The 2013 World Congress on
Advances in Structural Engineering and Mechanics (ASEM13)
Jeju, Korea, September 8-12, 2013

Experimental study of aseismic performance of recycled concrete filled steel tubular columns

Feng Liu[1)], Yin-Yin Yu[2)], *Li-Juan Li[3)], Lan Zeng[4)]

[1), 2) 3), 4)] *School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, 510006, China*
[3)] *lilj@gdut.edu.cn*

ABSTRACT

Quasi-static test was carried out for 10 recycled concrete filled steel tubular columns with 165mm diameter, 4mm and 2mm steel tube thickness respectively. The failure mode, hysteresis property, skeleton curves, stiffness degeneration curves and energy dissipation property were obtained for recycled concrete filled steel tubular columns with different coarse aggregate substitution rates under vertical earthquake loads. The aseismic performance of recycled concrete filled steel tubular columns was analyzed.

1. INTRODUCTION

The fast development of urbanization in China results in large amount of abandoned concrete. However, the abandoned concrete can be reused to produce recycled concrete if properly treated such as crushing, washing and grading. The aggregate made from abandoned concrete can be used to replace some or all of the coarse aggregate in concrete mixture. To date, extensive research has been carried out on the mechanical properties of recycled aggregate concrete, including the study of recycled concrete members and structures. The research of Butler et al. (2011) showed the recycled aggregate concrete can be used mainly in the structures with low stress or force level because of the characteristic limitations of recycled aggregate itself. In recent years, the combination of the recycled concrete material and steel tubular concrete structures, which has been widely used in structures in practice, has been put forward by researchers. The method of filling the steel tube with waste concrete material partially or completely not only reduces the whole weight of buildings, but also decreases the price of concrete members. As the recycled aggregate concrete has something to do with the ductility of recycled concrete columns, it is desired for

[1)] Professor
[2)] Graduate Student
[3)] Professor
[4)] Graduate Student
Note: Copied from the manuscript submitted to “Steel and Composite Structures, An International Journal” for presentation at ASEM13 Congress

applications on buildings with aseismic resistance requirements, which provides a new potential use of the waste concrete. Meanwhile, Parker (1997) had expressed waste concrete will provide high and obvious economic and social benefits and prospect application future.

The basic mechanism of the confinement of steel tube on recycled concrete is similar with the situation of normal concrete. The research on the structures of recycled concrete filled steel tubular columns (RCFSTC) was initiated in the late 90's by Konno et al. (1997). A series of investigations on the mechanical property, durability, and the structural performance of recycled aggregate concrete have been carried out in the past 15 years. In China, one of the earliest research on RCFSTC was in 2005 by Xiao et al. (2012b). The related studies are mainly on the performance of RCFSTC under axial or eccentric compression, as showed in Kotsovos and Pavlovic (1995), Konno et al. (1997) , Mohanraj et al. (2011), Chen et al. (2010) and Malathy et al. (2009) , the shrinkage and creep of the core of RCFSTC (Yang et al. 2008), the mechanical properties of RCFSTC (Xiao et al. 2012a), the failure mode of RCFSTC subjected to bending and compression (Shane et al. 2011), the working mechanism of RCFSTC (Andrzej and Alina 2002), the coarse aggregates of RCFSTC (Wu 2012), the energy dissipation abilities of RCFSTC (Yang et al. 2009), and so on. The test for basic performance of recycled concrete by Yang and Han (2006) has shown that the Poisson's ratio of recycled concrete is nearly the same as normal concrete, which indicates that the steel tube can be used to confine recycled concrete as with normal concrete. The dynamic mechanical property of structures, the effect of adhering mechanism and fracture property between recycled aggregate and cementitious materials, the durability of recycled aggregate on the macroscopic mechanical properties and seismic performance of structural components are the main concern of engineers when recycled concrete is used in structures. The further study of the performance of RCFSTC is related with the analysis of its mechanism by Teng et al. (2012) and Liu et al. (2012). As the properties of recycled aggregate are mainly affected by structural aging properties, the study of mechanical and dynamical properties of RCFSTC is limited up to now.

In this paper, quasi-static tests were conducted for 10 RCFSTC with 165 mm diameter, 4 mm and 2 mm steel tube thickness respectively. The specimens were designed by the slenderness ratio and axial compressive ratio of columns which was commonly used in projects. Different aggregate substitution rates and steel rates were chosen as testing parameters. The failure mode, hysteresis property, skeleton curves, ductility coefficient, stiffness degeneration curves and energy dissipation property of RCFSTC under vertical earthquake loads were obtained. The aseismic performance of RCFSTC was analyzed.

2. DESIGN OF TEST

2.1 Material Properties

The following materials were used in the experiment: ordinary Portland cement with 42.5 MPa compressive strength, river sand with a maximum size of 5 mm and a fineness modulus of 2.6, crushed stone aggregate and recycled coarse aggregate with a size of 0-10 mm. The basic performance of coarse aggregate is shown in Table 1.

The mix proportion of concrete is shown in Table 2. The material property of steel tube is shown in Table 3.

Table 1 Basic performance of coarse aggregate

Type of aggregate	Size (mm)	Apparent density (kg/m^3)	Bulk density (kg/m^3)	Water absorption (%)	Crushing index (%)
Natural coarse aggregate	0~10	2785	1448	0.75	4.54
Recycled coarse aggregate	0~10	2456	1287	4.12	15.72

Table 2 Mix proportion of concrete

Speci-men	Contents Per cubic							Water cement ratio	Sand percent-age (%)
	Ce-ment	Wa-ter	Sand	Fly ash	Recy-cled aggre-gate	Coarse aggre-gate	Water reduc-ing agent		
M0	330	156	710	120	/	1064	9	0.35	0.4
M30	330	156	710	120	319	745	9	0.35	0.4
M50	330	156	710	120	532	532	9	0.35	0.4

Notes: MN, M refers to recycled aggregate concrete, while N refers to rates (%) of coarse aggregate substitution. For example, M30 means the concrete with 30% recycled coarse aggregate substitution.

Table 3 Properties of steel tubes

Thickness (mm)	Yield strength (MPa)	Ultimate strength (MPa)	Elastic modulus (MPa)	Elongation (%)
4	440	340	228×103	13.12
2	580	490	240×103	13.78

2.2 Specimen Design

10 specimens of concrete filled steel tubular columns were designed. The columns are 1200 mm high and their basement is design as rigid. The design parameters of each specimen are shown in Table 4. The 150 mm test cubes were poured simultaneously and their strength are shown in Table 5.

Table 4 Design parameters of specimens

Specimen number	D×t×L (mm)	D/t	Slenderness	Rates (%)of substitution	Steel ratio
HM0-1	165×4×1200	41.25	29.09	0	0.105
HM0-2	165×4×1200	41.25	29.09	0	0.105
HM30-1	165×4×1200	41.25	29.09	30	0.105
HM30-2	165×4×1200	41.25	29.09	30	0.105
HM50-1	165×4×1200	41.25	29.09	50	0.105
HM50-2	165×4×1200	41.25	29.09	50	0.105
BM30-1	165×2×1200	82.50	29.09	30	0.05
BM30-2	165×2×1200	82.50	29.09	30	0.05
BM50-1	165×2×1200	82.50	29.09	50	0.05
BM50-2	165×2×1200	82.50	29.09	50	0.05

Notes: HMN-K, H refers to thick-walled steel tube, B refers to thin-walled steel tube, M refers to recycled aggregate concrete, N refers to rates (%) of substitution of aggregate, and K refers to the specimen number.

Table 5 Strength of concrete

Test cube of specimen	f_{cu1} (MPa)	f_{cu2} (MPa)	f_{cu3} (MPa)	f_{cu} (MPa)
M0-1	55.4	54.9	55.0	55.1
M0-2	57.9	56.7	55.9	56.8
M30-1	55.7	63.1	58.9	59.3
M30-2	56.4	58.6	63.3	59.4
M50-1	56.1	64.8	51.1	57.3
M50-2	58.7	54.8	52.8	55.4

2.3 Basic Parameters of Specimens

The basic parameters of specimens are shown in Table 6 where fa is the design value of tensile and compressive strength of steel tubes, f_c is the design value of compressive strength of concrete, θ is the confinement index of concrete filled steel tubes, N is the average value of axial force loaded, N_u is the design value of load bearing capacity of concrete filled steel tubular column, and n is the axial compressive ratio witch can be calculated from DG/TJ 08-2018-2007 (Technical Specification for Application of Recycled Concrete 2007) and DB34/T1262-2010 (Technical Specification for Concrete-filled Steel Tubular Structures 2010). The designed axial compressive ratio is 0.2, while the actual value has some fluctuations in test process.

Table 6 Parameters of specimens

Specimen	f_a (MPa)	f_c (MPa)	θ	N (kN)	N_u (kN)	n
HM0-1	308.0	36.9	0.9	320.0	1585.9	0.20
HM0-2	308.0	36.9	0.9	300.0	1585.9	0.19
HM30-1	308.0	39.6	0.8	320.0	1647.9	0.19
HM30-2	308.0	39.6	0.8	290.0	1647.9	0.18
HM50-1	308.0	38.3	0.8	290.0	1619.0	0.18
HM50-2	308.0	38.3	0.8	320.0	1619.0	0.20
BM30-1	343.0	39.6	0.4	230.0	1338.1	0.17
BM30-2	343.0	39.6	0.4	260.0	1338.1	0.19
BM50-1	343.0	38.3	0.5	240.0	1310.3	0.18
BM50-2	343.0	38.3	0.5	230.0	1310.3	0.18

2.4 Equipments and Loading System

The vertical axial forces were loaded through a hydraulic jack with 5000 kN capacity, while the horizontal forces were exerted by the American MTS system which was shown in Fig. 1.

Displacement meters were set in the location of loading on top of column, middle and bottom positions of columns in both vertical and horizontal directions respectively to measure the displacements of columns in testing. 26 strain gauges were pasted on the surface of each steel tube to obtain the tensional, compressive and torsional strains of the columns. The strains and displacements were obtained automatically by TDS system. The tests adopted the method of load and displacement control according to JGJ101-96 Specification of Testing Methods for Earthquake Resistant Building (1996) in China.

3. EXPERIMENTAL RESULTS AND ANALYSIS

3.1 Failure Mode of Specimens

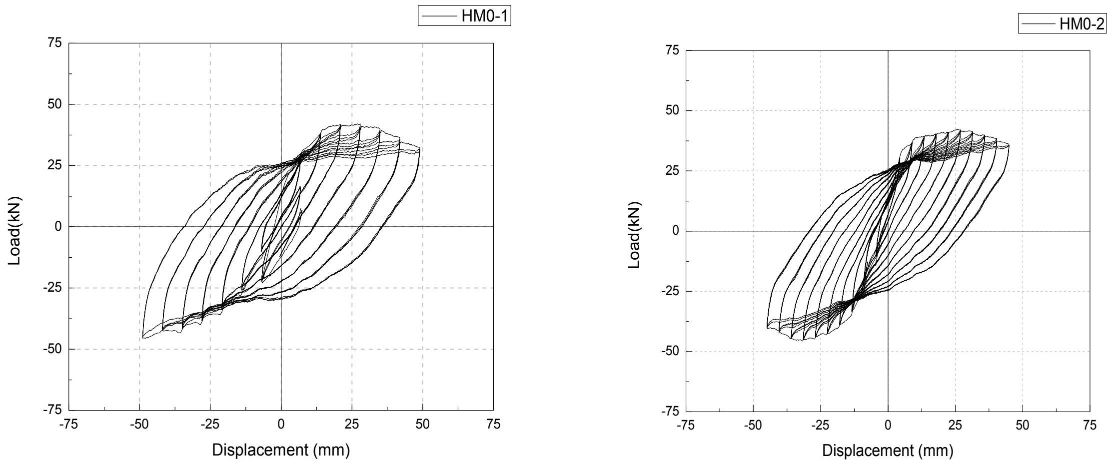
The failure process of RCFSTC is similar to that of normal concrete filled steel tubular columns, and the failure morphology is shown in Fig. 2. Local buckling like the shape of “elephant’s leg” takes place at the 20mm above of the column bottom. The local buckling of BM column series appears earlier than that of the HM ones. Little local buckling shows up on the surface of compressive side at the bottom of the BM column series when the horizontal displacement becomes 2△y. The bulking extends to the wall of tubes on the side of the compressive zone with the increase of displacement gradually. The shape of local buckling of BM columns is narrow and slim compared with that of thicker wall HM columns. The bulking area of the BM column series expands rapidly when the lateral displacement reaches 5△y, and finally the lateral confinement of BM tubes has no effect no longer. There is no obvious difference between the HM columns and the normal concrete filled steel tubular columns when local buckling happens. The time of local buckling happening for BM columns with different recycled aggregate substitution was the same, which indicates that the substitution rates of recycled coarse aggregate has little effects on the local buckling of steel tubes.

Fig.1 Test equipments

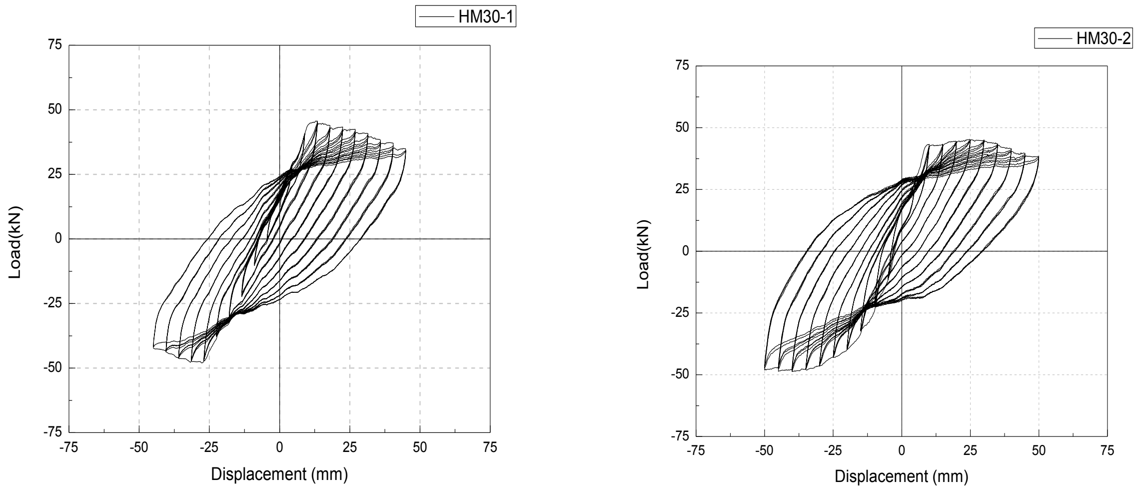
Fig.2 Failure morphology of specimen

3.2 Property of Hysteresis

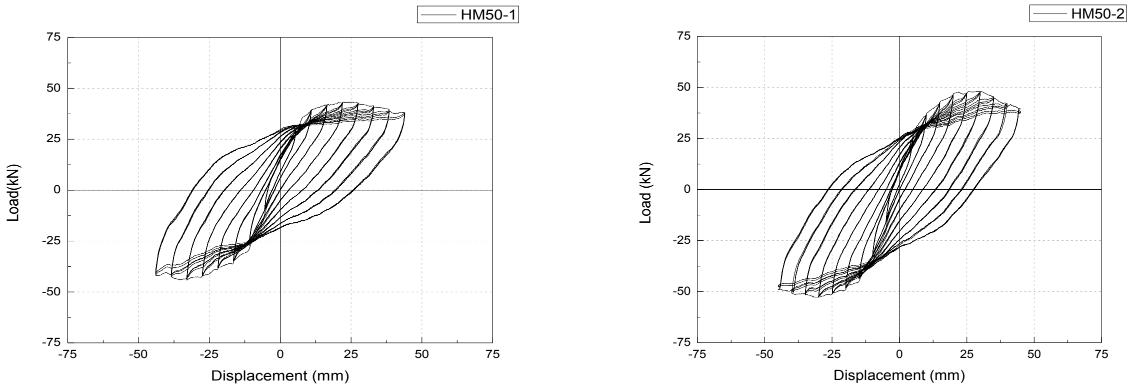
The load-displacement hysteretic curves of RCFSTC are shown in Fig. 3. It can be seen from Fig. 3 that the hysteretic performance of RCFSTC is as good as that of the normal concrete filled ones. Although a pinch phenomenon happened in the BM columns in large deformation, the load bearing capacity of the HM columns, designed based on CECS28:90 Design and Construction Specification for Concrete Filled Steel Tubular Structures (1990), doesn’t drop down sharply under earthquake before the ultimate load is reached. Thanks to the interactions between the steel tube and the core concrete, the seismic performance of RCFSTC is fully expressed, which indicates that the RCFSTC has the same performance as the normal concrete filled steel tubular columns. The elastic stiffness and seismic load-bearing capacity of RCFSTC increased with the increase of steel ratio. In contrast to the BM columns, the speed of load degradation for the HM columns is slower, there is no obvious pinch phenomenon, and the hysteresis loop is full. The degeneration of stiffness and strength of HM columns is unobvious at large deformation. In the series of HM, the horizontal load-bearing capacity of columns is inversely proportional to the strength of the core concrete, however, the situation is complete different for the series of BM, which may be associated with the forces carried by wall of the specimens.



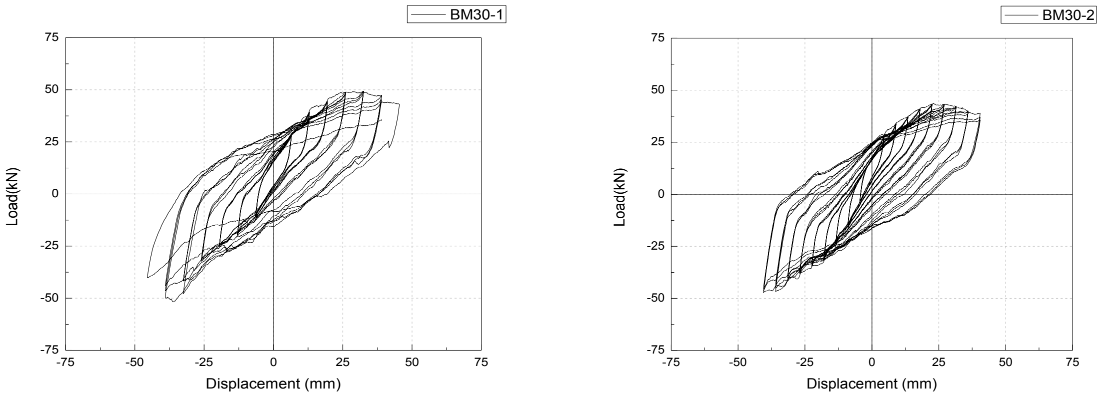
(a) Hysteresis curve of HM0-1 and HM0-2



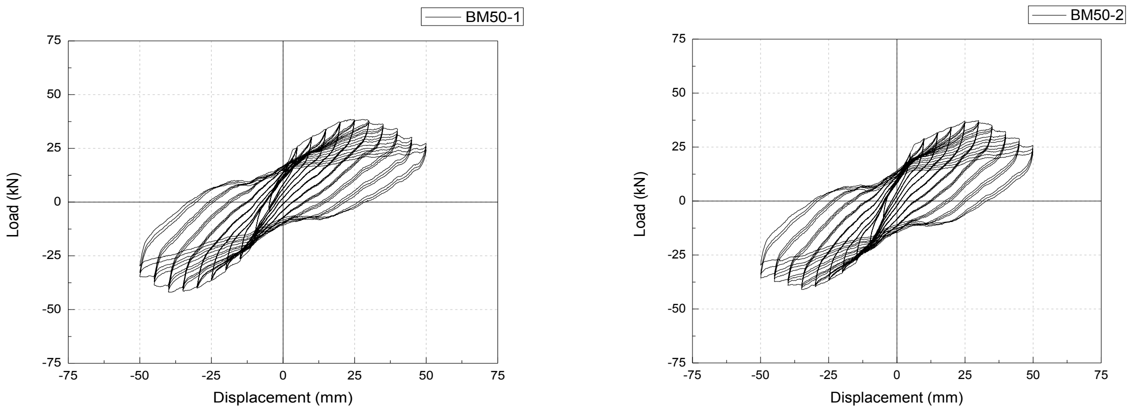
(b) Hysteresis curve of HM30-1 and HM30-2



(c) Hysteresis curve of HM50-1 and HM50-2



(d) Hysteresis curve of BM30-1 and BM30-2



(e) Hysteresis curve of BM50-1 and BM50-2

Fig.3 Hysteresis curves of steel tube columns filled with recycled concrete

In this test, it can be seen from Table 6 that the compressive strength of RCFSTC with 30% and 50% aggregate substitution rates is higher than that of normal concrete. The compressive strength of concrete M30, M50 and M0 is 39.6 MPa, 38.3 MPa and 36.9 MPa respectively. The recycled aggregate affected the hysteretic performance and ductility of the columns but had no direct relations with aggregate substitution rates. The hysteretic performance decreased with the increase of f_c for HM columns, however, the hysteretic curve of BM30 shows better performance than that of BM50 for BM columns. For the two columns with same parameters, the declining of the bearing capacity of BM50 series is smooth after damage, which suggests that the interaction between steel tubes with core concrete is better for 50% substitution rate than that for 30% one.

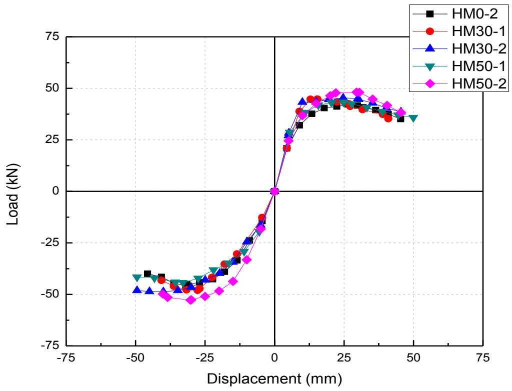
3.3 Skeleton Curves and Ductility

The ductility coefficient of each column is shown in Table 7. The horizontal load-displacement skeleton curves are shown in Figure 4.

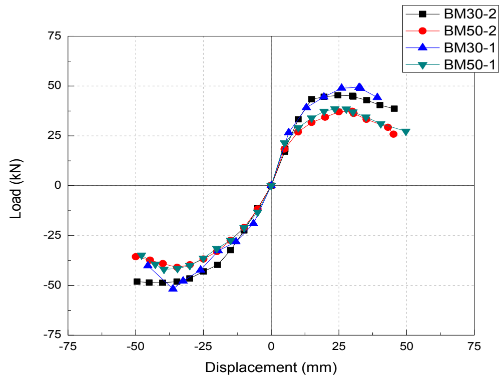
Table 7 The ductile coefficients

Specimen	P_{ue1}	P_{ue2}	P_{ue}	Δu	Δy	u	P	P/P_{ue1}
HM0-1	--	--	--	--	--	--	--	--
HM0-2	42.22	-45.76	43.99	43.81	4.43	9.89	38.19	1.11
HM30-1	44.77	-48.07	46.42	33.93	4.45	7.62	40.38	1.11
HM30-2	45.34	-48.67	47.00	45.52	5.01	9.09	40.07	1.13
HM50-1	43.29	-44.23	43.76	45.54	5.48	8.31	40.53	1.07
HM50-2	48.13	-52.80	50.47	41.62	5.03	8.27	37.50	1.28
BM30-1	49.38	-51.83	50.61	37.49	6.50	5.77	28.68	1.72
BM30-2	43.71	-46.37	45.04	45.13	5.29	8.53	24.69	1.77
BM50-1	38.49	-41.93	40.21	38.08	5.01	7.62	26.98	1.43
BM50-2	37.29	-41.00	39.15	37.98	5.00	7.60	27.03	1.38

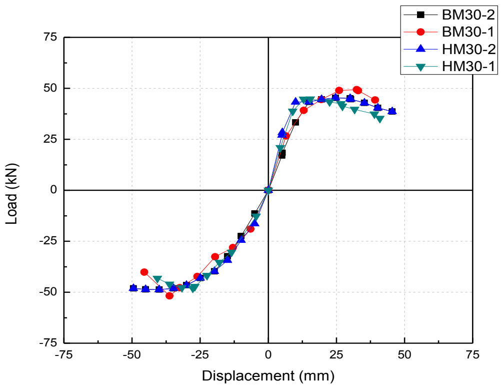
Note: P_{ue1} and P_{ue2} are two different load bearing capacity for loading and reverse loading direction. P_{ue} is the absolute average value of P_{ue1} and P_{ue2}. $\triangle u$ is the damage displacement corresponding to the minimum of the three absolute values of $0.85P_{ue1}$, $0.85P_{ue2}$ and $0.85P_{ue}$. P is the horizontal bearing capacity of specimens calculated by DB34/T1262-2010 Technical Specification for Concrete-filled Steel Tubular Structures (2010). u is ductility coefficient $u=\triangle u/\triangle y$.



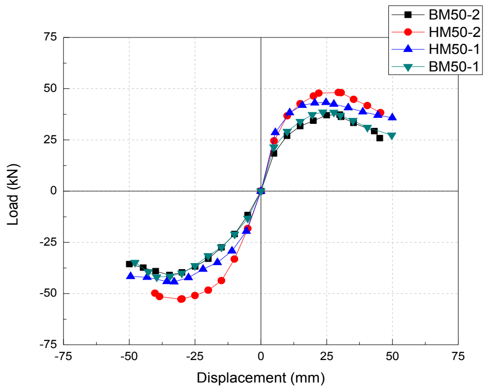
(a) Skeleton of HM with different recycled aggregate rates



(b) Skeleton of BM with different recycled aggregate rates



(c) Skeleton curves of 30% recycled concrete columns with different steel tubes



(d) Skeleton curves of 50% recycled concrete columns with different steel tubes

Fig.4 Skeleton curves

From Table 7 and Fig. 4, the following conclusions are obtained:

(1) For the thick-wall (HM) columns, the recycled aggregate substitution rate has little effect on the initial part of skeleton curve, indicating that recycled aggregate has little effect on the lateral stiffness of columns. The horizontal load-bearing capacity of HM column is higher than that of normal concrete filled column (Column HM0-1 failed, only HM0-2 is left). However, the skeleton curves of the HM columns drop faster than that of normal concrete filled columns after the peak point, the ductility coefficient of the latter is thus a little bit larger than the former.

(2) For the thin-wall (BM) columns, the recycled aggregate replacement rate has a certain effect on the initial part of the skeleton curve. The initial stiffness of the BM30

columns is slightly larger than that of the BM50 columns. Moreover, the percentage of recycled aggregate has little influence on the lateral stiffness of columns.

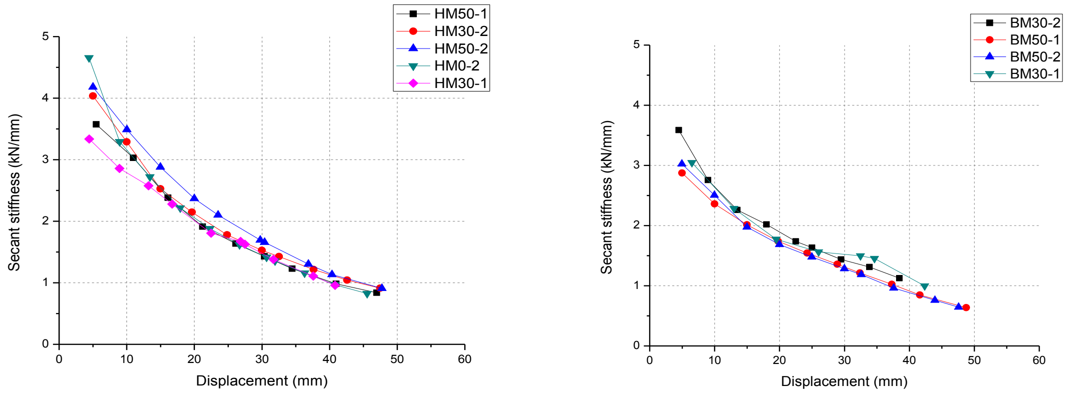
(3) For the columns with 30% (M30) recycled aggregate substitution rate, the ductility of HM30 is better than that of BM30, however, the load-bearing capacity is almost the same. In this paper, the tensile strength of thin-wall steel tubes is higher than that of the thick-wall ones, so both the horizontal load-bearing capacities and skeleton curves in the decreasing phrase of two different steel tubes are similar. As expected, the thick-wall carried more axial pressure than the thin-wall, and for the same axial compressive ratio, more axial load of steel tube is transferred to the core concrete when local buckling happens for thick-wall columns. If all the axial compressions were taken by the core concrete, ignoring the vertical load-bearing capacity of steel tubes after local buckling, then the axial compressive ratio (the ratio of axial load to axial ultimate load) of the core concrete increases sharply, from 0.19 to 0.42 for HM30-1 and 0.19 to 0.32 for BM30-2. The local bulking makes the ferrule effect weaker, finally results in the decrease of advantage of thick-wall columns.

(4) For the columns with 50% recycled aggregate replacement rate, the ductility of thick-wall columns (HM) are better than that of the thin-wall ones (BM). The horizontal load-bearing capacity of thick-wall columns (HM) is larger than that of thin-wall columns (BM). However, for reverse loading cases, the situations of M50 columns are almost the same, with reason explained above.

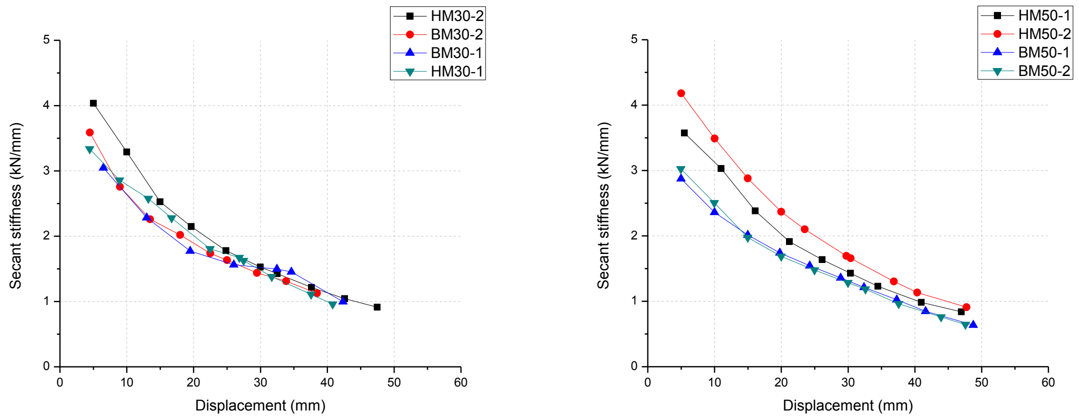
(5) The lateral load-bearing capacity of the HM columns matched well with the data calculated from DB34/T1262-2010 Technical Specification for Concrete Filled Steel Tubular Structures (2010). The test results are genrerally a little bit larger than the calculated ones, with the ratio of test to calculation values being 1.07~1.28, which indicates it is safe to use the current standard to calculate the lateral bearing capacity of RCFSTC. For the lateral load-bearing capacity of BM columns, the ratios of test to calculation values are 1.72~1.77 and 1.38~1.43 for BM30 and BM50 respectively. It shows that the lateral bearing capacity of recycled concrete filled thin-wall steel tubular columns based on calculation is relatively conservative.

3.4 Curves of Stiffness Degeneration

Curves of stiffness degeneration of columns are shown in Fig. 5. It can be seen from Fig. 5 that the stiffness degradation occurred mainly in the cyclic loading of level 1△y, 2△y and 3△y, then the stiffness degradation slowed down with the increases of lateral displacement. The recycled aggregate substitution rates have little effect on the stiffness degradation curves for columns with different thickness of tubes. Stiffness degradation curves are substantially the same for columns with the same steel ratio. The first cycle peak stiffness of HM columns are lower than that of normal concrete filled columns under the first-level displacement loading, and the first cycle peak stiffness of HM30 columns is lower than that of HM50 ones. The results of BM columns are similar. The influence of steel ratio on stiffness degradation curves of columns with same aggregate substitution rates is similar. The peak stiffness of the HM columns is higher than that of the BM ones. The degradation of stiffness occurred mainly in the earlier circles especially for the M50 columns.



(a) Stiffness degeneration of HM and BM



(b) Stiffness degeneration of M30 and M50

Fig.5 Stiffness degeneration

3.5 property of energy dissipation

In this paper, energy dissipation coefficient and equivalent viscosity coefficient are calculated by the first hysteresis loop corresponding to the peak load and the failure load of the displacement amplitude, respectively. The results are shown in Table 8.

Table 8 Coefficient of energy dissipation and equivalent viscous damping

Speci-men	Peak hysteresis loop				Damage hysteresis loop				E_t
	S_{ABCDEA}	$S_{\Delta OBF}$ + $S_{\Delta ODG}$	E	ξ_{eq}	S_{ABCDEA}	$S_{\Delta OBF}$ + $S_{\Delta ODG}$	E	ξ_{eq}	
H0-1	--	--	--	--	--	--	--	--	--
H0-2	1352.20	1157.39	1.168	0.186	3776.90	1851.16	2.040	0.325	45669
H30-1	301.09	447.06	0.673	0.107	2624.10	1635.61	1.604	0.255	30995
H30-2	1072.19	1099.69	0.975	0.155	3654.64	2162.84	1.690	0.269	41704
H50-1	1395.02	1171.36	1.191	0.190	4361.11	2182.41	1.998	0.318	43252
H50-2	1835.10	1509.68	1.216	0.194	4280.65	2130.00	2.010	0.320	43994
B30-1	1924.45	1475.50	1.304	0.208	521.80	394.00	1.324	0.211	24029
B30-2	1109.30	1098.54	1.010	0.161	2621.82	1588.60	1.650	0.263	28922
B50-1	871.07	1166.85	0.747	0.119	1967.80	1544.46	1.274	0.203	20983
B50-2	944.16	1153.36	0.819	0.130	2017.50	1484.71	1.359	0.216	21297

Note: E is energy dissipation coefficient, E_t is the total energy consumption and ξ_{eq} is equivalent coefficient of viscosity.

The following conclusions can be made from Table 8. The equivalent viscous damping coefficient range is between 0.255~0.320 and 0.203~0.263 for HM columns and BM columns respectively, while the equivalent viscous coefficient of reinforced concrete columns is usually 0.1~0.2, which shows that the energy absorption capacity of RCFSTC is as good as the normal concrete columns. The energy dissipation capacity of the HM columns is inversely proportional to the strength of the core concrete under the same steel ratio, while for the BM columns the trend is on the contrary. In general, the capability of energy dissipation of the M30 columns is variable (those M30-1 and M30-2 vary widely), but the M0 and M50 columns show samiliar energy consumption capacity.

4. CONCLUSIONS

From the analyses of hysteresis curves, skeleton curves, ductility, stiffness degradation and energy dissipation based on the experimental results of 10 RCFSTC, the following conclusions can be obtained.

(1) Under the same condition of steel ratio, hysteretic performance of RCFSTC is weakened for different aggregate substitution. Recycled aggregates do not reduce the lateral stiffness of columns. Recycled aggregate substitution rate has no nearly effect on the horizontal load-bearing capacity of columns. Different recycled aggregate

substitution rates have a little influence on the stiffness degradation of columns, with the stiffness degradation curves of the same steel ratio columns being substantially the same.

(2) The stiffness and seismic performance of RCFSTC increase with the increase of steel ratio during the elastic period. The energy dissipation capacity of RCFSTC is not less than that of the normal concrete filled ones. Ductility of thick-wall columns with a higher steel ratio is better than that of thin-wall ones, Steel ratios have little influence on the load-bearing capacity of the columns with 30% replacement of aggregate. The influence of steel ratio on curves of stiffness degradation of columns with different recycled aggregate substitution is similar.

(3) The effect of substitution rate on energy dissipation is more significant for 30% substitution columns than 50% substitution ones under the same recycled aggregate substitution rate. The design of lateral load bearing capacity for RCFSTC based on standard of DB34/T1262-2010 Technical Specification for Concrete filled Steel Tubular Structures (2010) is of the same safe ability as normal concrete filled steel tubular columns. The design for recycled concrete filled thin-wall tubular columns based on the present standard of DB34/T 1262-2010 Technical Specification for Concrete Filled Steel Tubular Structures (2010) is conservative.

ACKNOWLEDGMENTS

This research was jointly funded by the National Natural Science Foundation of China (Project No. 51278132, 51278129), the Science and Technology Foundation of Guangdong Province, China (Project No.2011B010400024) and the Foundation of Guangdong Provincial Transportation Department (Project No. 2012-02-008). These foundations are greatly appreciated.

REFERENCES

Andrzej, A. and Alina K. (2002), "Influence of recycled aggregates on mechanical properties of HS/HPC", *Cem Concr Comp*, **24**(2), 269-279.

Butler, L., West, J.S. and Tighe, S.L. (2011), "The effect of recycled concrete aggregate properties on the bond strength between RCA concrete and steel reinforcement", *Cem Concr Res*, **41**(10), 1037-1049.

CECS 28:90 Design and construction specification for concrete-filled steel tubular structures (1990). (in Chinese)

Chen, Z.P. et al. (2010), "Experimental study on the mechanical behavior of recycled aggregate coarse concrete-filled square steel tube column", *Proceedings of 2010 International Conference on Mechanic Automation and Control Engineering (MACE).*

DG/TJ 08-2018-2007 Technical specification for application of recycled concrete (2007). (in Chinese)

DB34/T1262-2010 Technical specification for concrete-filled steel tubular structures (2010) . (in Chinese)

JGJ101-96 Specification of testing methods for earthquake resistant building (1996). (in Chinese)
Konno, K., Sato, Y., Kakuta, Y., Ohira, M. (1997), "Property of recycled concrete column encased by steel tube subjected to axial compression", *J Trans Jap Concr Inst*, **19**(2), 231–238.
Kotsovos, M.D. and Pavlovic, M.N. (1995), *Structure concrete: finite-element analysis for limit-state design*, Thomas Telford Publication.
Liu, F., Yan,Y., Li, L.J. (2012), "Experimental study on impact performance of recycled plastic reinforced concrete", *Proceedings of the First International Conference on Performance-based and Life-cycle Structural Engineering, December, HongKong*
Malathy, R., Mohanraj, E. and Kandasamy, S. (2009), "Comparative study on behavior of concrete-filled steel tubular columns using recycled aggregates", *Proceedings of International Conference on Concrete Construction, Kingston Univ. London, London, England.*
Mohanraj, E., Kandasamy, S. and Malathy, R. (2011), "Behavior of steel tubular stub and slender columns filled with concrete using recycled aggregates", *J South Afr Inst Civil Eng*, **53**(2), 31-38.
Parker, F.L., et al. (1997), "Economic, risk, and efficacy analysis of recycling radioactively contaminated concrete", *Proceedings of Decommissioning, Decontamination, and Reutilization of Government and Commercial Facilities, Knoxville, USA.*
Shane, M., Daniel, C. and Christopher, W. (2001), "Compressive behavior of concrete with vitrified soil aggregate", *J Mater Civil Eng*, **13**(5), 389-394.
Teng, J.G., Zhao, J.L., Yu, T., Li, L.J. and Guo, Y.C. (2012), "Recycling of coarsely-crushed concrete for use in FRP tubular columns", *Proceedings of the First International Conference on Performance-based and Life-cycle Structural Engineering, December, HongKong.*
Wu, B., Zhao, X.Y., Zhang, J.S., Liu, Q.X. (2012), "Seismic tests on square thin-walled steel tubular columns filled with demolished concrete lumps", *Key Eng Mater*, 517-958.
Xiao, J., Huang, Y., Yang, J., Zhang, Ch., (2012a), "Mechanical properties of confined recycled aggregate concrete under axial compression", *J Constr Build Mater*, **26**(1), 591-603.
Xiao, J., Li, W., Fan, Y., Huang, X., (2012b) , "An overview of study on recycled aggregate concrete in China", *J Constr Build Mater*, **31**, 364–383.
Yang, Y.F. and Han, L.H. (2006), "Experimental behavior of recycled aggregate concrete filled steel tubular", *J Constr Steel Res*, **62**(12), 1310-1324
Yang, Y.F., Han, L.H. and Wu, X. (2008), "Concrete shrinkage and creep in recycled aggregate concrete-filled steel tubes", *J Adv Struct Eng*, **11**(4), 383-396.
Yang, Y.F., Han, L.H. and Zhu L.T. (2009), "Experimental performance of recycled aggregate concrete-filled circular steel tubular columns subjected to cyclic flexural loadings", *J Adv Struct Eng*, **12**(2), 183-194.