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Experimental investigation of creep and shrinkage of reinforced concrete with influence of reinforcement ratio

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Abstract. Predictions about shrinkage and creep of concrete are very important for evaluating time-dependent effects on structural performance. Some prediction models and formulas of concrete shrinkage and creep have been proposed with diversity. However, the influence of reinforcement ratio on shrinkage and creep of concrete has been ignored in most prediction models and formulas. In this paper, the concrete shrinkage and creep with different ratios of reinforcement were studied. Firstly, the shrinkage performance was tested by the 10 reinforced concrete beams specimens with different reinforcement ratios for 200 days. Meanwhile, the creep performance was tested by the 5 reinforced concrete beams specimens with different ratios of reinforcement under sustained load for 200 days. Then, the test results were compared with the prediction models and formulas of CEB-FIP 90, ACI 209, GL 2000 and JTG D 62-2004. At last, based on ACI 209, an improved prediction models and formulas of concrete shrinkage and creep considering reinforcement ratio was derived. The results from improved prediction models and formulas of concrete shrinkage and creep are in good agreement with the experimental results.

Keywords: concrete creep; concrete shrinkage; reinforcement ratio; prediction model

1. Introduction

Creep of concrete is generally caused by sliding and consolidation processes between gel particles due to external forces. Furthermore, if the crystal in the cement stone is subjected by a larger external force and elastic deformation, it can result in the increase of the deformation. In addition, micro cracks appear continuously in the contact zone of aggregates and cement paste, which can further increase the creep of concrete (Gilbert 1988, Neville and Dilger 1970, Babafemi 2016). The shrinkage of concrete is a physical phenomenon of volume reduction caused by water binder ratio, chemical reaction, environmental temperature, and so on. The total shrinkage generally consists of plastic shrinkage, autogenous shrinkage and drying shrinkage (Padron 1990, Aly *et al*. 2003). The creep and shrinkage of concrete are inherent to concrete characteristics and can lead to redistribution of internal forces and deformation of concrete structures in the long term. When the tensile strain reaches the ultimate value of the concrete, it will seriously affect the durability and serviceability of the structures and can even cause the concrete to crack (Weiss 1998, Wen 2006, Chen 2015). Hence, the capability of resisting shrinkage and creep is of vital importance in the concrete preformation.

The creep and shrinkage of concrete contain a multitude of interrelated factors, such as environmental temperature and humidity, the type of cement, concrete mix, and cross-sectional dimension size. So far, there has been no theory that could satisfactorily and fully explain them (Liu and Teng 2014, Mari *et al*. 2010). For the past several decades, various prediction models for creep and shrinkage have been presented by researchers based on large numbers of tests, such as CEB-FIP 90 (Podhorsky and Marić 1990), Bažant-Baweja B3 (Bažant and Baweja 1996, Bažant 2000), ACI 209 (1992), GL2000 models (Gardner and Lockman 2001), and JTG D62-2004 (2004). All those models are empirical formulas or fitting formulas from test data, and different prediction models use different expressions for creep and shrinkage. It is more effective to evaluate the safety of concrete structures by considering the stochastic character of variables. The creep equation of the ACI 209 model is sensitive to water content, while the CEB-FIP 90 model is extremely sensitive to relative humidity. Bažant-Baweja B3 and GL2000 models provide acceptable predictions in regard to shrinkage (Luca *et al*. 2007). It should be noted that, it is important to choose suitable prediction models for different projects, because of specific applicable conditions for each model. CEB-FIP 90, B3, ACI 209, GL2000 models ignore the influence of reinforcement on concrete. However, reinforced concrete components are widely built so that it is necessary to investigate the creep and shrinkage of reinforced concrete.

Most researches on the shrinkage and creep of concrete have mainly been focused on concentrated plain and prestressed concretes. Di (2006) proposed that the reinforcement restrains the shrinkage and creep of pre-stressed concrete. Ali (2017) investigated the effects of ambient temperature, relative humidity, cement hardening

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speed and aggregate type on concrete column shortening. The CEB-FIP 70 (1970) shrinkage model takes into account the impact of the non-prestressed steels on shrinkage through a simple formula with a constant influence coefficient. Tadros *et al*. (1997) presented a method for calculating the pre-stress loss and curvature at a cross-section based on the concrete stress at the centroid of total steel area for pre-stressed concrete members. Alvarado (2017) analyzes the influence of the construction process on short- and long-term deflections on a reinforced concrete structure poured on-site by a portable industrialized system. Gilbert (1999) recommended a relatively approximate method accounting for time-dependent cracking in deflection calculations of reinforced concrete beams and slabs. pre-stress loss and deflection calculation have made preliminary progress with the action of pre-stressed concrete shrinkage and creep (Xie 2009, Xu 2008, Huo 1997). Xiang (2017) proposed an analytical method considering axial equilibrium for the short- and long-term analyses of shear lag effect in reinforced concrete (RC) box girders. Chia (2014) investigated creep and shrinkage behaviour of an ultra lightweight cement composite (ULCC) up to 450 days. However, there is few research on reinforcement ratio of concrete shrinkage and creep, and the previous researches are mostly based on theoretical derivation or approximate calculation without experimental verification.

In this paper, the concrete shrinkage and creep with different reinforcement ratios were studied. Creep and shrinkage performance of the concrete were obtained from the tests of 10 reinforced concrete beams specimens with different ratios of reinforcement (0, 0.5%, 1%, 2% and 3.9%, respectively) for 200 days 5 reinforced concrete beams specimens with different ratios of reinforcement (0, 0.5%, 1%, 2% and 3.9%, respectively) under sustained load for 200 days. Prediction models of CEB-FIP 90, ACI 209, GL 2000 and JTG D 62-2004 were adopted to compare the test data of plain concrete beams. Finally, an improved prediction model and formula of concrete shrinkage and creep considering ratio of reinforcement was derived, considering the influence of different reinforcement ratios.

2. Prediction models of creep and shrinkage

Creep and shrinkage of concrete can be affected by the environment temperature, humidity, cement type, concrete mix ratio, section size of the components and so on. The difficulties of quantitative calculations on creep and shrinkage are extraordinary. Different prediction models have reasonable explanation method based on the test data and theoretical derivation, and explain of results have different formulas such as CEB-FIP 90 (Podhorsky and Marić 1990), ACI 209 (1992), GL2000 (2001), JTG D62-2004 (2004) models. Main formulas of four prediction models are as follows:

CEB-FIP 90 (Podhorsky and Marić 1990) model has the proposed scope of application: average temperature is 5-30℃ and average relative humidity is 40%-100%. Creep coefficient is given by Eq. (1) and Eq. (2), and shrinkage strain is given by Eq. (3). The creep coefficient mainly considers the relative humidity of the environment, the compressive strength of the concrete, and the duration of the loading. Shrinkage strain mainly considers the relative humidity of environment, age and the type of concrete.

$$\varphi(t,t_0)=\varphi_{RH}\cdot\beta(f_{cm})\cdot\beta(t_0)\cdot\beta(t,t_0) \tag{1}$$

$$\beta(t,t_0)=\left((t-t_0)/(t-t_0+\beta_H)\right)^{0.3} \tag{2}$$

Where, $\varphi(t,t_0)$ is the creep coefficient; φ_{RH} is influence coefficient of environmental relative humidity; $\beta(t_0)$ is influence coefficient of loading age; $\beta(t_0)$ is influence coefficient of duration of the loading; β_H is influence coefficient of component size.

$$\varepsilon_{cs}(t,t_s)=\beta_{RH}\left[160+\beta_{SC}(90-f_c)\right]\cdot\beta_s(t-t_s) \tag{3}$$

Where, $\varepsilon_{cs}(t,t_s)$ is shrinkage strain; β_{RH} is influence coefficient of environmental relative humidity; $\beta_s(t\text{-}t_s)$ is influence coefficient of age.

ACI 209 (1992) model uses a hyperbolic model to predict the shrinkage and creep. The concrete material composition, slump and other factors are considered in the formula. Creep coefficient and shrinkage strain are given by Eq. (4) and Eq. (5).

$$\varphi(t_0,t)=2.35K_1K_2K_3K_4K_5K_6\frac{(\mathrm{t}-\mathrm{t}_0)^{0.6}}{10+(\mathrm{t}-\mathrm{t}_0)^{0.6}} \tag{4}$$

Where, t_0 is the loading age, and $t_0 \geq 7$; K_1 is influence coefficient of loading age, and K_1=1.25t0-0.118; K_2 is humidity influence coefficient, and K_2=1.27-0.0067H ($H \geq 40\%$); K_3 is influence coefficient of average thickness of concrete, and K_3=1.14-0.00091ha (loading time, which is less than 1 year); K_4 is influence coefficient of concrete consistency, and K_4=0.82+0.0264S (S is concrete slump, mm); K_5 is influence coefficient of mixed fine aggregate content, and K_5=0.88+0.0024f (f is fine aggregate accounted for the total aggregate ratio); K_6 is influence coefficient of air content, and K_6=0.46+0.09Ad (A_d is the volume of air contained in concrete).

$$\varepsilon_s(\mathrm{t})=-780\times10^{-6}\times\left(\frac{t}{35+t}\right)r_{cp}r_Hr_dr_sr_pr_{ce}r_{AC} \tag{5}$$

Where, r_{cp} is influence coefficient of curing time before drying, and r_{cp}=1; r_H is humidity influence coefficient, and r_H=1.4-0.01H (40%<H<80%); rd is influence coefficient of component size, and r_d=1.23-0.0015d (d is average thickness); r_p is influence coefficient of sand ratio, and r_p=0.30+0.014f; r_{ce} is influence coefficient of cement dosage, and rc_e=0.75+0.00061C (C is cement content); r_{AC} is influence coefficient of gas content in concrete, and r_{AC}=0.95+0.008A (A is Air volume in fresh concrete).

GL2000 (2001) model considers the body surface ratio when calculating the creep strain. Creep coefficient and shrinkage strain are given by Eq. (6) and Eq. (7).

$$\varphi(t,t_0)=\varphi(t_c)\left[2\left(\frac{(\mathrm{t}-\mathrm{t}_0)}{(\mathrm{t}-\mathrm{t}_0)^3+14}\right)+\sqrt{\left(\frac{7(\mathrm{t}-\mathrm{t}_0)}{\mathrm{t}_0((\mathrm{t}-\mathrm{t}_0)+7)}\right)}\right.$$
$$\left.+2.5\left(1-1.086h^2\right)\sqrt{\left(\frac{(\mathrm{t}-\mathrm{t}_0)}{(\mathrm{t}-\mathrm{t}_0)+0.5\left(v/s\right)^2}\right)}\right] \tag{6}$$

Table 1 Mixture proportions of concrete (kg/m^3)

Cement	Fly ash	Fine aggregate	Coarse aggregate	Water	Admixture
280	63	688	1015	172	6.68

Table 2 Compressive strength of concrete

Concrete age/d	4	8	16	28
Cubic Compressive Strength (MPa)	27.67	37.92	40.82	43.04

Where, $\varphi(t_c)$ is influence coefficient of body surface ratio.

$$\varepsilon_s(\mathrm{t}) = \varepsilon_f \cdot \beta(\mathrm{h}) \cdot \beta(\mathrm{t}) \tag{7}$$

Where, ε_f is influence coefficient of concrete strength; $\beta(h)$ is influence coefficient of environmental relative humidity; $\beta(t)$ is influence coefficient of age.

JTG D62-2004 (2004) model is a standard method for calculating creep coefficient and shrinkage strain in reinforced concrete and prestressed concrete in China, which are given by Eq. (8) and Eq. (10).

$$\varphi(t,t_0) = \varphi_{RH} \cdot \beta(f_{cm}) \cdot \beta(t_0) \cdot \beta(t,t_0) \tag{8}$$

$$\beta(t_0) = \frac{1}{0.1 + (\mathrm{t}_0 / \mathrm{t}_1)^{0.2}} \tag{9}$$

Where, φ_{RH} is influence coefficient of environmental relative humidity; $\beta(t_0)$ is influence coefficient of loading age; $\beta(t,t_0)$ is influence coefficient of duration of the loading.

$$\varepsilon_{cs}(t,t_s) = \beta_{RH} \cdot \beta_s(f_{cm}) \cdot \beta_s(t-t_s) \tag{10}$$

Where, β_{RH}, $\beta_s(t\text{-}t_s)$, and $\beta_s(f_{cm})$ are influence coefficients of environmental relative humidity, age, and strength, respectively.

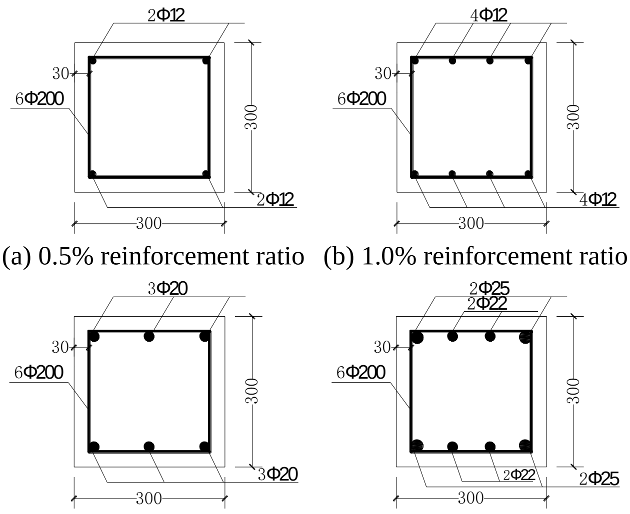
3. Component materials and properties of concrete

The mixture ratio of concrete is shown in Table 1 used in the shrinkage and creep tests. The cement used was Portland cement (P.O42.5), and the second-grade fly ash took its source from Jiangsu, China. The fineness of fly ash was 20.6%, the water content was 0.1%, and the activity index was 75%. The fine aggregate was taken from Yangtze River in Hubei, China, and had fineness modulus of 2.6 and a particle size of about 5mm. The coarse aggregate gravel was produced in Huzhou, China, and particle size grading was 10-25mm. The concrete admixture was TMS-YJ efficient polycarboxylate superplastic produced by Jiangsu concrete admixture Co. Ltd., and the water reducing rate was 25.5% and the solid content was 19.6%.

The cubic compressive strength and modulus of elasticity in standard curing conditions are shown in Table 2 and Table 3. The cubic standard cure strength specimens were casted in 150 mm×150 mm×150 mm steel molds, and the measurement of age are 4d, 8d, 16d and 28d. Meanwhile, modulus specimens were casted in 100 mm×100 mm×300 mm steel molds, and the measurement of age were 6d, 8d, 14d, 28d and 90d.

Table 3 Elasticity Modulus of concrete

Concrete age/d	6	8	14	28	90
Modulus of Elasticity (GPa)	9.45	13.4	16.9	25.9	31.3



(a) 0.5% reinforcement ratio (b) 1.0% reinforcement ratio

(c) 2.0% reinforcement ratio (d) 3.9% reinforcement ratio

Fig. 1 Section reinforcement

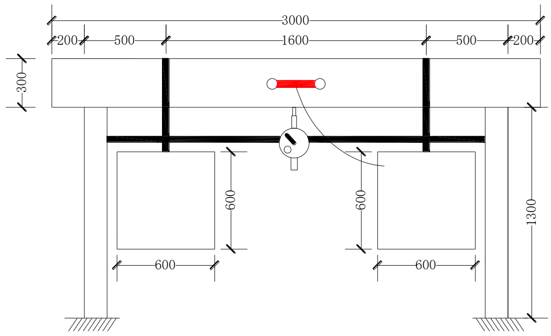
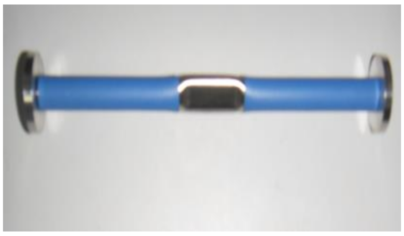


Fig. 2 Testing beam for measuring creep

4. Tests on creep and shrinkage of reinforced concrete beam experimental beam specimens

The purpose of the experiment is to determine creep and shrinkage of concrete beams with different reinforcement ratios. Firstly, the 10 concrete beams for shrinkage of reinforced concrete were designed, whose cross section is 300 mm×300 mm and all length is 1000 mm. The reinforcement ratios of the five groups were 0, 0.5%, 1%, 2% and 3.9%, respectively. In each group, two specimens were made to ensure the accuracy of the measured data. In accordance with reinforcement ratios from low to high, the ten specimens were encoded as S1-S5. Then the 5 concrete beams for creep of reinforced concrete were designed, whose cross section is 300 mm×300 mm and all length is 3000 mm. In accordance with the reinforcement ratios from low to high, the five specimens were coded as C1-C5. Details of sectional reinforcements is shown in Fig. 1.



(a) Strain gauge

(b)Thermistor and cable

Fig. 3 Each component of strain gauge

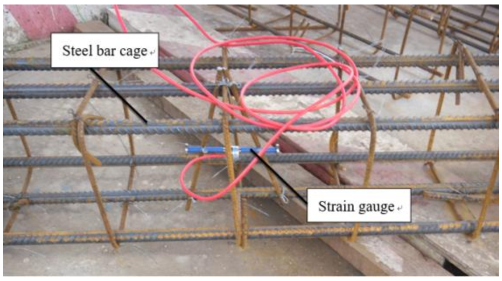


Fig. 4 Installation position of strain gauge

Installation detail of creep concrete beam was shown in Fig. 2. Strain gauge was embedded in the middle span of concrete beam to record the longitudinal deformation of beam. The distance from the end of the beam to the loading point is 700 mm. The load is 5184 N using a counterweight (600 mm×600 mm × 600 mm) in test for concrete creep.

5. Experiment process

Firstly, 15 (10 shrinkage beams, 5creep beams) wooden templates and steel reinforcement cages were fabricated according to the designed size of beam. The embedded strain gauges were fixed on the cage before beam specimens were casted. The strain gauge is shown in Fig. 3 and the installation location of strain gauge embedded in concrete is shown in Fig. 4. Secondly, after casting, the creep and shrinkage specimens were cured in a room where the ambient temperature was 25±2℃ and the relative humidity was approximately 70%. The ten shrinkage beam specimens are shown in Fig. 5. Then the time-dependent shrinkage strains were monitored every day during the first 28 days and then once a week after 28 days. The creep specimens were loaded at 28 days using the counterweights (Fig. 6). The time-dependent creep strains were monitored once a week from the beginning of the loading.

6. Test results

Fig. 5 The shrinkage specimens

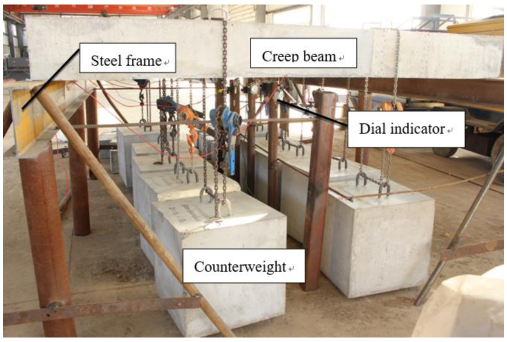


Fig. 6 The creep specimens

The shrinkage strain was measured by shrinkage beam specimens directly, and the creep strain is calculated by Eq. (11).

$$\varepsilon_{c,i} = \varepsilon_{total,i} - \varepsilon_{sh,\mathrm{i}} - \varepsilon_{\mathrm{e,i}} \tag{11}$$

Where: i indicates different reinforcement ratios given as 0, 0.5%, 1%, 2%, and 3.9%, respectively. ε_{total} is the total strain of creep beam. ε_e is the instantaneous elastic strain. ε_{sh} is the shrinkage strain for the corresponding age.

Fig. 7 shows the shrinkage strain measured on the beam specimens (S1-S5) of 200 days. The total shrinkage presents a large fluctuation in early age due to the sensitivity to environment. After about 10 days, the expansion stress reaches the maximum value, and self-shrinkage of concrete in early-time can be measured. After about 28 days, hydration of cement tends to be stable and shrinkage strain tends to increase. The reinforcing bar effectively restrained the shrinkage of concrete, and the restriction effect increases significantly with the increase of the reinforcement ratio. Compared with plain concrete, the shrinkage strain of beam with 0.5%, 1.0%, 2.0%, 3.9% reinforcement ratios decrease by 10%, 14%, 20%, 25%, respectively at 200 days. With the increase of the age, the variation trends of the shrinkage strain of concrete with different reinforcement ratios are basically consistent. The shrinkage strain increased rapidly during the first 25 days and increased slowly after 25 days.

Fig. 8 shows the creep coefficient of the beam specimens (C1-C5) of 200 days. The creep coefficient can reflect creep degree (Pan *et al*. 2011, Pan and Meng 2016) and is calculated by Eq. (12).

$$\varphi(t,t_0) = \frac{\varepsilon_{total} - \varepsilon_e - \varepsilon_{sh}}{\varepsilon_e} \tag{12}$$

where $\varphi(t,t_0)$ is the creep coefficient. ε_{total} is the total strain of creep beam. ε_e is the instantaneous elastic strain. ε_{sh} is the shrinkage strain for the corresponding age.

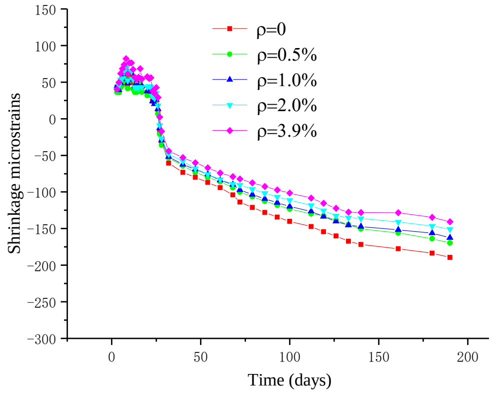


Fig. 7 Shrinkage strain curve with age

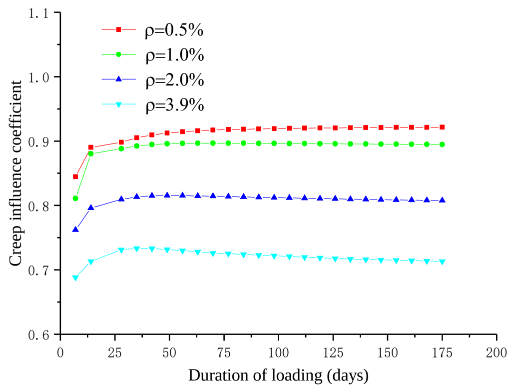


Fig. 9 Creep influence coefficient curve with age

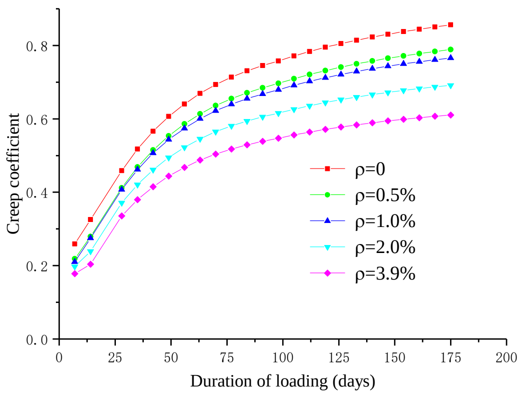


Fig. 8 Creep coefficient curve with age

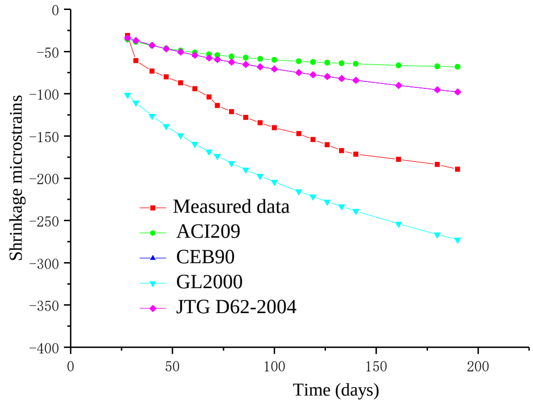


Fig. 10 Comparison between predicted and measured shrinkage

The creep coefficient increases faster at early age than later age. High reinforcement ratio can effectively inhibit the development of creep. The creep influence coefficient (Luca and Antonino 2008) of different reinforcement ratios can be calculated by Eq. (13).

$$\gamma_p(\mathrm{t}) = \frac{\varphi_p(\mathrm{t}, \mathrm{t}_0)}{\varphi(\mathrm{t}, \mathrm{t}_0)} \tag{13}$$

where $\gamma_p(t)$ is creep influence coefficient. $\varphi_p(t,t_0)$ is creep coefficient of reinforced concrete with t_0 to t at the age of loading. $\varphi(t,t_0)$ is creep coefficient of plain concrete with t_0 to t at the age of loading.

Fig. 9 shows that the creep influence coefficients are comparable with the reinforcement ratio of 0.5% and 1.0%, and low reinforcement ratio has little influence on creep of concrete. After 175 days, the creep influence coefficients were 0.92, 0.89, 0.81, and 0.71, corresponding to the reinforcement of 0.5%, 1.0%, 2.0%, and 3.9%, respectively. High reinforcement ratio can effectively restrain the increase of creep.

Due to the material of concrete beam is not homogeneous, the stress of particle in the cross section of beam is different and the larger deformation is formed in the middle of the beam under the vertical load. The shrinkage and creep strain of concrete is larger than that of steel bar, so proper reinforcement can share the internal stress of concrete caused by creep and shrinkage. Meanwhile, the deformation of the concrete will be restrained, and the creep and shrinkage strain of the concrete will be reduced (Branson 1977, Sun 1992, Gosaye Gardner *et al.* 2014). With the increase of reinforcement ratios, the surface area of the steel bar becomes larger, which can resist the creep and shrinkage of reinforced concrete. Therefore, creep and shrinkage strain of high reinforcement ratio in the concrete is much lower than that in plain concrete.

7. Prediction model comparison of shrinkage and creep

An appropriate model is important to analyze the time-dependent effects of creep and shrinkage. In this paper, models of CEB-FIP 90, ACI 209, GL 2000 and JTG D 62-2004 are selected to calculate shrinkage and creep of plain concrete. Fig. 10 and Fig. 11 show the comparisons of the predicted shrinkage and creep from the four models with the experimental results.

The variation trend of shrinkage strain with the age, from the four types of prediction models, is consistent with the test measurement. The results from CEB-FIP90 and JTG D62-2004 models are similar. However, the result from CEB-FIP 90, ACI 209, and JTG D 62-2004 model is smaller than test result. On the contrary, the result from GL2000 model is larger than test result. Creep coefficients obtained from theoretical models and experiments also show a consistent trend of change with the age. Compared

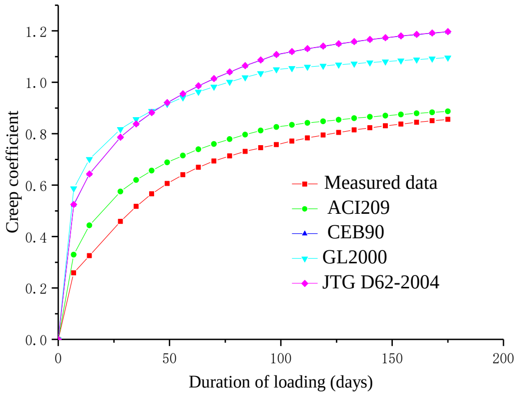


Fig. 11 Comparison between predicted and measured creep

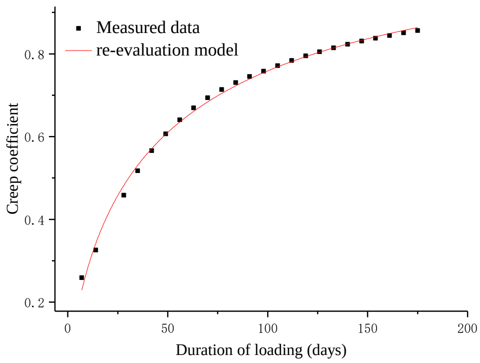


Fig. 12 Comparison between calculation values and test data of creep specimens

with measurements, all models greatly overestimate the values. CEB-FIP 90 and JTG D62-2004 models have higher creep coefficient, and ACI 209 model for the prediction of the creep coefficient is more accurate. Shrinkage strain and the creep coefficient from the four models all have some discrepancy in comparison with the measured data, so the ACI 209 model is modified to fit the influence coefficient of reinforced concrete.

8. Influence of reinforcement ratios on creep and shrinkage

8.1 Re-evaluation of the ACI 209 model

When predicting shrinkage and creep, ACI 209 model takes into consideration the concrete mix, slump, cement. Therefore, this model is re-evaluated by using the test data and following Eqs. (14) and (15) described below. Eqs. (14) and (15) indicate creep coefficient and the shrinkage strain respectively.

$$\varphi(t_0,t)=1.16\times\frac{(\mathrm{t}-\mathrm{t}_0)^{0.95}}{25.87+(\mathrm{t}-\mathrm{t}_0)^{0.95}} \tag{14}$$

Where, t_0 is the loading time. t is the time after creep is considered, that is, after the end of the loading time. The factor related to the size of the concrete section, the composition of the material and the environmental conditions is 1.16.

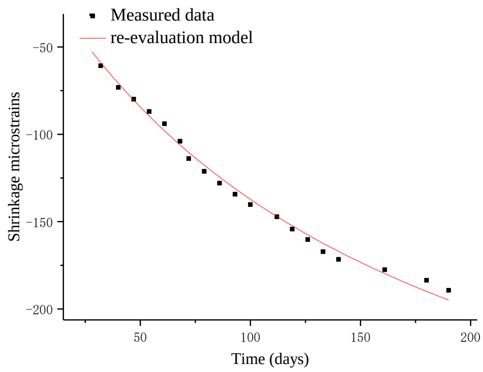


Fig. 13 Comparison between calculation values and test data of shrinkage specimens

$$\varepsilon_s(\mathrm{t})=-\left(\frac{t}{166.4+t}\right)\times365.53\times10^{-6} \tag{15}$$

Where, t is the time after shrinkage is considered, that is, after the end of the initial wet curing. The ultimate value of shrinkage is 365.53×10^{-6}.

Fig. 12 shows the comparison of creep coefficient between re-evaluation ACI 209 model and the test data of plain concrete. Fig. 13 shows the comparison of shrinkage strain between re-evaluation ACI 209 model and the test data of plain concrete. As illustrated in the figures, the fitting of creep coefficient and shrinkage strain become better with the correlation coefficients of 99.57% and 98.08% respectively. Therefore, the modified prediction model can better match the results of the experiments.

9. Fitting reinforcement influence coefficient of creep and shrinkage

According to re-evaluation ACI 209 model, the influence coefficient on reinforcement ratio was introduced to explain the effect of reinforcement in reinforced concrete. Combined with the test results of different reinforcement ratios, shrinkage strain and creep coefficient of reinforcement influence coefficients were fitted by Eqs. (16)-(19) as follow

$$\varphi(t_0,t)=1.16\times\frac{(\mathrm{t}-\mathrm{t}_0)^{0.95}}{25.87+(\mathrm{t}-\mathrm{t}_0)^{0.95}}K_P \tag{16}$$

$$K_p=0.83\times e^{-0.072\rho} \tag{17}$$

$$\varepsilon_s(\mathrm{t})=-\left(\frac{t}{166.4+t}\right)\times365.53\times10^{-6}R_p \tag{18}$$

$$R_p=0.90\times e^{-0.05\rho} \tag{19}$$

Where, K_p is reinforcement on creep influence coefficient. R_p is reinforcement on shrinkage influence coefficient. ρ is the reinforcement ratio (0.5%-3.9%).

According to the test results of different reinforcement ratios, K_p is 0.80, 0.78, 0.71, 0.63 correspond to the reinforcement of 0.5%, 1.0%, 2.0%, 3.9%, and R_p is 0.88, 0.85, 0.81, 0.74 correspond to the reinforcement of 0.5%, 1.0%, 2.0%, 3.9%, respectively. Table 4 shows the value of K_p and R_p of different reinforcement ratios. Figs. 14 and 15 show re-evaluation creep coefficient and shrinkage strain and the test results.

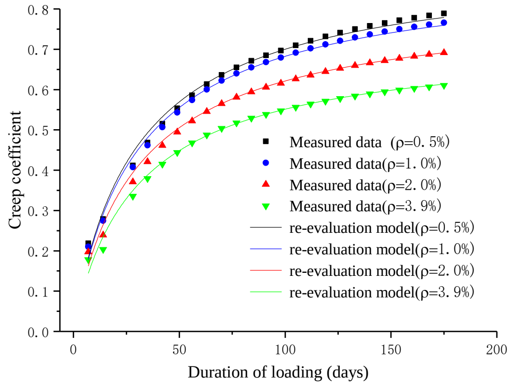


Fig. 14 Comparison between re-evaluation values and test data of creep specimens

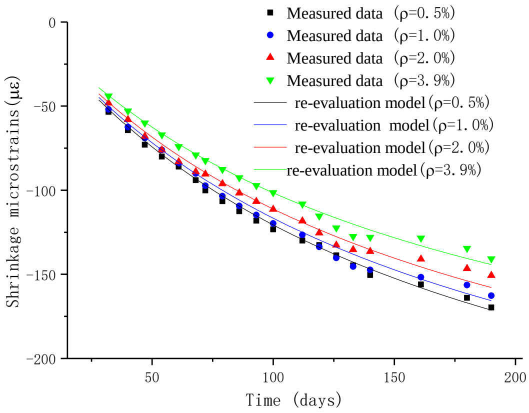


Fig. 15 Comparison between re-evaluation values and test data of shrinkage specimens

As seen in Figs. 14-15 and Table 4, the re-evaluation of ACI 209 model is reasonable and can be used to show the effect of reinforcement on shrinkage and creep of concrete. With the increase of the ratio of reinforcement, the restraint effect is more obvious.

10. Conclusions

Reinforced concrete is widely used in engineering construction and some prediction models and formulas of concrete shrinkage and creep have been proposed with diversity. However, most of the available reinforced concrete prediction models for creep and shrinkage are derived through approximate calculation of plain concrete. In this paper, based on the tests of shrinkage and creep on concrete beams with different reinforcement ratios, the influence of reinforcement ratio on shrinkage and creep is investigated. Some conclusions were obtained and summarized below:

(1) Reinforcement can effectively restrain the development of concrete shrinkage and creep, and the restraint is more obvious with higher reinforcement ratio.

Table 4 Reinforcement on creep and shrinkage influence coefficient

Reinforcement ratio%	0.5	1.0	2.0	3.9
K_p	0.80	0.78	0.71	0.63
R_p	0.88	0.85	0.81	0.74

(2) The results from shrinkage test show that the shrinkage strain of the concrete fluctuates obviously due to the heat of hydration of cement, which is sensitive to environmental factors in the early period. After about 28 days, hydration of cement tends to be stable. The shrinkage strain increases, and the increment is larger with smaller reinforcement ratio.

(3) The results from creep test show that The creep coefficient increases faster at early age than later age. The reinforcing bar effectively restrained the creep of concrete, and the effect of high reinforcement ratio is more obvious.

(4) The creep coefficients from the CEB-FIP90, ACI209, GL2000, D62-2004 JTG models are larger than the creep coefficients from measured dates. The creep coefficients from ACI209 model is more consistent with the experimental results.

(5) According to test results, re-evaluation of ACI209 model is fitted by Origin software, and the correlation coefficient reach 98%. Meanwhile, the reinforcement ratio coefficient on the reinforcement shrinkage and creep were proposed, and the formulas on the reinforcement ratio coefficient were obtained.

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