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Loading Process Simulation of GFRP Tube Filled with Steel-Reinforced High-strength Concrete Columns Subjected to Eccentric Compression

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Abstract: For the further study of bearing compressive capacity of GFRP tube filled with SHC (steel-reinforced high-strength concrete) columns subjected to eccentric compression, and analysis its whole bearing compressive process under eccentric compression. Based on the flat section assumption finite strip method, the calculating program of bearing eccentric compressive capacity of GFRP tube filled with SHC columns is proposed according to existing retrofit theory and related technical procedures. The relation curves of load-deformation is gotten using this calculating program, at the same time it can get the effect curves of concrete strength, slenderness ratio, eccentricity and containing bone rate to load-deformation. Calculations show that the ultimate bearing compressive capacity of composite column decreases with the increase of slenderness ratio, and elastic stage of component curve gradually shortens and stiffness gradually loses; The ultimate bearing compressive capacity of composite columns decreases with the increase of eccentricity; component ductility improves; the ultimate bearing compressive capacity of composite columns increases with the increase of concrete strength. The calculated results agree well with the experimental results and this study provides a basis for practical design.

Introduction

In practical projects, due to load action position uncertainty, heterogeneous concrete, construction deviation and so on, eccentric phenomenon may emerge[1], forming eccentric loading column. So eccentric loading is the one of the most stress forms for GFRP tube composite columns filled with steel-reinforced high-strength concrete in practical projects. Therefore, mastering their mechanical properties and general rules has important instruction meaning for engineering application. At present, domestic and foreign experts have studied the mechanical properties of GFRP tube filled with concrete columns [2-11], but it is still relatively rare to study the mechanical properties of composite columns in domestic. So, there are not enough studies in computer simulation analysis. Based on literatures [12-13], using numerical calculation method, considering the nonlinear of materials, the author has compiled the calculation program of reinforcement structure flexural capacity. The calculated results agree well with the experimental results.

1 Basic assumptions and constitutive relation model

For simplified calculation, according to the test phenomenon, make below basic assumptions:

(1)Section strain distributes along the flat section;(2)Only consider balance of midspan cross-section between inside and outside;(3)The both ends of component are hinged and the deflection-line is sine half wave curve;(4) Between steel and concrete have not relatively slipped;(5)The stress-strain relationships of concrete and GFRP tube are gotten according to the following equation (1) , (2) and (3).

The steel-reinforced high-strength concrete section's intensity in the GFRP tube uses the following model

$$f_{\mathrm{cc}}^{'} = f_{\mathrm{s}}^{'} + 6.5\sigma_{\mathrm{R}}^{0.708} \quad (1)$$

In the formula, $f_{cc}^{'}$-In the GFRP tube's steel-reinforced high-strength concrete section's axis presses the intensity; $f_s^{'}$ - Concrete section conversion intensity

The GFRP tube's axial compressed stress uses the following model

$$\sigma_{f2} = \left(\frac{\sigma_{f1}\nu_{f21}}{E_{f1}} + \varepsilon_{f2} \right) E_{f2} \quad (2)$$

In the formula, σ_{f2} —GFRP tube's axial stress; σ_{f1} —GFRP tube's hoop stress; E_{f1} —GFRP tube's hoop elasticity coefficient; E_{f2} —GFRP tube's axial elasticity coefficient; ε_{f2} —GFRP tube's axial strain; ν_{f21} —GFRP tube's axial Poisson ratio

For ordinary concrete composite column, using formula (3) calculation, just making $\omega = 1$; for combination of high strength concrete column, using directly formula (3) to calculate; In equation (3), ω is the intention influence coefficients of concrete. When f_{cu}=50 (Mpa) ,then ω=0.8 ; when f_{cu}=70 (Mpa) , then $\omega = 0.76$, the value ω of other strength concrete can be obtained through the linear interpolation.

$$\varepsilon_{cc} / \varepsilon_{co} = \omega\left(1 + 8\sigma_R / f_{co}^{'}\right)\left(1.294 + 0.357\varepsilon_{f1} / \varepsilon_{co}\right) \quad (3)$$

2 Correlation formulas deduction and the computer programming

2.1 Synthesis iteration equation

According to the textile fiber modeling's related knowledge, in parallel to the neutral axis direction; the sections of reinforcing steel, the concretes and the GFRP tube pipe wall are divided into many bandings, and supposes the stress is uniform distribution in each banding; The longitudinal stress of reinforcing steel top and bottom flange is looked upon as independent steels. Supposing the GFRP tube reinforcing steel excel in concretes bias test sample section centroid's strain is ε_c .According to horizontal section hypotheses, the GFRP tube's stress σ_{ci} , σ_{si} , σ_{fi} can be extracted on the section any banding concretes. Divides the section into the equal 2n parts; each section's corresponding circle angle is $\Delta\theta = \pi / n$ .According to the horizontal section hypothesis, any spot place strain on the section is gotten by the following equation

$$\varepsilon_i = \varepsilon_i + \varphi y_i$$

In the formula,

y_i —the distance of any banding unit highly center to section centroid

According to assumption (3), curvature value can be gotten according to the following equation

$$\varphi = \pi^2 u_{\mathrm{m}} / l^2 \quad (4)$$

According to the strength equilibrium conditions, obtain the primary iteration equation

$$N_{\mathrm{in}} = \sum_{i=1}^{n_0} 2\sigma_{\mathrm{ci}}\Delta A_{\mathrm{ci}} + \sum_{i=1}^{m_0} 2\sigma_{\mathrm{fi}}\Delta A_{\mathrm{fi}} + \sum_{i=1}^{k} \sigma_{\mathrm{si}}\Delta A_{\mathrm{si}} + \sigma_{\mathrm{bf}} A_{\mathrm{bf}} + \sigma_{\mathrm{tf}} A_{\mathrm{tf}} \quad (5)$$

$$M_{\mathrm{in}} = \sum_{i=1}^{n_0} 2\sigma_{\mathrm{ci}}\Delta A_{\mathrm{ci}} y_{\mathrm{ci}} + \sum_{i=1}^{m_0} 2\sigma_{\mathrm{fi}}\Delta A_{\mathrm{fi}} y_{\mathrm{fi}} + \sum_{i=1}^{k} \sigma_{\mathrm{si}}\Delta A_{\mathrm{si}} y_{\mathrm{si}} + \sigma_{\mathrm{bf}} A_{\mathrm{bf}} y_{\mathrm{bf}} + \sigma_{\mathrm{tf}} A_{\mathrm{tf}} y_{\mathrm{tf}} \quad (6)$$

2.2 Computation steps

Using the equation (5) and (6), the graduation adds the distortion Δu_{m} .According to the fundamental assumption (3), the corresponding curvature ϕ is gotten. Assuming the centroid strain is ε_{c} , progressive seeking endogenic force N_{in} , M_{in} .when differential value of inner and external force is smaller than error D, output computed results. When the supporting capacity drops after limiting supporting capacity 80%, calculation is stopped.

3 The contrast of program calculation results and test results

According to the load-deformation entire process computational program GPYZL of the GFRP tube reinforcing steel in concretes eccentric compression component. The calculated results agree well with the experimental results.

Main parameter influence curves are obtained, according to calculation used nonlinear analysis program, seeing Figure 1.

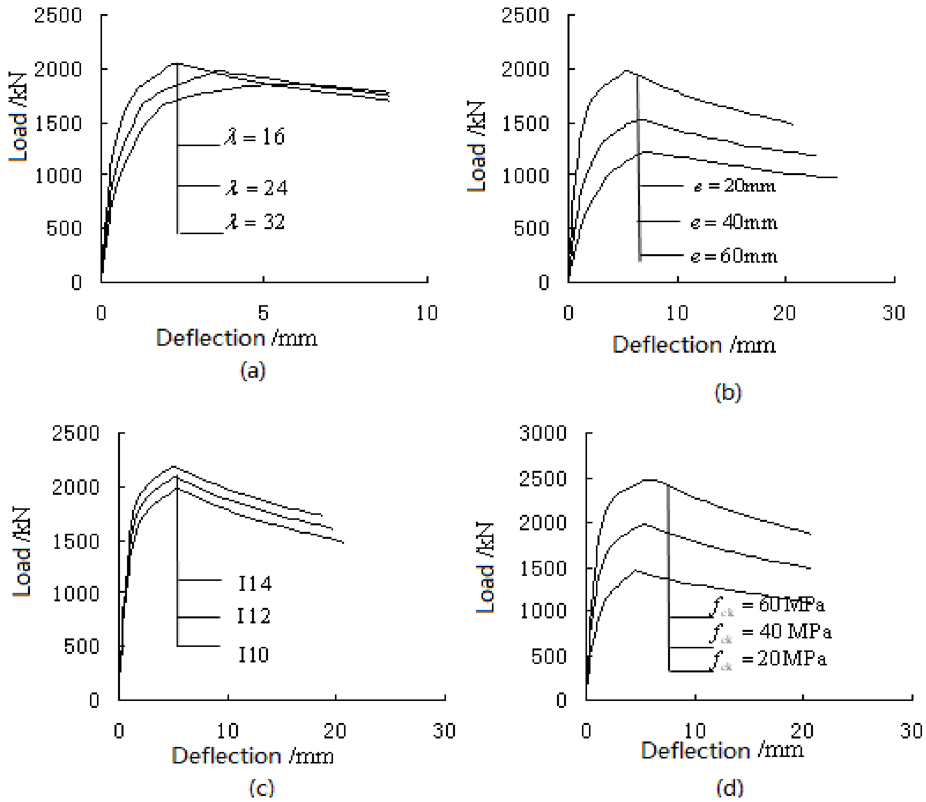

Fig.1 The load-deflection relationship curves

The concretes intensity f_{ck} is 48.6MPa ; the slenderness ratio is 24; the twist of GFRP tube is 80 degrees; wall thickness of tube is 3mm; the eccentricity is 20; the reinforcing steel model is the I10 number I-Beam, which is taken as the basic computation parameters. According to change some stress parameter, the eccentric compression component's load-deflection entire process curves are calculated and analyzed. The concrete study is as follows:

(1) Slenderness ratio

When the test sample slenderness ratio respectively is 16, 24 and 32, load - elastic curves are obtained, seeing Figure 1(a). From the chart, with the slenderness ratio reduces, the test sample limiting bearing capacity increases, and the component curve's elastic stage reduces gradually, and the rigidity loses gradually;

(2)Eccentricity

When the test sample eccentricity respectively is 20mm and 40mm, the load-elastic curves are obtained, seeing Figure 1(b). From the chart, with the eccentricity increases, the test sample limiting bearing capacity reduces. This is tallied with the experimental obtained result;

(3)Containing bone rate

When test sample reinforcing steel model respectively is I10, I12 and I14, the load-deformation curves are obtained, seeing Figure 1(c).From the chart, with the reinforcing steel model increases, the test sample limiting bearing capacity increases, and the distortion increases gradually. This indicates that the component ductility has the improvement;

(4)Concretes intensity

When the test sample concretes intensity respectively is $f_{ck} = 20$MPa , $f_{ck} = 40MPa$ and $f_{ck} = 60MPa$,the load - elastic curves are obtained, seeing Figure 1(d).From the chart, the change of concretes intensity is not big to the initial rigidity's influence, but it has certain influence to component's limiting bearing capacity. The test sample limiting bearing capacity enhances with the concretes intensity's enhancement.

4 Conclusions

(1)The computed results indicate that the limiting bearing capacity of the GFRP tube reinforcing steel excel in concretes eccentric compression test samples increases with the slenderness ratio reduces, and the component curve's elastic stage reduces gradually, and the rigidity loses gradually;(2)The limiting bearing capacity of the test sample increases with the eccentricity reduces;(3) The bearing capacity increases with the concretes intensity enhances and the reinforcing steel cross sectional area enhances.

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