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Axial Compression Properties FEA on RC Filled Double Skin Square Steel Tube Short Columns

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Abstract. With calcined diatomite and vitrified micro bubbles (VMB) content as the main changing parameters, experiment studies the properties of VMB recycled concrete blocks; By using ANSYS, this article analyzes different width- thickness ratios(64,88), hollow rates (0,0.35) and VMB contents (80%,100%) influence on axial compression properties of the composite columns. The result shows that: while calcined diatomite content is 3%, the compressive strength of the 100% VMB content test block can reach 32.12 MPa; when the width-thickness ratio is same, stress distribution of hollow specimens is more balance than solid ones, and their axial displacement decreases by 3.5% compared with solid specimens when they reach ultimate bearing capacity, while the ultimate bearing capacity increases by 2%; according to calculation and comparison, this article gets the applicability of the various procedures when calculated the axial compression bearing capacity of recycled concrete filled double skin square steel tube short columns.

Keywords: *double skin square steel tube; vitrified micro bubbles recycled concrete; calcined diatomite ; stress-strain relation; axial compression bearing capacity*

I. Introduction

Currently, the vitrified micro bubbles (VMB) is widely used as a new sort of environment-friendly and inorganic lightweight insulation materials, which can be used to make the VMB recycled concrete when it is added into the recycled concrete. Its strength and thermal insulation properties can reach the ideal performance that is tested by the experiment[1]. Recycled concrete filled square steel tubes (CFST) is the structure style casting recycled concrete into the steel pipe, core concrete bears three directions force due to the restraint of the steel tube, which improves the bearing properties and recycled concrete engineering application value; Besides the same advantages with CFST, concrete filled double skin steel tube(CFDST) could also expand cross section,with a higher bending rigidity lighter weight and better performance in earthquake resistant and fire resistant and so on. Compared with those structural parts in style of SHS outer and SHS inner, SHS outer and CHS inner has better malleability [2-3].

Therefore, this article studies the properties of VMB recycled concrete blocks by means of experiment and adopts ANSYS to make an analysis on vertical stress distribution, strain, displacement of steel tube and core concrete and bearing capacity of RC filled double skin square steel tube short columns, then compares the influence of different width-thickness ratios, hollow ratios and VMB contents to the axial compression properties of RC filled double skin square steel tube short columns.

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II. General situation of experiment

A. The Experiment of VMB Recycled Concrete

Experiment uses 42.5 ordinary Portland cement; recycled coarse aggregate with a broken jaw crusher whose screening particle size is 5~20mm, bulk density is 1280kg/m^3 and bibulous rate is 4.8%; sand fineness modulus is 2.9; the original fly ash is from Yanji Heating Plant, basically reaches the level Ⅱ for fly ash fineness requirements; Jilin Linjiang Tianyuan catalyst co.LTD., production of 325 mesh calcined diatomite, its performance parameters are shown in table 1;VMB is produced by Linghai City Longyan Building Materials Factory, stacking density is 128kg/m^3, whose performance parameters are shown in table 1; polycarboxylate superplasticizer is produced by Yanji Fangsheng Building Materials Company, which contains 0.3% of gas composition and its water reducing rate is 25% or higher; mixing water is ordinary tap water.

After trial mixing, eventually water-binder ratio of VMB recycled concrete mixture ratio is 0.45, sand ratio is 30%. Results of each test block of experiment parameters and maintenance of indoor cured 28d are shown in table 2.

Table I. Performance of Calcined Diatomite and VMB

Performance of calcined diatomite					Performance of VMB				
Fe_2O_3 Content /%	S_iO_2 Content /%	Specific surface area /(cm^2/g)	Ignition loss /%	Bulk density /(g/cm^3)	Grain size /(mm)	Density /(kg/m^3)	Thermal conductivity /[W/(m·k)]	Surface vitrified /%	Water absorption /%
≤1.5	≥92	600 thousand	≤0.5	≤0.42	0.5~1.5	50~200	0.0284~0.054	≥95	20~50

Conclusions according to table 2：when the calcined diatomite is 3% and the VMB content is 100%, compressive strength of test block can reach 32.12 MPa and its density is just 1936 kg/m^3, compared with the ordinary concrete dry apparent density of 2000~2500 kg/m^3, which can achieve reducing building self quality and improving anti-seismic performance.

Table II. VMB Recycled Concrete Experimental Parameters and Test Results

Specimen number	Material utilization amount/（kg/m^3）								Compressive strength /MPa	Dry density /（kg/m^3）
	Cement	Fly ash	Calcined diatomite	Recycled coarse aggregate	Sand	VMB	Water reducer	Water		
RC-80-3	458.1	122.6	18.4	1114.95	479.5	102	13.48	270	34.25	1964
RC-80-0	476.5	122.6	0	1114.95	479.5	102	13.48	270	31.96	1982
RC-100-3	458.1	122.6	18.4	1114.95	479.5	128	13.48	270	32.12	1936
RC-100-0	476.5	122.6	0	1114.95	479.5	128	13.48	270	30.64	1951
RC-130-3	458.1	122.6	18.4	1114.95	479.5	154	13.48	270	27.43	1910
RC-130-0	476.5	122.6	0	1114.95	479.5	154	13.48	270	25.31	1923

Note: RC-80-3, RC represents VMB recycled concrete, 80 represents the VMB volume contains compare to the total volume is 80%, 3 represents the calcined diatomite content is 3%，others can be get by the parity of reasoning.

B. Specimen Design

We design eight VMB recycled concrete filled square thin-walled steel tubes and put them into two groups, which include four hollow specimens and solid specimens, their width-thickness ratios are 64 and 88 , Steel type is Q235, main parameters of test specimens are shown in the table 3, $\chi = D_i / (B-2t)$, $\xi = A_{so} f_y / (A_{co} f_{ck})$, in the formula, A_{so} is the outer steel pipe cross-sectional area, f_y is outer steel pipe yield strength,A_{co} is the area contained by the outer steel tube, f_{ck}=0.67f_{cu} is standard value of recycled concrete compressive strength. Length-width ratio of the specimen is 3[4].

Table III. Specimen Number and Main Parameters

Specimen number	B×t×L/（mm^3）	Di×ti/（mm^2）	Hollow ratio χ	Width-thickness ratio(B/t)	Confining factor ξ	f_y/（MPa）	f_{cu}/（MPa）
S1-K1-80	160×2.5×480	——	0	64	0.662	235	34.25
S1-K1-100	160×2.5×480	——			0.716		32.12
S1-K2-80	160×2.5×480	54×2.5	0.35		0.662		34.25
S1-K2-100	160×2.5×480	54×2.5			0.716		32.12
S2-K1-80	220×2.5×660	——	0	88	0.475		34.25
S2-K1-100	220×2.5×660	——			0.514		32.12
S2-K2-80	220×2.5×660	75×2.5	0.35		0.475		34.25
S2-K2-100	220×2.5×660	75×2.5			0.514		32.12

Note: All the specimens' calcined diatomite content of recycled concrete are 3%; S1 and S2 represent width-thickness of specimens are 64and 88, K1and K2 represent hollow ratios of specimens are 0 and 0.35; 80、100 mean the VMB volume contains compare to the total volume is 80% and 100%.

III. Establishment of finite element model

A. *Selection of Element Types*

Steel uses the Solid45 element simulation, Es=2.06×10^{5}MPa, Vs=0.3; Concrete uses the Solid65 element simulation, elastic modulus is calculated by recycled concrete elastic modulus formulas that is put forward by reference [5],and Vt=0.2.

$$E_C = \frac{10^5}{2.2+34.7/\mathrm{fcu}} / (0.2811\delta + 1.065) \quad (1)$$

In the formula : δ represents the replacement rate of recycled coarse aggregates,f_{cu} is the cube compressive strength of concrete.

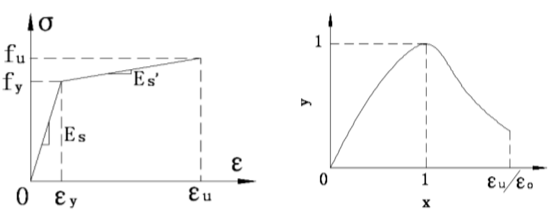
B. *3.2 Constitutive Relations of Material*

1) *Constitutive relation of steel*

The steel uses dual linear kinematic hardening model (BKIN), which is shown in the figure 1 (a).

2) *Constitutive relation of concrete*

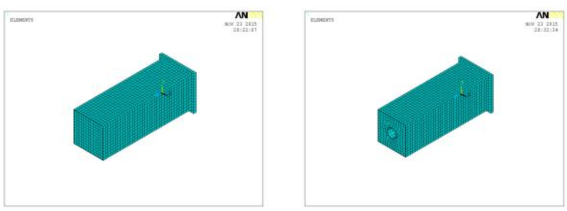
As concrete filled steel tube, the interaction between steel tube and concrete makes the working performance of the core concrete complicate. Therefore, this article uses theory that the core of the recycled concrete stress-strain relationship model[6] , as shown in figure 1 (b).



(a) Constitutive relation of steel

(b) Constitutive relation of concrete

Figure 1. Material stress-strain relations



(a) Solid specimen

(b) Hollow specimen

Figure 2. Finite element model

C. *Modeling and Meshing*

Regardless of slip between concrete and steel tube, modelings add 15mm rigid plate in order to prevent the phenomenon of stress concentration on both ends of pillars. Quality of meshing directly affects the precision and speed of calculation, so hexahedron unit division side length of solid45 and solid65 are 20 mm. As shown in figure 2.

D. Control of Convergence

1) Loading and boundary conditions

Add axial load on the upper plate, axial load generated by the rigid plate into uniformly distributed load on the model, at the same time add x, y, z three directions of displacement constraints on the column bottom plate.

2) Concrete crush Settings

The open crack of concrete shear transfer coefficient and closed joint shear transfer coefficient is set to 0.35 and 0.9 respectively, uniaxial tensile strength is 3 MPa, close the concrete crush option.

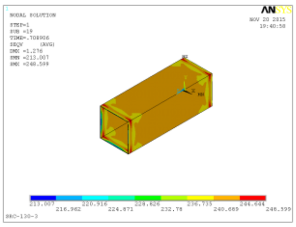
3) Nonlinear analysis options

Open the large deformation of static analysis and the automatic time step length, set steps of 200 , maximum equilibrium iteration times is set to 40, the Newton - Laposen (N- R method) is used to solve and convergence of 2 norm control method, tolerance is set to be 0.05.

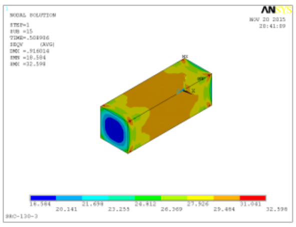
IV. Result analysis of finite element calculation

A. Stress Analysis of Specimen

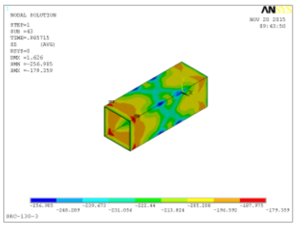
As shown in figure 3(a),(b)and(c), von Mises stress nephogram of the solid specimens in the square steel tube corner distributes complexly and the value of stress is the maximum; von Mises stress of the core concrete stress is approximately elliptic constraint zone, central is larger than the side of constraint and load; The axial stress of steel from the load and constraint transits to central distribution, and uneven distribution;In figure 4(a),(b)and(c), outer steel tube axial stress distribution of hollow specimens transits smoothly, the presence of steel pipe makes specimens of the stress distribution more uniform; the compression ends stress of core concrete is bigger; Axial stress distribution of inner round steel tube near middle of the component is larger.



(a) Von Mises stress nephogram of steel tube

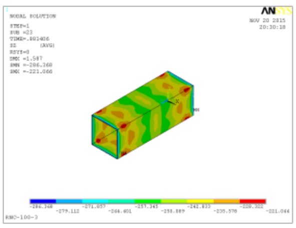


(b) Von Mises stress nephogram of concrete

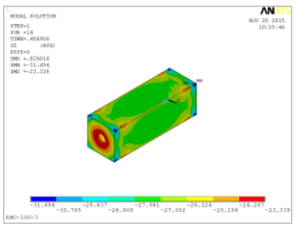


(c) Axial stress nephogram of steel tube

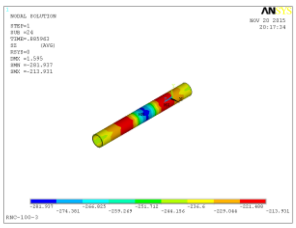
Figure 3. S1-K1-80 CFST stress nephogram



(a) Axial stress nephogram of outer steel tube



(b) Axial stress nephogram of concrete

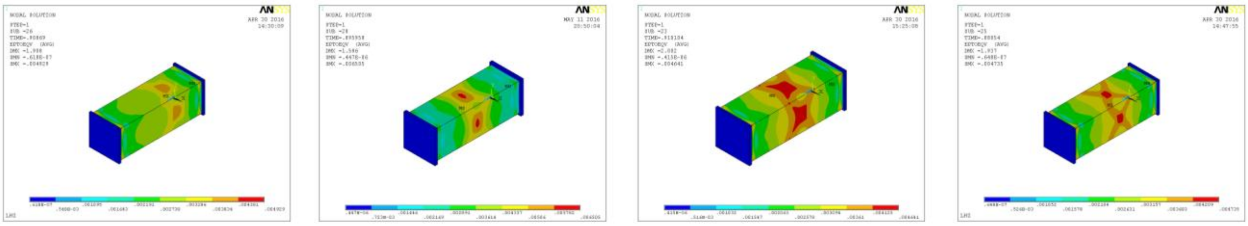


(c)Axial stress nephogram of inside the steel tube

Figure 4. S1-K2-80 CFDST stress nephogram

B. Strain and Displacement Analysis of Specimen

Figure 5 is the strain and displacement nephogram of specimen S1-K2-80、S2-K2-80、S2-K1-100 and S2-K2-100 that arrive the ultimate bearing capacity. As shown in figure 5 (a) and (b), with width-thickness ratio of steel tubes changing from small to big, local buckling appears observably, axial displacement changes from 1.76mm to 1.908mm that increases by 8.4%, which shows that with width- thickness ratio of steel tubes increasing, steel tube constraints weaker on core concrete; as shown in figure 5 (c) and (d), hollow specimens appear the local buckling, but does not change apparently in the middle, which indicates the inner steel tube can prevent or delay local buckling of the component, axial displacement changes from 2.004mm to 1.937mm that decreases by 3.5% compared with the solid ones, which shows the setting of inner steel tube enhances the deformation capacity and improves the ductility; as shown in figure 5 (b) and (d), with the VMB content increasing from 80% to 100%, uniaxial compressive strength of core concrete reduces and steel tube constraints stronger on core concrete, but the whole deformation ability of the specimens does not show strengthen that could due to elastic modulus of RC decreases, core concrete deforms obviously under the action of load, while axial displacement of the specimens changes from1.908mm to 1.937mm that increases by 1.5%.



(a)S1-K2-80 axial strain nephogram | (b) S2-K2-80 axial strain nephogram | (c) S2-K1-100 axial strain nephogram | (d)S2-K2-100 axial strain nephogram

Figure 5. Strain and displacement nephogram of specimens

C. Ultimate Bearing Capacity Analysis of Specimen

At present, the research on CFST has achieved fruitful results and established regulations at home and abroad, this article uses AIJ[7], CECS[8], DBJ[9], EC4[10] and GJB[11] technical orders to analyze the ultimate bearing capacity of 4 solid specimens, and based on the formulas we add inner steel tube bearing capacity as the ultimate bearing capacity computational formula of hollow specimens.The calculation results compared with the ANSYS finite element values are shown in table 4.

Results of ANSYS analysis are following: with VMB content of recycled concrete increasing, the ultimate bearing capacity of specimen reduces; when the hollow ratio is same, the ultimate bearing capacity of specimen increases significantly with width-thickness ratio increasing; when the width-thickness ratio is same, though CFDST have reduced the amount of concrete, because of the inner steel tube, compared with solid specimens, their ultimate bearing capacity increase by 2%, which reduces weight and enhances the anti-seismic performance of specimens.

It can be seen from Table 4:for solid specimens, calculation results of DBJ 13-51-2003 (μ=0.971,σ=0.0301) compared with the ANSYS finite element values are very approximate, EC4-2004(μ=0.965,σ=0.0275)takes second place, calculation results of GJB 4142-2000 are a little higher than ANSYS values , calculation results of AIJ-1997 and CECS 159:2004 are inferior to ANSYS values; for hollow ones, calculation results of DBJ 13-51-2003 (μ=0.993,σ=0.0424) compared with ANSYS finite element values are very approximate , AIJ-1997 (μ=1.034,σ=0.0492) takes second place, calculation results of EC4-2004 and GJB 4142-2000 are a little higher than ANSYS ones, calculation results of CECS 159:2004 are inferior to ANSYS values.

Table IV. Comparison between ANSYS Finite Element Values and Calculation Results

Section type	Specimen number	ANSYS /kN	AIJ-1997		CECS 159:2004		DBJ 13-51-2003		EC4-2004		GJB 4142-2000	
			N_{ue}/kN	$\frac{N_{ANSYS}}{N_{AIJ}}$	N_{ue}/kN	$\frac{N_{ANSYS}}{N_{CECS}}$	N_{ue}/kN	$\frac{N_{ANSYS}}{N_{DBJ}}$	N_{ue}/kN	$\frac{N_{ANSYS}}{N_{EC4}}$	N_{ue}/kN	$\frac{N_{ANSYS}}{N_{GBJ}}$
Solid specimen	S1-K1-80	964	951	1.013	921	1.046	1023	0.942	1028	0.937	1044	0.923
	S1-K1-100	928	915	1.014	887	1.046	985	0.942	987	0.94	1005	0.923
	S2-K1-80	1751	1629	1.074	1572	1.113	1759	0.995	1777	0.985	1806	0.969
	S2-K1-100	1699	1559	1.089	1506	1.128	1684	1.008	1698	1	1729	0.982
	average value (μ)			1.047		1.083		0.971		0.965		0.949
	mean squared error (σ)			0.0344		0.0376		0.0301		0.0275		0.0266
Hollow specimen	S1-K2-80	982	991	0.99	964	1.018	1027	0.956	1060	0.926	1046	0.938
	S1-K2-100	940	958	0.981	933	1.007	992	0.947	1023	0.918	1010	0.93
	S2-K2-80	1801	1655	1.088	1604	1.122	1732	1.039	1790	1.006	1940	0.928
	S2-K2-100	1719	1592	1.079	1544	1.113	1664	1.033	1719	1	1863	0.922
	average value (μ)			1.034		1.065		0.993		0.962		0.929
	mean squared error (σ)			0.0492		0.0527		0.0424		0.0406		0.0057

V. Conclusions

1) When calcined diatomite content is 3% and VMB content is 100%, compressive strength of block can reach 32.12 MPa, and its density is just 1936 kg/m^3;

2) When the hollow ratio is same, with width-thickness ratio of steel tubes changing from small to big, ultimate bearing capacity increases significantly, but local buckling appears observably and ductility decreases, axial displacement increases by 8.4% when they arrive the ultimate bearing capacity; when the width-thickness ratio is same, though hollow specimens have reduced the amount of concrete, because of the inner steel tube setting that reduces weight and enhances the anti-seismic performance of components and makes stress distribution of hollow specimens distribute more balance than solid ones, the ultimate bearing capacity of them increases by 2% and axial displacement decreases by 3.5% compared with solid ones.

3) Compared with the ANSYS finite element values, we have got the applicability of technical orders when they are used to calculate the ultimate bearing capacity of CFDST; for hollow specimens, based on the formulas we add inner steel tube bearing capacity as the ultimate bearing capacity computational formula of them; DBJ 13-51-2003, AIJ-1997 and EC4-2004 compared with the ANSYS finite element values are very approximate.

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SONG Bing, Postgraduate Student, associate constructor, attended an international conference and won the first prize, has published five papers in the domestic and foreign important journals and academic meetings, two of them have been retrieved by EI and ISTP.

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