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Axial compression capacity calculation of slenderness CFST filled with DCLs

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Abstract. The demolished concrete lumps (DCLs) has been demonstrated to replacement partial coarse aggregates when casting concrete. The experimental studied involved 12 Concrete-Filled Steel Tube (CFST) columns. Each columns diameter was 159mm, the length of specimens was 2000, 2200 and 2400 mm. The Diameter-to-thickness (D/t) ratio was 79, 53 and 40. The replacement ratio of FC by DCLs was 0, 20, 40 and 60%. The DCLs had slightly affect on the mechanical performances of slender CFST columns. the code CECS 28:2012 was used to calculate the bearing capacity of slender CFST columns filled with DCLs under axial compression

Keyword: CFST DCLs Axial compression Calculation

1. Introduction

Concrete-Filled Steel Tube (CFST) columns has been widely used in the civil engineering fields[1]. With the acceleration of global urbanization and the rapid development of civil engineering construction, a large number of abandoned concrete had been produced while building, rebuilding and expanding all kinds of buildings on a large scale, which seriously pollutes the environment. In addition, the rapid increase in aggregate demand had resulted in excessive development, which had led to the exhaustion of resources and the great destruction of the ecological environment, so that the contradiction between the sustainable development of concrete and aggregate demand has become increasingly prominent [4-5].

In order to reduce the cost of producing recycled aggregate (RA), The demolished concrete lumps (DCLs) had been demonstrated to replace some coarse aggregates when casting concrete. [5-8]. This method could reduce energy consumption.

However, few studies have focused on the sensitivity of factors affecting mechanical behavior of slender circular steel columns filled with DCLs and FC under axial compression. This research was carried out on the basis of Bo Wu's study. The Orthogonal design method was adopted in this experiment. This study aims to investigate the sensitivity of factors affecting mechanical behavior of slender circular steel columns filled with DCLs and FC under axial compression..

2. Experimental program

2.1. Materials and specimen details

The experimental study involved 12 CFST columns. Each column diameter was 159mm, the length of specimens was 2000, 2200 and 2400 mm. The thickness of the steel tubes was 2, 3 and 4mm, so the

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D/t ratio was 79, 53 and 40. The replacement ratio of FC by DCLs was 0, 20, 40 and 60%. 1Aa0, 5Bb0 and 9Cc0 were control specimens that were designed without DCLs in FC. The D/t ratio in these tests met most of the codes' requirements. According the EC4, the slenderness ratio (λ=4L/D) was obtained. The slenderness ratio was 50, 55 and 60. Strain gauge was placed in the mid-height of specimens to measure the strain. The details of the specimens are shown in Table 1.

Table 1. Detail of the test specimens Formatting sections

Specimen	L / mm	D / mm	t / mm	D / t / %	λ	η / %	N / kN
1Aa0	2 000	159	2	79	50	0	890
2Aa1	2 000	159	2	79	50	20	890
3Ac2	2 000	159	4	40	50	40	1 266
4Ab3	2 000	159	3	53	50	60	1 081
5Bb0	2 200	159	3	53	55	0	1 042
6Bb1	2 200	159	3	53	55	20	1 042
7Ba2	2 200	159	2	79	55	40	857
8Bc3	2 200	159	4	40	55	60	1 220
9Cc0	2 400	159	4	40	60	0	1 178
10Cc1	2 400	159	4	40	60	20	1 178
11Cb2	2 400	159	3	53	60	40	1 006
12Ca3	2 400	159	2	79	60	60	827

Note: L, D and t are respectively the length, diameter and thickness of the specimens. λ and η are respectively the slenderness ratio of specimens and the replacement ratio of DCLs.

2.2. Material properties

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The DCLs were produced from RC beams. Before concrete casting, the DCLs were pre-wetted by pouring water. The DCLs physical properties were list in Table 3.

Table 2. Mechanical properties of steel tubes

Thickness /mm	f_y / MPa	f_u / MPa	E_s /MPa
2	345.6	414.0	2.04×10^5
3	314.2	401.3	2.08×10^5
4	332.7	407.6	2.17×10^5

Table 3. DCLs physical properties

Apparent density kg/m^3	Packing density kg/m^3	Clay percentage /%	Water absorption /%
2957	2130	2.1	7.03

3. Test resultsand discussion

3.1. Calculation

Accompanied by the slight sound of concrete and steel tube separation, the steel tube and concrete separation would produce stress concentration phenomenon. The load ratio of concrete and steel tube varied here. The specimens entered the plastic working stage, the load-bearing capacity of the column decreased rapidly, the deformation increased rapidly, the deformation of the slender column also developed greatly, and there was a little iron pin powder on the surface of the mid-height of the specimens. The maximum lateral deflection was located in the mid-height of the specimens, and the two sides distribute symmetrically along the mid-height of the specimens. The failure mode of the specimens was arched. The failure mode of the specimens belonged to the instability failure.

To calculate the ultimate bearing capacity of the CFST slender columns with DCLs, design codes AIJ, AISC, CE4, CECS 28: 2012, DL/T 5085-1999 were used to predicted the ultimate bearing capacity. According to code AIJ, the predicted ultimate bearing capacity of CFST column can be expressed as follows

$$N_{\mathrm{cr}} = sN_{\mathrm{cr}} + cN_{\mathrm{cr}}$$

Where $sN_{\mathrm{cr}}, cN_{\mathrm{cr}}$ are the bearing capacity of steel tube and concrete.

In code AISC, the ultimate bearing capacity is expressed as follows

$$N_{\mathrm{u}} = F_{\mathrm{cr}} A_{\mathrm{s}}$$

$$\lambda_{\mathrm{C}} = \frac{KL}{r_{\mathrm{m}}\pi}\sqrt{\frac{F_{\mathrm{my}}}{E_{\mathrm{m}}}}$$

Where λ_{c} is the slenderness ratio of the specimens; when $\lambda_{\mathrm{c}} \le 1.5$, $F_{\mathrm{cr}} =$ $(0.658^{\lambda_{\mathrm{c}}^2})F_{\mathrm{my}}$, $\lambda_{\mathrm{c}} \ge 1.5$ $F_{\mathrm{cr}} = \left(\frac{0.877}{\lambda_{\mathrm{c}}^2}\right)F_{\mathrm{my}}$; A_{s} is area cross of steel; L is the length of specimens;

CE4 also provides a mode for calculating the bearing capacity of CFST with DCLs.

$$N_{\mathrm{u}} = k_1 N$$

$$k_1 = \frac{1}{\theta + \sqrt{\theta^2 - \lambda^2}}$$

$$\theta = 0.5\left[1 + 0.21(\lambda - 0.2) + \lambda^2\right]$$

$$\lambda = \sqrt{\frac{N_{\mathrm{k}}}{N_{\mathrm{e}}}}$$

$$N_{\mathrm{k}} = \eta_2 f_{\mathrm{y}} A_{\mathrm{s}} + (1 + \eta_1 \frac{tf_{\mathrm{y}}}{Df_{\mathrm{c}}'})$$

$$N_e = \pi^2 (0.6 E_c I_c + E_{\mathrm{s}} I_{\mathrm{s}}) / L^2$$

Where λ is the slenderness ratio of the specimens; f_{y} is the yield strength of steel; A_{s} is area cross of steel; η_1 and η_2 are coefficient; E_c is elastic modulus of concrete; E_s is elastic modulus of steel; L is the length of specimens; I_c is moment of inertia of concrete; I_s is moment of inertia of steel; f_{c}' is compressive strength of concrete prism, D is the diameter of steel tube.

According to code CECS 28: 2012, the predicted ultimate bearing capacity of CFST column can be expressed as follows

$$N_{\mathrm{u}} = \varphi f_{\mathrm{sc}} A_{\mathrm{sc}}$$

$$f_{\mathrm{sc}} = (1.212 + \eta_{\mathrm{s}} \xi_0 + \eta_{\mathrm{c}} \xi_0^2) f_{\mathrm{c}}$$

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$\eta_s = 0.1759 f / 235 + 0.794$

$\eta_c = -0.1038 f_c / 20 + 0.0309$

Where f_{sc} is design Value of Axial Compressive Strength of Concrete Filled Steel Tubular Composite; ξ_0 is design value of hoop coefficient; f_c is strength Design Value of Core Concrete in Steel Tube; A_{sc} is section Area of Composite Members; φ is margin of stability.

According to code DL/T 5085-1999, the predicted ultimate bearing capacity of CFST with DCLs column can be expressed as follows

$\xi = A_s f_y / A_c f_c$

$N_c = \varphi N_0$

$N_0 = 0.9 f_c A_c (1 + \theta + \sqrt{\theta})$

Where A_s , A_c is the area of steel and concrete; f_y is the yield strength of steel; f_c is the cylinder strength of the concrete; φ is bearing capacity reduction factor considering slenderness ratio; θ is hoop Coefficient of Concrete Filled Steel Tubular; $[\theta]$ is limit value of hoop coefficient relating to concrete strength grade.

Comparisons of the predicted ultimate bearing capacity of CFST columns with DCLs obtained using five code calculation methods with the measured results are presented in Table 4 and Table 5.

Table 4 Comparison of ultimate bearing capacity

Specimens	Measured value / Calculated value				
	AIJ	AISC	CE4	CECS 28：2012	DL / T5085—1999
1Aa0	0.978	1.210	1.056	0.998	0.942
2Aa1	1.011	1.098	1.342	0.976	1.121
3Ac2	0.942	1.125	1.206	1.102	0.876
4Ab3	0.960	1.064	1.102	1.006	0.956
5Bb0	1.107	1.066	1.064	0.959	0.987
6Bb1	1.021	1.209	1.267	0.978	1.105
7Ba2	1.004	1.145	1.472	0.943	0.996
8Bc3	1.100	1.557	1.068	1.097	1.153
9Cc0	1.045	1.321	1.342	1.064	1.142
10Cc1	0.909	1.427	1.495	0.964	0.972
11Cb2	1.207	1.502	1.341	0.945	0.943
12Ca3	1.064	1.466	1.025	1.062	0.989

Table 5 Statistical characteristics

Statistical characteristics	AIJ	AISC	CE4	CECS 28：2012	DL / T5085—1999

Average value	1.029	1.266	1.231	1.008	1.015
Variance	0.006	0.029	0.026	0.003	0.008
Standard deviation	0.077	0.170	0.161	0.055	0.089

From Table 4 and Table 5, it could be seen that the bearing capacity calculated by American AISC Code and European CE4 Code was less than the ultimate bearing capacity obtained by test. It showed that the calculation capacity of AISC code in the United States and CE4 code in Europe were conservative and had a large safety reserve. From variance and standard deviation, the results of AIJ and DL/T5085-1999 were more discrete than those of CECS 28:2012. Therefore, it was suggested that the code CECS 28:2012 was used to calculate the bearing capacity of slender CFST columns filled with DCLs under axial compression.

4. Conclusion

The mechanical behavior of CFST filled with DCLs under axial compression was presented. The following conclusions are drawn from the test results:

(1) The bearing capacity of 12 specimens was calculated by the domestic and foreign codes. Through mean and variance analysis, it was found that the domestic CECS 28:2012 codes were in good agreement with the test results and could be applied to the calculation of the ultimate bearing capacity of slender CFST column with DCLs.

(2) All the 12 specimens were destroyed by instability failure, and the ultimate failure form was arch. Through comparative analysis of load-strain relationship curve and load-displacement relationship curve, the following basic rules can be obtained: compared with CFST slender columns without DCLs, the rising and falling sections of the curve were steeper and the ultimate bearing capacity was slightly lower for the specimens with DCLs.

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