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Calculation Model of Ultimate Bearing Capacity of Concrete Short Column of CFRP Round Steel Pipe

Mengran Xu[1,2,a,*]

[1]*College of Civil Engineering and Architecture, Zhejiang University, Hangzhou 310000, Zhejiang, China*

[2]*Urban Rail Engineering Company, Zhejiang Construction Investment Transportation Infrastructure Group Co., Ltd, Hangzhou 310000, Zhejiang, China*

[a]*xumengran@zju.edu.cn*

[*]*corresponding author*

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Abstract. Carbon fiber reinforced composite materials (CFRP) have a wide range of applications in the field of engineering reinforcement. This article establishes a constitutive model, constructs a calculation model for ultimate bearing capacity, and derives formulas for the axial compressive strength and ultimate compressive bearing capacity of confined concrete. By comparing the calculated bearing capacity with the design value, the feasibility of the formula is verified, indicating that the strip CFRP circular steel tube lithium slag concrete column is in a safe state, indicating that the prediction model has good applicability.

1. Introduction

In the field of engineering structure reinforcement, carbon fiber reinforced composite material (CFRP) is the most commonly used fiber composite material, has the advantages of high strength, small density, thin thickness, suitable for building different structure parts enhanced repair, can greatly improve building load, solve the building performance degradation, material aging, structural cracking, widely used in port engineering, water conservancy and hydropower construction engineering field. When the concrete filled with steel tube is pressed, the steel pipe and the core concrete will expand, and the CFRP material wrapped on the surface of the steel pipe will tighten the constrained steel pipe to provide uniform circumferential restraint and delay the cracking and failure of the structure. At home and abroad about the constraints of lithium slag concrete filled steel tube column pressure scheme is not fully studied, and the construction of engineering structure constraints less, how to effectively launch CFRP constraint round steel tube the limit bearing capacity of lithium slag concrete column formula into the wide use of the new green concrete combination structure indispensable important step [1].

2. Constitutive Model

To understand the overall stress ability of the whole material, we should start with CFRP constitutive relationship, steel model and concrete constitutive relationship.

2.1. CFRP Conductive Model

Carbon fiber reinforced composite (CFRP) is a constraint reinforcement material with excellent mechanical properties. Under the elastic modulus of steel, the tensile performance is similar to five times that of steel. In this axial compression test, the annular deformation of the CFRP and the core concrete improved the stability and ultimate strength of the specimen. In this paper, CFRP is regarded as an ideal elastic material, which does not bear the vertical load and satisfies Hooker's law [2]:

$$\sigma_{CFRP} = E_{CFRP}\varepsilon_{CFRP} \tag{1}$$

The constitutive relationship is shown in the figure:

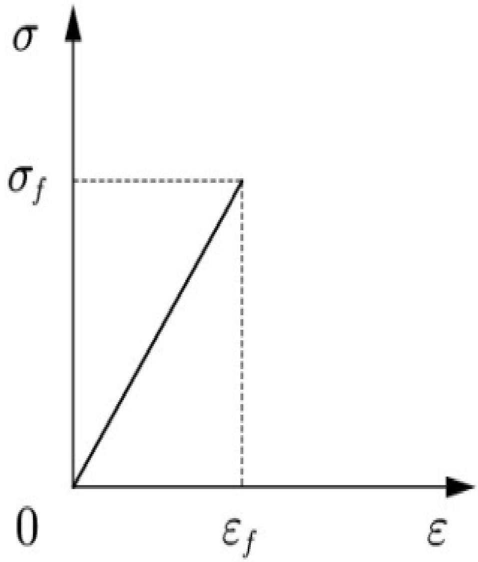

Figure 1: Constitutive relation curve of CFRP

2.2. Steel Pipe Constitutive Model

Round steel pipe stress-strain curve can reflect the steel mechanical properties change, in the structure design, commonly used steel stress-strain curve with double line model, three line and double line model, for convenient calculation, the steel stress-strain relationship curve into ideal elastic-plastic state secondary plastic flow model [3].

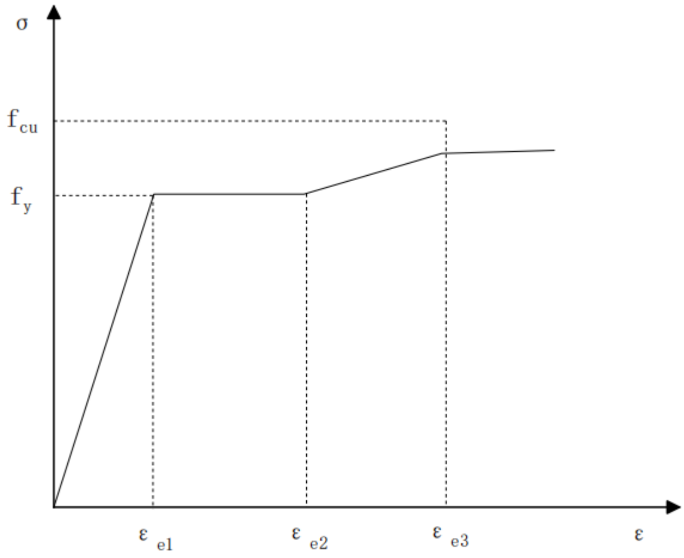

Figure 2: Secondary Plastic Flow Model of Circular Steel Pipe

2.3. Concrete Constitutive Model

Concrete constitutive relationship of the linear elastic constitutive model, nonlinear elastic constitutive model, plastic fracture theory constitutive model and other mechanical theory models [4].

3. Assumptions for Bearing Capacity Calculation

In response to the experimental phenomena and curve data analysis in this experiment, CFRP confined circular steel tube lithium slag concrete was found to have three types of materials are subjected to common forces, and the structural form and stress situation are relatively complex [5]. Under axial load, vertical load. It is jointly borne by lithium slag concrete and circular steel pipes, and carbon fiber cloth does not bear vertical loads. To simplify the calculation. The following assumptions are made:

(1) When the circular steel tube lithium slag concrete column is subjected to axial load, it is assumed that the cross-section conforms to the assumption of a flat cross-section;

(2) The joint working performance between strip carbon fiber cloth, circular steel pipe and core concrete is good, and the test process maintain its integrity and continuity;

(3) Neglecting the relative slip between strip carbon fiber cloth, circular steel pipe and core concrete;

(4) The longitudinal initial stress is uniformly distributed along the cross-section of the steel pipe;

(5) Not considering the tensile strength of concrete and not considering the compressive strength of CFRP;

(6) As an ideal elastic-plastic body, the steel strength criteria and constitutive model equations provided in Chapter 4 are adopted.

4. Analysis of Influencing Factors

4.1. Strength of Steel Pipe Concrete

The compressive strength of circular steel tube lithium slag concrete columns in this article mainly consists of the properties of circular steel tube and core concrete. The joint effect of sex. For circular steel pipes, the cross-sectional form and wall thickness of the steel pipe affect its load-bearing capacity. Ability, while for circular steel pipe components, the steel pipe can provide uniform circumferential constraints on the core concrete, and vice versa [6].The internal core concrete has uniform compressive stress on the circular steel pipe. For core concrete, the ratio of lithium slag replacing cement. The rate is the influencing factor of this experiment. It can be concluded that, adding lithium slag can improve the compressive strength and deformation bearing capacity of concrete.

4.2. CFRP Strip Restraint

The mechanical mechanism of CFRP strip constrained circular steel tube lithium slag concrete columns is that when loaded to the core lithium slag concrete. When the Poisson's ratio of soil is greater than that of steel pipes, CFRP provides lateral restraint force on the surface of steel pipes. The core concrete is in a three-dimensional stress state under the joint constraint of CFRP strip and square steel pipe. Steel pipe Withstand external load and its own circumferential tensile stress, as well as partial compression provided by lithium slag concrete and CFRP strips stress is a three-dimensional stress state. The strip is in a bi-directional stress state, bearing its own circumferential tensile stress and steel circumferential compressive stress transmitted by pipes [7]. The effective constraint of CFRP is an important factor affecting the bearing capacity of the test column, the effective constraint effect is mainly related to the wrapping form of CFRP, which is divided into full wrapping and strip wrapping. This article mainly focuses on consider the influence of package spacing and number of layers on the constraint effect, which in turn affects the bearing capacity of the test column.

5. Maximum Bearing Capacity calculation Model

According to the calculation of the research, but not at home and abroad for CFRP constraint of the design specification of the ultimate bearing capacity of the concrete, this paper according to the existing design specification of ordinary concrete filled steel tube column for strip CFRP constraint the bearing capacity of lithium slag concrete specimen. At present, the calculation specifications of axial pressure bearing capacity at home and abroad can be divided into: unified strength theory, quasi-steel theory, quasi-concrete theory and superposition theory [8].

In order to simplify the calculation process and optimize the model of CFRP concrete column, the European Standard Association EC4 superposition strength theory is used for calculation. European Standards Association EC4 (2004) considers the axial compression bearing capacity formula that the whole section of the component enters the plastic stage of the material, that is, the steel enters the plastic state, concrete has also reached the ultimate compressive bearing capacity of. Superlay theory calculation, axial stability bearing capacity is composed of steel pipe and concrete [9].

$$N_u = \frac{f_s}{1.1} A_s + \frac{f'_c}{1.5} A_c \tag{2}$$

In formula:

$$A_c = \pi(\frac{D}{2})2 \tag{3}$$

$$A_a = \pi(\frac{D}{2})2\text{-}\pi(\frac{d}{2})2 \tag{4}$$

$$f'_c=0.79\times f_{cu} \tag{5}$$

Where d is the diameter of the core concrete, 1.1 and 1.5 are the steel material sharing coefficient and the concrete material sharing coefficient respectively. This calculation method is superposition theory, which considers the contribution of steel pipe and core concrete to the bearing capacity [10].

Lam L and CNR-DT, the calculation model of CFRP reinforced CFmembers is as follows:

$$\frac{f_{cc}}{f_{co}}=1+k_1\frac{f_1}{f_{co}} \tag{6}$$

In formula:

f_{cc} —restrain the axial compressive strength of the concrete;

f_{co} − the axial compressive strength of unconstrained concrete;

f_1-the lateral restraint compressive stress;

k_1-effective constrained stress coefficient

For the bearing capacity of unwrapped CFRP strip round steel pipe lithium slag concrete column respectively by steel pipe and core concrete combination, according to the research and the test standard cube concrete block axial pressure test, the lithium slag content of 0% -20% interval, due to the incremental gradient, the introduction of lithium slag content influence coefficient □ to characterize the influence of lithium slag content on the compressive strength. After 28d of curing, the compressive strength of the standard test block increases with the increase of the lithium residue [11]. According to the amount of C30 concrete according to Qin study of compressive strength, in the range of 0% -20% lithium slag substitution rate, with the increase of lithium slag mixing amount, the compressive strength-substitution rate curve presents a quadratic curve distribution [12], and when the mixing amount of lithium slag is 20%, the compressive strength of lithium slag concrete reaches the peak. Therefore, the influence coefficient of the lithium residue mixture is obtained.

Fit the curve equation expression:

$$a = -0.000005Li_{per}^2+0.00638Li_{per}+1 \tag{7}$$

In formula:

effect coefficient of lithium slag mixing content;

Li_{per}-percentage of lithium slag mix

For the wrapping method of carbon fiber cloth, this paper introduces Saadatmanesh to calculate the lateral binding force of the interval CFRP strip:

$$f'_{l.CFRP} = k_g f_{l,CFRP} \tag{8}$$

$$f_{l,CFRP} = \frac{2f_{CFRP}t_{CFRP}}{D} \tag{9}$$

In formula:

$f'_{l.CFRP}$-band-binding side-binding force;

k_g-band spacing coefficient;

$f_{l,CFRP}$-full package constraint side binding force;

t_{CFRP}-carbon fiber cloth covers the thickness.

After micrometer measurement, the thickness of carbon fiber strip is 0.17mm

$$t_{CFRP}=0.17n \tag{10}$$

The influence coefficient of band constraint in Eformula is

$$k_g=\frac{(1-\frac{S_{CFRP}}{2D})^2}{1-\rho_{sc}} \tag{11}$$

In formula:

S_{CFRP} = net spacing of strips;

ρ_{sc}=longitudinal reinforcement ratio

Thus the strip package lateral binding expression:

$$f'_{l.CFRP}=\frac{(1-\frac{S_{CFRP}}{2D})^2}{1-\rho_{sc}}\times\frac{2f_{CFRP}\times 0.17n}{D} \tag{12}$$

To present the prediction model suitable for this trial:

$$f'_{cc}=f'_{co}+k_1\frac{(1-\frac{S_{CFRP}}{2D})}{1-\rho_{SC}}\times\frac{2f_{CFRP}\times 0.17n}{D} \tag{13}$$

$$N_u=\frac{f_s}{1.1}A_s+0.53af'_{cc}A_C \tag{14}$$

6. Comparison of Calculated Value and Design Value

Based on relevant literature and design specification, the prediction model formula of CFRP constraint is proposed. In order to verify the feasibility of the modified calculation formula of the concrete column of CFRP round steel pipe, the test parameters were inserted into the calculation formula to obtain the axial pressure bearing capacity of the concrete column of CFRP round steel pipe, calculated value and compared with the test value, as shown in Table 1. As can be seen from the test value and the calculated value, we know that the error range between the test value and the calculated value is 0.0173~0.0781, and the average value is 0.0519. The error between the test value and the calculated value is small, the data is stable, and the formula is safe.

Table.1. Comparison on tested and predicted results

number	Lithium residue replacement rate (%)	CFRP GAP (mm)	CFRP number of plies	trial value N_u^t (kN)	calculated valueN_u^c (kN)	(N_u^c-N_u^t)/N_l^l
B40-1-0	0	40	1	818	754.09	7.81
B40-3-0	0	40	3	966	1037.35	7.38
B25-1-0	0	25	1	848	823.83	2.85
B25-3-0	0	25	3	1034	1101.36	6.42
B25-2-10	10	25	2	932	902.28	3.19
B40-2-10	10	40	2	865	880.77	1.73
B40-1-10	10	40	1	838	788.95	5.97
B40-1-20	20	40	1	892	837.46	6.17

7. Summary of This Chapter

Based on the test results, this chapter analyzes the working process of strip CFRP round steel pipe lithium slag concrete column, and discusses and analyzes the influencing factors. Then, based on the bearing capacity calculation of the European Standards Association EC4, combined with Lam and Saadatmanesh etal. On the band CFRP constraints and lithium slag coagulation study of soil column, the influence coefficient of strip and lithium slag content influence coefficient on CFRP constraint column are introduced to calculate the formula and establish the prediction model of lithium slag concrete column with CFRP round steel pipe. Finally, the compression bearing capacity of the designed specimen is calculated through the improved prediction model formula, and compared with the value obtained by the experiment. The difference between the two is small, and the specimen is in a safe state. Shshows that the prediction model has good applicability.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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