Study on the Effect of the Strength Grade on the Creep Behavior of Concrete

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Abstract: The internal factors which influenced the concrete creep behavior have been mostly divided by the creep model at home and abroad, but the computing is complex. In order to directly use the creep model in engineering conveniently, it is necessary to consider the effect of concrete strength grade on concrete creep. 302 creep test data with a loading age of 28 d, a lasting age of 360 d, and meet certain environmental conditions were collected. The strength of prism with different aspect ratio and high ratio of cylinder specimen was equivalent to the standard cube strength. The relationship between the creep compliance and creep degree and the cube compressive strength of concrete was fitted, and influence coefficient of the strength grade on the creep degree and creep coefficient were obtained. The influence coefficient can be used to determine creep value, creep coefficient, creep degree of concrete. In this paper, the effect of the strength grade on creep was considered directly, which involves the cube compressive strength of concrete from 15 MPa to 180MPa. The research results can be used in broad scope and has certain practical value.

Keywords: Concrete, creep, strength grade, influence coefficient.

1. INTRODUCTION

Creep performance is an important index in the long term properties of concrete, and the linear compressive creep deformation can reach 1-4 times of the short term elasticity compressive deformation. Therefore, the creep behavior must be considered in the design of concrete structures in order to provide necessary safety and comfortableness. For the important engineering structures, creep experiment of the specimen, which is made from the same concrete used in the structures, is the most reliability method. However, due to the complexity and diversity, there are not always sufficient condition to carry out creep experiment, so the empirical formula fitted from the obtained experimental data is essential [1].

There are many creep models used at home and abroad, such as CEB-FIP series models, ACI 209 series models, GL-2000 model, B3 model, China Academy of Building Research model, Zhu Bofang model and Li Chengmu model *et al.* [2-5]. However, there are many difference in the influence factors, formula form, applicable scope and prediction accuracy of these models due to limitation of specific experimental condition and the emphasis of different researchers. The inner factors, which are influenced the creep behaviors, are differentiate carefully by the obtained models at home and abroad. The correction factor of mixture ratio of concrete was given in CEB-FIP series models. The correction factor of collapsibility, sand ratio and air content was considered in ACI 209 series models. The correction factor of water cement ratio, cement content, sand ratio and concrete density was consider in B3 model. It can be concluded that the correction factor is miscellaneous, and it is necessary to promote a simplified model to consider these factors.

A large number of creep experiments of concrete were conducted by Concrete institute of China Academy of Building Research and scientific research units and institutions of higher learning in China from 1982 to 1986, and the China Academy of Building Research model-1986 was built up based on the experimental data. The experimental results show that the strength has great influence on the creep coefficient of concrete, and the creep coefficient is decreased with the increasing of strength of concrete. Moreover, the recommendation value of the influence coefficient of the creep coefficient of C20 concrete, C30 concrete and C40 concrete are1.15, 1 and 0.8, respectively. The strength of concrete was considered as the only factor that influenced the creep in the China Academy of Building Research model-1986, which is different with other models. Advantage of this model is the convenience and practical, while the shortcoming is the smaller fit range and low evaluation precision of the influence coefficient. It is necessary to supplement more experimental data to optimize this model.

The relation between the strength of concrete and the creep is developed based on the 284 data collected from the experimental data in references, and the collected data was

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transformed to a uniform from under different strength. Moreover, the collected data include experimental creep results with the compressive strength in the region of 15MPa~180MPa, which has a wide application in the civil engineering.

2. DATA COLLECTING

The creep data was collected with uniform loading age of 28d, load lasting time of 360d and standard environment because the creep of concrete will be affected by the stress level, loading age, load lasting time and the environment. The linear creep compliance data was collected In the region of linear creep (stress level $\sigma/f_c \leq 0.5$), the creep compliance is not depended on the stress level [1-2], so the linear creep compliance data was collected. 284 data was collected which are fulfilled the requirement of loading age of 28d, load lasting time of 360d and standard environment stated before. The dimension of specimen, the strength at loading age of 28d and the corresponding creep compliance were shown in Table **1**.

The creep compliance is defined as the sum of creep strain at unit stress and the short time strain, which is express as

$$J = \frac{1}{E_c} + \frac{\varepsilon_{cr}}{\sigma} \quad (1)$$

where E_c is the elastic modulus, MPa; ε_c is the creep strain of concrete; σ is lasting stress, MPa.

Table 1. Experimental data of linear creep.

Reference	Dimensions (mm×mm)	f'_{28} (MPa)	$J\times10^{-6}$ (MPa^{-1})	Reference	Dimensions (mm×mm)	f'_{28} (MPa)	$J\times10^{-6}$ (MPa^{-1})	Reference	Dimensions (mm×mm)	f'_{28} (MPa)	$J\times10^{-6}$ (MPa^{-1})
[6]	C76×660	22.0	87.0	[15]	C38×255	41.6	62.8	[27]	C50×200	41.9	95.9
	C76×406	34.0	67.0		C38×255	20.7	112.3	[28]	C100×400	36.6	119.4
[7]	C50×400	25.4	117.0		C38×255	29.9	60.4		C100×400	45.4	63.3
	C100×800	25.4	117.0		C38×255	28.1	50.8	[29]	C100×400	111.6	14.0
	C150×1200	25.4	107.0		C38×255	26.7	53.7		C100×400	71.0	17.8
	C300×1800	25.4	96.0		C38×255	20.0	102.6		C100×400	81.5	15.5
	C50×400	28.0	120.0		C38×255	29.4	62.1		C100×400	96.2	12.0
	C50×400	28.0	145.0		C38×255	34.3	54.7		C100×400	32.2	55.0
	C50×400	46.9	78.0		C38×255	35.4	38.1		C100×400	40.7	38.2
	C50×400	46.9	90.0	[16]	C76×305	52.4	72.4		C100×400	41.1	46.1
	C50×400	28.0	190.3		C76×305	52.4	93.1	[30]	C55×220	25.5	73.1
	C50×400	28.0	204.5		C76×305	63.0	67.0		C55×220	49.3	89.5
	C50×400	46.9	97.6		C76×305	63.0	56.0		C55×220	69.2	60.6
	C50×400	46.9	100.7	[17]	C76×305	78.6	82.7		C55×220	20.0	121.5
[8]	C100×800	26.9	177.4		C76×305	91.9	66.1		C55×220	45.2	59.3
	C100×800	26.9	145.5		C76×305	118.9	48.7		C55×220	68.6	34.2
	C100×800	26.9	152.9		C76×305	107.0	50.4	[31]	C75×300	22.6	202.0
	C100×800	41.9	143.6	[18]	C150×600	80.5	43.7		C75×300	31.1	194.0
	C100×800	41.9	109.7		C150×600	80.5	47.9		C75×300	38.8	152.0
	C100×800	41.9	108.7		C150×600	36.5	117.0		C75×300	19.7	211.0
	C100×800	43.1	77.5	[19]	C50×400	31.5	113.1		C75×300	33.1	167.0
	C100×800	35.3	92.2		C50×400	37.0	106.1		C75×300	38.4	140.0
	C100×800	19.0	175.8		C50×400	51.0	95.3		C75×300	20.6	224.0
[9]	C100×800	24.4	144.6		C50×400	48.5	90.9		C75×300	31.3	204.0
	C100×800	25.8	93.6		C50×400	72.0	62.1		C75×300	38.9	164.0
	C100×800	26.4	129.0		C50×400	70.0	49.0		C75×300	21.1	172.0

Table 1. Contd....

Reference	Dimensions (mm×mm)	f'_{28} (MPa)	J ×10^{-6} (MPa^{-1})	Reference	Dimensions (mm×mm)	f'_{28} (MPa)	J ×10^{-6} (MPa^{-1})	Reference	Dimensions (mm×mm)	f'_{28} (MPa)	J ×10^{-6} (MPa^{-1})
	C100×800	23.4	148.7		C50×400	93.0	43.1		C75×300	33.1	172.0
	C100×800	27.8	133.1		C50×400	108.0	40.9		C75×300	41.1	131.0
	C100×800	28.4	88.4	[20]	C75×450	54.8	53.2	[32]	C75×300	56.6	30.8
[10]	C150×600	29.0	116.0		C75×450	96.5	35.5		C75×300	42.4	58.6
	C150×600	34.0	84.0	[21]	C50×400	95.0	38.2		C75×300	35.2	60.3
	C150×600	45.0	81.8		C50×400	95.0	32.3		C75×300	26.5	77.7
	C150×600	39.0	93.2		C50×400	86.0	39.9		C75×300	56.6	35.1
	C150×600	43.0	78.4		C50×400	86.0	50.2		C75×300	42.4	62.3
	C150×600	37.0	68.1	[22]	C80×1000	101.0	33.0		C75×300	35.2	64.9
[11]	C75×600	54.0	66.1		C80×1000	101.0	29.7		C75×300	26.5	81.7
	C75×600	46.0	85.1		C80×1000	49.2	82.5	[33]	C61×250	42.6	128.8
	C75×600	60.0	65.9		C80×1000	49.2	53.8		C49×200	42.6	150.8
	C75×600	55.0	84.7	[23]	C80×1000	43.5	47.5		C61×250	34.3	170.2
	C75×600	65.0	51.7		C80×1000	92.1	28.7		C49×200	34.3	179.9
[12]	C100×800	33.0	122.6		C80×1000	94.3	27.6		C61×250	40.1	160.6
	C100×800	33.0	131.8		C80×1000	93.3	28.3		C49×200	40.1	174.9
	C100×800	47.0	104.6		C80×1000	99.4	31.9		C61×250	57.9	98.0
	C100×800	34.9	185.9		C80×1000	74.6	34.7		C49×200	57.9	106.3
	C100×800	34.9	157.4		C80×1000	97.3	26.0	[34]	C51×203	59.8	76.7
	C100×800	39.9	146.0		C80×1000	79.5	31.3		C51×203	62.1	71.4
	C100×800	39.1	139.3		C80×1000	67.2	34.8		C51×203	64.6	50.1
	C100×800	34.1	109.1		C80×1000	74.6	28.6		C51×203	64.6	73.0
	C100×800	33.2	122.9		C80×1000	94.3	28.8		C51×203	62.3	86.6
	C100×800	30.8	144.2		C80×1000	101.8	26.1		C51×203	63.3	76.5
[13]	C75×300	17.7	161.6		C80×1000	84.0	30.9		C51×203	36.5	127.4
	C75×300	17.7	173.5		C80×1000	78.0	29.8		C51×203	38.4	102.6
	C75×300	19.0	132.0	[24]	C28×300	69.0	91.0		C51×203	38.5	152.8
	C75×300	19.0	140.3		C28×300	82.0	54.9		C51×203	38.4	127.6
	C75×300	23.9	117.1		C28×300	86.0	68.4		C51×203	39.8	121.0
	C75×300	23.9	126.9		C28×300	101.0	52.1		C51×203	34.5	157.4
	C75×300	10.8	210.1		C28×300	58.0	96.5		C51×203	34.5	178.4
	C75×300	10.8	230.0		C28×300	79.0	60.0		C51×203	40.7	123.9
[14]	C38×255	70.9	62.7		C28×300	91.0	65.8		C51×203	21.6	230.5
	C38×255	85.5	54.6		C28×300	91.0	52.5		C51×203	24.4	203.9
	C38×255	69.1	66.6		C28×300	106.0	50.5		C51×203	23.4	281.0
	C38×255	80.9	65.1		C28×300	126.0	34.6		C51×203	21.6	223.1
	C38×255	67.3	79.1		C28×300	111.0	57.0		C51×203	22.8	301.2

Table 1. Contd....

Reference	Dimensions (mm×mm)	f'_{28} (MPa)	$J \times 10^{-6}$ (MPa^{-1})	Reference	Dimensions (mm×mm)	f'_{28} (MPa)	$J \times 10^{-6}$ (MPa^{-1})	Reference	Dimensions (mm×mm)	f'_{28} MPa)	$J \times 10^{-6}$ (MPa^{-1})
	C38×255	70.9	60.2		C28×300	136.0	33.8		C51×203	22.8	290.0
	C38×255	85.5	56.6		C28×300	118.0	44.3		C51×203	24.9	269.6
	C38×255	69.1	75.5		C28×300	116.0	42.3		C51×203	64.6	62.4
	C38×255	80.9	72.6		C28×300	118.0	32.1		C51×203	23.4	255.5
	C38×255	67.3	77.7		C28×300	132.0	34.3		C51×203	38.5	149.3
[15]	C38×255	16.7	292.7	[25]	C75×600	33.3	101.5		C51×203	59.8	64.6
	C38×255	22.3	251.8		C75×600	37.2	85.2		C51×203	21.6	188.6
	C38×255	35.1	173.6		C75×600	28.6	115.4		C51×203	36.5	114.2
	C38×255	37.3	163.8		C150×520	44.8	41.5	[35]	C76×305	71.4	40.9
	C38×255	41.8	99.2		C150×520	78.0	28.6		C76×305	85.2	38.3
	C38×255	16.6	317.6		C150×520	98.5	16.3		C76×305	87.9	39.7
	C38×255	23.1	226.4		C150×520	38.3	36.6		C76×305	82.3	38.8
	C38×255	31.5	145.5		C150×520	61.9	27.4		C76×305	76.3	40.8
	C38×255	34.0	86.9		C150×520	95.3	24.9		C76×305	74.5	49.1
	C38×255	41.6	72.3	[26]	C100×400	85.2	28.0		C76×305	90.7	37.8
	C38×255	20.7	147.0		C100×400	82.3	26.9		C76×305	86.7	38.3
	C38×255	29.9	114.7		C100×400	75.6	28.8		C76×305	89.5	35.0
	C38×255	28.1	90.0		C100×400	46.4	87.8	[36]	P150×550	51	93.6
	C38×255	26.7	69.7		C100×400	67.3	40.5		P150×550	51	95.7
	C38×255	20.0	255.1	[27]	C50×200	74.1	40.5		P150×550	51	76.9
	C38×255	29.4	180.6		C50×200	50.1	59.1		P150×550	51	90.3
	C38×255	34.3	133.3		C50×200	30.3	103.2		P150×550	51	84.6
	C38×255	35.4	83.6		C50×200	119.1	23.4		P150×550	51	95.5
	C38×255	16.7	131.3		C50×200	102.2	29.8		P150×550	51	70.9
	C38×255	22.3	97.5		C50×200	54.5	61.2		P150×550	51	65.5
	C38×255	35.1	54.0		C50×200	79.0	64.5		P150×550	51	78.0
	C38×255	37.3	43.6		C50×200	79.0	53.0		P150×550	51	83.5
	C38×255	41.8	39.4		C50×200	41.9	135.3		P150×550	51	78.6
	C38×255	16.6	133.4		C50×200	41.9	96.0		P150×550	51	81.0
	C38×255	23.1	121.4		C50×200	79.0	64.1	[37]	P100×300	57.1	66.2
	C38×255	31.5	86.0		C50×200	79.0	53.0		P100×300	69.4	63.0
	C38×255	34.0	65.2		C50×200	41.9	135.3				

Note: C76×660 means a cylinder with radius r=76mm and height h=660mm; P150×550 means a prism with side length a=150mm and height h=550mm. For the cylinder, f'_{28} means the compressive strength at loading age of 28d, and for the prism, f'_{28} means the compressive strength of standard cubic. J is the creep compliance at the load lasting time of 360d.

3. STRENGTH TRANSFORMING

It is necessary to transform the compressive strength in Table **1** to the compressive strength of standard cubic (150mm×150mm×150mm), because dimensions of specimens in the experimental creep data collected in Table **1** are different, which include different height width ratio prisms and different height diameter ratio cylinders. For the prism specimen, the f'_{28} in Table **1** is tested with standard cubic specimen, and it is not need to transform. However, for the cylinder specimen, the height diameter ratio ($h/(2r)$) was calculated first, then the function of transforming coefficient and the height diameter ratio was fitted according to the data in reference [39-43], which is shown in Fig. (**1**). The compressive strength of different height diameter ratio cylinders was transformed to the compressive strength of the cylinders with a height diameter ratio of 1 according to equation (2), and that will be transformed to the compressive strength f_c' of the cylinder with a dimension of Φ150mm×300mm. Finally, the compressive strength f_c' was transformed to the compressive strength of standard cubic $f_{cu,m}$ using $f_c' \approx 0.8 f_{cu,m}$.

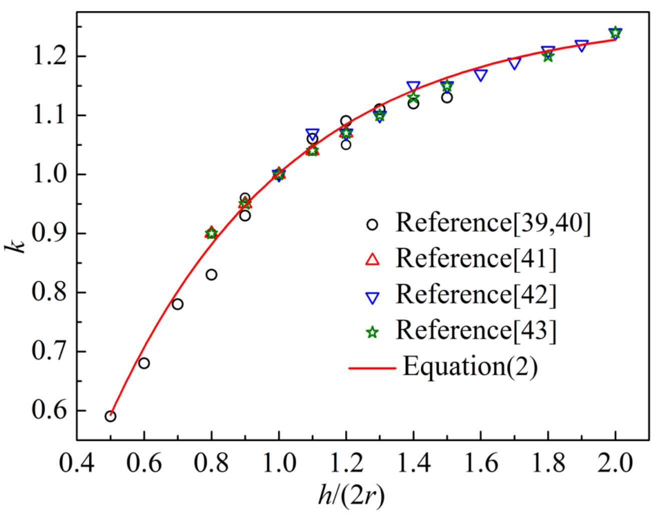

Fig. (1). Transforming coefficient of cylinders with different height diameter ratio.

$$k = -1.71e^{\left(\frac{-h/(2r)}{0.54}\right)} + 1.27 \qquad 0.5 \le h/(2r) \le 2 \qquad (2)$$

where k is the transforming coefficient of strength; $h/(2r)$ is the height diameter ratio; h is the height of cylinder specimen, mm; r is the radius of cylinder specimen, mm.

4. RELATION BETWEEN COMPRESSIVE STRENGTH AND THE COMPRESSIVE CREEP

Fig. (**2**) shows the scatter figures of (J, $f_{cu,m}$), which was calculated from the transformed strength data of the collected creep data in Table **1**. It can be seen from Fig. (2) that the creep compliance is decreased with the increasing of the strength of concrete. The relation between the creep compliance J at load lasting time of 360d and the averaged compressive strength of standard cubic $f_{cu,m}$ was established using the least square fitting method, which is shown in equation (3). Equation (3) means the averaged value of the creep compliance of the concrete cubic with different compressive strength, which is tested from the creep experiment at the loading age of 28d, loading lasting time of 360d and the standard environment. The relation between the creep compliance and the compressive strength has a little scatter due to the uncertainty of the creep testing environment, such as the standard environment or room environment. The envelope curve with 95% confidence of the data is shown in equation (4) and equation (5). Equation (4) and equation (5) mean the maximum and minimum value of the creep compliance of different compressive strength of concrete, which is tested from the creep experiment at the loading age of 28d, loading lasting time of 360d and the standard environment, respectively.

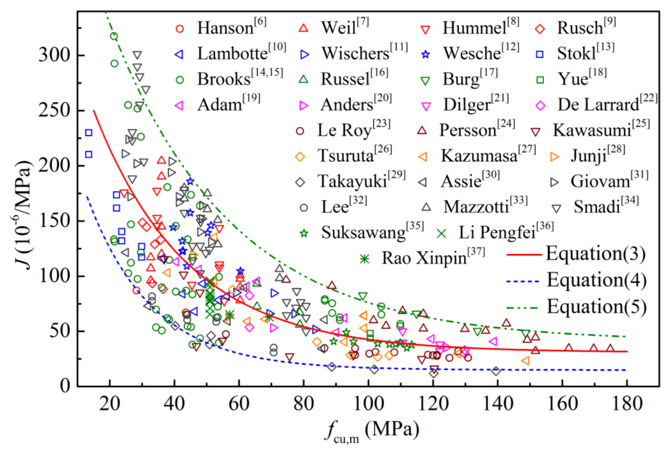

Fig. (2). Creep compliance of concrete with different compressive strength.

$$J = 320e^{(4-f_{cu,m})/29} + 31 \qquad 15\text{MPa} \le f_{cu,m} \le 180\text{MPa} \qquad (3)$$

$$J = 320e^{(16-f_{cu,m})/38} + 41 \qquad 15\text{MPa} \le f_{cu,m} \le 180\text{MPa} \qquad (4)$$

$$J = 300e^{(-f_{cu,m})/20} + 15 \qquad 15\text{MPa} \le f_{cu,m} \le 180\text{MPa} \qquad (5)$$

where J is the total strain of unit stress at load lasting time of 360d, $10^{-6}MPa^{-1}$; $f_{cu,m}$ is compressive strength of the standard concrete cubic, MPa.

The empirical formula between the elasticity modulus of concrete and the compressive strength of the standard concrete cubic is developed in reference [4], which is shown in equation (6), and the elasticity modulus of concrete at different strength in 'Concrete structure design code(GB 50010-2010)' is also calculated using equaton (6)

Table 2. The standard and averaged value of the compressive strength of the concrete cubic.

Strength	C15	C20	C25	C30	C35	C40	C45	C50	C55	C60	C65	C70	C75	C80
$f_{cu,k}$ (MPa)	15	20	25	30	35	40	45	50	55	60	65	70	75	80
$f_{cu,m}$ (MPa)	22.9	28.4	33.9	39.0	44.5	49.8	56.1	61.1	67.2	71.8	77.8	83.8	89.8	95.8

$$E_c = 10^5 / (2.2 + 34.7 / f_{cu,k}) \quad (6)$$

where E_c is the elastic modulus, MPa; $f_{cu,k}$ is Cube compressive strength of standard values, MPa.

Table **2** shows the statistical data of the standard and averaged value of the compressive strength of the standard concrete cubic. Fitting $(f_{cu,m}, f_{cu,k})$ using least square fitting method, the relation function is obtained

$$f_{cu,k} = 0.9 f_{cu,m} - 5.1 \quad (7)$$

Creep degree C means the creep at unit stress, and the relation between the creep degree C and the creep compliance J is

$$C = J - 1/E_c \quad (8)$$

Substitute equation (3), equation (4), equation (5) and equation (6), equation (7) into equation (8), the relation between the creep degree C and the averaged value of the compressive strength of the standard concrete cubic $f_{cu,m}$ is

$$C = 320 e^{((4 - f_{cu,m})/29)} - 347/(0.9 f_{cu,m} - 5.1) + 9 \quad (9)$$

where C is the creep degree, which means the creep at unit stress with load lasting time of 360d,(10^{-6}MPa^{-1}); $f_{cu,m}$ is the averaged value of the compressive strength of the standard concrete cubic.

The influence coefficient of strength on the creep degree, which is defined as the ratio between creep degree of the concrete with different strength and the creep degree of $f_{cu,m} = 30$MPa at the same load lasting time, is expressed as

$$k_{f_{cu},C} = 2.59 e^{((4 - f_{cu,m})/29)} - 2.81/(0.9 f_{cu,m} - 5.1) + 0.073 \quad (10)$$

The creep degree of concrete with different strength at load lasting time of 360d was calculated from equation (9), and the influence coefficient of strength on the creep degree calculated from equation (10) are shown in Table **3**. It can be seen from Table **3** that the creep degree is depend on the strength, and the creep degree is decreased with the increasing of the strength.

The influence coefficient of strength on the creep of the concrete $k_{f_{cu},C}$, which is defined as the ratio between creep of the concrete with different strength and the creep of $f_{cu,m}$=30MPa at the same stress level, is expressed as

$$k_{f_{cu},\varepsilon} = (f_{cu,m}/30) k_{f_{cu},C} \quad (11)$$

Table **4** shows the influence coefficients of strength on the creep at the same stress level. It can be seen from Table **4** that the creep value has little difference when the stress level is equivalent and the compressive strength of the cubic is at the region of 20MPa~50MPa.

CONCLUSION

In this paper, the effect of the strength grade on the creep behavior of concrete was studied. Some important conclusions are summarized as follow:

(1) The effect of compressive strength on the creep compliance, the creep degree and the creep strain of concrete was obtained by the fitting of creep testing data collected from references. The fitting results show that the creep compliance and the creep degree is decreased with the increasing of compressive strength.

(2) The creep is decreased with the increasing of the compressive strength of concrete at the same load lasting time. The creep of concrete is increased first and then decreased with the increasing of the compressive strength, and the maximum value is at the compressive strength of the cubic at the region of 30MPa~35MPa at the same stress level. The creep value has little difference when the stress level is equivalent and the compressive strength of the cubic is at the region of 20MPa~50MPa.

(3) The effect of compressive strength on the compressive creep of concrete is analyzed systematically, and it is very convenient and practical. The influence coefficients of strength grade on the creep of concrete with the compressive strength in the region of 15MPa~180MPa is developed in this paper, which has a wide application in the civil engineering.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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Table 3. Creep degree and influence coefficient of strength on the creep degree.

$f_{cu,m}$ (MPa)	15	20	25	30	35	40	45	50	55	60	65	70	75	80
C (10^{-6}MPa^{-1})	186.7	166.4	144.2	123.7	105.7	90.2	77.0	65.8	56.3	48.3	41.6	35.9	31.1	27.1
$k_{f_{cu},C}$	1.51	1.35	1.17	1.00	0.85	0.73	0.62	0.53	0.46	0.39	0.34	0.29	0.25	0.22

Table 4. Influence coefficients of strength on the creep of concrete.

$f_{cu,m}$ (MPa)	15	20	25	30	35	40	45	50	55	60	65	70	75	80
$k_{f_{cu},\varepsilon}$	0.75	0.90	0.97	1.00	1.00	0.97	0.93	0.89	0.83	0.78	0.73	0.68	0.63	0.58

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