Numerical Analyses on Ratio of Axial Reinforcement in RCFT Columns

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1. INTRODUCTION

Known experimental study results[1] on reinforced concrete filled tubular steel (RCFT) columns with varying ratio of axial reinforcement have revealed that the ratio of axial reinforcement has the effects on the performance of RCFT, neither the larger ratio nor the smaller ratio but the proper ratio of axial reinforcement will help in increase bearing capacity, ductility and toughness of RCFT.

In order to examine the proper ratio of axial reinforcement which will put the RCFT into better performance, in this study, numerical investigations are performed with varying ratio of axial reinforcement and thickness of steel tube using the validated numerical simulation model. Through a plenty of comparisons and analyses, the effect of the axial reinforcement ratio is discussed, and a range for the ratio of axial reinforcement is proposed.

2. SELECTION OF RCFT COLUMNS FOR SIMULATION

The size of RCFT columns for numerical simulation is selected corresponding to the size of specimens in the experiments[1)-2)]. The varying ratio of axial reinforcement ρ for RCFT is determined based on the specifications of JSCE code on the range of ρ for RC columns, namely 0.8%≤ρ≤6.0%, and other two smaller values than 0.8% are also used considering extra small ρ for RCFT. Thickness of steel tubes are selected as t=1.2mm, t=2.4mm, t=3.2mm and t=4.5mm. The concrete is same for all columns used as uniaxial strength f_{co}=40.80MPa. The **Fig.1** shows the model of the selected columns. The determined 13 values for ρ and the corresponding labels for numerical analyses are list in **Table 1**. Besides, all other parameters are same with that of experiments in Ref.1)-2).

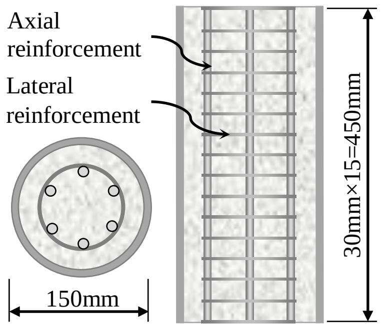

Fig.1 Model of RCFT columns

3. NUMERICAL SIMULATION AND RESULTS

A numerical simulation model for RCFT proposed by Xiamuxi *et al.*[2)] is employed.

The curves of load versus average strains for the reinforcements of 13 RCFT columns with t=1.2mm are plotted in **Fig.2**. It can be clearly observed from the **Fig.2** that the degradations in strength of the reinforcements are happening, and its amount is varying with varying ρ and strains.

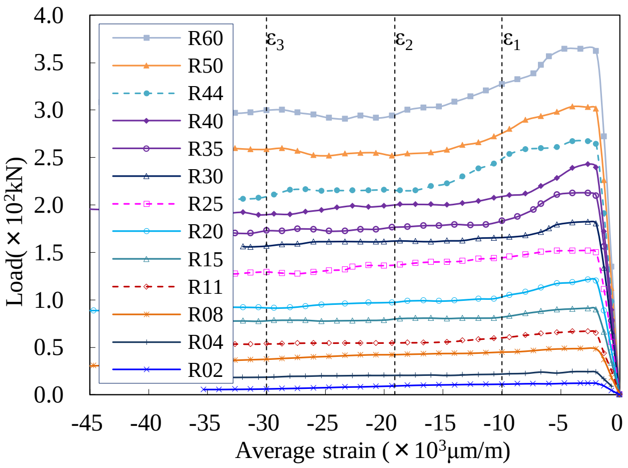

Fig.2 Load-strain curves of axial reinforcement with t=1.2mm

It can be noticed in the material test of reinforcement[1)] that the relationship between the strain at start point of strain hardening ε_{ry} (ε_{ry}=-19100μm/m) and the yield strain ε_e (ε_e=2500μm/m) is $\varepsilon_{ry}\approx 8\varepsilon_e$. Thus, to evaluate the amount of the degradations, three strain points are defined, namely, $\varepsilon_1=4\varepsilon_e$=-10000μm/m, $\varepsilon_2=\varepsilon_{ry}$=-19100μm/m and $\varepsilon_3=12\varepsilon_e$=-30000μm/m, and marked with vertical dotted lines in **Fig.2**. Then, the ratio of degradation ΔN can be calculated for these three strain points by:

$$\Delta N = (N_u^r - N_\varepsilon^r)/N_u^r$$

where N_u^r is maximum load, N_ε^r is load corresponding to ε_1, ε_2 and ε_3.

When t=1.2mm, the calculated ΔN, maximum load N_u and corresponding displacement δ_u and toughness of concrete core χ_c corresponding to ε_2 for every ρ are listed in **Table 1**. It is clear from the table that the ΔN, N_u, δ and χ_c are varying with varying ρ. The CFT shows the smallest bearing capacity, and bearing capacity of RCFT is increasing with the increase of ρ.

The ductility ratio μ of RCFT can be the ratio of δ_u against the yield displacement δ_y of the column. Thus, the relationship between μ and ρ, and the relationship between χ_c and ρ when t=1.2mm are plotted in **Fig.3**. Again, the relationships between ΔN and ρ corresponding to those three stain points for t=1.2mm, t=2.4mm, t=3.2mm and t=4.5mm are plotted respectively in **Fig.4.**

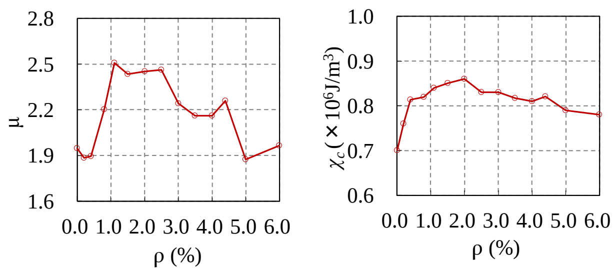

Fig.3 Ductility ratio of RCFT and toughness of concrete core with t=1.2mm

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Table 1 Results of numerical simulation with the t=1.2mm

Labels	ρ (%)	N_u^r (kN)	ε_1		ε_2		ε_3		N_u (kN)	δ_u (mm)	χ_c ($\times 10^6$J/m^3)
			$N_{\varepsilon 1}^r$	$\Delta N_{\varepsilon 1}$	$N_{\varepsilon 2}^r$	$\Delta N_{\varepsilon 2}$	$N_{\varepsilon 3}^r$	$\Delta N_{\varepsilon 3}$			
CFT	0.0	-	-	-	-	-	-	-	1039.2	2.19	0.70
R02	0.2	12.1	10.7	0.12	9.1	0.25	5.9	0.52	1080.3	2.12	0.76
R04	0.4	24.3	22.0	0.09	19.5	0.20	13.6	0.44	1103.2	2.13	0.81
R08	0.8	48.6	44.2	0.09	40.8	0.16	35.1	0.28	1121.2	2.48	0.82
R11	1.1	66.8	61.3	0.08	56.8	0.15	52.7	0.21	1154.8	2.82	0.84
R15	**1.5**	**91.1**	**83.9**	**0.08**	**78.6**	**0.14**	**75.4**	**0.17**	**1168.6**	**2.74**	**0.85**
R20	**2.0**	**121.5**	**112.1**	**0.08**	**105.8**	**0.13**	**101.8**	**0.16**	**1181.0**	**2.76**	**0.86**
R25	**2.5**	**151.8**	**141.0**	**0.07**	**131.7**	**0.13**	**127.0**	**0.16**	**1254.7**	**2.77**	**0.83**
R30	**3.0**	**182.2**	**165.4**	**0.09**	**156.3**	**0.14**	**150.8**	**0.17**	**1260.9**	**2.52**	**0.83**
R35	3.5	212.6	183.0	0.14	173.6	0.18	169.1	0.20	1291.4	2.43	0.82
R40	4.0	243.0	203.7	0.16	194.0	0.20	189.0	0.22	1305.0	2.43	0.81
R44	4.4	267.3	221.6	0.17	213.4	0.20	206.2	0.23	1364.7	2.54	0.82
R50	5.0	303.7	249.6	0.18	241.9	0.20	233.6	0.23	1391.5	2.11	0.79
R60	6.0	364.4	296.4	0.19	291.5	0.20	296.7	0.19	1454.5	2.21	0.78

Through the general considerations with **Fig.3**, **Fig.4** and **Table 1**, the following discussions are drawn: the μ, χ_c and ΔN are not proportional to ρ. The larger μ and χ_c are happening in the range of 1.1%≤ρ≤3.0% and decreasing with smaller and larger ρ. On the contrary, the smaller ΔN is happening in the same range for all three strain points and increasing with smaller and larger ρ. In other words, the ductility and toughness of RCFT are increasing with smaller strength degradation ratio of axial reinforcement. Therefore, it can be concluded that the smaller degradation in strength of axial reinforcement will be the better performance will be achieved with RCFT columns.

It can be observed in **Fig.4** that the ΔN is not changing or changing in a very small range with t=3.2mm and t=4.5mm (see **Fig.4** (b) and (c)) while it is fluctuating significantly with t=1.2mm and t=2.4mm (see **Fig.4** (a)). This means the effect of reinforcement ratio is small with thicker steel tube and is significant with thinner ones. The reason for this may be understood as that the lateral pressure will be imposed with thick steel tube stronger than thin steel tube, the stronger lateral pressure, then, put the axial reinforcement into full utilization without more degradation in strength.

Based on the discussions above, and according to **Table 1** and **Fig.4**, whatever the thickness of steel tube, the optimal ratios ρ_o for axial reinforcement in RCFT columns may be proposed as 1.5%≤ρ_o≤3.0%.

In addition, it can be noticed in **Table 1** and **Fig.4** that the reinforcement with smaller ratio (e.g. ρ=0.2%) showed significant degradation in strength in all strain points, this may be assumed that the reinforcements will be yielded prior to the failure of the concrete due to its smaller amount, and its behavior is easily controlled by the behavior of the concrete.

4. CONCLUSIONS

The proper ratio of reinforcement can make the RCFT possess better confined effect, ductility and toughness, and improve overall performance. Optimal ratios for axial reinforcement proposed in this study may have applicable means in the design or construction of RCFT structures.

REFERENCES

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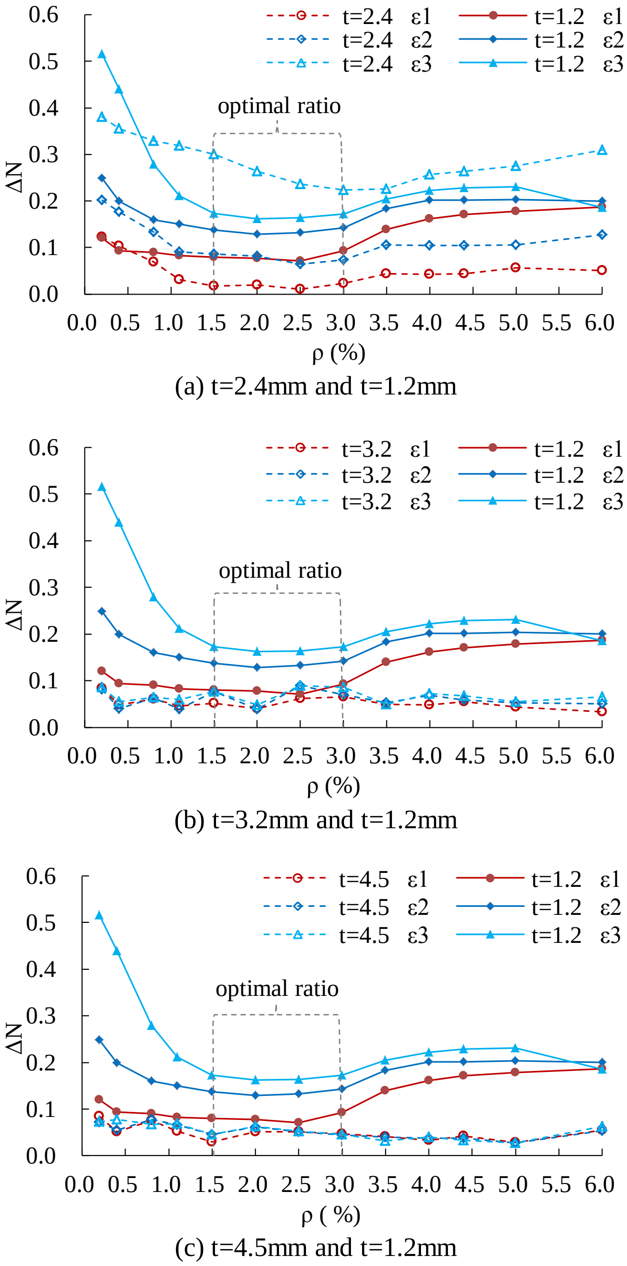
2) Xiamuxi, A., Hasegawa, A.: Nonlinear Analysis of RCFT Columns under Axial Forces with Confinement Effect and Failure History, *Proceedings of Constructional Steel*, Vol.19, pp.49-56,2011.11.



(a) t=2.4mm and t=1.2mm

(b) t=3.2mm and t=1.2mm

(c) t=4.5mm and t=1.2mm

Fig.4 Optimal ratio of axial reinforcement