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Static behaviour of circumferential stress releasing anchor for large-capacity FRP cable

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Abstract

In this study, an optimized anchor system is proposed and evaluated to enhance the anchor performance of FRP cables with 37 FRP tendons. The integrated load transfer component (LTC) with variable stiffness was prepared by winding different fibers and compression molding. Tensile force and axial strain were recorded during the loading process of four cables. The derived radial stress formula verifies the necessity of releasing circumferential stress of LTC. The results show that the optimized anchor can effectively perform tension behaviour of 37 BFRP tendons and avoid shear concentration of FRP cables at the loading end. The mean anchor efficiency coefficient of BFRP cables with 37 BFRP tendons is 99.2%. The tensile strain of FRP cables at the middle portion varies linearly as a function of tensile force. The vacation of tensile strain of FRP tendons at different locations under the same load is negligible, and no shear lag effect on the inner and outer FRP tendons is observed.

Keywords: fiber reinforced polymer (FRP); anchor; cable; variable stiffness; load transfer component

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1 Introduction

Considering the deficiency of current anchor methods for FRP cables, the authors previously proposed an integral wedge anchor with a gradient stiffness load transfer component to anchor the large-tonnage FRP cables [1]. The proposed anchor system relieved excessive radial extrusion pressure at the loading end of FRP cables, which was realized by changing winding angle of fiber roving [1, 2]. Although the anchor system has shown good static performance, it still existed the following deficiencies, e.g., difficult in controlling winding angle, limitative range of elastic modulus, excessive stiffness of LTC at the loading end, circumferential stress weakening the clamping force of FRP cable. Therefore, this paper proposes several optimization measures to overcome the existing shortcomings, e.g., using different fibers in each section, keeping vertical winding angle, increasing the number of FRP tendons, releasing circumferential stress of LTC. Furthermore, the static tensile test and simulation analysis for FRP cables with 37 BFRP tendons have also been carried out in this study. The ultimate tensile force and tensile strain of BFRP cables and the axial displacement of LTC were measured. In addition, the elastic modulus and anchor efficiency coefficient of BFRP cables were calculated to further verify the optimization effect.

2 Releasing Circumferential Stress of LTC

The steel sleeve could produce radial extrusion pressure on the surface of LTC when the BFRP cable was in the tension state (see Fig. 1(a)). At the same time, the LTC produced corresponding circumferential resistance owing to the circumferential arrangement of fiber (see Fig. 1(b)). The generation of circumferential resistance limited the radial deformation of LTC, which would lead to insufficient radial extrusion pressure and pull-out failure for BFRP cables. Thus, the necessity of releasing circumferential stress will be further clarified through theoretical analysis.

Assuming that no relative slippage occurs between the FRP cable and the LTC, and the pull-out failure of the FRP cable is ignored, then it has been proven that the radial stress of the FRP cable in the anchor zone provides the main anchor force [3]. Then, the next analysis is based on two parts, i.e., LTC with slits and LTC without slits.

(1) No circumferential stress will exist after releasing circumferential stress of LTC (see Fig. 1(c)), then the stress relationship of σ_{11} and σ_2 can be expressed as equation (1).

$$\sigma_{11} = \sigma_2 \frac{r+h}{r} \tag{1}$$

Where σ_{11} represents the radial stress of BFRP cables after releasing circumferential stress of LTC; σ_2 represents the radial stress of LTC; r represents the radius of BFRP cables; h represents the height of LTC at the position of section A-A.

(2) When the LTC exists circumferential stress (see Fig. 1(d)), the stress relationship of radial stress of LTC and circumferential stress can be expressed as equation (2).

$$\sigma_3 = \sigma_2 \cos\theta = \sigma_2 \frac{\sqrt{(r+h)^2 - y^2}}{r+h} \tag{2}$$

Where σ_3 represents the circumferential stress of LTC; θ represents the degree of the microelement body of circumferential stress ring and radius of BFRP cables; y represents the distance between the outer edge of the circumferential stress ring and the center of BFRP cable.

By balancing the vertical force of the half section and building integral formula (see Fig. 1(e)), the stress relationship of radial stress of LTC and radial stress of BFRP cables can be expressed as equation (3).

$$2\int_0^{\frac{\pi}{2}}\sigma_2(r+h)\sin\alpha\, d\alpha = 2\int_0^{\frac{\pi}{2}}\sigma_{12} r\sin\alpha\, d\alpha + 2\int_r^{r+h}\sigma_2\frac{\sqrt{(r+h)^2-y^2}}{r+h}dy \tag{3}$$

Where σ_{12} represents the radial stress of BFRP cables before releasing circumferential stress of LTC; α represents the integration variable of radial stress.

The relationship of σ_{12} and σ_2 can be further simplified basing on equation (3).

$$\sigma_{12} = \sigma_2\left(\frac{(4-\pi)(r+h)}{4r} + \frac{\sqrt{h^2+2rh}}{2(r+h)} + \frac{r+h}{2r}\arcsin\frac{r}{r+h}\right) \tag{4}$$

The effect of releasing circumferential stress can be evaluated by using equation (5).

$$\lambda = \frac{\sigma_{11}-\sigma_{12}}{\sigma_{12}} \times 100\% \tag{5}$$

Where λ represents the increment of the radial stress of BFRP cable after releasing circumferential stress.

Based on the dimension of LTC and the BFRP cables in this study, the radius of BFRP cable r is 17 mm, and the height of LTC at different section h is 10.5 to 52.25 mm. The relationship of h and λ can be obtained by submitting corresponding values to equation (5). The increment of radial stress of BFRP cable after releasing circumferential stress increases obviously from 26% (loading end of LTC) to 117% (free end of LTC), which indicates the necessity of releasing circumferential stress of LTC, especially the free end of LTC. Therefore, cutting several slits with equal spacing along the longitudinal direction of LTC was carried out to release the circumferential stress.

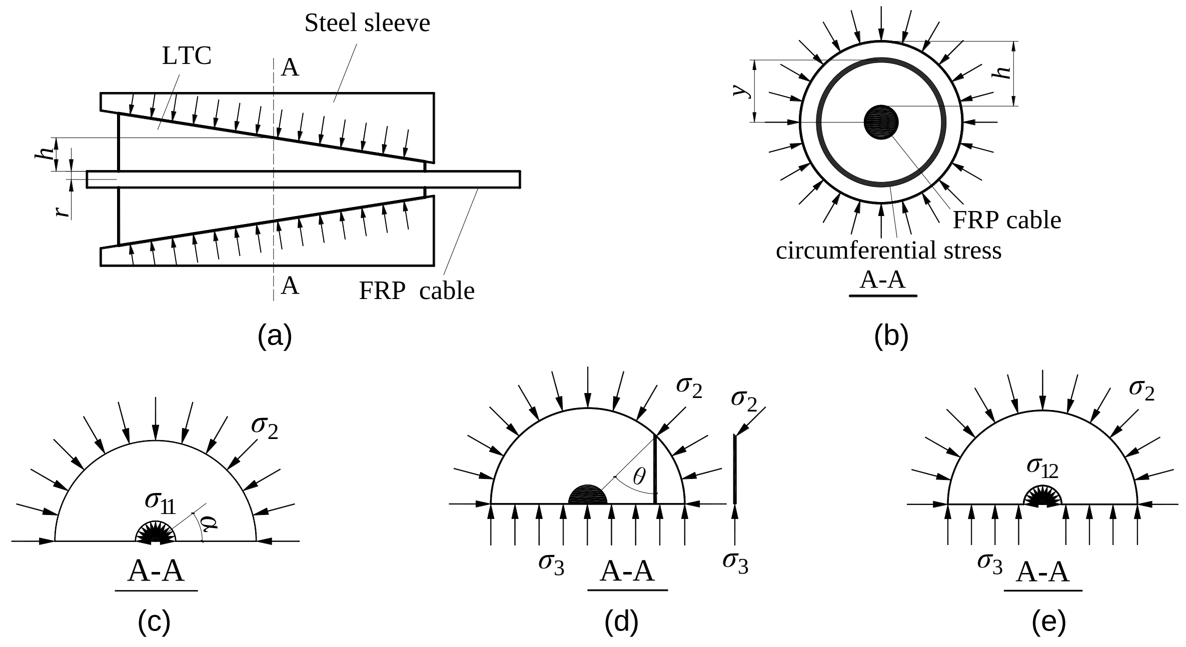
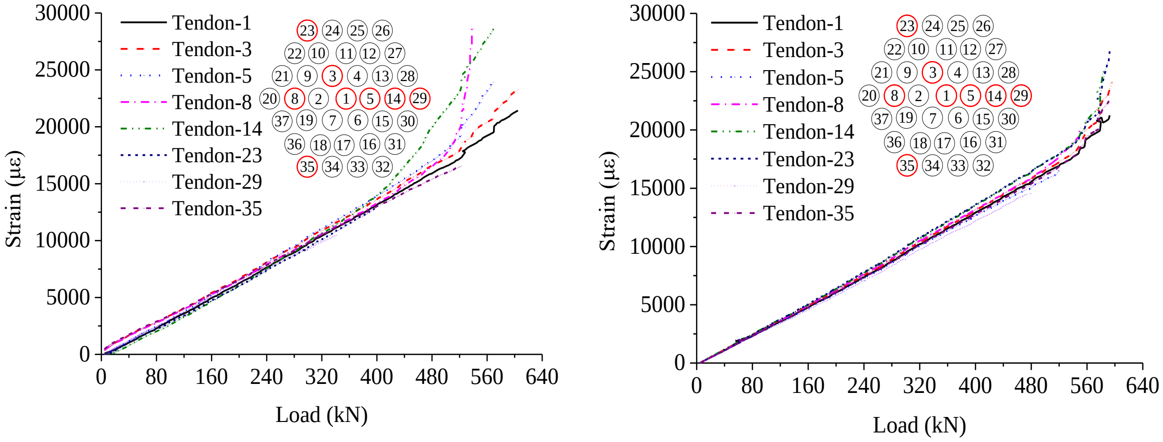


Fig. 1. Force diagram of LTC: (a) stress state of anchor system; (b) existence of circumferential stress; (c) analysis diagram without slits; (d) analysis of circumferential stress; (e) distribution of circumferential stress; (f) analysis diagram with slits

3 Axial Strain in the Middle Portion of BFRP Cable

Strain-load curves of BFRP cables shows obvious linear relationship (see Fig. 2). The preparation process of CB-3-1 and CB-3-2 is strict and meticulous, thus the tensile strain of each BFRP tendon in the free section is more concentrated. The vacation between the maximum and the minimum tensile strain is controlled within 10%, and it indicates that the preparation process of fineness is significant to tensile strain of BFRP cables at free section (see Fig. 12(a) and Fig. 12(b)). However, the stress of the outer BFRP tendons near the slits is uneven, which affects the performance of BFRP tendons synchronously following up with the inner BFRP tendons. In the tensile process, the inner BFRP tendons bear more force, which shows that the strain value of the whole cables is larger. Based on good synchronization performance of BFRP cables, multiple BFRP tendons can be equivalent to single large-diameter tendon for theoretical analysis [3]. In addition, the experimental results verify the feasibility of equating multiple tendons to a single large-diameter tendon in finite element analysis.



(a) (b)

Fig. 2. Strain-load curves of four cables: (a) CB-3-1; (b) CB-3-2

References

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