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Study on axial bearing capacity of steel pipe waste fiber reinforced concrete column based on ABAQUS

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ABSTRACT

In order to study the mechanical properties of the short column of recycled steel fiber recycled concrete under axial compression, the finite element software ABAQUS was used to simulate the 13 sets of specimens. The effects of the change of the three parameters of waste fiber length, fiber incorporation, and recycled aggregate incorporation on the compressive properties of the waste steel recycled concrete short column shaft were investigated, and the ultimate bearing capacity simulation values were compared with Cai Shaohuai, Zhong Shantong, and Han Linhai compares the calculated values of formulas proposed by Han Linhai. The results show that the calculated values of the three formula and the simulated values show a consistent trend with the different grouping conditions, indicating that the simulation results are good; the axial load carrying capacity of waste steel fiber recycled concrete short columns increases with the length of waste fibers. The decrease, with the increase of the amount of recycled aggregates, decreases, and increases with the increase of the waste fiber volume incorporation. The simulated value of axial compressive ultimate bearing capacity is slightly larger than the value calculated by Cai Shaohuai formula, which is partial to safety Considering, it is suggested that the ultimate bearing capacity of a short column of recycled steel concrete waste fiber reinforced concrete under axial compression is calculated according to the formula of Cai Shaohuai, which can be applied to engineering practice.

1. PREFACE

Steel-concrete-filled concrete combines the advantages of steel pipes and concrete, while at the same time enhancing the respective properties of steel pipes and concrete, and thus has advantages over the simple addition of the two. Because of such

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advantages of concrete-filled steel tubes, the study of concrete-filled steel tubes has never stopped, and it has been developing in depth and breadth.

The combined structure of steel pipe and recycled concrete can solve the problem of occupying land resources and polluting the environment. It is a composite material with a good application prospect in Yang Youfu (2006), and many scholars have studied it. (Ke Xiaojun 2017) and other studies have shown that when the peak load of concrete-filled steel tubular columns lags behind that of hollow reinforced concrete columns, the bearing capacity and ductility of the composite columns increase as a whole, and the area ratio of the steel tubes is increased. The bearing capacity decreases and the ductility increases. The results of Chen Zongping (2012). showed that the stress process and failure pattern of the steel pipe-recycled concrete eccentric column and the ordinary steel pipe eccentric column were similar, and the final performance of the steel pipe was buckling failure, eccentricity, The slenderness ratio has a significant effect on the mechanical properties of the steel reinforced concrete biased column, but the replacement ratio of the recycled coarse aggregate has little effect on the performance. (Zeng Jun 2014) and others conducted axial compression tests on a composite column composed of an external FRP tube, an inner steel tube, and a recycled aggregate concrete filled between two tubes. The results showed that the new composite column was comparable to a double tube filled with ordinary aggregate. The bearing capacity of the column has decreased, but the ductility has increased significantly.

(Zhou Jinghai 2013) and other studies have shown that the incorporation of waste fibers into recycled concrete improves the compressive strength and splitting tensile strength of recycled concrete, improves the ratio of tension to compression of recycled concrete, and improves the brittleness of concrete. For 30 mm, the fiber compressive strength of waste fiber recycled concrete with 0.12% fiber content is the best; the splitting tensile strength of waste fiber recycled concrete with fiber length of 19 mm and fiber volume incorporation of 0.12% is the best. Good; (Zhou Jinghai 2013). also showed that the split tensile strength of waste fiber recycled concrete is higher than that of ordinary concrete.

There have been no reports on the combination of steel pipes with waste fiber recycled concrete. The study of the bearing capacity of waste steel fiber recycled concrete columns is conducive to the promotion of this kind of composite structure. It is of great significance for concrete-filled concrete to be more economical, green, and reasonable. Therefore, in this paper, axial compression simulations are conducted on short steel recycled concrete short columns, and the effects of changes in waste fiber length, fiber incorporation, and recycled aggregate incorporation on the axial compression performance of the short columns are studied and compared with existing steel tubes. The formulas for bearing capacity of axial compression concrete are compared, and the calculation formulas for axial compression bearing capacity of short steel recycled concrete short columns are proposed.

2. CONSTITUTIVE RELATIONS OF MATERRIALS

The stress-strain relationship is a generalization of the relationship between the force and deformation of the specimen in the stress process of the specimen. It is a macroscopic formula that can express the internal microscopic mechanism of the structure. To calculate and analyze the concrete-filled steel tube model, it is necessary to first determine the steel tube. The stress-strain relationship with concrete. The following is the constitutive model used in this simulation process. When data is input in ABAQUS, the data needs to be converted into the relationship between true stress and true strain. This is not described here.

2.1 Constitutive Model of Steel

The constitutive relation of steels adopts the double-line model proposed in the design principle of concrete structure in Southeast University:

When $\varepsilon_s \le \varepsilon_y$, $\sigma_s = E_s\varepsilon_s \quad \left(E_s = f_y/\varepsilon_y\right)$; When $\varepsilon_y \le \varepsilon_s \le \varepsilon_{s,h}$, $\sigma_s = f_y$

σ_s is the steel stress (N/mm^2); ε_s is steel strain; ε_y is the strain at which the steel reaches its yield strength(N/mm^2); E_s is the elastic modulus(N/mm^2); $\varepsilon_{s,h}$ is the strain at the beginning of the strengthening phase; f_y is the yield strength.

2.2 Concrete Constitutive Model

(1)

The expression of compressive stress-strain curve is based on the formula proposed by Han Linhai:

$$y = 2x - x^2 \qquad (x \le 1)$$

$$y = \begin{cases} 1 + q\left(x^{0.1\xi} - 1\right) & (\xi \ge 1.12) \\ \dfrac{x}{\beta(x-1)^2 + x} & (\xi < 1.12) \end{cases} \qquad (x > 1)$$

$$x = \frac{\varepsilon}{\varepsilon_0};\quad y = \frac{\sigma}{\sigma_0};\quad q = \frac{\xi^{0.745}}{2+\xi}$$

$$\sigma_0 = [1 + (-0.054\xi^2 + 0.4\xi)\left(\frac{24}{f_c}\right)^{0.45}]f_c$$

$$\varepsilon_0 = \varepsilon_{cc} + [1400 + 800\left(\frac{f_c}{24} - 1\right)]\xi^{0.2} \times 10^{-6};\quad \varepsilon_{cc} = (1300 + 12.5f_c) \times 10^{-6}$$

$$\beta = (2.36 \times 10^{-5})^{[0.25+(\xi-0.5)^7]} f_c^2 \times 3.51 \times 10^{-4}$$

$\xi = A_s f_y / A_c f_{ck}$ is the coefficient of constraint effect; A_s、A_c are the area of steel pipe and concrete, respectively(mm^2); f_y、f_{ck} are the standard values of the yield strength of steel tubes and the axial compression strength of concrete(N/mm^2); σ_0 is the peak compressive stress of the core concrete(N/mm^2); ε_0 is the core concrete peak compressive strain; f_c is the axial compressive strength of a concrete cylinder(N/mm^2); β、ε_{cc}、q is the coefficient;

Note: The strength of concrete in this paper is calculated according to the strength formula of waste fiber recycled concrete:

$f_{ck} = 0.88 \times f_{cu} \times 1.38 \times 0.76 \times \left(1.372V_f + 0.834\right) \times (-0.001L + 0.983) \times (-0.195r + 1.027)$;

Waste fiber recycled concrete elastic modulus $E_f = 0.78E_c \times \left(0.374V_f + 0.965\right) \times (0.004L + 0.931) \times (-0.1r + 1.132)$;

Waste fiber recycled concrete Poisson's ratio $\mu = 0.246 \times \left(-0.868V_f + 1.088\right) \times$

$(-0.008L+1.199)\times(-0.223r+1.094)$;
V_f is the amount of waste fiber volume; L is the waste fiber length(mm); r is the amount of recycled aggregate; f_{cu} is the compressive strength of the cube, taking 40(N/mm^2); E_c is the concrete elastic modulus(N/mm^2).
(2)

The stress-strain curve of the tension stage adopts the single axis Tensile formula of ordinary concrete given in the specification of the concrete structure design in Standard:

$$\sigma=(1-d_t)E_{cf}\varepsilon$$
$$d_t=\begin{cases}1-\rho_t(1.2-0.2x^5) & x\le 1\\ 1-\dfrac{\rho_t}{\alpha_t(x-1)^{1.7}+x} & x>1\end{cases}$$
$$x=\frac{\varepsilon}{\varepsilon_{t,r}},\ \rho_t=f_{t,r}/E_{cf}\varepsilon_{t,r},\ \alpha_t=0.312f_{t,r}^2,\ \varepsilon_{t,r}=f_{t,r}^{0.54}\times 65\times 10^{-6}$$

d_t is the single axis tensile damage evolution coefficient of concrete; ρ_t is the coefficient; α_t is the parameter value of the falling segment of the stress-strain curve of concrete under single axis tension;$f_{t,r}$is the representative value of the single axis tensile strength of concrete(N/mm^2); $\varepsilon_{t,r}$ is the peak tensile strain of concrete corresponding to $f_{t,r}$.

3 THE ESTABLISHMENT OF A FINITE ELEMENT MODEL

3.1 Basic parameters of materials

The steel tube is made of Q235 steel, outer diameter D=200mm, inner diameter d=192mm, thickness t=4mm; short column design length is L_d=800mm; there are cover plates on both ends of the steel tube, the cover size is 220mm×220mm×20mm; The standard value of fiber-recycled concrete strength is C40; concrete and cover plates are all established as solid elements, and steel tubes are used as shell elements.

In the setting of material properties, the elastic modulus of the steel pipe is 2.06×10^5, the Poisson's ratio is 0.3, the plastic strain is 0, the elastic modulus of the cover plate is 2.1×10^6, and the Poisson's ratio is 0.3. The plastic damage model is adopted for the concrete. The expansion angle in the model is 30. The eccentricity of the flow potential is 0.1. The ratio of the double uniaxial compressive ultimate strength is 1.16. The ratio of the second stress invariant on the pulling and pressure meridian is 2/3. The viscosity coefficient is taken as 0 in Ding Faxing (2009).

3.2 Contact and interaction

The advantage of CFST is that steel tubes can interact with concrete. This interaction can be defined in ABAQUS as normal contact and tangential contact in Shi Jun (2012). In this paper, the contact between steel tube and core coagulation diagram is set as “ "Bound", the core concrete is the main surface; the constraint form of the steel pipe, concrete and the cover plate are all set to "bind" and the cover plate is the main surface.

The simulated grouping of the specimens is listed in Table .1 The model meshing and simulation results are shown in Figure .1

Specimen grouping	Fiber length/mm	Recycled aggregate Incorporation	Fiber volume incorporation	Modulus of elasticity/ MPa	Poisson's ratio
A1	19	50%	0.08%	27565	0.258
A2	19	25%	0.08%	28202	0.272
A3	19	75%	0.08%	26928	0.243
B1	19	0	0.08%	28839	0.287
B2	19	100%	0.08%	26291	0.229
B3	6	50%	0.08%	26141	0.283
B4	38	50%	0.08%	29645	0.220
C1	12	50%	0.08%	26798	0.272
C2	30	50%	0.08%	28796	0.236
C3	19	50%	0.04%	27150	0.267
D1	19	50%	0	26736	0.275
D2	19	50%	0.12%	27979	0.249
D3	19	50%	0.16%	28394	0.240

Table. 1 Sample grouping

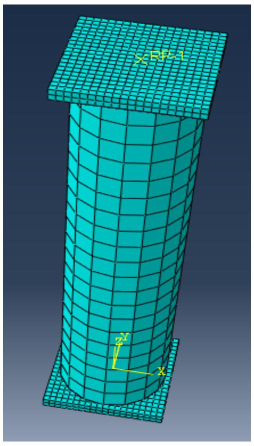

Fig. 1 Model meshing

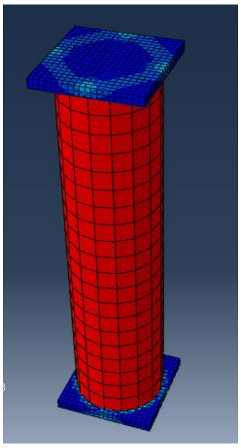

Fig. 2 Model calculation results

4 ANALYSIS OF SIMULATION RESULTS

4.1 Result analysis

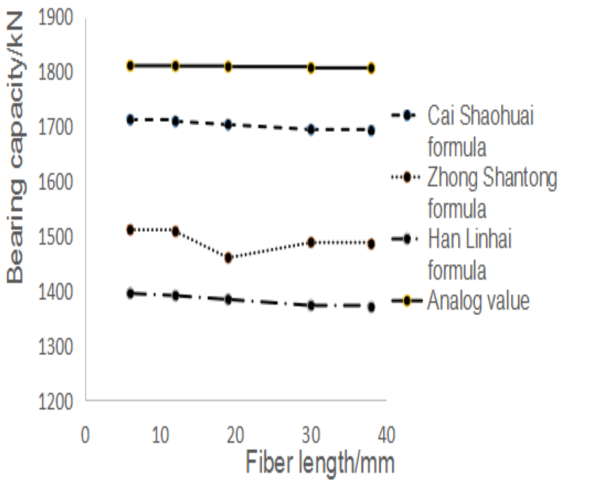

Fig. 3 Relationship between bearing capacity and fiber length for different results

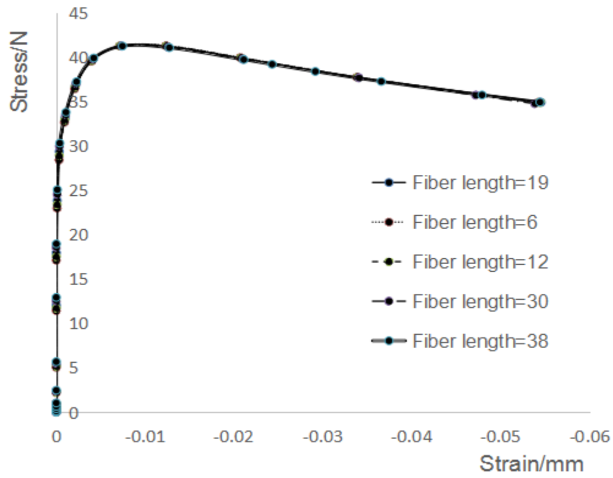

Fig. 6 The stress-strain curve of concrete when the fiber length changes

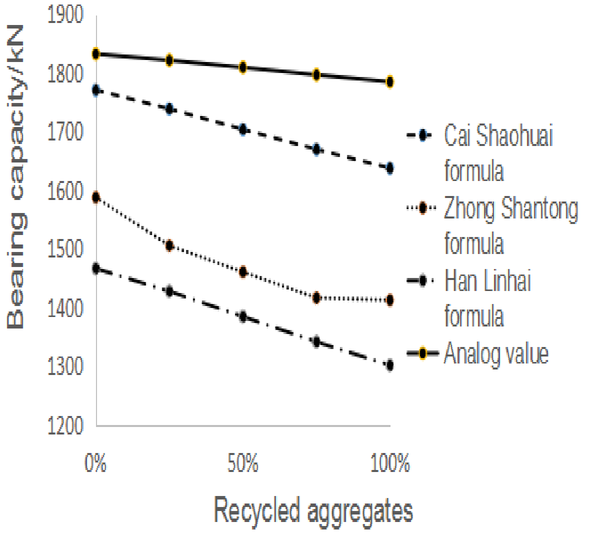

Fig. 4 Relationship between bearing capacity of different results and recycled aggregate mix

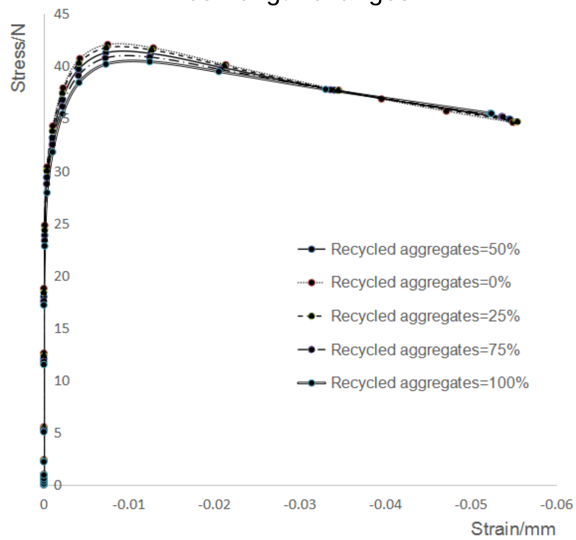

Fig. 7 The stress-strain curve of concrete when the amount of recycled aggregate is changed

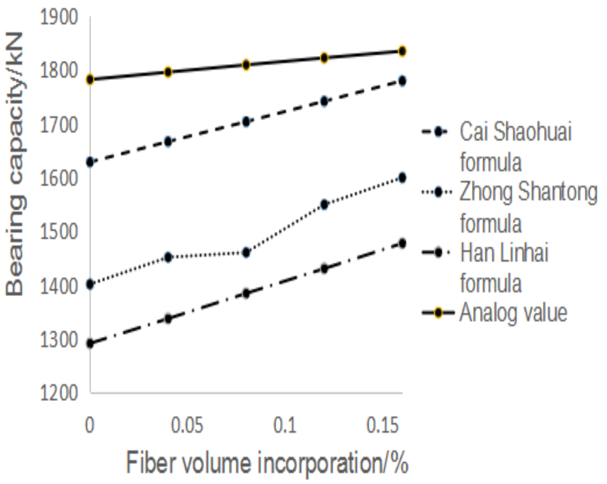

Fig. 5 Relationship between bearing capacity of different results and fiber volume incorporation

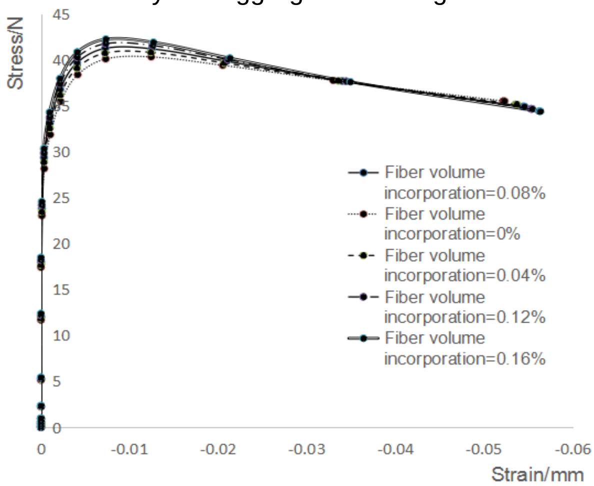

Fig. 8 The stress-strain curve of concrete when the volume of fiber is mixed

From Fig. 3 to Fig. 5, it can be clearly seen that the simulated values of axial compression bearing capacity of recycled steel concrete short fiber reinforced concrete short columns are all greater than those calculated by the three formulas, but the trend of change is basically the same and will be the closest to the simulated value. The error between the value and the analog value is listed in the error 1 in Table. 2. It can be seen that the maximum error of the bearing capacity between the two is 8.6%. The analog value curve is more gradual than the curve calculated by the three formulas; from Fig.6 to Fig.8 shows that the stress-strain curve of the core concrete of the waste concrete recycled concrete short column core column concrete is consistent with that described in Han Linhai's. That is, when the restraint coefficient is $\xi < \xi_0$, there is a descending segment; the above analysis shows that the establishment of the model is correct. From the figure, it can be seen that the axial compression bearing capacity of the recycled steel short column of waste steel fiber tube decreases with the increase of fiber length and the amount of recycled aggregate, and increases with the increase of fiber volume incorporation.

	Cai Shao Huai calculated value	Zhong Shantong's calculation	Han Lin Haifa calculation	Analog value	Error 1	Formula calculated value	Error 2
A1	1703	1460	1384	1808.6	5.8%	1808.6	0%
A2	1738	1505	1427	1820.7	4.5%	1845.8	1.4%
A3	1669	1416	1341	1795.9	7.1%	1772.5	1.3%
B1	1770	1587	1466	1831.5	3.4%	1879.7	2.6%
B2	1637	1412	1301	1784.1	8.2%	1738.5	2.6%
B3	1712	1511	1395	1810.4	5.4%	1818.1	0.4%
B4	1692	1485	1370	1805.9	6.3%	1796.9	0.5%
C1	1709	1508	1391	1809.9	5.6%	1815.0	0.3%
C2	1694	1488	1373	1806.4	6.2%	1799.0	0.4%
C3	1666	1451	1337	1795.1	7.2%	1769.3	1.4%
D1	1628	1401	1291	1781.4	8.6%	1728.9	2.9%
D2	1741	1549	1430	1821.6	4.4%	1848.9	1.5%
D3	1779	1599	1477	1834.1	3.0%	1889.3	3.0%

Table. 2 Comparison of bearing capacity

4.2 Three kinds of bearing capacity formula and comparison

(1) The formula proposed by Cai Shaohuai:

$$N_u = A_c f_c(1 + 2\emptyset), \emptyset = A_s f_s / A_c f_c$$

(2) Formula proposed by Zhong Shantong:

$$N_u = f_{sc} A_{sc}, f_{sc} = (1.212 + B\xi + C\xi^2) f_c$$

$$\xi = A_s f_y / A_c f_{ck}, \mathrm{B} = \frac{0.1759 f_y}{235} + 0.974, \mathrm{C} = -\frac{0.1038 f_{ck}}{20} + 0.0309$$

(3) Formula proposed by Han Linhai:

$$N_u = A_{sc} f_c (1.14 + 1.02\xi), \xi = A_s f_s / A_c f_c$$

f_{sc}, A_{sc} are the column combination strength(N/mm^2), combined cross-sectional area(mm^2); f_c, f_s are the design values of concrete and steel strength(N/mm^2); Ø are constraint effect coefficients; Calculate the strength of waste fiber recycled concrete according to 2.2.

The results of the above three formulas are shown in Table.2 along with the analog values.

It is found that the simulated value is larger than the calculated value of the three formulas. The author thinks that this is the reason that the simulation calculation is more idealized; the simulated value is similar to the calculated value of Cai Shaohuai formula, and it is somewhat safe. It is recommended that the axial compression of the waste concrete recycled steel short column should be used. The calculation of bearing capacity is calculated using Cai Shaohuai's formula to meet the engineering practice.

5 CONCLUSIONS

(1)

The axial compression bearing capacity of the short column of recycled steel concrete with fiber waste decreases with the increase of fiber length and the amount of recycled aggregate, and increases with the increase of fiber volume incorporation.

(2)

The simulated value is similar to the calculated value of Cai Shaohuai's formula, and it is considered to be safe. It is suggested that the calculation of the axial bearing capacity of the short column of waste concrete recycled with steel fiber should be calculated using Cai Shaohuai's formula to meet the engineering practice.

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REFERENCES

Yang Youfu, Han Linhai. (2006), “Experimental behavior of recycled aggregate concrete filled steel tubular columns”, Journal of Constructional Steel Research, **62**(12), 1310-1324.

Ke Xiaojun, An Jin and Liao Dingguo. (2017), “Analysis of Axial Compression Performance of Full-recycled Concrete Composite Column with Built-in Steel Tube”, Journal of Building Structures, **38**(Supplement 1), 291-296.

Chen Zongping, Li Qiliang and Zhang Xianggang. (2012), “Calculation of bearing behavior and bearing capacity of steel-pipe recycled concrete bias columns”, China Civil Engineering Journal, **45**(10), 72-80.

Zeng Yu, Li Lijuan and Chen Guangming. (2014), “Experimental study on axial pressure behavior of GFRP-recycled concrete-steel tubular composite columns”, China Civil Engineering Journal, **47**(Supplement 2), 21-27.

Zhou Jinghai, Li Tingting and Yang Guozhi. (2013), “Experimental study on the strength of waste fiber recycled concrete”, Concrete, (3), 1-4.

Zhou Jinghai,Liu Zihe and Li Tingting. (2013), “Cracking tensile strength test of waste fiber recycled concrete”, Journal of Shenyang Jianzhu University Natural Science, **29**(5), 796-802.

Southeast University, Tianjin University, Tongji University, etc. Design Principles of Concrete Structures [M]. Beijing: China Building Industry Press (Fifth Edition).

Han Linhai. Concrete-filled steel tube structure—theory and practice[M]. Beijing: Science Press.

Standard of the People's Republic of China GB50010-2010. Design Specification for Concrete Structures [S]. Beijing: China Building Industry Press.

Ding Faxing,Zhou Linchao and Yu Zhiwu. (2009), “Nonlinear Finite Element Analysis of Concrete Filled Steel Tubular Short Columns”, Sciencepaper Online, **4**(7), 472-479.

Shi Jun. (2012), “Analysis of calculation method for axial compression bearing capacity of concrete-filled steel tubular columns”, Dalian: Dalian University of Technology.

Cai Shaohuai. Modern concrete-filled steel tube structure[M]. Beijing: China Communications Press.

Zhong Shantong.Steel tube concrete structure[M]. Beijing: Tsinghua University Press (third edition).