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Prediction of Shrinkage and Creep of Concrete

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SYNOPSIS

New prediction equations of shrinkage and creep of concrete are proposed, and the efficiency of the new equations are investigated through a number of experimental data. Furthermore,the characteristics and applications of the prediction equations presented in the codes of many countries are also discussed.

The results showing that the new equations could estimate shrinkage and creep of concrete within a certain measure of accuracy were obtained.

1. INTRODUCTION

The durability of concrete structure and crack are closely related. The deterioration of concrete may be caused by the attack by harmful liquids and gasses through crack. Furthermore, in the case of reinforced concrete, the penetration of moisture and air will result in the corrosion of steel.

On the other hand, limit state design method has become accepted as an alternative to working stress design method in designing of concrete structures throughout the world. In this design method, not only the strength characteristics but also the deformation characteristics should be well understood. In checking the serviceability limit states, the calculated width of crack and the deflection must be smaller than the specified limits.

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In order to predict correct deformations, the estimation of the reasonable values of shrinkage and creep strains, which cause crack and deflection, is very important as a presupposition in checking the serviceability limit states or the durability of concrete structures.

In such a background, the prediction methods of these strains and their application to design are being investigated very actively, and various prediction methods for these strains are presented in the codes of many countries.

In this study, the new prediction equations of shrinkage and creep are proposed on the basis of many experimental results by the authors, and their adequacy is investigated. Furthermore, the characteristics and applications of the prediction equations presented in the codes of many countries are also discussed.

2. PREDICTION OF SHRINKAGE AND CREEP

The typical prediction equations of shrinkage and creep were proposed by Rüsch1), Bažant2) and Branson3). Rüsch's equation is adopted in CEB/FIP Model Code(1978), German Prestressed Concrete Code DIN 4227 (1979), JSCE(Japan Society of Civil Engineers) Standard Specifications for Prestressed Concrete(1978) and JSCE Tentative Recommendations for the Limit State Design of Concrete Structures(1983), and has spread throughout the world. The feature of this equation is its simplicity and practicability.

Branson's equation is the basis of ACI-209 equation(1982). It is expressed as a product of the applicable correction factors which estimate the effects of curing period, ambient humidity, shape and size of specimen and properties of concrete. CEB/FIP-70 equation is also expressed as a product of various correction factors.

Bažant's equation can estimate the influences of many significant parameters on shrinkage and creep. The subcommittee of ACI Committee 209 recommends the use of this equation for complicated conditions, or for special structures.

The principal factors which are adopted in these equations are summarized in Table 1. As is evident from Table 1, the factors which are adopted in these equations, are considerably different. Bažant's equation can estimate the influences of many significant parameters. On the other hand, Rüsch's equation is simple and practical one, in which several parameters are considered.

Further details of the prediction equations in Table 1 are to be refered to the references.

Table 1 Factors adopted in prediction equations

Factors	Rüsch		Bažant		CEB/FIP -78		CEB/FIP -70		ACI-209	
	Cre	Shr	Cre	Shr	Cre	Shr	Cre	Shr	Cre	Shr
C			*	*			*	*		*
W/C			*	*			*	*		
S			*	*						
G			*	*						
S/a			*						*	*
fc'			*	*	*					
Slump	*	*			*	*			*	*
Air									*	*
Shape			*	*						
V/S,A/u	*	*	*	*	*	*	*	*	*	*
Av.thi.									*	*
Temp.	*	*	*	*	*	*	*			
R.H.	*	*	*	*	*	*	*	*	*	*
to		*	*	*		*				*
t'	*		*		*		*		*	

Av.thi.: Average thickness
R.H. : Relative humidity
to : Age when drying starts
t' : Age when loading starts

3. DISCUSSION ON THE CONSIDERATION OF SHRINKAGE AND CREEP IN DESIGN

In the "Tentative Recommendations for the Limit State Design of Concrete Structures" published by Japan Society of Civil Engineers (JSCE), it is mentioned that shrinkage strain and creep coefficient should be determined in due consideration of the effects of the factors, such as relative ambient humidity, shape and size of member (or specimen), mix proportion of concrete and age when loading starts. When any experiment is not conducted to determine the values of shrinkage strain and creep coefficient, it is recommended that they should be predicted by Rüsch's equation. For ordinary concrete, shrinkage strain shown in Table 2 can be used. In the commentary, ordinary concrete is defined as the concrete under the conditions shown in Table 3.

Table 2 Shrinkage strain ($X10^{-5}$)

Age*	Within 3 days	4～7 days	28 days	3 months	1 year
outdoors	25	20	18	16	12
indoors	40	35	27	21	12

Table 3 Conditions for ordinary concrete

	temp.	R.H.	Ave.thi.	A/u≒V/S	Slump
outdoors	15°C	70%	40 cm	13.3	8 cm
indoors	20°C	40%	40 cm	20	8 cm

Ave.thi.; Average thickness

Table 4 Creep coefficient

Age*	4~7 days	14 days	28 days	3 months	1 year
outdoors	2.8	2.5	2.2	1.9	1.4
indoors	4.3	3.6	3.1	2.4	1.6

* age when loading starts

Table 5 Conditions for calculating

	Temp.	R.H.	eff.thi.	A/u=V/S	Slump
Outdoors	15°C	70%	60cm	20cm	8cm
Indoors	20°C	40%	60cm	30cm	8cm

Temp.: Temperature
R.H. :Relative Humidity
eff.thi. : effective thickness

For prestressed concrete, creep coefficients shown in Table 4 can be used. The conditions for calculating creep coefficients shown in Table 4 are shown in Table 5. The effective thickness of the member is given by the following equation:

$$h_{th} = \lambda \cdot A/u \quad \text{--} \quad (1)$$

where, A is the cross-sectional area, and u is the area exposed to drying, including internal surfaces. The values of λ are 2 and 3, when the ambient relative humidity are 70% and 40%, respectively. If the shape of the cross section is assumed to be square, the calculated side length is 80 cm and 120 cm for outdoors and indoors, respectively. The mix proportions, slumps, air contents and strengths at the age 28 days of the concretes which are used for this study are shown in Table 6. In Table 6, the specimens in Group A are considered as ordinary concretes, especially 300/150 specimen is called standard concrete. The specimens in Group B and C are high and low strength concrete specimens, respectively. The standard concrete is used for the calculation of the creep coefficients in Table 4.

Table 6 Mix proportions and properties of concretes

Specimens		C kg/m³	W kg/m³	W/C %	S kg/m³	G kg/m³	Slump cm	Air %	fc′ kg/cm²
A	300/150	300	150	50	658	1189	7.7	5.2	400*
	420/210	420	210	50	720	973	10.4	1.4	360
	280/160	280	160	57	830	1093	4.5	1.1	338
	260/160	260	160	62	837	1103	5.2	1.0	306
	360/180	360	180	50	774	1009	12.5	1.0	389
	360/175	360	175	49	786	1009	10.9	-	392
	320/180	320	180	56	762	1055	10.0	-	337
	320/170	320	170	53	773	1070	9.2	-	376
	320/165	320	165	52	778	1078	6.9	-	384
B	460/180	460	180	39	742	978	11.7	0.3	535
	420/160	420	160	38	780	1027	4.0	1.1	569
	400/160	400	160	40	787	1036	2.4	1.7	524
C	260/170	260	170	65	826	1088	6.0	0.8	243
	280/180	280	180	64	807	1079	9.7	0.1	238

* estimated value

The shrinkage strains predicted by the equations except CEB/FIP-70 equation decrease with the age when drying starts (Fig.1). The predicted value by CEB/FIP-78 equation is about 30% bigger than that by Rüsch's equation. It is because the fundamental values of shrinkage for the both equations are different. The predicted value by Rüsch's equation is determined with consideration of the effect of reduction in strain due to

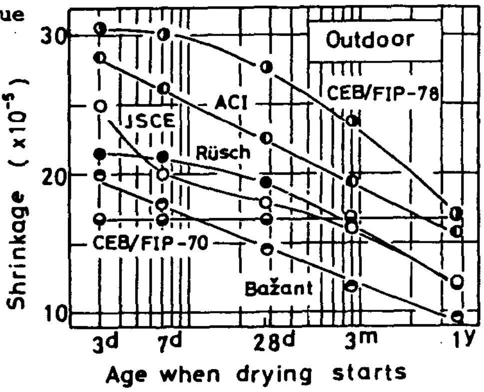

Fig.1 The effect of age when drying starts

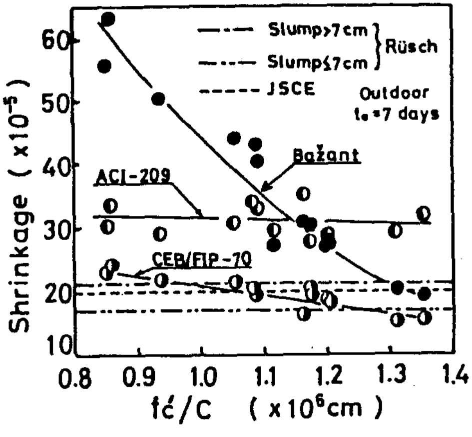

Fig.2 The relation between f'c/C and shrinkage

constraints by reinforcements in concrete.

Fig.2 shows the relationship between the predicted shrinkage of concretes shown in Table 6 except standard concrete and compressive strength per unit weight of cement in concrete. The reason, by which we chose such an abscissa, is that shrinkage decreases with strength and increases with cement content. The predicted shrinkage by Bažant's equation shows the above-mentioned tendency.

Fig.3 shows the shrinkage test results of concretes in Table 6 except the standard concrete. It is clear that shrinkage decreases with the parameter of f'c/C.

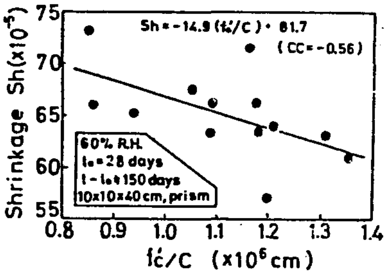

Fig.3 The relation between f'c/C and shrinkage

The items which affect shrinkage can be divided into three categories, such as properties of concrete, ambient conditions and geometries of specimen. Among these items, the influences of the factors which relate to the properties of concrete are not well considered in the prediction equations except Bažant's equation. Test results shown in Fig.3 can explain that the mix proportion of concrete is an important parameter which determines the fundamental value of shrinkage. Therefore, we should consider the effect of mix proportion of concrete, especially cement and water contents in concrete on shrinkage when we estimate shrinkage.

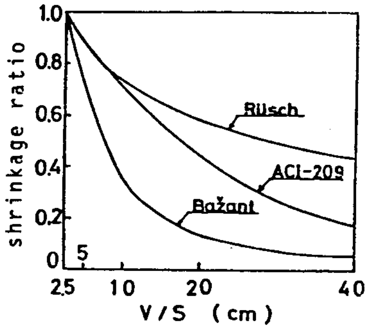

Fig.4 The effect of specimen size on shrinkage

Fig.4 shows the effect of specimen size (V/S) on shrinkage. It is clear from Fig.4 that ACI-209 and Bažant's equations over-estimate the effect of specimen size.

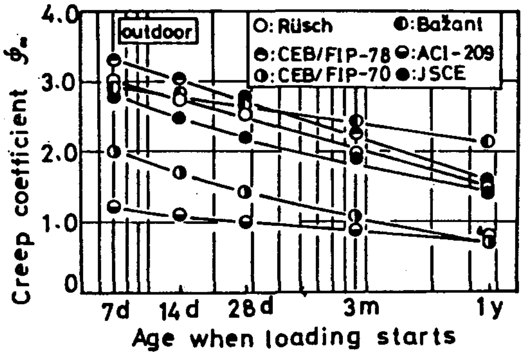

Fig.5 Influence of age when loading stars

Fig.5 shows the relationships between the creep coefficients of the standard concrete and age predicted by various equations for the specimens kept outdoors. The values of creep coefficients predicted by the equations shown in Table 1 are different, and they all decrease with the age at the application of load. The influences of the age at the application of load on creep coefficient are different according to the prediction equations. The rates of decrease in creep coefficients by Bazant's and ACI-209 equation are differenr from the other equations.

The creep coefficients predicted by Bažant's, Rüsch's and CEB/FIP-78 equations are similar and nearly equal to the values shown in Table 4. The creep coefficients predicted by ACI-209 and CEB/FIP-70 equations are small, especially the former is pretty small. In that equation the ultimate creep coefficient in given the following expression:

$$\phi_\infty = 2.35 \cdot \gamma_c \quad \text{------------------------------------} \quad (2)$$

where, γ_c represents the product of the applicable correction factors.

Under the standard condition, γ_c is equal to 1. Therefore, under ordinary condition, the creep coefficient predicted by ACI-209 equation is smaller than 2.35 in general. When volume surface ratio (V/S) is equal to 38mm, the correction factor is equal to 1. In the case of this study, V/S ratio is equal to 200 mm for outdoors, and therefore, the correction factor is equal to 0.677.

Fig.6 shows the relationships between the predicted creep coefficients of concretes shown in Table 6 except for standard concrete and compressive strengths at the age of 28 days. The creep coefficients in Fig.6 are predicted for the application of load at the age of 7 days. As in Fig.6, the influences of compressive strength on creep coefficients predicted by the various equations are insignificant for the compressive strengths between 200 kgf/cm^2 and 400 kgf/cm^2. However, the values of creep coefficients predicted by the various equations are pretty different. The predicted values by Bažant's equation are a little greater than those by Rüsch's equation and the values given by JSCE in Table 4, but the values by CEB/FIP-70 equation are a little smaller.

On the other hand, the effect of strength on creep coefficient is different for the compressive strength of concrete exceeding about 500 kgf/cm^2. As is evident from Table 1, by Rüsch's equation and ACI-209 equation, creep coefficients

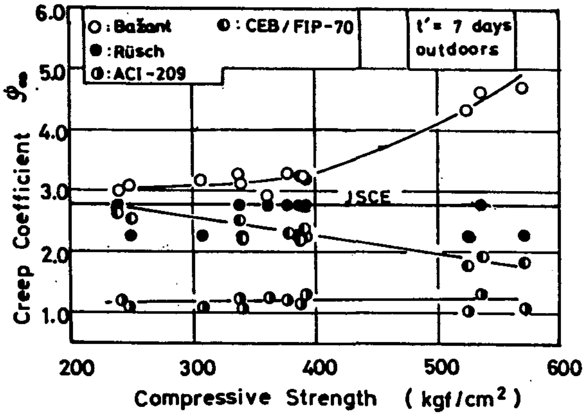

Fig.6 Influence of compressive strength

are not related the effects of strength. Therefore, the creep coefficient of high strength concrete is equal to that of normal concrete for same conditions. In Bažant's equation and CEB/FIP-70 equation, the effects of strength of concrete are considered. Therefore, the predicted creep coefficients are different according to the strength of concrete.

As shown in Fig.6, the creep coefficient predicted by Bažant's equation increases with increase in the strength of concrete exceeding about 500 kgf/cm^2, but those by CEB/FIP-70 equation decrease with increase in the strength of concrete. It seems that the difference of those tendencies is due to the difference in understanding about the mechanism of the influences of strength of concrete on creep.

CEB/FIP-70 equation is based on the concept that high strength concrete restrains creep deformation. On the other hand, it seems that the predicted creep coefficient by Bažant's equation suggests the following mechanism. If the strength of concrete increases, the mix proportion of concrete is rich, and cement paste content increases. Therefore, creep strain is considered to increase. It is not clear which explanation is appropriate.

Fig.7 shows the influence of water-cement ratio (or strength of concrete) on specific creep[4]. The predicted values by Bažant's equation are shown by solid lines and the experimental values are shown by the dotted line. Creep of concrete for the compressive strength smaller than 300 kgf/cm^2 increases because the restraint to defomation due to strength is small. Creep of high strength concrete increases because cement paste content increases. Bažant's equation can express such a complicated effect of mix proportion of concrete on creep.

As shown in Fig.7, experimental results indicate that creep decrease with increase in the strength of concrete.

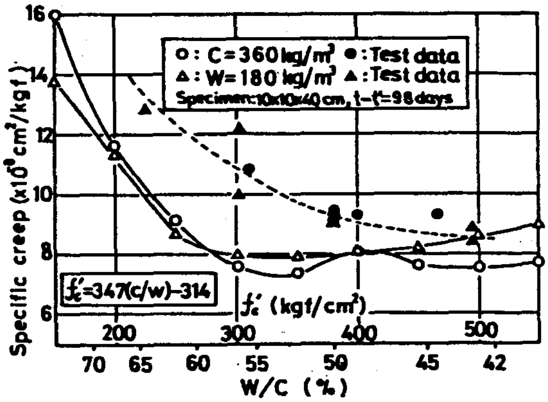

Fig.7 Influence of strength of concrete on creep

4.PROPOSITION OF PREDICTION EQUATION OF SHRINKAGE AND CREEP

Prediction equations of shrinkage and creep are proposed as follows:

(1) Shrinkage equation

$$SH(\hat{t}) = SH_n \cdot S(\hat{t}) \tag{3}$$

$$SH_n = 2.07 \cdot SH_{st} \cdot (1-RH/100)^{0.2} \cdot (V/S)^{-0.15} \cdot (\log t_o)^{-0.01} \tag{4}$$

$$SH_{st} = 0.177 \cdot C + 121 \cdot W/C - 16.0 \cdot \log f'(t_o) - 31.4 \tag{5}$$

$$S(t) = 1 - \exp(-0.186 \cdot \hat{t}^{0.5\phi}) \tag{6}$$

$$\phi = (V/S)^{-0.1} \cdot (1-RH/100)^{0.02} \tag{7}$$

$$f'(t) = [0.340 \cdot f'(28) + 51.5] \cdot \log t + 0.487 \cdot f'(28) - 80 \tag{8}$$

$$f'(28) = 1.59 \cdot C - 4.07 \cdot W + 554 \tag{9}$$

where, $SH(\hat{t})$=predicted shrinkage ($X10^{-5}$), SH_n=ultimate shrinkage($X10^{-5}$) SH_{st}=standard shrinkage, which is the shrinkage strain at the age of 98 days after drying starts ($X10^{-5}$), RH=ambient relative humidity (%), V/S=volume-surface ratio (cm), C and W=cement and water content, respectively (kg/cm^3), $f'(t)$=compressive strength of concrete at the age of t days (kgf/cm^2), t=age of concrete (days), t_o=age when drying starts (days) and $\hat{t}$=duration of drying ($=t-t_o$;days).

(2) Creep equation

$$C(\bar{t}) = BC(\bar{t}) + DC(\bar{t}) \tag{10}$$

$$BC(t) = BC_n \cdot [1-\exp(-0.2614 \cdot \bar{t}^{\kappa})] \tag{11}$$

$$BC_n = 1.77 \cdot BC_{st} \cdot (\log t')^{-0.9} \tag{12}$$

$$BC_{st} = 1.50X10^{-3} \cdot C + 1.65 \cdot W/C - 1.02 \tag{13}$$

$$\kappa = 0.5 \cdot t'^{-0.1} \tag{14}$$

$$DC(t) = DC_n \cdot [1-\exp(-0.0305 \cdot \bar{t}^{\gamma})] \tag{15}$$

$$DC_n = 94.9 \cdot DC_{st} \cdot (1-RH/100)^{0.36} \cdot (V/S)^{-2.8} \tag{16}$$

$$DC_{st} = 1.16X10^{-4} \cdot C + 0.532 \cdot W/C - 0.165 \tag{17}$$

$$\gamma = (1-RH/100)^{0.3} \cdot (V/S)^{-0.06} \tag{18}$$

where, $C(\bar{t})$=predicted specific creep ($X10^{-5}$cm^2/kgf), hereinafter, creep strains are specific strains. $BC(\bar{t})$=basic creep ($X10^{-5}$cm^2/kgf), $DC(\bar{t})$= drying creep ($X10^{-5}$cm^2/kgf), BC_n=ultimate value of basic creep ($X10^{-5}$cm^2/kgf), DC_n=ultimate value of drying creep ($X10^{-5}$cm^2/kgf), BC_{st} = standard value of basic creep, which is the basic creep strain at the age of 98 days after loading ($X10^{-5}$cm^2/kgf), DC_{st}=standard value of drying creep, which is the drying creep strain at the age of 98 days after loading ($X10^{-5}$cm^2/kgf), t'=loading age (days) and $\bar{t}$=duration under load ($=t-t'$;days).

The requirements considered for representation of shrinkage and creep strains in the above-mentioned prediction equations are as follows:

(1) The equations must account for the effects of many significant factors on shrinkage and creep, and must be capable of representing the features and facts which were observed in experiments.

(2) The equations must be simple and be of convinient form for computer use.

(3) It must be easy to improve and reform the equations.

(4) The accuracy of the equations must be excellent.

5. OUTLINE OF EXPERIMENTS

An ordinary portland cement was used. The coarse and fine aggregates used were crushed stone and river sand, respectively. The physical properties of the aggregates are shown in Table 7. The mix proportions of concretes used in the shrinkage tests are shown in Table 8. In the creep tests, the concretes except for N-220/360 and N-200/360 were used. The ages when drying starts and the loading ages were 3, 7, 14, 28 and 56 days. Ambient humidity were 60 and 80%R.H. In the shrinkage tests, 160 different prismatic specimens of 10X10X40 cm, 15X15X53 cm and 30X30X120 cm were used. In creep tests, 104 different prismatic specimens of 10X10X38 cm and 15X15X51 cm were used.

Table 7 Physical properties of aggregates

	Coarse Aggregate				Fine Aggregate		
	Max.Size (mm)	Specific Gravity	Absorption (%)	F.M.	Specific Gravity	Absorption (%)	F.M.
K	20	2.66	1.80	6.85	2.53	2.60	2.90
H	20	2.71	0.51	6.77	2.58	1.78	3.20
I	20	2.67	1.23	6.85	2.58	2.74	3.07
O	20	2.73	0.68	6.73	2.57	1.43	3.00
N	20	2.72	0.81	6.91	2.60	1.68	2.86

Fig.8 shows the frequency distribution of the compressive strengths of concretes in Table 8 at the age when drying starts.

In order to change the value of V/S, some surfaces of some specimens were sealed with paraffin as in Table 9. Strain was measured by Whittmore strain meter. The period of measurement was about 150 ~200 days.

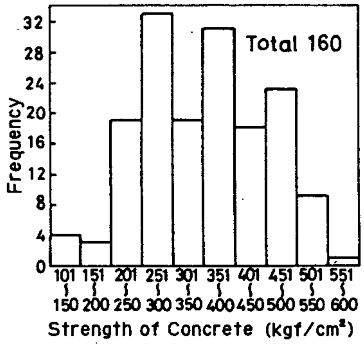

Fig.8 Frequency distribution of the compressive strengths of concretes

Table 9 Specimen size and surface condition

V/S (cm)	Size (cm)	Drying Surface
2.22	10x10x40	6 faces
2.50	10x10x40	4 side faces
3.29	15x15x53	6 faces
3.75	15x15x53	4 side faces
5.00	10x10x40	2 side faces
6.67	30x30x120	6 faces
7.50	15x15x53	2 side faces
10.00	10x10x40	1 side face
15.00	15x15x53	1 side face
15.00	30x30x120	2 side faces
30.00	30x30x120	1 side face

6. RESULTS AND DISCUSSION

Figs.9~14 show the relationships between the predicted values by the above-mentioned equations and experimental data. In the figures, the time-dependent behaviors of 160 kinds of specimens are shown.

In Fig.9, the predicted values by Rüsch's equation are much smaller than the experimental ones. The reason the predicted values become smaller is because the base values of shrinkage are small. In consideration of this tendency, the base values of CEB/FIP-78 equation were made a little larger than those in Rüsch's equation. However, the predicted values are also much smaller than the experimental ones shown in Fig.10.

The predicted values by CEB/FIP-70 equation agree approximately with the experimental values as in Fig.11. This equation can estimate the effects of the factors, such as properties of concrete, ambient conditions and geometries of specimen. In this equation, the restraint of reinforcement is separately considered.

Table 8 Mix proportion of concrete

Specimen	W/C %	W kg/m³	C kg/m³	S kg/m³	G kg/m³	S/a %
K-200/420	47.6	200	420	677	1009	41.4
K-195/420	46.4	195	420	689	1009	41.8
K-190/420	45.2	190	420	702	1009	42.2
K-185/420	44.0	185	420	714	1009	42.7
K-180/420	42.9	180	420	727	1009	43.1
K-180/360	50.0	180	360	774	1009	44.6
K-175/360	48.6	175	360	786	1009	45.0
K-185/320	57.8	185	320	756	1048	43.0
K-180/320	56.3	180	320	762	1055	43.0
K-175/320	54.7	175	320	767	1063	43.0
K-170/320	53.1	170	320	773	1070	43.0
K-165/320	51.6	165	320	778	1078	43.0
K-175/280	62.5	175	280	799	1064	44.0
K-170/280	60.7	170	280	805	1072	44.0
H-180/420	42.9	180	420	757	1012	44.0
H-200/360	55.6	200	360	756	1010	44.0
H-180/360	50.0	180	360	779	1041	44.0
H-160/360	44.4	160	360	801	1071	44.0
H-180/320	56.3	180	320	792	1059	44.0
H-180/280	64.3	180	280	807	1079	44.0
I-220/500	44.0	220	500	683	899	44.0
I-200/500	40.0	200	500	705	929	44.0
I-230/460	50.0	230	460	686	903	44.0
I-180/460	39.1	180	460	742	978	44.0
I-180/435	41.4	180	435	751	990	44.0
I-210/420	50.0	210	420	723	952	44.0
I-160/420	38.1	160	420	780	1027	44.0
I-180/400	45.0	180	400	764	1006	44.0
I-160/400	40.0	160	400	787	1036	44.0
I-180/380	47.4	180	380	771	1016	44.0
I-220/360	61.1	220	360	733	965	44.0
I-190/360	52.8	190	360	767	1010	44.0
I-180/360	50.0	180	360	778	1025	44.0
I-180/340	52.9	180	340	786	1035	44.0
I-200/320	62.5	200	320	770	1014	44.0
I-160/320	50.0	160	320	816	1074	44.0
I-190/280	67.9	190	280	796	1048	44.0
I-160/280	57.1	160	280	830	1093	44.0
I-170/260	65.4	170	260	826	1088	44.0
I-160/260	61.5	160	260	837	1103	44.0
I-130/260	50.0	130	260	871	1148	44.0
0-210/420	50.0	210	420	720	973	44.0
0-220/360	61.1	220	360	730	987	44.0
0-180/360	50.0	180	360	775	1048	44.0
0-162/360	45.0	162	360	796	1076	44.0
0-160/320	50.0	160	320	812	1098	44.0
0-160/260	61.5	160	260	834	1127	44.0
0-143/260	55.0	143	260	853	1153	44.0
0-130/260	50.0	130	260	868	1173	44.0
N-180/360	50.0	180	360	784	1044	44.0
N-160/320	50.0	160	320	822	1094	44.0
N-140/280	50.0	140	280	859	1144	44.0
N-220/360	61.1	220	360	739	984	44.0
N-200/360	55.6	200	360	762	1014	44.0

Bazant's equation can estimate the influences of many significant

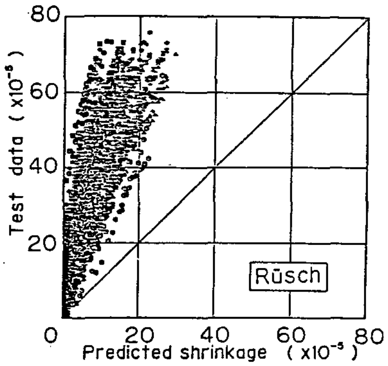

Fig.9 The relationships between the predicted and experimental shrinkage

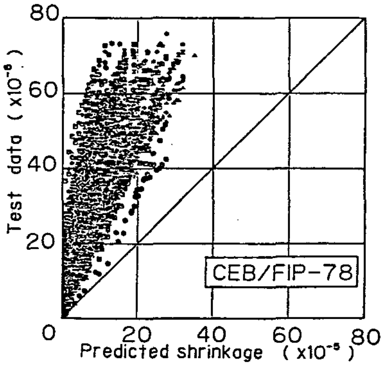

Fig.10 The relationships between the predicted and experimental shrinkage

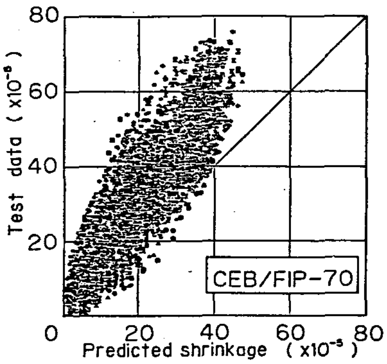

Fig.11 The relationships between the predicted and experimental shrinkage

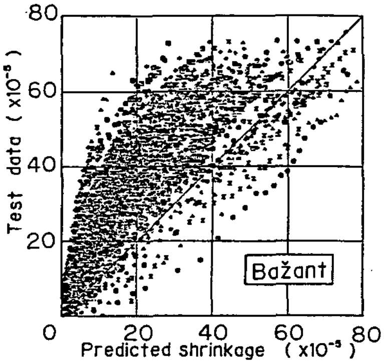

Fig.12 The relationships between the predicted and experimental shrinkage

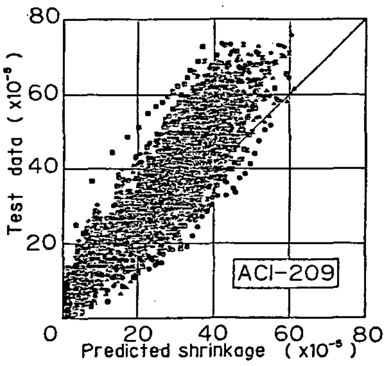

Fig.13 The relationships between the predicted and experimental shrinkage

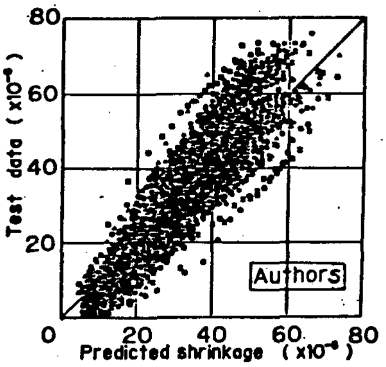

Fig.14 The relationships between the predicted and experimental shrinkage

parameters and is applicable widely. The predicted values by Bazant's equation are scattered more widely than those by the other equations (Fig.12). The reason of this tendency is because the equation overestimates the effects of properties of concrete, especially the mix proportion of concrete.

The predicted values by ACI-209 equation and authors' equation agree with the experimental values (Figs.13 and 14). They are satisfactory to estimate shrinkage strain in ordinary plain concrete. For ACI-209 equation, however, the function which expresses the development of strain over time is the subject for future study. For authors' equation, the consideration of the effect of specimen size on shrinkage should be investigated in future.

In Figs.15~20, the comparisons between the experimental data and the predicted values of creep by the above-mentioned prediction equations. In the figures, the time-dependent behaviors of 104 kinds of specimens are shown.

Fig.15 shows the comparisons between the experimental data and the predicted values of creep by Rüsch's equation. The predicted values by Rüsch's equation are a little smaller than the experimental ones, but that tendency is not so much as the above-mentioned equation of shrinkage. It is because the basic flow coefficients of Rüsch's equation are small.

CEB/FIP-78 equation is the modified Rüsch's equation and can estimate the effect of strength of concrete on creep. As in Fig.16, it is considered that the accuracy of the predicted value by the equation is somewhat improved.

The predicted values by CEB/FIP-70 equation are a little bigger than the experimental ones (Fig.17).

In Fig.18, the predicted values by Bažant's equation are a little scatter. It is because the effects of composition of concrete are overestimated. However, it can estimate the influences of many significant parameters and is applicable widely.

In Fig.19, the predicted values by ACI-209 equation are a little smaller than the experimental ones. In ACI-209 equation, the developement of creep over time may be expressed by the hyperbolic function. It is important to consider whether such a expression is good or not.

The predicted values by authors' equation agree with the experimental values as is evident from Fig.20.

In order to confirm the adequacy of the equations of shrinkage and creep proposed in this study, the data of concrete specimens

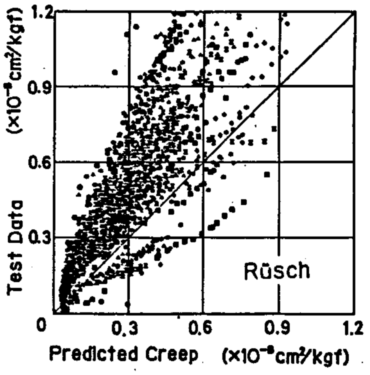

Fig.15 The relationships between the predicted and experimental creep

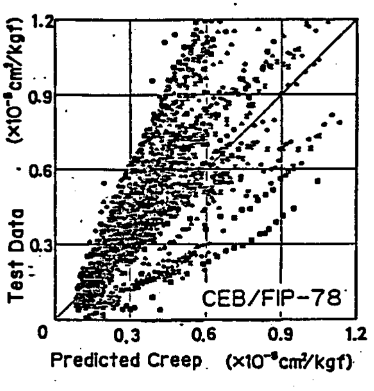

Fig.16 The relationships between the predicted and experimental creep

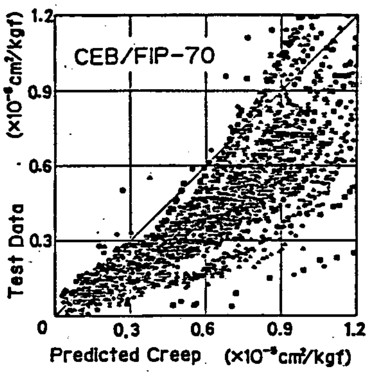

Fig.17 The relationships between the predicted and experimental creep

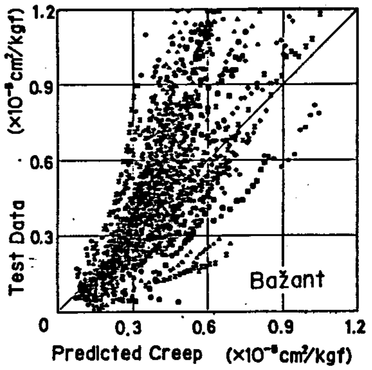

Fig.18 The relationships between the predicted and experimental creep

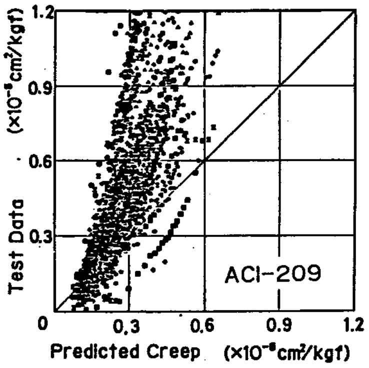

Fig.19 The relationships between the predicted and experimental creep

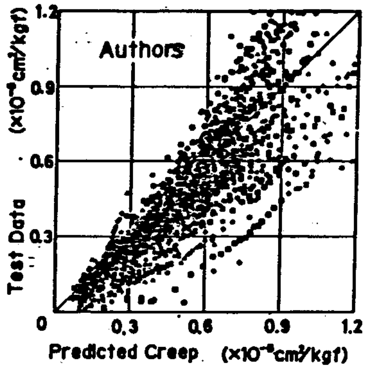

Fig.20 The relationships between the predicted and experimental creep

except in Table 8 should be used.

In Figs.21 and 22, we investigated by the data available in literatures,5)~9) whether our proposed equations are acceptable or not. The predicted values by our equations agree with the experimental data in the literatures.

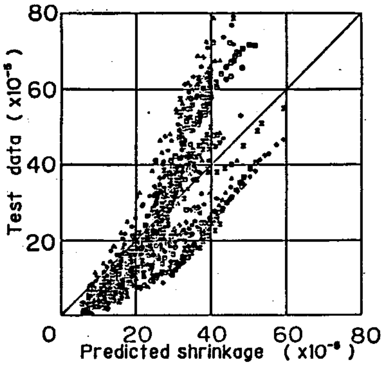

Fig.21 The relationships between the predicted and experimental shrinkage

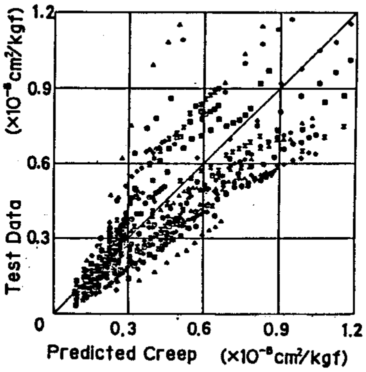

Fig.22 The relationships between the predicted and experimental creep

7. CONCLUSION REMARKS

The new prediction equations of shrinkage and creep were proposed and their adequacy were also investigated. The results showing that the equations could estimate shrinkage and creep strains of concrete within a certain measure of accuracy were obtained in this study.

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