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A Study on Shear Connectors of Square Concrete Filled Steel Tubes

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***Abstract*— In the Concrete Filled Steel Tube (CFST) column-beam joint, the stress of the beam is firstly transferred to the steel tube, then transferred from the steel tube to the concrete by bond and shear connectors, hence, the shear connector of the CFST is a very important part. The author carried out a research on shear connector (steel rings) in square CFST. In order to compare with the test results, a FEM analysis on the steel rings of the CFST was carried out. The parameter was the B/t ratio of the steel tube, the number of steel rings, the thickness of the steel rings and the length between the steel rings. The analysis results fit well with the test results, and the influence of the length between two steel rings and the thickness of the steel rings was studied.**

***Index Terms*—concrete filled steel tube, shear connector, steel rings, experimental study, FEM study**

I. Introduction

The Concrete Filled Steel Tube (CFST) structure is now widely used worldwide. Considering the column-beam joint composed of CFST column and steel beam, the vertical load is passed to concrete filled steel tube through the joint. Generally, steel beam is connected to steel column; a part of vertical load is passed to concrete inside by steel column. If the bond between steel column and concrete inside is not made full use of, the flexural bearing capacity of concrete filled steel tube column may not be fully acted. There are some standards; such as Japanese SRC standard gives the corresponding calculate methods. However, the bond is in unreliable, most of the time, can’t be the reference of structural design. Therefore, the shear connector at the CFST column is necessary. In this study, the steel ring, which is one kind of the shear connectors, is researched.

At present, steel plate welded inside the round steel pipe for shear resistance is systematically researched home and abroad [1]-[8]. According to the preliminary study on concrete filled steel tubes, some conclusions about designing and corresponding design formula is gained. However, the lack of systematical research on concrete filled square steel tubes is not negligible. Therefore, the author carried out a research on shear connector in concrete filled square steel tube，as shown in Fig. 1 [9]. The test results are in reference [9]. This paper studied the properties of steel rings in square concrete filled steel tube by method of theorem and finite element analysis.

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II. Experimental Study

In reference [9], the author carried out 4 push-out test on concrete filled square steel tube. As reported in reference [9],the parameters are the width-thickness ratio(B/T=50 or 25), the number of the shear connectors(one low shear connectors or two lows shear connectors).The test setup is shown in Fig. 1. Test results show that the specimens with B/t ratio of 25 have higher strength than the specimen with B/t ratio of 50. The specimens with eight shear connectors has higher strength than the specimen with four shear connectors, however, the relationship between the strength and number of shear connectors is not a linear one.

III. Finite Element Analysis

A. Material Behavior

According to the concrete cylinder test, the cylinder compression strength is 63.2 MPa, the Young’s modulus is 37364Mpa. The concrete compression strength is $f_{\mathrm{cu,k}} = 63.2/0.79 = 80\mathrm{MPa}$, The standard value of concrete compressive strength is $f_{\mathrm{ck}} = 0.76 f_{\mathrm{cu,k}} = 60.04\mathrm{MPa}$.The compressive strength of cube concrete is $f_{\mathrm{cu,k}}$.

B. Constitutive Relation

1) Constitutive relation of the concrete

Finite element analysis software ABAQUS was selected in this research. Damage plasticity model was applied to simulate the concrete. The constraint factor of the steel tube to the concrete, $\xi = A_s \cdot f_y / A_c \cdot f_{ck} = 1.13$ the constitutive relationship model proposed by Prof. Han [10] is adopted; the equation of the model is as below:

$$y = 2 \cdot x - x^2 \quad (x \le 1) \tag{1}$$

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$$y=\frac{x}{\beta\cdot(x-1)^{\eta}+x}\qquad(x>1)\qquad(2)$$

where,

$$x=\frac{\varepsilon}{\varepsilon_0},\quad y=\frac{\sigma}{\sigma_0}$$

$$\sigma_0=\left[1+\left(-0.0135\cdot\xi^2+0.1\cdot\xi\right)\cdot\left(\frac{24}{f_c^{'}}\right)^{0.45}\right]\cdot f_c^{'}$$

$$\varepsilon_0=1300+12.5\cdot f_c^{'}+\left[1330+760\cdot\left(\frac{f_c^{'}}{24}-1\right)\right]\cdot\xi^{0.2}$$

$$\eta=1.6+1.5/x$$

$$\beta=\frac{\left(f_c^{'}\right)^{0.1}}{1.35\sqrt{1+\xi}}$$

The cylinder compression strength is $f_c^{'}$, $f_c^{'}=0.79f_{cu,k}$.

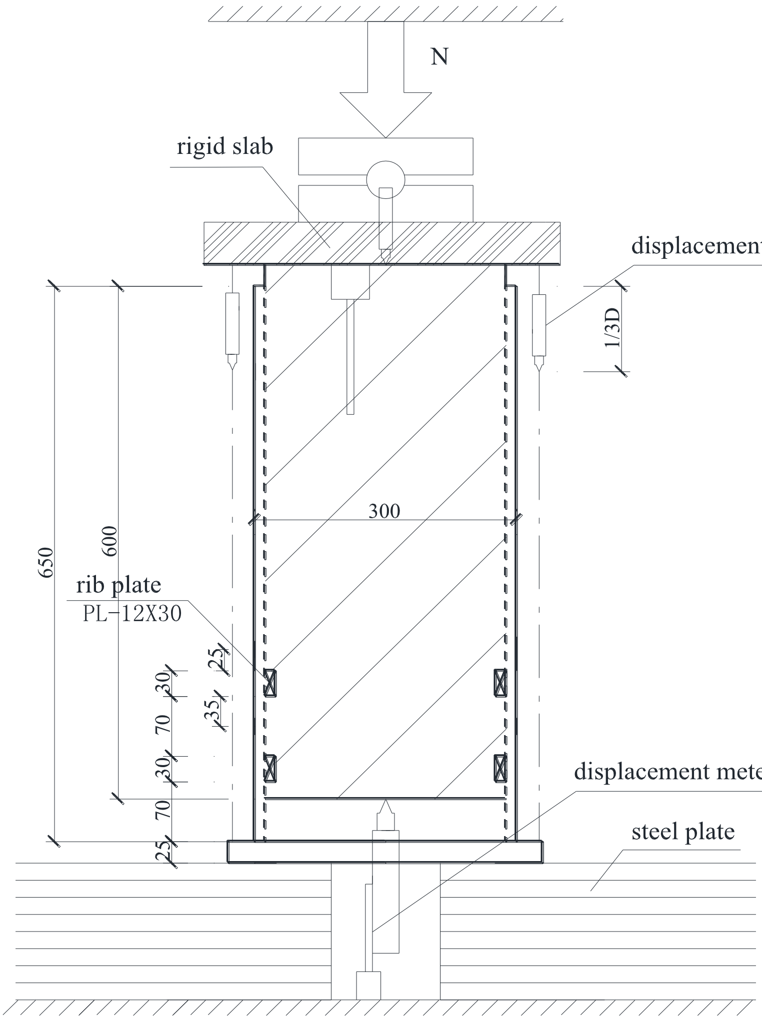
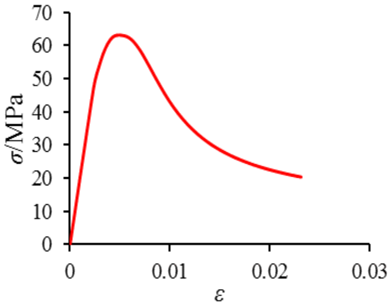
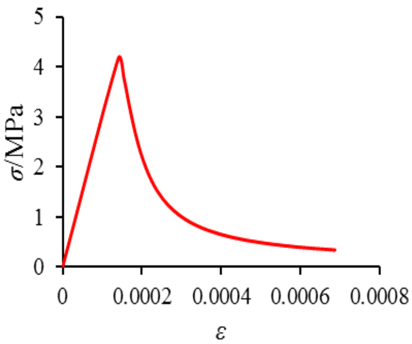


Figure 1. Test setup

The stress-strain relationship curve of the core concrete is shown in Fig. 2.



(a) Compression curve



(b) Tension curve

Figure 2. Stress-strain curves of concrete

2) Constitutive relation of the steel

The Constitutive relation curves are shown in Fig. 3, ε_y , ε_u is the yield strain and ultimate strain of the steel, f_y is the yield stress of the steel. Poisson's ratio of steel is 0.3.

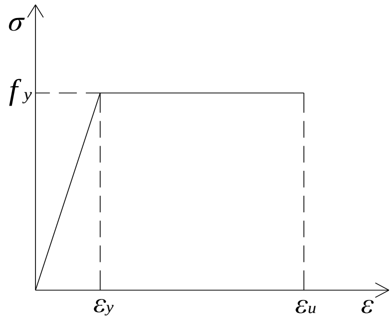
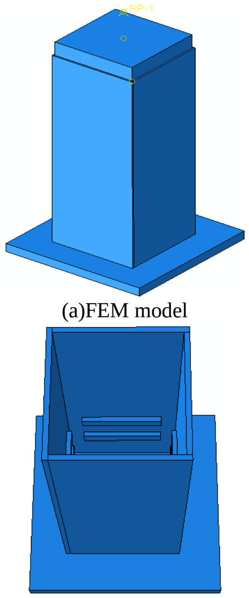


Figure 3. Stress-strain curve of steel

C. FEM Analysis Model

1) FEM analysis model

For all the steel and concrete material, the 3D deformable model is adopted, the model is shown in Fig. 4.



(a)FEM model

(b)Model of steel part

Figure 4. Finite element analysis model

2) The interface contact model and loading

The interface of steel tube and the surface of concrete is contacted with each other. The interface of steel plate is the primary surface. The affiliated surface is the surface of concrete, finite sliding method is chosen in this circumstance. Considering the contact attribute, tangential behavior use the reprobate function formula. The friction coefficient between steel plate and concrete is 0.5, which is measured through a great deal of computation. Normal direction uses hard touching. Shear connector and interface of steel plate are bond together, the same thing happens on upper surface of concrete groove. The bottom section of the tube is bindingly contacted with the plate beneath.

The model is subjected to displacement load. Magnitude of which is 20mm. The maximum of the load is according to ABAQUS software by default.

3) Unit selection and mesh

In order to make sure the accuracy and efficiency of the calculation, 8 node 3-D reducing integral solid elements C3D8R and the structured mesh technology were used for concrete. The mesh model is shown in Fig. 5.

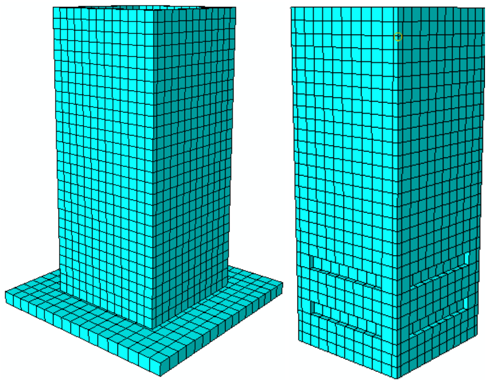


Figure 5. Mesh of the finite element model

D. The Result of FEM Analysis

1) Simulative results and analysis

A numerical simulation was carried out for the four test specimens according to the above method. When entitling the specimens, take specimen 2-S-25 as an example. The 2 means two rows of shear connectors, S means square CFT column, 25 means the B/t ratio is 25.

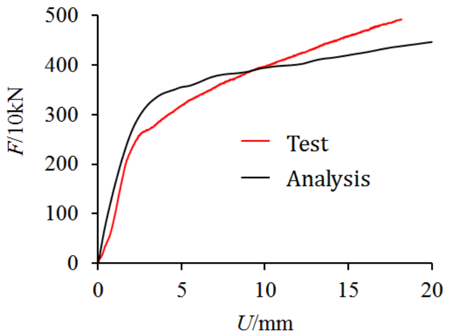


Figure 6. Comparison between the two *F-U* curves of specimen 2-S-25

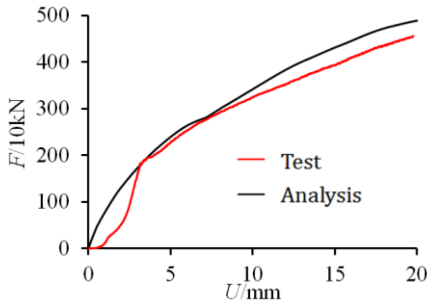


Figure 7. Comparison between the two *F-U* curves of specimen 1-S-25

Fig. 6- Fig. 9 show the comparison of the test results and the analysis results. Table I shows the comparison of the ultimate strength between the test and the analysis. In Fig. 6-9, the red line stands for the test results obtained in

reference [9], the black line stands for the results obtained from the FEM analysis. As shown in the Fig. 6 and Fig.7, when the B/t ratio is 25, the test analysis results fit well with the test results. When the B/t ratio is 50, as shown in Fig. 8 and Fig. 9, the test results are slightly smaller than the analysis results. This can be considered as the local buckling of the steel tubes in the tests. However, in total, for all the four specimens, the analysis results show good agreement with the test results.

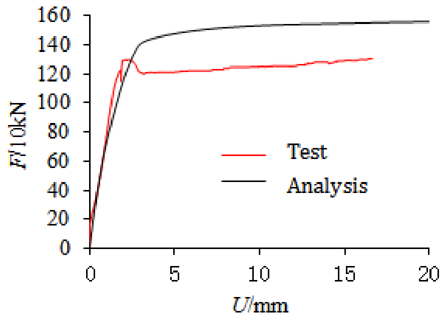


Figure 8. Comparison between the two *F-U* curves of specimen 2-S-50

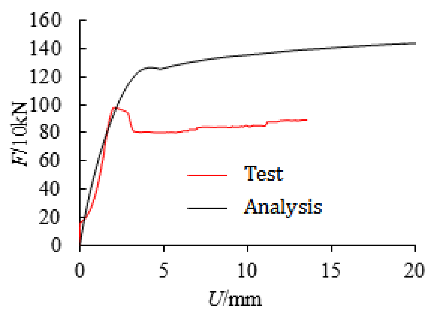


Figure 9. Comparison between the two *F-U* curves of specimen 1-S-50

Also, as shown in Table I, the ratio of FEM result and experiment result is from 0.91 to 1.32, the average of which is 1.12. From above, the FEM method is proved to be acceptable when evaluating the effects of the shear connectors.

TABLE I. COMPARISON OF TEST AND ANALYSIS RESULTS

Specimen	F_{u1}/10kN	F_{u2}/10kN	F_{u1}/ F_{u2}
2-S-25	484.3	453.4	1.07
1-S-25	444.7	489.6	0.91
2-S-50	145.9	125.8	1.16
1-S-50	126.0	95.3	1.32

*The maximum of horizontal force in FEM and experiment is F_{u1} and F_{u2} respectively. The ratio of FEM result and experiment result is F_{u1}/ F_{u2}

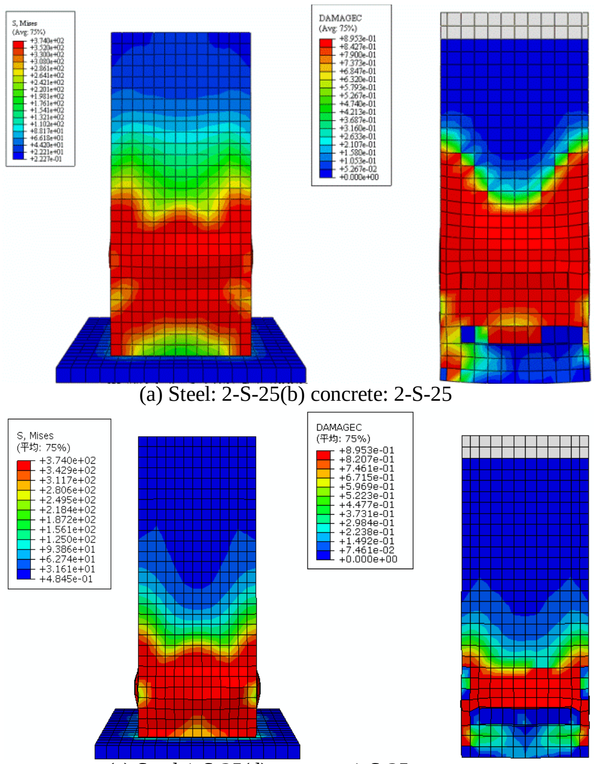
2) The analysis of stress and concrete damage

Fig. 10 shows the stress nephogram of the specimens 2-S-25 and 1-S-25. From the figures, we can see the stress nephogram of the steel part and the concrete part.

3) Parametrical study

(1) The length between two steel rings

In the specimens, the length between the two steel rings is 70mm. In the FEM analysis, the effect of the length between the two steel rings is studied. The length studied includes 40mm, 70mm, 100mm, 200mm and 300mm.



(a) Steel: 2-S-25(b) concrete: 2-S-25

(c) Steel:1-S-25(d) concrete:1-S-25

Figure 10. The stress nephogram

The results indicate that shear capacity becomes larger when the length increases. The specimen, which the length is 200mm, is more capable of endurance stress than the 100mm. when the comparison is between 300m and 200m, the discipline is not adequately obvious, which prove that the relationship between length and capacity is not a linear one. If the length increases by a certain amount, it will no longer affect the capacity. As shown in Fig. 11.

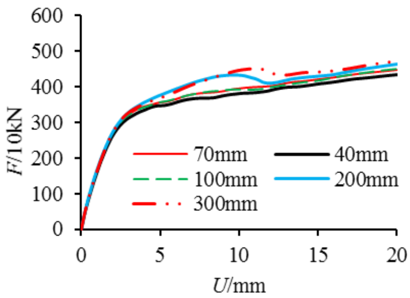


Figure 11. The length affection

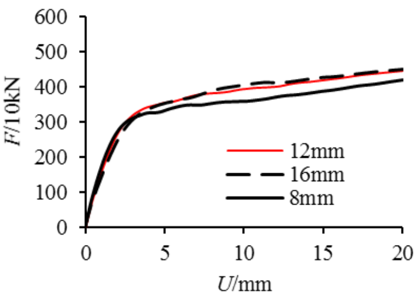


Figure 12. The thickness affection

(2) The thickness of steel rings

In FEM, the thickness of steel rib is studied. The magnitude is 8mm, 12mm and 16 mm. Results is shown in Fig. 12. Compared with 8mm one, the 12mm one have a higher compressive capacity. However, there's nearly no difference between 16mm and the 12mm specimens. Thus, when the thickness reaches a certain level, it has no effect on compressive capacity. As shown in Fig. 12.

IV. Conclusion

(1) A FEM analysis on the steel rings in the square CFT column was carried out, and the analysis results fit well with the test results.

(2) With regard to the length between the steel rings, it is proved that relationship between length and capacity is not a linear one. If the length increases by a certain amount, it will no longer affect the capacity.

(3) The thickness of the steel rings effect the capacity of the specimens, however, when the thickness reaches a certain level, it has no effect on compressive capacity.

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