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論 文

[1101] Experimental Studies on the Basic Creep of Cement Paste, Mortar and Concrete

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1. INTRODUCTION

Scanning the available literature on creep of concrete, it can be observed that the vast majority of the experimental works on creep have been conducted only on concrete specimens. However, it is believed that in order to enhance the current knowledge of creep mechanism of concrete, a studying of the creep response of its mortar and hydrated cement paste is necessary. In consequence, the present paper describes an experimental program that was performed for investigating the basic creep and creep recovery mechanisms of normal- and high-strength concretes having 28 days compressive strengths of about 400 and 800 kgf/cm^2, respectively as well as their individual constituents; that are the mortars and the hydrated cement pastes. In this program, the basic creep tests were conducted on cylindrical sealed specimens (10 cm in diameter and 18 cm height) of cement paste, mortar and concrete. In the creep tests, the sustained stress can be applied using prestressing steel bar passing through the centroid of the specimen. The creep sustained stress levels were not exceeding 40 percent of the ultimate compressive strength existing at the time of load application and were maintained for about one month, with creep recovery observed for a period of 7 days. All basic creep measurements were performed in a temperature controlled room maintained at a temperature of about $20 \pm 2\ ^{\circ}{}_{c}$. The test conditions included ages at loading of 3,7,14 and 28 days. From the obtained results, the contributions of mortar and cement paste on the basic creep of normal- and high-strength concretes were evaluated. Furthermore, based on the data of the present experimental work the simple formula of the double power law was developed in order to predict the basic creep of concrete from the basic creep of its hydrated cement paste. In the proposed formula, the aggregate content as well as its mechanical properties were taken into account. Finally, the proposed formula was tested on creep results and was found to be accurate enough to model the basic creep of normal- and high-strength concretes over time.

2. EXPERIMENTAL PROGRAM

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2.1 CREEP APPARATUS

Fig.1 illustrates the creep test apparatus used in the present tests. In this apparatus, under the applied loading conditions the steel tube does not undergo creep deformation. Consequently, the magnitude of the sustained load is only reduced by the change in the length of the specimen due to creep and by the relaxation of prestressed steel bar, and a sensibly constant load is maintained.

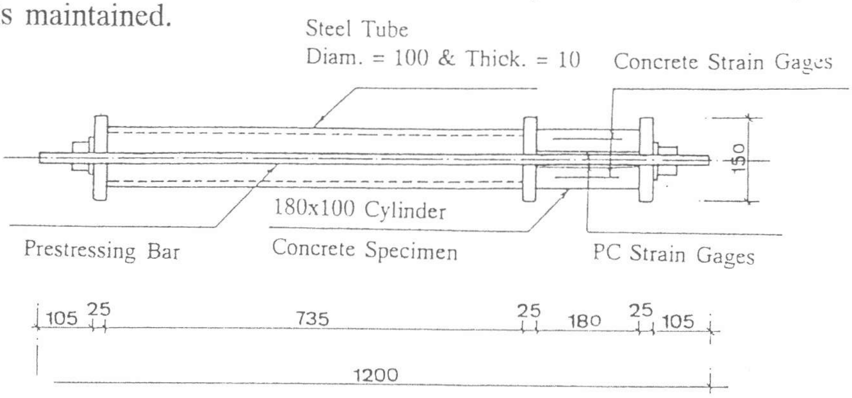

Fig. 1 Schematic of Creep Test Apparatus. (All Dim. in mm)

2.2 MATERIALS AND MIX PROPORTIONS

Table 1 Mix Proportions by Weight.

Components	**Quantities in kg/m^3**					
	Normal–Strength			**High–Strength**		
	Concrete	**Mortar**	**Cement paste**	**Concrete**	**Mortar**	**Cement Paste**
Water (W)	205	315	625	142	233	382
Superplasticizer (SP)	–	–	–	18	29	48
Cement (C)	387	595	1179	576	946	1550
Silica fume (SF)	–	–	–	64	105	172
Fine aggregate	805	1238	–	593	974	–
Coarse aggregate	876	–	–	972	–	–
Air cont. red. admix.	–	–	–	0.023	–	–
(W+SP)/(C+SF)	0.53	0.53	0.53	0.25	0.25	0.25
Slump in mm	60	–	–	230	–	–
Flow in mm	–	185	–	–	–	–
Air content %	–	–	–	1.10	4.55	6.25

High–early strength portland cement with a specific surface area of 4420 cm^2/g and a specific gravity of 3.14 was used in this experimental work. This cement meets the requirements of JIS R 5210 standards. The fine aggregate was natural mountain sand with a fineness modulus of 2.12 and a specific gravity of 2.50. The maximum size of the sand was 5 mm. The coarse aggregate was 13 mm maximum size crushed stone with a fineness modulus of 5.99 and a specific gravity of 2.67. For high–strength mixes a silica fume and a kind of superplasticizer were used. The silica fume used was microsilica with 90 percent SiO_2 content and 200000 cm^2/g specific surface area, whereas the superplasticizer used was poly carboxylic ether complex with a specific gravity of 1.05. The quantity of superplasticizer was adjusted to obtain a slump of around 240 mm. The liquid portion of the superplasticizer was counted as part of the mixing water. In addition, a Poly alkyleneglycol derivative air content reducing admixture was used in high-strength concretes which is loaded at 3 and 7 days. The designed concrete mixes have 28 days compressive strengths of 400 and 800 kgf/cm^2, for normal- and high-strength concretes, respectively. The mix proportions for cement paste and mortar should represent the paste and the mortar constituents of their concrete. Mix proportions for concretes, mortars and cement pastes are summarized in Table 1.

3. DISCUSSION OF THE EXPERIMENTAL RESULTS

3.1 NORMAL-STRENGTH MIXES

The effects of age at loading on total strain (i.e. initial strain + basic creep) after 30 days under sustained stress are shown in **Fig.2** for normal-strength concrete as well as its mortar and hydrated cement paste. The curves were drawn to represent the average of the values obtained from three specimens corrected for the shrinkage (i.e. autogenous shrinkage and shrinkage caused by temperature variation) of one unloaded sealed companion specimen. In order to simplify the comparisons, the curves in **Fig.2** were plotted to represent the observed values obtained from specimens subjected to the same sustained stress of 90 kgf/cm^2. **Fig.3** demonstrates the contributions of the hydrated cement paste and mortar on the creep functions (total strain per unit stress) of their concrete for two ages at loading and for different duration of loading. The following observations are noted from **Figs.2** and **3** :

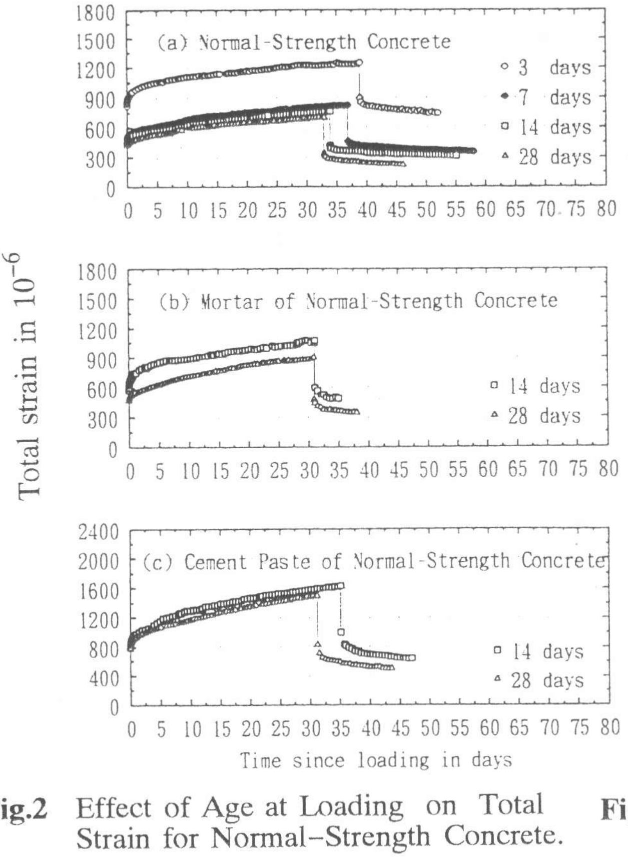

Fig.2 Effect of Age at Loading on Total Strain for Normal-Strength Concrete.

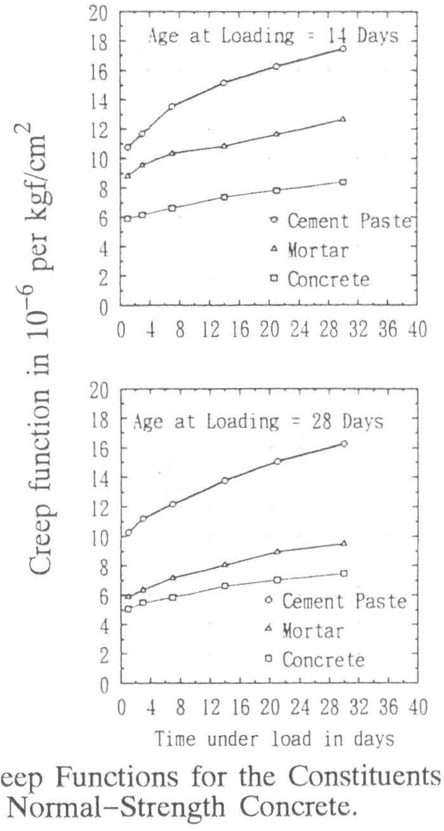

Fig.3 Creep Functions for the Constituents of Normal-Strength Concrete.

(a) For the same age at loading, the basic creep for concrete is about 0.62 and 0.38 of that for its mortar and hydrated cement paste,respectively.
(b) The observed creep function and specific creep (creep strain per unit stress) values of the hydrated cement paste are about 2.0 and 2.80 of the corresponding values for concrete loaded at either 14 or 28 days.
(c) The observed creep functions for mortar are about 1.50 and 1.20 of that for concrete loaded at ages of 14 and 28 days, respectively. However,the specific creep values are about 2.10 and 1.60 of that for concrete loaded at ages of 14 and 28 days, respectively.

3.2 HIGH-STRENGTH MIXES

Similar to the case of normal-strength mixes, **Fig.4** shows the effect of age at loading on total strains and creep recoveries for high-strength concrete as well as its mortar and hydrated cement paste. The sustained stress for concrete and mortar specimens was 285 kgf/cm^2. However, for cement paste specimens the sustained stress was 140 kgf/cm^2. **Fig.5** illustrates the contributions of the hydrated cement paste and mortar on the basic creep functions of their concrete for both 14 and 28 days ages at loading. A preliminary investigation of the obtained results had indicated that the trend of the behavior of high-strength mixes is approximately similar to that for normal-strength mixes. However, the following additional points are noted from **Figs. 4** and **5** :

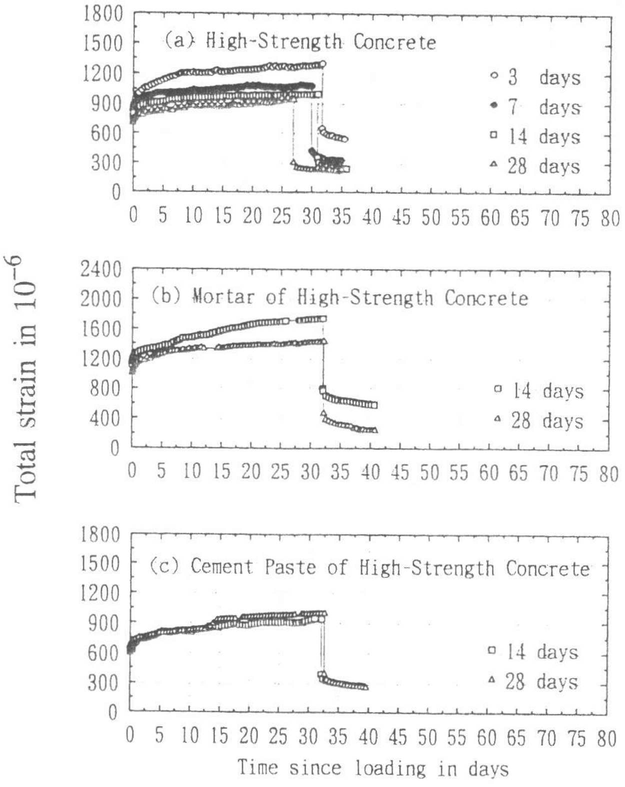

Fig.4 Effect of Age at Loading on Total Strain for High-Strength Concrete.

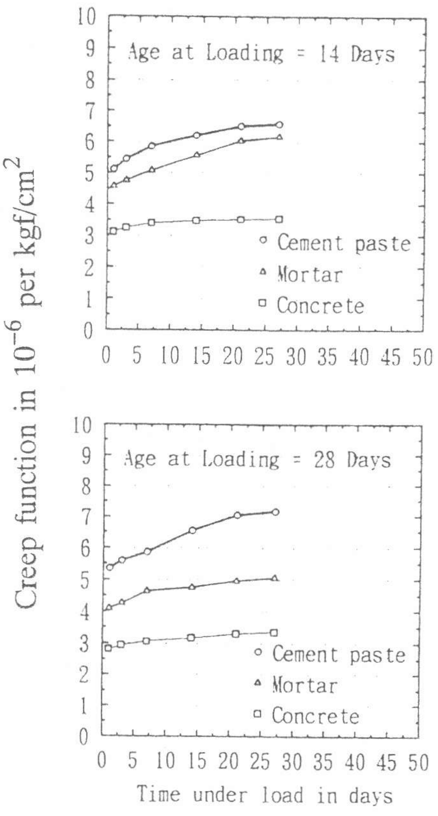

Fig.5 Creep Functions for the Constituents of High-Strength Concrete.

(a) The basic creep values for concrete loaded at ages of 14 and 28 days are about 0.40 and 0.60 of the corresponding values for its mortar. On the other hand, for concrete loaded at either 14 or 28 days, the basic creep is about 0.40 of that for its hydrated cement paste.

(b) The observed values of creep function and specific creep for the hydrated cement paste loaded at either 14 or 28 days are about 1.90 and 2.20 of the corresponding values for concrete.

(c) For both ages at loading, the observed creep function and specific creep values for mortar are about 1.55 and 1.75 of the corresponding values for concrete.

4. PROPOSED FORMULA FOR THE BASIC CREEP OF CONCRETE

In this section, the present experimental results were used in order to determine the resistance of the aggregate to the flow of hydrated cement paste for normal- and high-strength concretes. Combining the Pickett equation for the restraining effect of aggregate on shrinkage of concrete which modified by Neville [1] in order to apply to creep of concrete and the double power law for basic creep of concrete proposed by Bazant et al. [2] and [3], the following expression for the specific creep of concrete can be obtained :

$$C = \frac{\psi_1}{E_o}(t_o^{-m}+\alpha)(t-t_o)^n(1-g)^\beta \qquad (1)$$

Where

t_0 : age of concrete at loading (days).

t : age of concrete for which the strain is calculated (days).

$1/E_0$: is a constant which indicates the leftside asymptote of creep curve when plotted in log $(t-t_0)$ scale.

g : volume concentration of aggregate.

β : a parameter depending on the elastic moduli and poissons ratios of both aggregate and concrete.

n, m, α and ψ_1 : the material parameters that depend on various properties of concrete.

Table 2 shows the estimated parameters m,n, α , ψ_1 and E_0 of eq.1 obtained from linear regression analysis on the experimental data of cement paste specimens.

Table 2 Estimated Values of the Parameters m,n, α , ψ_1 and E_0

Cement Paste Mix Type	**Parameter**				
	m	n	α	ψ_1	**$E_0 \times 10^5$ kgf/cm^2**
Normal-Strength	**1/3**	**1/3**	**0.05**	**0.90**	**1.50**
High-strength	**1/3**	**1/6**	**0.05**	**1.20**	**4.00**

In addition, Table 3 gives the experimental values of the coefficient β after various periods under sustained load for the sealed specimens of normal- and high-strength concretes loaded at 14 and 28 days. Finally, Table 4 compares the derived specific creep values calculated using eq.1 with those obtained from the present experiments.

Table 3 Experimental Values of Coefficient β

Time under Load (days)	Concrete Type			
	Normal-Strength		High-Strength	
	Age at Loading (days)		Age at Loading (days)	
	14	28	14	28
1	0.887	1.145	0.557	0.585
3	0.979	0.971	0.650	0.611
7	1.105	0.969	0.749	0.667
14	0.991	0.861	0.884	1.013
21	0.975	0.905	0.982	1.100
30	0.931	0.919	0.971	1.084

Table 4 Observed and Derived Specific Creep Values for Normal-and High-Strength Concretes.

Concrete Mix Type	Age at Loading (days)	Specific Creep (10^{-6} per kgf/cm^2) after a Period under Load of											
		1 day		3 days		7 days		14 days		21 days		30 days	
		Obs.	Der.	Obs.	Der.	Obs.	Der.	Obs.	Der.	Obs.	Der.	Obs.	Der.
Normal-Strength	14	0.82	1.10	1.07	1.44	1.52	1.67	2.29	2.37	2.73	2.76	3.31	3.26
	28	0.49	0.69	0.92	1.18	1.28	1.57	2.07	2.22	2.47	2.43	2.90	2.69
High-Strength	14	0.45	0.84	0.59	0.93	0.74	0.97	0.81	0.97	0.87	0.94	0.90	0.99
	28	0.31	0.68	0.44	0.76	0.57	0.79	0.68	0.79	0.81	0.77	0.87	0.81

5. CONCLUSIONS

1. For both normal- and high-strength concretes, the resistance of the aggregate to the basic creep of concrete is determined.
2. A proposed relation between the basic creep of concrete and its hydrated cement paste is suggested. In this formula, the fractional volume of the aggregate in concrete as well as its elastic properties are taken into account.
3. Comparison of the results calculated using the proposed formula with the present experimental data showed that this formula can model the basic creep of concrete.

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