2. Poisson's ratio shows a relatively constant value regardless of time, thus reaching 0.21 after 90 days which is also larger than the Poisson's ratio for design, 0.18.

Fig. 1 shows the test results on specific creep according to different ages of loadings. It can be seen that creep strains increase steeply up to one month, and then increase smoothly with ages.

Table 5 Measured σ_{ck}, E and μ in curing ages

Curing Ages (days)	7	28	90	180	365
28-day Compressive Strength, σ_{ck} (kgf/㎠)	366	470	483	600	811
Modulus of Elasticity, E_c (kgf/㎠)	301,330	346,704	351,857	406,218	466,190
Poisson's Ratio, μ	0.1987	0.1982	0.2139	0.2367	0.2350

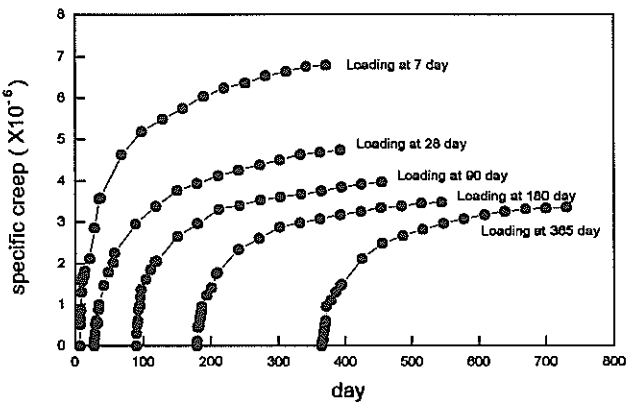

Figure 1 Specific creep from creep tests

CREEP PREDICTION

Major prediction equations of creep considered in this study are the equations of the AASHTO-94[6], the ACI-209[3], the CEB/FIP-90[4] and the JSCE-96[5]. Creep prediction procedure including the definition of specific creep used in this study is presented in Table 6. Table 7 shows the parameters to be considered at each creep prediction equations, such as structural shape, concrete internal properties and external environment condition. Especially, external environment conditions consist of curing time, curing method, temperature, relative humidity and loading age.

Table 6 Creep prediction procedure

Creep strain(ε_c) under applied constant stress(σ_c)

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Steady linear creep compliance

- Creep coefficient ϕ
  $\varepsilon_c = \phi \varepsilon_0$
  where ε_0 : initial elastic strain
- Specific creep C
  $C = \varepsilon_c / \sigma_c$

↓

Creep prediction for ϕ

- AASHTO-94
- ACI-209
- CEB/FIP-90
- JSCE-96

↓

Creep analysis method

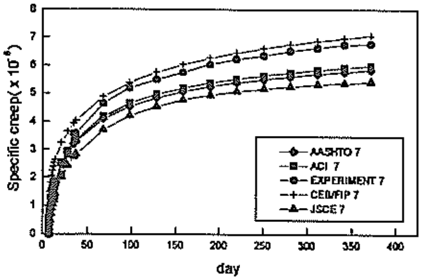
↓

Creep strain under the various stress histories

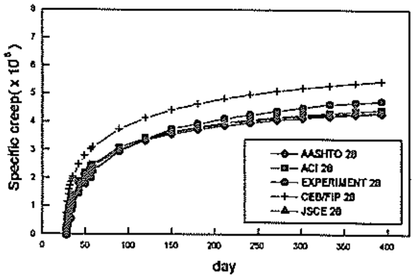
Table 7 Creep prediction parameters

	Parameter	AASHTO-94	ACI-209	CEB/FIP-90	JSCE-96
internal	C				*
	W				*
	W/C				*
	s/a		*		
	σ_{ck}	*		*	
	Slump		*		
	Air		*		
	Type of Cement			*	
structure	Volume/Surface, (V/S)	*	*		*
	Ave. thickness		*	*	
external	Curing time		*		
	Curing method		*		
	Temperature			*	
	Relative humidity	*	*	*	*
	Age when loading starts	*	*	*	*

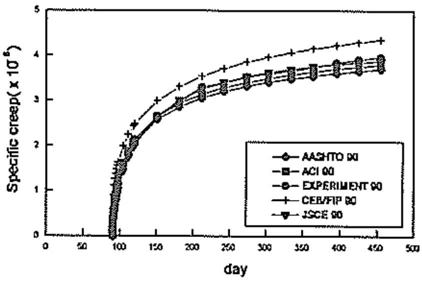
Fig. 2 and Table 8 show the results about the specific creep predicted by the equations along with test results according to different loading ages.



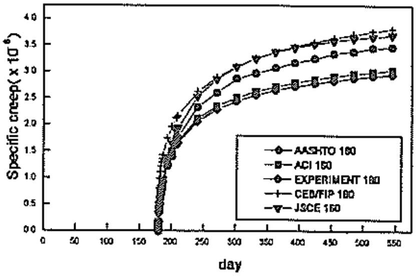
(a) Loading at 7 days



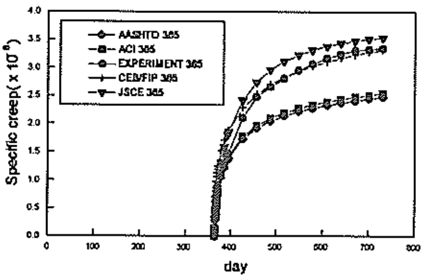
(b) Loading at 28 days



(c) Loading at 90 days



(d) Loading at 180 days



(e) Loading at 365 days

Figure 2 Specific creep due to loading at 7, 28, 90, 180 and 365 days

Table 8 Comparison of specific creep (unit : $\times 10^{-6}$)

Method \ Day	7		28		90		180		365	
	specific creep	ratio	specific creep	ratio	specific creep	ratio	specific creep	ratio	specific creep	ratio
AASHTO-94	5.84	0.86	4.31	0.91	3.70	0.93	2.95	0.85	2.48	0.74
ACI-209	6.00	0.88	4.42	0.93	3.80	0.95	3.03	0.87	2.54	0.76
CEB/FIP-90	7.07	1.04	5.44	1.15	4.35	1.10	3.81	1.10	3.32	0.99
JSCE-96	5.41	0.79	4.33	0.91	3.88	0.98	3.70	1.07	3.54	1.06
Experiment	**6.78**	**1.00**	**4.74**	**1.00**	**3.96**	**1.00**	**3.47**	**1.00**	**3.35**	**1.00**

From the comparison, it is shown that both measured and calculated specific creep show general tendency of decreased specific creep according to the loading age. The prediction by the equations of the AASHTO and the ACI underestimates specific creep and the underestimation is fairly large for the case of loading at 365 days. The prediction by the JSCE also underestimates specific creep for early age loading except for the case of loadings at 180 days and 365 days. The prediction equation of the CEB/FIP-90 predicts specific creep conservatively in general and predicts well the changes of specific creep according to different loading ages.

CONCLUSION

In this paper, the creep characteristics of concrete for reactor containment concrete structure made of the type V cement are shown from creep tests. Then, the applicability of major creep prediction equations by the AASHTO LRFD Design Specification, the Japanese Standard Specification for Concrete Structure of JSCE, the ACI Committee 209, and the CEB/FIP-90 Model Code is evaluated by the comparison with the creep test results. It is concluded that the creep prediction equation of the CEB/FIP Model-90 can be well applied to predict specific creep for concrete made of the type V cement for the reactor containment concrete structures.

REFERENCE

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