Creep of CFRP confined reinforced concrete members under large eccentric compression

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Abstract. Based on the multiaxial stress state theory of concrete under and B3 model for calculating concrete creep, combined with the mechanical characteristics of reinforced concrete members under large eccentric compression, considering the influence of member deflection, reinforcement configuration and hoop force, the creep model of CFRP confined reinforced concrete members under long-term load is established. Compared with the experimental results, the theoretical calculation results are in good agreement with the experimental values. It has a certain guiding significance to the actual engineering structure.

1. Introduction
Compared with steel bonding and prestressing, CFRP has the advantages of high strength, light weight, good durability, high flexibility and simple construction technology, which has been widely used in the repair and reinforcement of existing structures and new structures. Carbon fiber confinement effect makes concrete in multi axial stress state, which not only improves the bearing capacity and ductility of members, but also improves the mechanical properties of members [1-3].

For CFRP confined concrete members, firstly, both CFRP and core concrete will creep under sustained stress, and with the creep of core concrete, the strain state of CFRP confined concrete column will change continuously, and even creep will lead to damage. Therefore, it is of great significance for structural analysis to accurately predict the time-dependent variation of the component deformation.

At present, the research of CFRP confined concrete members mainly focuses on the axial compression of plain concrete short columns, which is quite different from the actual structural members in geometric form and mechanical characteristics[4-6].

In this paper, based on the concrete calculation theory and concrete creep B3 model under multi axial stress state, the creep theoretical calculation formula of CFRP confined large eccentric compression cylinder is established, and the theoretical model is verified by comparing with the experimental data.

2. Mechanical analysis of CFRP confined reinforced concrete members under large eccentric compression
Large eccentric compression is one of the most common mechanical forms in practical engineering. Before analyzing the creep of CFRP confined reinforced concrete members under large eccentric...
compression, the following assumptions are made on the mechanical characteristics of members.

1) The results show that the concrete members and CFRP materials are ideal elastic-plastic bodies;
2) The creep of core concrete accords with the principle of linear superposition, that is to say, it is linear creep;
3) The tensile force of concrete is not considered;
4) The results show that there is a good bond between CFRP and concrete, and the degradation of bond strength between CFRP and concrete is not considered;
5) CFRP does not bear the compressive stress, the axial pressure is all borne by the core concrete.

This paper takes the reinforced concrete member with circular section confined by CFRP as an example to analyze its stress under large eccentric compression.

2.1. Equilibrium equation

Large eccentric compression member of carbon fiber reinforced concrete structure diagram, stress diagram and strain diagram as shown in the Figure 1.

![Figure 1. The eccentric compression force diagram of carbon fiber reinforced concrete](image)

The equilibrium equations are listed as

\[ \Sigma N = 0 \]  
\[ \Sigma M = 0 \]

From the above relationship, there are

\[ N = \frac{2r \delta \sigma f w_1 - 2r^3 \sigma c w_1}{1 + \cos \beta_1} + \sigma_s A_s - \sigma_s' A_s \]  
\[ M = \frac{2r \delta \sigma f w_1 - 2r^3 \sigma c w_1}{1 + \cos \beta_1} + \sigma_s A_s (h_s - r \cos \beta_1) + \sigma_s' A_s (h_s + r \cos \beta_1) \]

Where \( N \) is the vertical load acting on the carbon fiber reinforced concrete member; \( M \) is the bending moment generated on the cross-sectional surface of the member due to the eccentricity of \( N \); \( \sigma_f \) is the maximum tensile zone stress of the carbon fiber cloth of the member section; \( \sigma_c \) the concrete of the member section The maximum stress in the compression zone; \( \sigma_s \) and \( \sigma_s' \) are the tensile reinforcement stress at the bottom of the member and the compression stress at the top of the member section; \( r \) is the core concrete radius; \( \delta \) is the carbon fiber thickness; \( \beta_1 \) is the half of the center angle of the tension zone of the member; \( h_s \) is the distance from the top reinforcement to the central axis, \( h_s = r - 25 \). \( w_1 \sim w_4 \) are coefficients related to \( \beta_1 \).

The stress relationship of tension and compression steel bar can be obtained

\[ \sigma_s' = \frac{(r \cos \beta_1 + h_s) \sigma_c}{E_s} \]  
\[ \sigma_s = \frac{h_s - r \cos \beta_1}{E_s} \sigma_c \]

According to the mechanics of materials, \( \eta = \frac{1}{N \left( \frac{1-N}{E} \right)} \)

\[ \cos \beta_1 = \frac{r}{2(e_0 + f)} = \frac{r}{2\eta e_0} \]

Where \( e_0 \) is the initial eccentricity of the loading point; \( f \) is the components deflection.
2.2. Initial stress

From the above formulas (3) to (6), the expression of the relationship between the internal force and stress on the concrete, carbon fiber cloth and steel bar at the maximum compressive fiber of the core concrete under the large eccentric compression state is obtained.

\[
N_c = \frac{2\sigma_c r^2 w_1}{1 + \cos \beta_1} \tag{8}
\]

\[
N_f = \frac{A_f \sigma_f \cos \beta_1}{1 + \cos \beta_1} \tag{9}
\]

\[
N_0 = \frac{2h_x + r \cos \beta_1}{r + r \cos \beta_1} \cdot \frac{E_s}{E_c} A_{s} \sigma_c \tag{10}
\]

Therefore, the initial stress of the concrete at the maximum compression fiber of the core concrete is derived

\[
\sigma_{c0} = \frac{2r \delta_n \varphi \sigma_{w2} - 2r \delta w_1}{1 + \cos \beta_1} + \frac{A_n (h - r \cos \beta_1) \varepsilon_c}{(r - r \cos \beta_1) E_c} \frac{A_f (h + r \cos \beta_1) \varepsilon_c}{(r + r \cos \beta_1) E_c} \tag{11}
\]

Maximum initial tensile stress of carbon fiber is

\[
\sigma_{f0} = n \varphi \sigma_{c0} \tag{12}
\]

The initial stresses of compressive and tensile steel bars are

\[
\sigma_{s0} = \frac{(r \cos \beta_1 + h_s) E_s}{(r + r \cos \beta_1) E_c} \sigma_{c0} \tag{13}
\]

\[
\sigma_{s0} = \frac{h_s - r \cos \beta_1 E_s}{r - r \cos \beta_1 E_c} \sigma_{f0} \tag{14}
\]

2.3. Bonding stress

In the large eccentric compression member, the bonding force between carbon fiber and concrete will be unevenly distributed due to the uneven stress distribution on the crosssection. The core concrete is in a three-dimensional stress state with unequal lateral compressive stress. According to Hook's law, the deformation coordination assumption is

\[
e_{c1} = \varphi e_{f1} , \quad e_{c2} = e_{f2} , \quad e_{c3} = e_{f3}
\]

The following relationship can be derived

\[
p = \sigma_{c2} = q \sigma_{c1} \tag{15}
\]

\[
p_1 = \sigma_{c3} = q_1 \sigma_{c1} \tag{16}
\]

\[
q_1 = \frac{n - \frac{\varphi n (1 + \mu_f)}{\varphi + \mu_f} - \left[ \left( n \mu_c + \varphi \mu_f \frac{2}{\varphi} \right) - \frac{\varphi (n (\mu_c + 1) + \mu_f (\varphi - 1))^2}{\varphi + \mu_f} \right]}{n \mu_c} \tag{17}
\]

In the above formula, \( \varphi \) is the deformation coordination coefficient, which is related to the material. From the geometric relationship, \( \varphi = (1 + \cos \beta_1)/(1 - \cos \beta_1) \); \( n \) is the carbon fiber elastic modulus and concrete elasticity Modulus ratio, \( n = E_f/E_c \); \( \sigma_{c1}, \sigma_{c2}, \sigma_{c3} \) are concrete longitudinal stress, radial stress, hoop stress; \( p \) is the binding force, \( p = \sigma_{c2} \); \( \alpha \) is the CFRP rate of the component, \( \alpha = A_f/A_c \).

The above is the expression of the relationship between the combined stress and axial stress of the carbon fiber reinforced concrete large eccentric compression member.

3. Creep analysis

After creep occurs, the stress changes of concrete, carbon fiber and steel bar are as follows

\[
\sigma_c' = \frac{1 + \cos \beta_1}{2r^2 w_1} N_c' \tag{17}
\]

\[
\sigma_f' = \frac{1 + \cos \beta_1}{2r \delta w_2} N_f' \tag{18}
\]
\[ N_{\xi} = \frac{2h_s + r \cos \beta_1}{r + r \cos \beta_1} \cdot \frac{E_s}{E_c} A_s \sigma_{\xi} \]  

(19)

Then there is relation
\[ \sigma_f^c = \frac{-rw_4}{\delta w_2} \sigma_c^c = -Y \sigma_c^c \]  

(20)

In the process of creep, compared with carbon fiber, the effect of steel bars on creep is relatively small, so the effect of steel bars on creep is ignored in the process of creep.

Strain changes when creep occurs
\[ \varepsilon^c_f = \frac{1}{E_f} (\sigma_f^c + \mu_f \frac{2}{\alpha} \Delta p) \]  

(21)

\[ \varepsilon^c_c = \sigma_c^c c_1 = (\sigma_c^c + \sigma_c^c c_1) c_1 \]  

(22)

According to the creep theory of concrete under multiaxial stress[7], the axial effective creep Poisson’s ratio \( \mu_{cp,1} \) of the core concrete is
\[ \mu_{cp,1} = 0.16 - 0.037 \frac{q}{q^2} + 0.007 \frac{q^2}{q^2} \]  

(23)

\[ c_1 = c(1 - \mu_{cp,1}(q_1 + q)) \]  

(24)

In the formula (24), \( c \) is the creep of concrete under uniaxial stress state. When considering lateral creep deformation, the radial strain change of carbon fiber is
\[ \varepsilon^c_f = -\frac{\mu_f}{E_f} (\sigma_f^c - \frac{2}{\alpha} \Delta p) \]  

(25)

Radial creep of core concrete at maximum compression
\[ \varepsilon^c_c = (p + \Delta P)c_2 \]  

(26)

\[ c_2 = c(1 - \mu_{cp,2}(\frac{q_1}{q} + \frac{1}{q})) \]  

(27)

\[ \mu_{cp,2} = 0.16 - \frac{q_1}{q} \left( \frac{q_1 + 1}{q} \right)^2 \]  

(28)

According to the radial deformation coordination \( \varepsilon^c_c e_c = \varepsilon^c_c e_c \), the stress increment of axial concrete due to creep is
\[ \sigma_{c_1}^c = \frac{2 \mu_f}{E_f} c_1 \left( \frac{\gamma \mu_f - q \varepsilon_c E_f}{\varepsilon_c E_f - \frac{2 \mu_f}{\alpha}} + \frac{1}{\gamma \mu_f - q \varepsilon_c E_f} \right) \]  

(29)

Therefore, based on the B3 model[8], the creep of concrete structural members reinforced with carbon fiber can be calculated
\[ \varepsilon^c_c = \sigma_c^c \cdot C(t, t_0) \]  

(30)

4. **Experimental verification**

In the previous section, the theoretical derivation of carbon fiber reinforced concrete members with large eccentric compression round cross-sections was theoretically deduced. Since there are no experimental reports of large eccentrically compressed carbon fiber-reinforced concrete members, the reinforced concrete with carbon fiber cloth is similar to large eccentric compression. The experimental data[9] of the corresponding tests of the mechanical properties are compared to verify the correctness of the formula derived in this paper. The comparison chart is as follows.
As shown in the Figure 2, the model of the calculated curve and test the test result curves are in good agreement in general. The test of the curve and theoretical calculation of the creep curves under the condition of same deviation mainly exist in the 200 days later, causing the deviation of the original. The cohesive strength between carbon fiber and concrete will gradually decline, due to time effect to a certain impact on the creep of concrete, but not in this article. And from the picture, we find that in the concrete 28 day until 200 days during this period, concrete creep theory calculation value and experimental value of the literature alignment is very high.

5. Conclusion
The stress of CFRP confined concrete members under large eccentric compression is analyzed, including stress analysis, stress state analysis, consideration of initial stress, binding force and deflection of long members. Combined with B3 model of concrete creep, the creep model of CFRP confined concrete is obtained. The program operation of the model deduced in this paper is compiled and compared with the existing tests. The analysis proves the feasibility of the model.

Acknowledgements
The authors would like to acknowledge the financial support of the Science and Technology Project Founded by the Education Department of Jiangxi Province(Grant No. GJJ170985) and the National Innovation and Entrepreneurship Training Program for College Students (Grant No. 201911319018).

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