Steel and Composite Structures, Vol. 11, No. 5 (2011) 391-402
DOI: http://dx.doi.org/10.12989/scs.2011.11.5.391

Compression test of RCFT columns with thin-walled steel tube and high strength concrete

Alifujiang Xiamuxi[1,2]* and Akira Hasegawa[1]

[1]*Department of Environmental and Civil Engineering, Hachinohe Institute of Technology, 88-1 Ohbiraki, Hachinohe 031-8501, Japan*
[2]*College of Architectural and Civil Engineering, Xinjiang University, Urumqi 830008, China*

(Received August 21, 2011, Revised May 03, 2011, Accepted June 22, 2011)

Abstract. It is clear from the former researches on reinforced concrete filled steel tubular (RCFT) structures that RCFT structures have higher strength and deformation capacity than concrete filled steel tubular (CFT) structures. However, in the case of actual applications to large-scaled structures, the thin-walled steel tube must be used from the view point of economic condition. Therefore, in this study, compression tests of RCFT columns which were made by thin-walled steel tube or small load-sharing ratio in cooperation with high strength concrete were carried out, meanwhile corresponding tests of CFT, reinforced concrete (RC), pure concrete and steel tube columns were done to compare with RCFT. By the a series of comparison and analysis, characteristics of RCFT columns were clarified, and following conclusions were drawn: RCFT structures can effectively avoided from brittle failure by the using of reinforcement while CFT structures are damaged due to the brittle failure; with RCFT structures, excellent bearing capacity can be achieved in plastic zone by combining the thin-walled steel tube with high strength concrete and reinforcement. The smaller load-sharing ratio can made the reinforcement play full role; Combination of thin-walled steel tube with high strength concrete and reinforcement is effective way to construct large-scaled structures.

Keywords: RCFT structures; CFT structures; large-scaled structures; compression test; thin-walled steel tube; load-sharing ratio; high strength concrete; brittle failure; bearing capacity.

1. Introduction

In the recent years, along with the enlargement of structures in the cities, the composite structures which have better bearing capacity and seismic performance are urgently expected, and also its applications are being promoted.

The composite structures obtained its excellent characteristic by combining the two kinds of materials which is totally different and has no so excellent characteristic singly.

(1) Taking merits of each material, the composite structures are neither only load-proof nor earthquake resistance, but also leads to an enormous reduction in the construction expense by possessing enough rigidity and deformation characteristic and shortening the construction time(or lowering construction cost).

(2) Because of its high strength, the cross-section of members of composite structures can be small in size and then slimming down of the whole structure, and so enable the construction of a building in more beautiful spectacle in the cities with the limited space.

In Hansin-Awaji earthquake of Japan in 1995, the CFT structures were avoided from collapse while

* Corresponding author, Mr., E-mail: d10301@hi-tech.ac.jp

most of other structures collapsed or seriously damaged (JSCE 1999). However, the brittle failure of CFT structures is concerned when it is considered to construct large-scaled structures and effective space (Wei *et al.* 2002, Xiao *et al.* 2005, Xu *et al.* 2009), and then, a new kind of structure - reinforced concrete filled steel tubular structures (RCFT) which have high strength like CFT and can be adapted to large-scaled structures is developed and studied in the terms of practical utilization. Fig. 1 shows the model of CFT and RCFT.

RCFT is a composite structure which is aimed at improving the shear strength of CFT structures by inserting reinforcement and making the steel tube play full role.

Some research results until now (Endo *et al.* 2000, Wang *et al. 2002*, Wei *et al.* 2005, Sato 2008, Han *et al. 2010*, Miao 2010) proved that the bearing capacity, ductility, deformation and seismic performance of RCFT structures are increased compared with CFT. But the steel tubes used in those researches were thick-walled steel tubes, and it is apparently not so economical. This must be taken into serious consideration especially when construct large-scaled structures.

In this study, compression tests of RCFT columns which were made by thin-walled steel tubes and high strength concrete were carried out. Basing on the test results, the effects of thin-walled steel tubes and reinforcement were described.

2. Compression test setup

2.1. The selection of load-sharing ratio of steel tube

The load-sharing ratio (γ) of steel tube is represented as the load-sharing ratio between steel tube and concrete. According to JSCE (1999), Scope of γ for CFT is $0.2 \le \gamma \le 0.8$.

γ can be calculated using the following equation:

$$\gamma = \frac{P_s}{P_s + P_c} \tag{1}$$

In which, P_s is load-sharing amount of steel tube, P_c is load-sharing amount of concrete, where $P_s = \sigma_s \times A_s$ (σ_s is yield strength of steel, A_s is the cross-section area of steel tube), $P_c = \sigma_c \times A_c$ (σ_c is strength of concrete, A_c is cross-section area of concrete).

To decide the essential parameters of the specimens, referring to former experimental studies (Sato

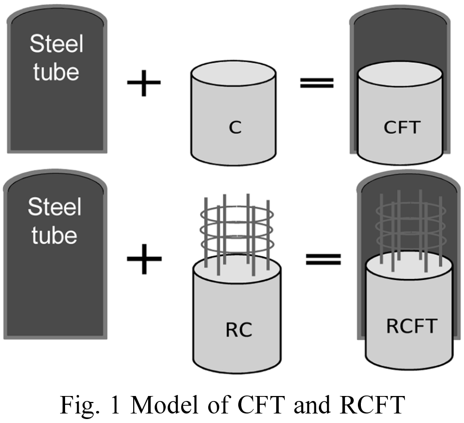


Fig. 1 Model of CFT and RCFT

2008, Suzuki 2008) shown as Table 1, the γ value of thin-walled steel tube in this experiment was chosen as 0.20, the corresponding thickness of steel tube was 1.2 mm, strength of concrete was 40MPa.

2.2. Outline of the compression test

The diameter D and height H of all specimens was D = 150 mm and H = 450 mm, respectively. Material of steel tube was SS400 (Japanese Industrial standard: JIS) and its thickness t was t = 1.2 mm. Two kinds of axial reinforcement were used, one was thin-cover reinforcement (diameter of the ring a_s was a_s = 100 mm,see Fig. 2) the other was thick-cover reinforcement (a_s = 60 mm, see Fig. 2), in both cases, numbers of reinforcement were 6, material was SD295 (JIS) and the diameter of reinforcement d_s was d_s=6mm. Lateral reinforcements were used with spiral shape on the transverse direction of RC and RCFT specimens, the lateral reinforcement was SS400 (JIS) and its diameter d_s was d_s=3mm, Fig. 2(b) shows the arrangement of reinforcement. To compare with the CFT and RCFT specimens, corresponding RC, steel tube and concrete specimens were also made with same reinforcement, thickness and concrete strength. More detailed information are listed in Table 1 and Table 2.

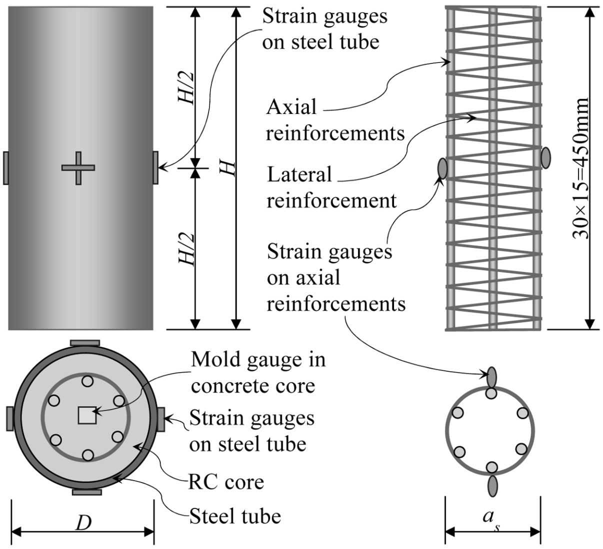
The items measured from the experiment were load, axial deformation and strains. 4 deformation transducers were installed on the top of specimens to measure axial displacement (see Fig. 3(a)). Strains of steel tube were measured by 8 strain gauges placed circumferentially and longitudinally at the outside longitudinal center of specimens (see Fig. 2a). Only 2 strain gauges were placed symmetrically for 2 of 6 axial reinforcements at the longitudinal center (see Fig. 2(b)). To measure the compressive strain of the concrete, a mold strain gauge was placed inside of the concrete at longitudinal center (see Fig. 2(a)).

The specimens were placed into the testing machine shown as Fig. 3, and the load were applied under control with increment of 24.1 kN. After the load reached the maximum value, if any of the displacement

Table 1 Load-sharing ratio γ

Items		This test	Former test					Remarks
Steel tube	t(mm)	1.2	2.3	3.2	3.2	4.5	6.0	*d = 150 mm, SS400(JIS)*
	σ_s (Mpa)	304.0	327.0	314.0	299.0	296.0	285.0	Values from material testing
	A_s (mm^2)	561.0	1067.2	1475.8	1475.8	2057.0	2714.3	$A - A_c$
	P_s (kN)	170.5	349.0	463.4	441.3	608.9	773.6	$\sigma_s \times A_s$
Concrete	σ_c (Mpa)	40.0	44.3	27.1	19.2	19.2	19.2	Values from experiment
	A_c (mm^2)	17110.5	16604.2	16195.7	16195.7	15614.5	14957.1	$(\pi \times d_c^2)/4$
	P_c (kN)	684.4	735.6	438.9	311.0	299.8	287.2	$\sigma_c \times A_c$
Axial reinforcement	σ_{sr} (Mpa)	295.0	295.0	352.0	235.0	235.0	235.0	Values from material property
	A_{sr} (mm^2)	190.0	190.0	190.0	190.0	190.0	190.0	
	P_{sr} (kN)	56.1	56.1	66.9	44.7	44.7	44.7	$\sigma_{sr} \times A_{sr}$
Total axial compressive strength: P_u(kN)		911.0	1140.6	969.2	796.9	953.3	1105.4	$P_s + P_c + P_{sr}$
Load-sharing ratio: γ		0.20	0.32	0.51	0.59	0.67	0.73	$P_s/(P_s+P_c)$
Strength ratio of steel Tube:		0.25	0.36	0.55	0.61	0.69	0.74	$(P_s+P_{sr})/P_u$
Strength ratio of reinforcement:		0.06	0.05	0.07	0.06	0.05	0.04	P_{sr}/P_u
Diameter of concrete: d_c(mm)		147.6	145.4	143.6	143.6	141.0	138.0	
Gross section of specimens: A(mm^2)		17671.5	17671.5	17671.5	17671.5	17671.5	17671.5	$(\pi \times 150^2)/4$

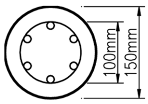
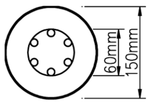
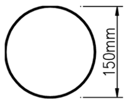
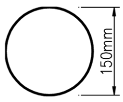
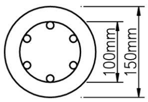
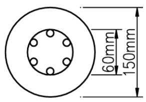
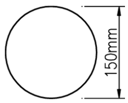
* In the table, t is thickness of steel tube, σ is strength, A is cross-section area and P is axial compressive strength, d is diameter, corresponding to each specimen.



(a) RCFT column (b) Reinforcement cage

Fig. 2 Arrangement of strain gauges and reinforcements

Table 2 Outline of the specimens

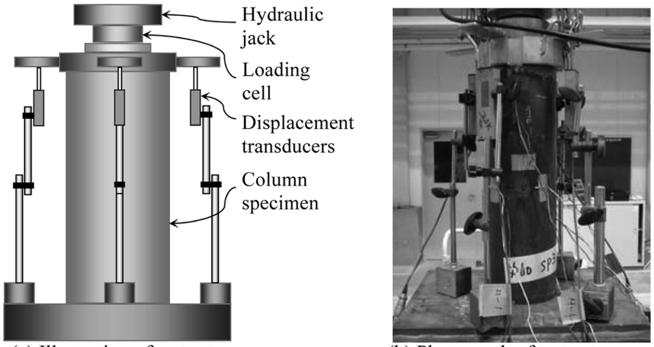
Class	RCFT with thin-cover reinforcement	RCFT with thick-cover reinforcement	CFT	Steel tube	RC with thin-cover reinforcement	RC with thick-cover reinforcement	Concrete
Label	RCFT-100	RCFT-60	CFT	S	RC-100	RC-60	C
Cross section							
Steel tube	SS400 t = 1.2 mm	SS400 t = 1.2 mm	SS400 t = 1.2 mm	SS400 t = 1.2 mm	-	-	-
Axial reinforcement	6 SD295 d_s = 6.0 mm	6 SD295 d_s = 6.0 mm	-	-	6 SD295 d_s = 6.0 mm	6 SD295 d_s = 6.0 mm	-
Lateral reinforcement	SS400 d_s = 3.0 mm Pitch 30 mm	SS400 d_s = 3.0 mm Pitch 30 mm	-	-	SS400 d_s = 3.0 mm Pitch 30 mm	SS400 d_s = 3.0 mm Pitch 30 mm	-
Ratio of axial reinforcement	1.11%	1.11%	-	-	1.08%	1.08%	-

transducers indicated 45 mm, test would be terminated.

3. Results and discussion

3.1. Load and displacement

Maximum load and displacement (corresponding to maximum load) obtained from the test are shown



(a) Illustration of test setup (b) Photograph of test setup

Fig. 3 Test setup of the specimens

as Table 3 and Fig. 4 shows the load-displacement curves.

By the comparison, following statements can be described from the Table 3 and Fig. 4:

(1) No significant differences can be observed between load-displacement curves of thin-cover and thick-cover reinforcements, in case of RCFT;

(2) CFT and RCFT specimens have far more greater bearing capacity than RC, steel tube and concrete ones;

(3) There are no significant difference of maximum load and displacement between CFT and RCFT, so it can be concluded that the reinforcement added into CFT has no effect to its maximum load and displacement (this may be only the case with reinforcement ratio of this study);

(4) The curve of CFT drops very rapidly after maximum bearing capacity while the curve of RCFT descends smoothly and gradually, in other words, curve of RCFT has more envelope area than that of CFT. Therefore it can be concluded that RCFT columns have more toughness than CFT ones and the failure of CFT is brittle failure, the failure of RCFT is ductile failure, and inserting reinforcement in CFT is very effective to prevent its brittle failure;

(5) Maximum load of concrete column is greater than that of RC column, this can be explained as follows: on the same loading stage, bond-failure between reinforcement and concrete will cause cracks on the bonding area of concrete while there are no cracks with pure concrete columns, with the increase of loading, bond-failure-cracks will help concrete of RC develop cracks more rapidly and force the RC column reach maximum load in advance of pure concrete column but with more ductility. Some other research results (Shioi 1998) also indicate that this kind of phenomena is related to reinforcement ratio of stirrups and cover thickness of reinforcement, higher the reinforcement ratio of stirrups or smaller the cover thickness of reinforcement is, the more significant this phenomena is (Shioi 1998).

3.2. Load and strains of reinforcement

The Fig. 5 shows the load-strain curves of reinforcements. From the figure, typical bilinear properties of reinforcement can be seen, and after yield strength, the curve gradient of reinforcement in RCFT is increasing while it is almost horizontal in RC, this indicates that the reinforcement in RCFT will be fully utilized because of the constraint effect of steel tube.

3.3. Load and strains of inside concrete

The Fig. 6 shows the load-strain curves drawn by strains of mold gauges. From the figure, the following

Table 3 Maximum (Max.) load and displacement (Disp.)

Labels		Max. load (kN)	Average Max. load (kN)	Disp. (mm)	Average Disp. (mm)
Steel tube	S-1	69.3	73.7	0.79	0.81
	S-2	77.8		0.89	
	S-3	73.9		0.75	
RCFT with thin-cover reinforcement	RCFT-100-1	870.5	847.0	2.70	2.65
	RCFT-100-2	818.2		2.57	
	RCFT-100-3	852.2		2.67	
RCFT with thick-cover reinforcement	RCFT-60-1	817.5	816.0	2.55	2.29
	RCFT-60-2	821.4		2.03	
	RCFT-60-3	809.0		2.29	
CFT	CFT-1	868.5	843.6	2.04	2.12
	CFT-2	821.4		2.20	
	CFT-3	841.0		2.13	
RC with thin-cover reinforcement	RC-100-1	599.7	594.3	1.36	1.77
	RC-100-2	527.1		2.61	
	RC-100-3	656.0		1.33	
RC with thick-cover reinforcement	RC-60-1	640.3	565.5	1.38	2.11
	RC-60-2	414.6		3.55	
	RC-60-3	641.6		1.40	
Concrete	C-1	619.3	621.7	1.28	1.32
	C-2	568.3		1.34	
	C-3	677.5		1.34	

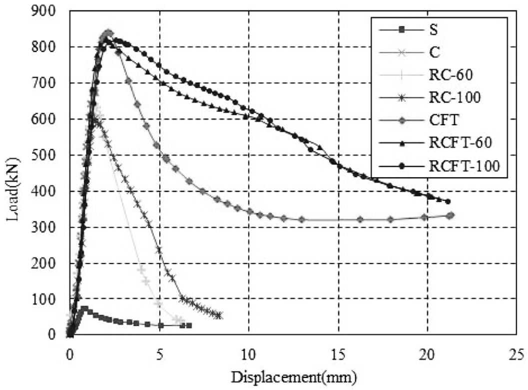


Fig. 4 Load-displacement curves

statements can be described:

(1) After −1,000 μm/m of strain value, the concrete of specimens begin to damage except concrete of RCFT;

(2) No significant differences can be observed between curves of thin-cover and thick-cover reinforcements in case of RCFT while there are significant differences in case of RC. Therefore, the cover thickness of reinforcement is not so important to performance of concrete due to the constraint effect of

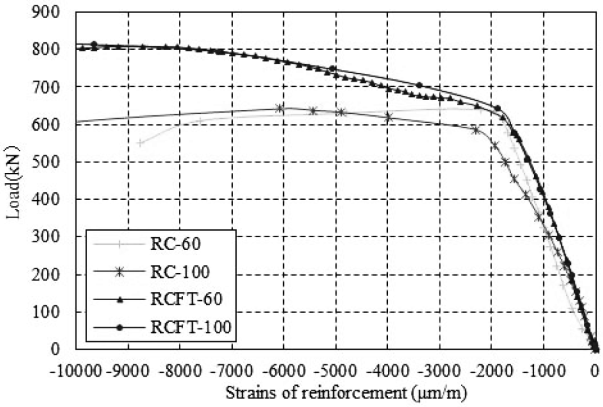


Fig. 5 Load-strain curves of reinforcement

steel tube in RCFT, but it should be taken into consideration in RC;

(3) When the strains reached at −3,000 μm/m of strain value, there are 300 kN of loading difference between concrete of CFT and RCFT specimens. Especially, the bearing capacity of concrete of CFT specimens decreased rapidly with rapidly increasing strains, but the concrete of RCFT specimens have excellent bearing and deformation capacity even under significant strains. In addition, after maximum load, curve of RCFT has far more envelope area than that of CFT, this means the concrete of RCFT has more toughness than the concrete of CFT, and this is, in turn, another reason why RCFT has better brittle resistance than CFT.

3.4. Axial and circumferential strains

The increasing load will generate compressive strain in axial direction and tensile strain in circumferential direction. The relationship between axial strain ε_y and circumferential strain ε_x of each specimen are shown as Fig. 7. When the load is small, the ε_y and ε_x values of all specimens are close, but when the load becomes larger, these values differed between different specimens.

In the case of concrete and RC specimens, the ε_y begun to decrease after −1,500 μm/m of strain value, meanwhile the ε_x begun to increase, and the ε_x are larger than ε_y.

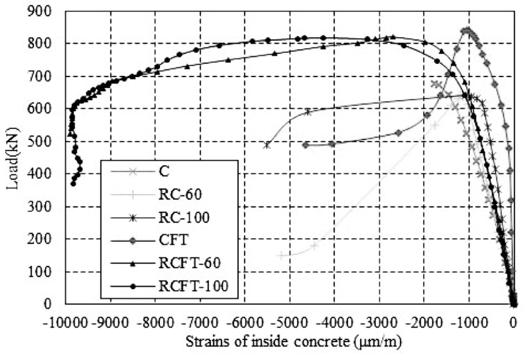


Fig. 6 Load-strain curves of inside concrete

In the case of CFT and RCFT specimens, the $å_y$ are larger compared to ε_x, this can be understood as that the steel tube suppressed the development of the circumferential strains and thus prevented the circumferential damages. Therefore, it is clear that covering RC structures with steel plates is an effective way to increase its strength.

3.5. Failure shapes of the specimens after compression test

(1) Outside failure shapes of the specimens

The Fig. 8 is outside failure shapes of specimens after compression test.

In case of steel tube specimens, the failure shapes are almost kept as original shapes and local buckling is happened on top and bottom end.

In case of RC specimens, although the reinforcement can prevent the specimens from comminuted fracture, shear failure can be observed and the external concrete is pared off to the axial reinforcement with different pare-off thickness between thin-cover and thick-cover reinforcement.

In case of CFT and RCFT specimens, the local buckling is happened to steel tubes because of the shear force, but the shapes of steel tube is nearly kept complete as original shapes.

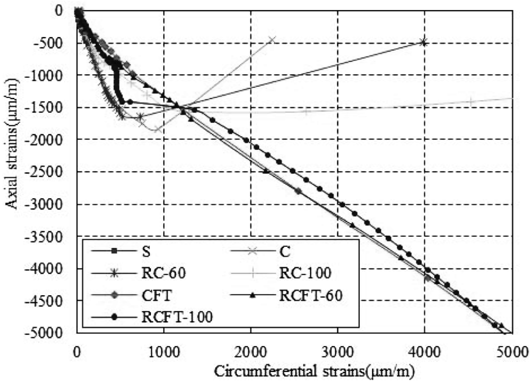


Fig. 7 Relationship between axial and circumferential strains

(a) S (b) RC-60 (c) RC-100 (d) CFT (e) RCFT-60 (f) RCFT-100

Fig. 8 Outside failure shapes

(2) Inside failure shapes of the CTF and RCFT specimens

The Fig. 9 is inside failure shapes of the CTF and RCFT specimens. Because no differences could be found between failure shapes of RCFT specimens with thin-cover and thick-cover reinforcement, only the thin-cover case is shown here.

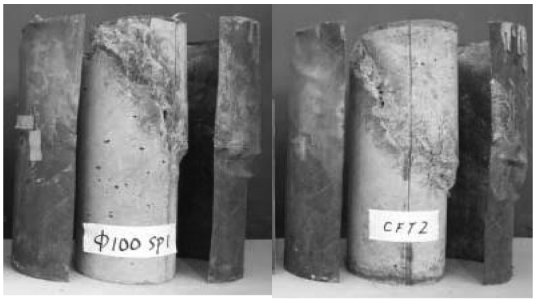
No big differences can be observed between inside failure shapes of CFT and RCFT specimens, this can be understood as follows: there is no any relevant relationship between arrangement of reinforcement and inside failure shapes; no big damage will happen to the inside concrete but micro cracks; although the microcracks cause the shear failure, the shapes are kept nearly complete as original shapes.

(3) Failure shapes of reinforcements

In case of RC and RCFT specimens, the Fig. 10 shows the failure shapes of reinforcements.

Because of no failure shape differences between thin-cover and thick-cover reinforcements, the thin-cover case is shown here. It is confirmed from the failure shape of both RC and RCFT specimen that the lateral reinforcements are cut off along the shear failure band (dotted line in the picture) just because of the bigger circumferential tensile force companying with axial compressive force.

In addition, the failure shapes of axial reinforcements are different. In case of RC specimen it is curved along the intervals of lateral reinforcements. In case of RCFT specimens it is bended almost 90 degrees in the axial direction. These can be explained as follows: the steel tube kept bearing capacity of RCFT specimen until significant deformation will happen and the circumferential clamping force by steel tube not allowed the axial reinforcement deform freely in the circumferential direction and finally force the



(a) RCFT (b) CFT

Fig. 9 Inside failure shapes

(a) RCFT-100 (b) RC-100

Fig. 10 Failure shapes of reinforcement

reinforcement to bend in axial direction.

3.6 Effects of load-sharing ratio γ compared with the previous study

(1) Actual value of γ in this test

The actual γ value of steel tube in this experiment can be calculated using the Eq. (1) given in Sec.2 and maximum load of specimen in the Table 3. After calculating, the actual γ value of steel tube in this experiment was 0.11. The actual value of γ(0.11) is smaller than the chosen value(0.20) in Sec.2, this is because the maximum load of steel tube (P_s) is small due to the thin wall, and the strength of concrete (P_c) is high due to the high strength concrete.

(2) Load and strains concerned with γ

The Fig. 11 and 12 show the load-strain curves of CFT and RCFT specimens from this experiment (γ = 0.11) and former experiment (γ = 0.59) (Suzuki 2008).

The following statements are clear by the comparison: In former experiment (γ = 0.59), the differences are very small, because the reinforcement is not fully utilized due to the bigger γ value; in this experiment (γ = 0.11), the differences are significant, the smaller γ value made the reinforcement play full role.

Therefore, the combination of thin-walled steel tube with high strength concrete is more economical and effective to construct large-scaled structures.

(3) Strength ratio of the plastic zone

The Fig. 13 shows the relationship between strength ratio and load-sharing ratio γ of RCFT and CFT specimens.

When the specimens are on the maximum strength, no significant changes are observed. However, after the maximum strength, when γ = 0.59, 0.67, 0.74, some small changes can be observed in case of ε = –1,000 μm/m and ε = –2,000 μm/m. When γ = 0.32, 0.11, the strength ratio is 1.2, 1.3 respectively in case of ε = –1,000 μm/m, and it is increased to 1.8, 1.7 respectively in case of ε = –2,000 μm/m. In other words, the strength ratio is almost increasing with smaller γ in the plastic zone.

4. Conclusions

From the study results above, conclusions can be drawn as follows:

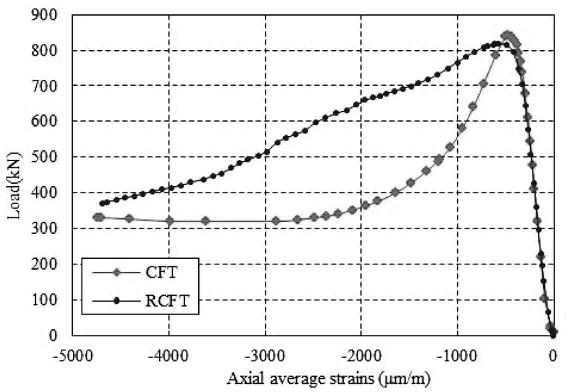


Fig. 11 Load-strain curves (γ = 0.11)

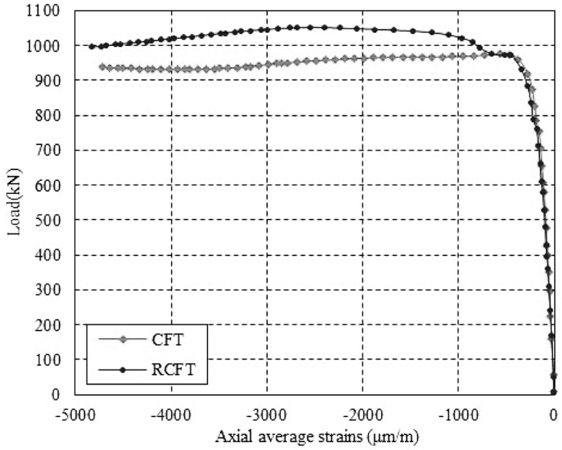


Fig. 12 Load-strain curves (γ = 0.59)

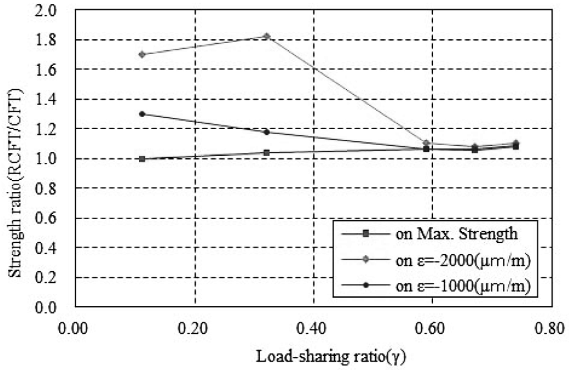


Fig. 13 Relationship between strength ratio and γ

(1) In case of thin-walled steel tube, RCFT structures are effectively avoided from brittle failure by the using of reinforcement while CFT structures are damaged due to the brittle failure.

(2) In plastic zone, strength ratio (1.7) of RCFT and CFT structures in this study (corresponding to $\gamma = 0.11$, t = 1.2 mm) are similar to the strength ratio (1.8) corresponding to $\gamma = 0.32$ (t = 2.3 mm). This means, in this study, the steel material is saved nearly by half and possessing strength ratio corresponding to $\gamma = 0.32$.

(3) Excellent bearing capacity with RCFT can be achieved in plastic zone by combining the thin-walled steel tube with high strength concrete and reinforcement.

(4) The smaller γ value can made the reinforcement play full role, and thus combination of thin-walled steel tube with high strength concrete and reinforcement is economical and effective way to construct large-scaled structures.

The conclusions suggest these: the circumferential binding effect of steel tube needs to be studied to further clarify the mechanical characteristics and mechanism of RCFT structures; the actual load-sharing ratio (γ) in this study is 0.11, this value exceeded scope of γ for CFT ($0.2 \leq \gamma \leq 0.8$) suggested by JSCE, thus it is worthy carrying out studies on scope of ã for RCFT.

Acknowledgements

The experiments conducted in this study were made possible at the Structural Laboratory at the Hachinohe Institute of Technology, Hachinohe Japan. The authors will appreciate to stuffs of the Laboratory. Mr. Suzuki Takuya (Kosaka technical research Co.Ltd.) provided us experimental papers, guidance and advices. Emeritus professor Shioi Yukitake listened to our problems and questions and provided sound advices. Supplemental cooperation and help were also provided by the students of Hasegawa laboratory. The authors thank all of them mentioned above.

References

Endo, T., Shioi, Y., Hasegawa, A. and Wang, H.J. (2000), "Experimental study on reinforced concrete filled steel tubular structure", *Proc.7th Int. Conf. on Steel. Struct.,* Singapore.

Han, J.S., Xu, Z.D., Cong S.P. et al. (2010), "Analysis of axial compressive performance for reinforced concrete filled tubular steel", *Architectural & Environmental Eng.,* **31**(3), 11-17.

JSCE (1999), "*Reality state and analysis of steel construction damaged by Hansin-Awaji Earthquake*", Japanese Society of Civil Engineers, Tokyo Japan.

JSCE (1999), "*Theory and design of steel-concrete hybrid structures part1: Theory and basic concept*", Japanese Society of Civil Engineers, Tokyo Japan.

Lee,S.J. (2007), "Capacity and the moment-curvature relationship of high-strength concrete filled steel tube columns under eccentric loads", *Steel. Comp. Struct., An Int'l Journal,***7**(2).

Miao,W. (2010) , "Experimental research and bearing capacity analysis of axially compressive reinforced concrete filled steel tube short column", *Shanxi Architecture,* **36**(5), 79-81.

Husem, M. and PUL, S. (2007), "Investigation of stress–strain models for confined high strength concrete", *Sadhana.,* **32**(3), 243-252.

Sato, M. (2008), "Study on structural characteristics of RCFT and the application to practical structures", MS thesis, *Hachinohe Institute of Technology*, Hachinohe Japan.

Shioi, Y. (1998) , "Study on arrangement of reinforcements to improve shearing capacity and ductility of piers", *Report of study of science research subsidy ,* Tokyo Japan.

Suzuki, T. (2008), "Study on new bridges that adopt hybrid structure", PhD thesis, *Hachinohe Institute of Technology*, Hachinohe Japan.

Wang, H.J., Ishibashi, H., Wei, H. and Hasegawa, A. (2002), "Experimental study on twin-column RCFT pier", the Second *Int. Conf. on Advances in Structural Engineering and Mechanics(ASEM'02),* Busan(Pusan), Korea .

Wei, H., Iwasaki, S., Hasegawa, A., Shioi, Y. and Miyamoto, Y. (2002), "Experimental study on mechanical characteristics of reinforced concrete filled circular steel tubular structures", *J. Const. Steel.,* JSSC, **10**, 519-526.

Wei, H., Wang, H.J., Hasegawa, A. and Shioi, Y. (2005), "Study on strength of reinforced concrete filled circular steel tubular columns", *Struct. Eng. Mech.,* **19**(6), 653-677.

Xiao, C.Z., Cai, S.H. and Xu, C.L. (2005), "Experimental study on shear resistance performance of concrete filled steel tube columns", *China. Civil. Eng. J.,* **12**(4), 10-16.

Xu, Y.F., Zhao, J.Y., Liu, N. et al. (2009), "The ductility analysis of circular steel tube compile column filled with steel reinforced concrete on cyclic loading", *J. Shenyang. Jianzhu. Univer.,* **10**(9), 83-87.

Yao, G.H., Huang, Y.J., Song, B.D. et al. (2008), "Research on behavior of the inner joint of concrete filled steel tube column-RC ring beam", *Steel. Const.,* **9**(6), 27-30.

CC