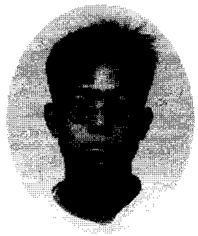
Time-dependent Material Properties in FCM Segment of Prestressed Concrete Box-Girder Bridge



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ABSTRACT

In designing the prestressed concrete box-girder bridge, dead load, prestressing force, creep and shrinkage of concrete are the main factors which influence the camber and deflection of segmental concrete structure under construction. Among these factors the creep and shrinkage are the functions of the time-dependent property which, therefore, must be considered with time. The prediction model for estimating creep and shrinkage of concrete has been suggested by ACI, CEB/FIP, JSCE and KSCE design code and EMM, AEMM, RCM, IDM and SSM has been suggested for analytical method in consideration of time-dependent characteristics. In this study, the creep test was carried out for four different curing ages of concrete which were applied to the prestressed concrete structure at the construction site, and the results of test were compared with the values of creep prediction proposed by the design code. Also the creep test was performed with step-wise incremental stresses and the results were compared to the analytical values.

Keywords : prestressed concrete, creep, shrinkage, time-dependent characteristic, prediction model, analytical model

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1. INTRODUCTION

In the PSC box-girder bridge the free cantilever method(FCM) joints the cantilever girders at the center after constructing 3 to 5 segments with balancing from main pier using moving traveler without strut which supports the load beneath the bridge.

In designing this PSC box-girder bridge, dead load, prestressing force, creep and shrinkage of concrete are the main factors which influence the camber and deflection of segmental concrete structure under construction. Among these factors the creep and shrinkage are the functions of the time-dependent properties which, therefore, must be considered with time.

Therefore, in this paper the creep test was carried out for four curing ages of concrete which were applied to the prestressed concrete structure at the construction site, and the results of test were compared to the values of creep prediction proposed by the design code. Also the creep test was performed with step-wise incremental stresses and the results were compared to analytical values.

2. RESEARCH SIGNIFICANCE

The prediction model for estimating creep and shrinkage of concrete has been suggested by ACI, CEB/FIP, JSCE and KSCE design code, and EMM, AEMM, RCM, IDM and SSM have been suggested for analytical method in consideration of time-dependent characteristics. The main subject of this study is that experimental results are compared with prediction and analytical models whose basic models are adopted by experimental model and CEB/FIP-78 model.

3. EXPERIMENTAL PROGRAM

Tests of creep and shrinkage in the PSC box-girder bridge were performed according to ASTM C-512 provision. Table 1 summarizes the conditions of creep and shrinkage test.

The specimens for creep and shrinkage test were made at the construction site and tested in constant temperature and humidity room. Fig.1 and 2 show the overall longitudinal view of the box-girder bridge and compressive creep test machine, respectively.

Also three $\phi 150\times 300$mm specimens were made for the determination of strength and elastic modulus of concrete, and were tested according to ASTM C-469 provision.

Table 1 Condition for creep and shrinkage test

	Creep test	Shrinkage test
shape (mm)	$\phi 150\times 300$	$\phi 150\times 300$
humidity (%)	50±4	50±4
temperature (℃)	23±2	23±2
age (day)	3, 7, 28, 90 3(incremental stress)	3, 7, 28, 90
measurement period	before and after loading, 2 to 6 hour later, then daily for 1 week, weekly until the end of 1 month, and monthly until the end of 6 months.	the same period as creep test
load control	load varies more than 2% from the correct value.	-

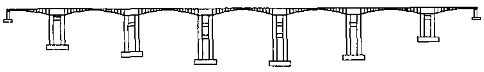

Fig.1 overview of box girder

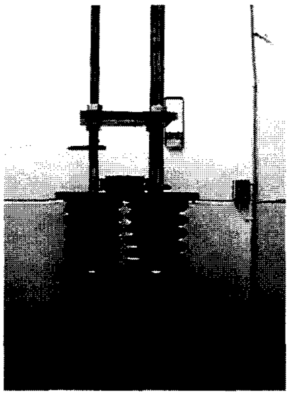

Fig.2 Compressive creep testing machine

3.1 Test of Creep with Incremental Loading

Table 2 represents the mean incremental stresses with time acting on fifth segment concrete which was measured ignoring the reinforcing steel and tendon effect.

3.2 Material Property

Table 3 summarizes the mix design proportion of concrete used to make specimens.

Table 3 Concrete mix design

Design Compressive Strength(kgf/cm^2)	400
Max. Aggregate Size (mm)	19
W/C (%)	30.5
s/a (%)	41
Water (kg)	163
Cement (kg)	534
Air content (%)	3.5
Superplasticizer (g)	3738
Air-entraining agent (g)	5430
Slump (cm)	15

Table 4 Mean compressive strength and elastic modulus

Ages (Day)	Mean Compressive Strength (kgf/cm^2)	Modulus of Elasticity ($\times 10^5$ kgf/cm^2)
3	330	2.13
7	454	2.42
28	544	2.68
90	550	2.91

Table 2 Mean compressive stress at each segment

Construction Procedure	Position	Section Stress (kgf/cm^2)									Time (Day)
		Dead Load		Pre-stressing Force		Top Section (1)+(3)	Bottom Section (2)+(4)	Mean Top Section	Mean Bottom Section	Mean Section	
		Top Section (1)	Bottom Section (2)	Top Section (3)	Bottom Section (4)						
Fifth Segment	A	0.6	-0.8	-21.9	2.7	-21.3	1.9	-19.45	-0.20	-9.83	0
	B	4.2	-5.5	-21.8	3.2	-17.6	-2.3				
Sixth Segment	A	4.8	-6.4	-44.0	5.7	-39.2	-0.7	-35.50	-4.70	-20.10	12
	B	11.7	-15.1	-43.5	6.4	-31.8	-8.7				
Seventh Segment	A	13.1	-17.6	-67.1	10.4	-54.0	-7.2	-48.75	-12.65	-30.70	24
	B	22.5	-29.0	-66.0	10.9	-43.5	-18.1				
Eighth Segment	A	25.0	-33.8	-78.6	12.7	-53.6	-21.1	-47.25	-27.35	-37.30	36
	B	36.3	-46.8	-77.2	13.2	-40.9	-33.6				
Ninth Segment	A	40.3	-54.7	-89.5	14.2	-49.2	-40.5	-42.15	-47.00	-44.58	48
	B	52.8	-68.2	-87.9	14.7	-35.1	-53.5				
Tenth Segment	A	56.7	-77.2	-100.4	15.7	-43.7	-61.5	-36.10	-68.05	-52.08	60
	B	70.1	-90.8	-98.6	16.2	-28.5	-74.6				

4.TEST RESULTS

Table 4 represents the mean compressive strength and elastic modulus at each age and Fig.3 shows the elastic modulus for each compressive strength.

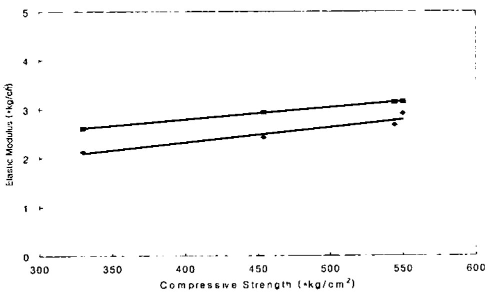

Fig.3 Elastic modulus with compressive strength

Experimental elastic moduli for compressive strength were generally lower than that of KSCE-96 Design Code.

4.1 Results of the Creep and Shrinkage Test

Fig.4 and 5 represent the shrinkage strain and the specific creep at each age, respectively. Specific creep that means the creep strain per unit stress is used here as a standard comparison value for creep property without regard to the modulus of elasticity and the stress.

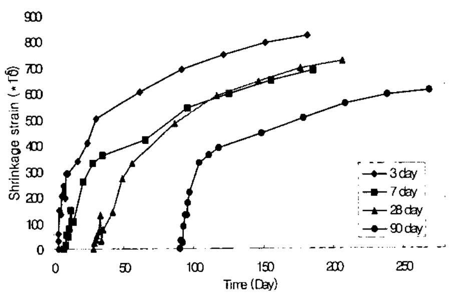

Fig.4 Shrinkage strain with time

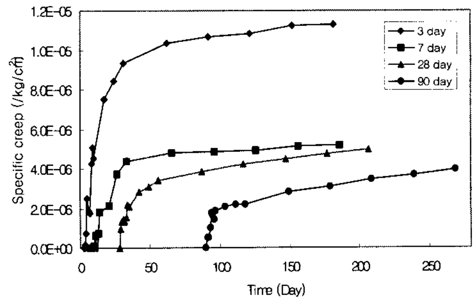

Fig.5 Specific creep with time

4.2 Results of the Incremental Loading Test

Fig.6 represents the total strain measured from the incremental stress test. Fig.7 to 9 represent the elastic strain, shrinkage strain and creep strain of concrete at curing age of the 3rd day in other to induce the creep strain at incremental stress from the total strains.

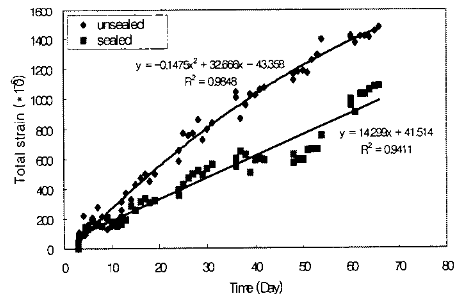

Fig.6 Total strain with incremental stress (measured)

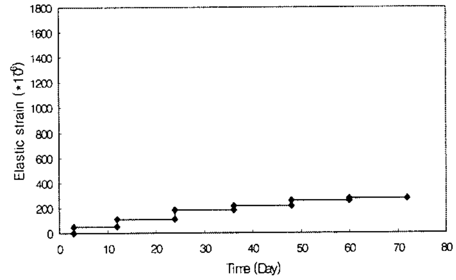

Fig.7 Elastic strain at curing age of 3rd day

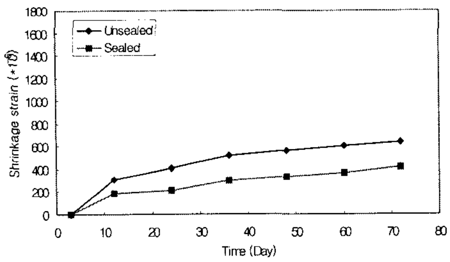

Fig.8 Shrinkage strain at curing age of 3rd day

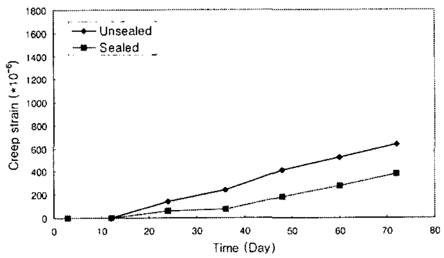

Fig.9 Creep strain with incremental stress (calculated)

5.PREDICTION MODELS

ACI, CEB/FIP, JSCE and KSCE design codes have been suggested for the prediction of creep and shrinkage. Table 5 and 6 summarize each model taken into consideration.

Table 5 Shrinkage prediction models

models	$\varepsilon_{sh}(t) = \frac{t}{a+t} k_s k_h \varepsilon_{su}$
KSCE-96	$\varepsilon_{sh}(t,t_0) = \frac{t-t_0}{a+(t-t_0)} \varepsilon_{sh,u}$
ACI-209	$\varepsilon_{sh}(t,t_0) = \varepsilon_{sho}[\beta_{sh}(t) - \beta_{sh}(t_0)]$
CEB/FIP-78	$\varepsilon_{sh}(t,t_0) = \varepsilon_{sho}\beta_s(t-t_0)$
CEB/FIP-90	$\varepsilon_{sh}(t,t_0) = \varepsilon_{sho}\beta_s(t-t_0)$
JSCE-96	$\varepsilon'_{cs}(t,t_0) = [1-\exp\{-0.108(t-t_0)^{0.56}\}]\varepsilon'_{sh}$

Table 6 Creep coefficient prediction models

models	Creep Coefficient Prediction
KSCE-96	$\phi(t,t_0) = 3.5K_cK_f\left(1.58-\frac{H}{120}\right)t_0^{-0.118}\frac{(t-t_0)^{0.6}}{10.0+(t-t_0)^{0.6}}$
ACI-209	$\phi(t,t_0) = \frac{(t-t_0)^{0.6}}{10.0+(t-t_0)^{0.6}}C_u$
CEB/FIP-78	$\phi(t,t_0) = \phi_d(t-t_0) + \beta_a(t_0) + \phi_f[\beta_f(t) - \beta_f(t_0)]$
CEB/FIP-90	$\phi(t,t_0) = \Phi_{RH}\beta(f_{cm})\beta(t_0)\beta(t-t_0)$
JSCE-96	$\varepsilon'_{cc}(t,t',t_0) = (1-\mathrm{Exp}(-0.09(t-t')^{0.6}))\varepsilon'_{cr}$

6.ANALYTICAL MODELS

6.1 Estimating Equation for Experi-Mental Results

The creep coefficients are induced from test results at the age of 3rd day

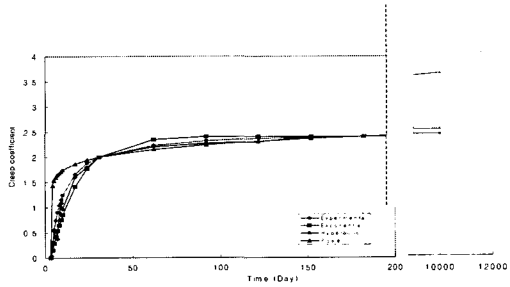

Fig.10 Creep coefficient represented by each equation

Creep coefficient equation is well represented by hyperbolic function, power function and exponential function. In this study these functions are compared with experimental results.

Fig.10 shows the experimental results and each function together. Hyperbolic function describes the experimental results very well and was adopted as an experimental model as shown in equation (1).

Experimental model

$$\phi(t,3)=\frac{(t-3)}{2.8184+0.3993(t-3)} \qquad (1)$$

6.2 EM Method(EMM)

In this method, the creep is regarded as reduced elastic strains and effective elastic modulus, which is shown in equation (2). In this study, EM method is only used for summing any other age creep strains ignoring the aging effect.

$$\begin{aligned}\varepsilon(t,t_0)&=\frac{\sigma}{E_c(t_0)}+\frac{\sigma}{E_c(t_0)}\phi(t,t_0)+\varepsilon_{sh}(t,t_0)\\&=\frac{\sigma}{E_c(t_0)}[1+\phi(t,t_0)]+\varepsilon_{sh}(t,t_0)\\&=\frac{\sigma}{E_e(t,t_0)}+\varepsilon_{sh}(t,t_0)\end{aligned} \qquad (2)$$

where, $E_e(t_0)=\dfrac{E_c(t_0)}{1+\phi(t,t_0)}$

6.3 AEM Method(AEMM)

AEM method is same as EM method, but aging coefficient is added to represent the trend of decreasing creep characteristics with time. Equation (3) shows the enhanced effective modulus used in AEMM.

The aging coefficient used in this paper is the coefficient recommended at CEB/FIP-78.

$$\begin{aligned}\varepsilon(t,t_0)&=\frac{\sigma}{E_c(t_0)}+\frac{\sigma}{E_c(t_0)}\phi(t,t_0)+\varepsilon_{sh}(t,t_0)\\&=\frac{\sigma}{E_c(t_0)}[1+\chi(t,t_0)\phi(t,t_0)]+\varepsilon_{sh}(t,t_0)\\&=\frac{\sigma}{\bar{E}_e(t,t_0)}+\varepsilon_{sh}(t,t_0)\end{aligned} \qquad (3)$$

where, $\bar{E}_e(t_0)=\dfrac{E_c(t_0)}{1+\chi(t,t_0)\phi(t,t_0)}$

$$\chi(t,t_0)=1-\frac{(1-\chi^*)(t-t_0)}{20+(t-t_0)}$$

where, $\chi^*=\dfrac{k_1 t_0}{k_2+t_0}$

and, $k_1=0.78+0.4e^{-1.33\phi^*(t_0)}$

$k_2=0.16+0.8e^{-1.33\phi^*(t,t_0)}$

6.4 RC Method(RCM)

RC method is based on the assumption that the rate of creep is independent of age at loading, therefore other age coefficients are found from Equation (4).

$$\phi(t,t_i)=\phi(t,t_0)-\phi(t_i,t_0) \qquad (4)$$

6.5 ID Method(IDM)

ID method considers that the creep strain is divided into two components: the delayed elastic strain, *d*, to the instantaneous elastic strain, *el*, and the flow component is treated in the same way as the total strain in the RC method. In this study the delayed elastic creep coefficient, 0.4 which is adopted by CEB/FIP-78 is used.

7.COMPARISON OF RESULTS

7.1 Comparison for Shrinkage Strains

Fig.11 to Fig.14 show comprasion of shrinkage strains between experiment and prediction models.

Experimental results were similar to KSCE-96 and JSCE-96 but very higher than other prediction models.

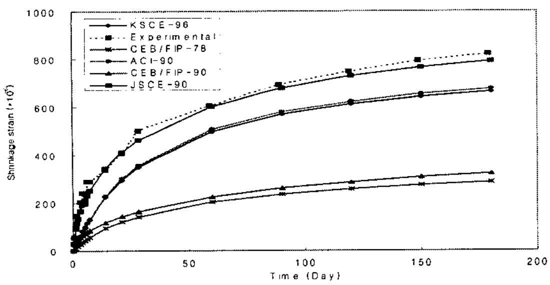

Fig.11 shrinkage strain comparison for curing age of 3rd day

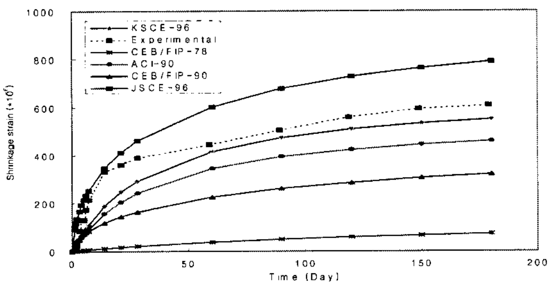

Fig.12 shrinkage strain comparison for curing age of 7th day

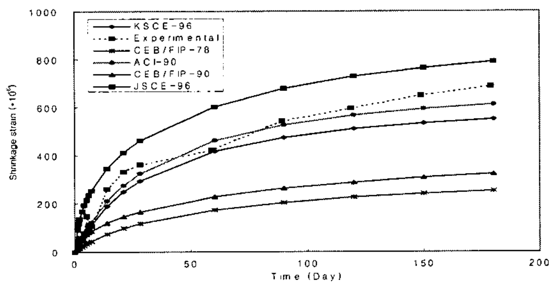

Fig.13 shrinkage strain comparison for curing age of 28th day

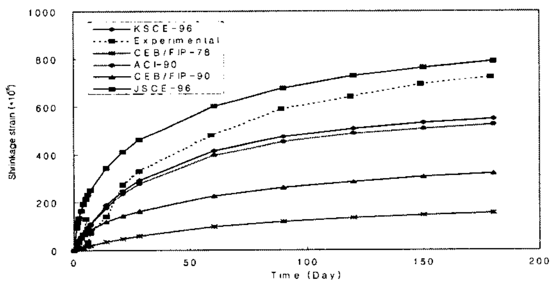

Fig.14 shrinkage strain comparison for curing age of 90th day

7.2 Comparison for Specific Creep

Fig.15 to Fig.18 compare the experiment specific creep with those of models.

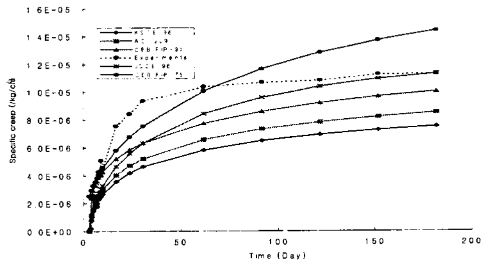

Fig.15 Specific creep comparison for curing age of 3rd day

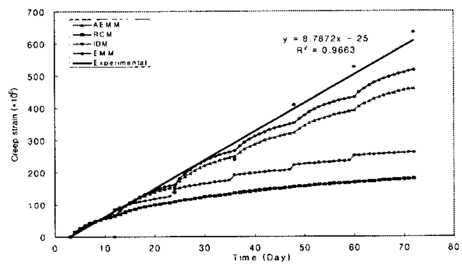

Fig.16 Specific creep comparison for curing age of 7th day

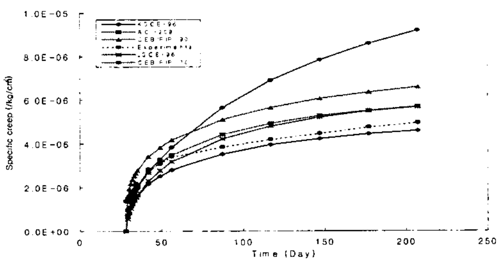

Fig.17 Specific creep comparison for curing age of 28th day

Experimental results of specific creep are generally similar to ACI-209 and KSCE-96 but lower than other prediction models in contrast to the shrinkage comparison.

Also specific creep shape shows that the creep at early age increases rapidly and becomes stable, which illustrates the difference from the prediction models.

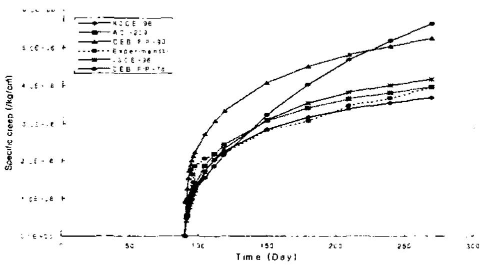

Fig.18 Specific creep comparison for curing age of 90th day

7.3 Comparison with Analytical Model

Figs.19 and 20 compare the unsealed creep strains from the incremental stress test with those of analytical CEB/FIP-78 models.

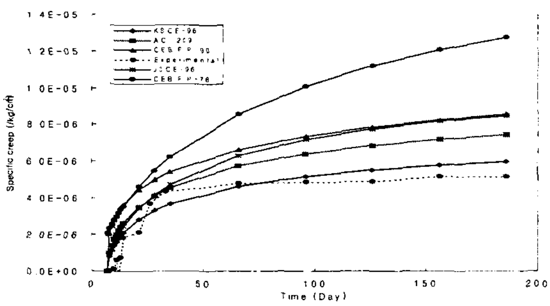

Fig.19 Comparison for analytical models based on experimental model

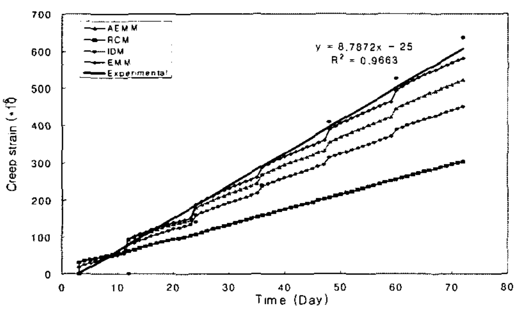

Fig.20 Comparison for analytical models based on CEB/FIP-78 model

Experimental creep was analyzed by RC or ID method because this model is well represented by the hyperbolic equation.

CEB/FIP-78 creep model shows the tendency that creep is increased continuously at early age. EM or AEM method agrees well with experimental results but RC or ID method shows some discrepancies.

8.CONCLUSIONS

Experimental results and the accompanying analytical studies resulted in the following conclusions.

1. The compressive strength at each age was higher than the design compressive strength, which indicates safe values of design. But the elastic modulus for compressive strength was lower than that of KSCE-96.
2. In case the shrinkage of concrete is compared with the prediction models, the quite differences exist with each models and the experimental results generally show higher values than other prediction models, especially CEB/FIP-78 model underestimate the shrinkage with increasing curing age.
3. In the comparison of specific creep with each curing age, experimental results were very similar to those of KSCE-96 or ACI-209 but lower than other models as opposed to shrinkage results.
4. The analytical method whose basic creep models is adopted by experimental model and CEB/FIP-78 model was generally underestimating the creep strain that was forced to incremental stress. Therefore, in designing the segment

concrete bridge, this time dependent creep characteristics must be considered.

5. The method, which analyzes creep of concrete, is based on the basic creep models. Therefore, in order to analyze the creep more precisely, other experimental studies based on materials, environmental conditions and local characteristics should be included further.

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