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Research on concrete-filled steel tube columns subjected to cyclic lateral force

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ABSTRACT

Eight concrete-filled steel tubular (CFT) columns were tested subjected to cyclic loading under constant axial load. Experimental parameters included axial compression ratio, loading sequences, and strength of concrete and steel. The failure mode of steel and core concrete were analyzed. The test results showed that different axial compression ratios and loading sequences have effects on the load carrying capacity, ductility and energy dissipation capacity of CFT columns, and the failure modes of the CFT columns, which can be categorized into two types, local buckling failure of steel tube in compression zone, and low cycle fatigue tearing rupture failure of steel tube. The paper also evaluated the seismic behavior through the energy index obtained from each cycle.

1. INTRODUCTION

In recent years, concrete filled steel tube (CFT or CFST) column structures have been widely used in high-rise buildings and bridges. Compared with the traditional reinforced concrete column, the CFT performs better in two aspects. First the tube can be used as longitudinal reinforcement to bear the axial load and the other it can replace the transverse reinforcement to provide an effective confinement for the core concrete. The problem of non-effective confined core concrete for hoop reinforcement was solved due to the continuity of steel tube. However, the design equations in standards, for example ACI and AISC etc. are conservative because the interaction between concrete and steel tube is typically neglected. (Knowles 1969) conducted twenty-eight axial and eccentricity compression tests on CFT columns with difference length-to-width and width-to-thickness ratios. Effect of capacity on the parameters was researched and the theory of tangent modulus used to calculate the ultimate capacity was proposed. Experimental studies on CFT column subject to axial compression have been conducted by (Schneider 1998). The failure mode and ultimate strength was considered because of the differences of the width-to-thickness and section shape.

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(Johansson 2002) discussed the relationship between the ultimate capacity of CFT and the bond strength of steel and concrete, and also the influence upon strength of CFT was improved due to the confinement effect applied by tube. A finite-element formulation has been developed for the analysis of CFT members under axial load by (Hu 2003), and limit of diameter-to-thickness which ensures confinement effect was proposed. (Sakino 2004) compiled experimental results for steel and CFT columns subjected to eccentricity load. The formula of circular and square CFT was verified. The uniform formula under axial load was presented based on elasticity theory and databases of experiment by (Yu 2012).

In practice the CFT member bear the axial or small eccentric load, and the CFT columns bear a combination of axial and flexural loading in earthquake. Thus test subjected to cyclic loading under constant axial load is an effective method to study its seismic performance. (Sakino1981) tests indicated that it would lead to the instability of bearing capacity of hysteretic behavior when the plastic bulking appeared in the bottom of the columns, under high axial compression ratio. (Nakanishi1999) conducted the eight pseudo-dynamic and cyclic tests with variable compound sections, and the results showed the best performance for the cyclic loading, which is able to resist strong earthquake. (Elremaily 2002) finished the six CFT columns subjected to cyclic loading under constant axial load, and suggested that the analysis model be used to predict the bearing capacity of CFT with the consideration of the interaction between the steel tubes and concrete. (Zhang 2009) considered the influence of the ratio of the different D/t and the loading programs for the performance of the low cycle fatigue, and the model of the damage was determined. A fiber mode considering the local bulking of steel has been developed for the analysis of square CFT columns under monotonic and cyclic load by (Zubydan 2011). The results indicated that the ultimate or post-peak capacity perhaps was exceed if neglect the local bulking. (Roeder 2012) conducted the detailed finite element model based on his test, and the simple model that calculate the relation between moment and drift ratio was proposed. (Rolando 2012) analyses the bearing strength and ductility performance of CFT bridge piers under the combination of axial and flexural loading numerically. The design method of capacity and the simple model which determine the ductility based on lateral maximum displacement was presented through the explicit modeling. (Qin 2012) compiled a comparison experiment between CFT and CFRP confined CFT column, and established a cumulative damage model of energy consumption on the basis of the testing data. (Zhu 2013) conducted Cyclic loading tests of 4 high scaled CFT bridge piers under constant axial loading, and two different constitutive model were adopted to calculate the moment - curvature and force - displacement skeleton curves, which were compared with test results.

2. Experimental program

2.1 Test specimen

Eight circular concrete filled steel tube columns subject to cyclic lateral force under constant axial load was tested for simulating the seismic respond. The 1/2 scale specimens were designed to simulate the columns of the building structure. Seven specimens were of the same size, and the height of column was 1500mm, the outside diameter was 336mm, and the thickness of the steel tube was 6mm, which corresponds to the ratio of 59 of diameter to thickness and satisfies the standard of stability in ACI and AISC et al. Considering the influence of steel tube in thickness, another specimen with a steel tube of 3mm in thickness was designed. The details of the size and material properties were shown in Table. 1. The test parameters included the level of axial load and loading path.

Table 1. Test matrix

Specimen	Diameter (mm)	t (mm)	D/t	Fc (MPa)	Fy (MPa)	Fu (MPa)	P (kN)	Po/Pu	Load path
CN-112-25-C	336	3	112	39	270		1300	0.25	Constant 6%
CN-56-20-A	336	6	56	35	339	439	1300	0.2	A
CN-56-20-B	336	6	56	35	339	439	1300	0.2	B
CN-56-40-A	336	6	56	35	339	439	2600	0.4	A
CN-56-40-B	336	6	56	35	339	439	2600	0.4	B
CH-56-20-A	336	6	56	55	393	500	2000	0.2	A
CH-56-20-B1	336	6	56	55	393	500	2000	0.2	B
CH-56-20-B2	336	6	56	55	393	500	2000	0.2	B

2.2 Test set-up

Experiment was conducted in the Ministry of Education Key Laboratory of Building Safety and Energy Efficiency at the Hunan University, and Fig. 2 shows a schematic of the set-up. To prevent the failure of connection the specimen was inserted into the rigid base, and the rigid base was fixed through the two steel beams and the bolt of reaction groove. The axial load was applied to the column through post-tensioning two 50-mm-diameter high-strength steel rods using two 1500kN capacity hydraulic hollow jacks. The forces of the rods were transferred to the model column by a cross beam mounted on top of the load stub. A load cell was connected under each jack to monitor the axial load during the test.

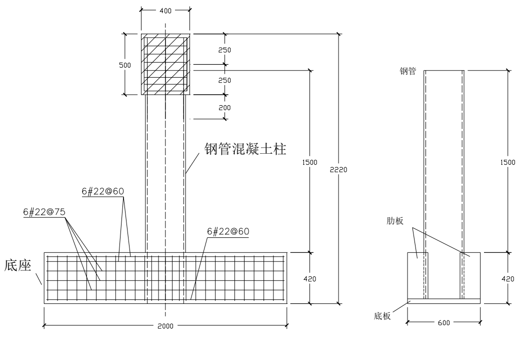


Fig. 1 Details of specimen

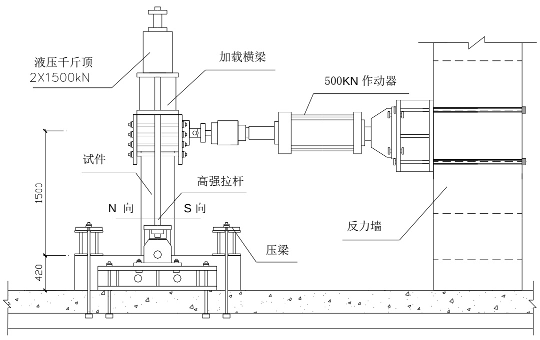


Fig. 2 Test setup

2.3 Test procedure

The lateral load was controlled by displacement (or the top drift rate-ratio of displacement of the top of column to the height of it). Fig. 3 shows the two load paths to simulate the seismic behavior of concrete filled with steel tube which is affected by appearance sequence of peak load of earthquake.

3. Experimental results

3.1 Failure mode

Two failure models of concrete filled steel tube were determined based on the difference of the load path. Fig. 4a shows the local buckling failure in plastic hinge of steel tube through the load path of type A and Fig.4b shows the tension failure at the bottom of steel tube through the load path of type B. Fig. 5 shows the failure of core concrete under the region where the tube had been removed after the test. The change of the height of the damaged concrete can be explained by difference of confinement effect of steel tube, which also indicated that the failure height of core concrete are correlate with the ratio of diameter to thickness and also the load path. The small diameter to thickness ratio made the height of core concrete increase (as shown in Fig.5 (a-b)), and load path A resulted in higher concrete damaged hight(as shown in Fig. 5 (c-d)).

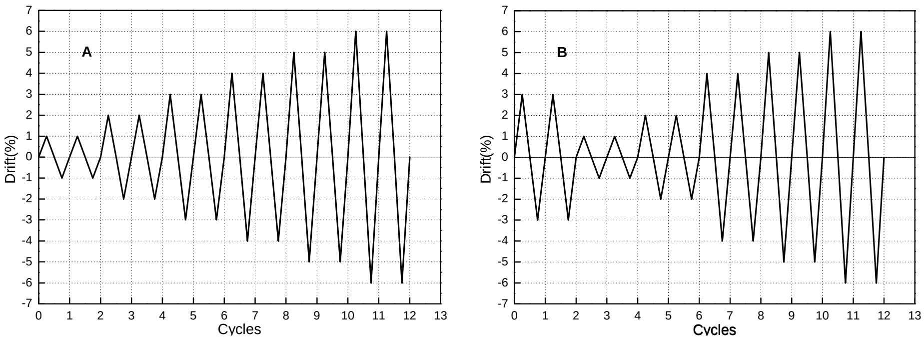


Fig. 3 Loading Program

a) local buckling failure b) tension failure

Fig. 4 Failure model of steel tube

3.2 Lateral load-deflection relationship

The relationship between lateral load and drift ratio is shown in Figs. 6a to 6h for eight specimens. In the Fig. 6g which presented the rupture of the tube along the weld line, all curves are spindle, plump and have no obvious knead approach, which show their excellent seismic-resistant performance. The Fig. 6 indicates that the ratio of diameter to thickness is the important index of seismic behavior since capacity and hysteresis behavior of Fig. 6a is worse than the others. The comparison from Fig. 6b-6c to 6d-6e indicates that various loading paths have different effect on hysteresis behavior. The maximum drift ratio of specimen is smaller in loading path of type B than in type A, and the bearing capacity decreased obviously when failure happens in type B. The comparison between specimens CH-56-20-A and Ch-56-20-B2 illustrates that the slight difference in hysteresis curve due to the higher strength steel was used, as shown in Fig. 6f and 6h. From Fig. 6b-6d to 6c-6e, it is indicated that the axial level within limits has smaller effect on hysteresis behavior.

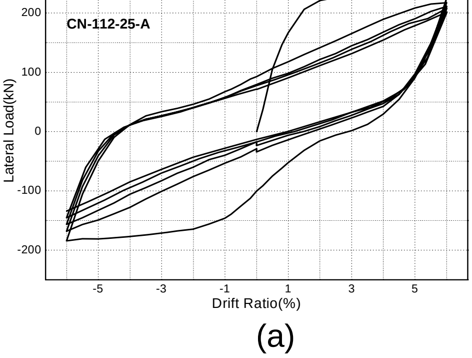
a) CN-112-25-A

b) CN-56-20-A

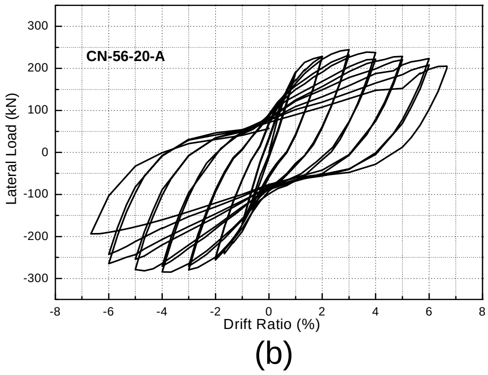
c) CH-56-20-A

d) CH-56-20-B2

Fig. 5 Failure of core concrete



(a)



(b)

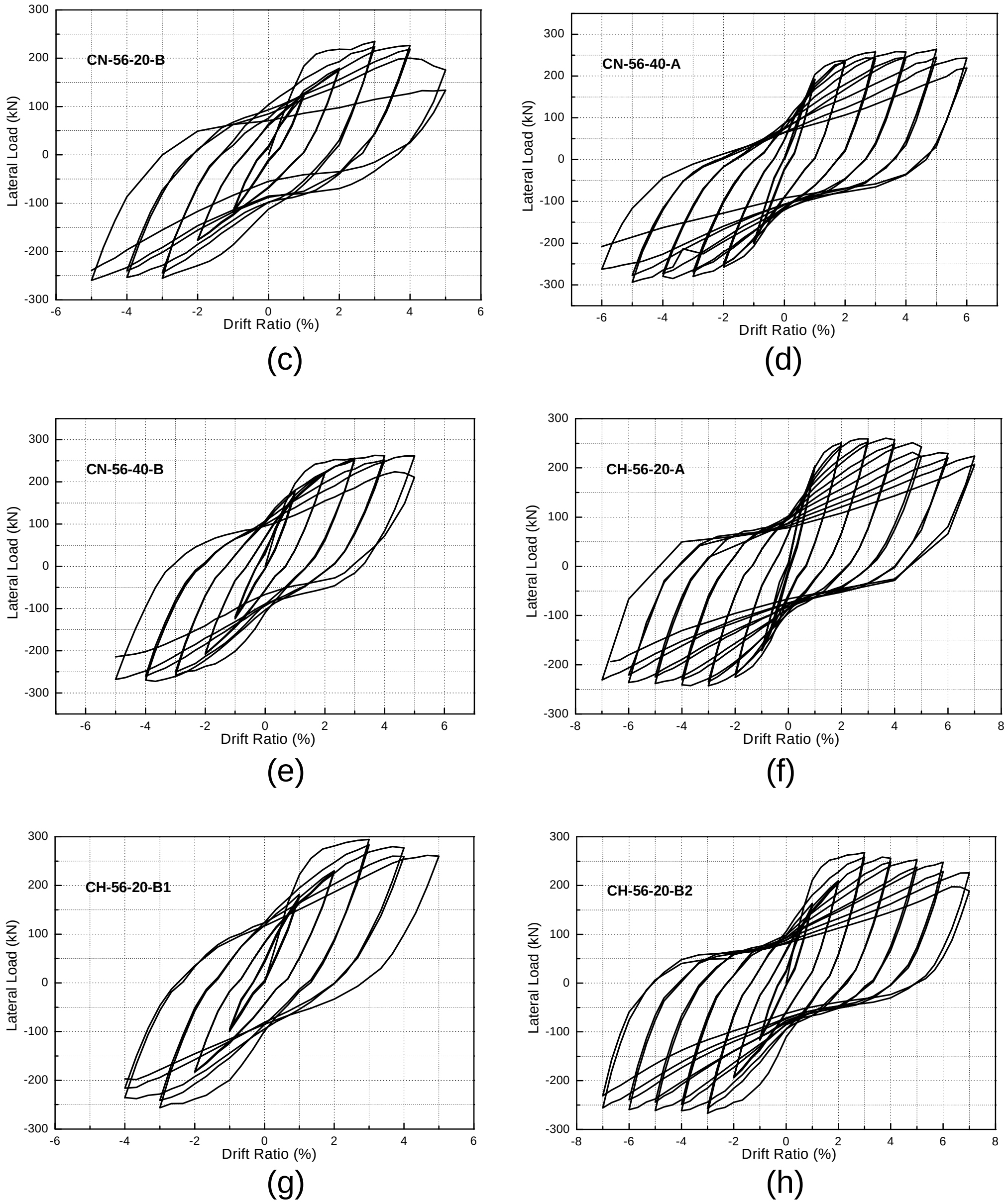


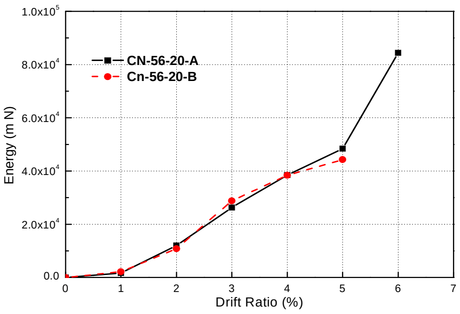
Fig. 6 Lateral load-deflection relation

3.3 Dissipated energy

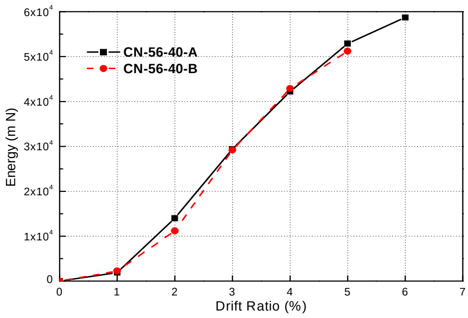
Dissipated energy of specimen is determined according to area in each of the hysteresis loop, and the values of which from zero to 3% drift and 4%、5% are shown in Table. 2. The comparison between two group specimens, CN-56-20-A to CN-56-20-B and CN-56-40-A to CN-56-40-B illustrates that the loading paths have significant influence on energy by the maximum difference of 40%. The comparison between specimens, CH-56-20-A and CH-56-20-B2, illustrates that energy is much closer when the high strength steel and concrete are used. The seismic behavior of specimens is evaluated through the energy index obtained from each cycle. Fig. 7 to 9 indicated the effects of energy index in axial level and loading path and material properties. This figure also indicate that the loading paths have great influence upon the drift ratio of 1% and the maximum is 43% as shown in Fig. 7c and minimum is 19%, as shown in Fig.7b. This explained that the specimens undergo the elastic deformation in type A, and the plastic deformation in type B at the drift ratio of 1%.

Table 2. Dissipated energy (m N)

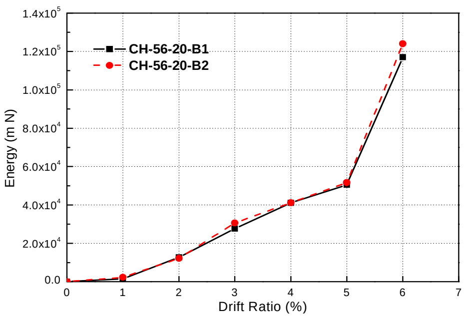
Specimen	Up to 3% drift	4% drift	5% drift	6% drift	Total
CN-112-25-C	——	——	——	——	1.02×10^5
CN-56-20-A	4.00×10^4	3.85×10^4	4.84×10^4	8.44×10^4	2.11×10^5
CN-56-20-B	4.18×10^4	3.84×10^4	4.43×10^4	——	1.24×10^5
CN-56-40-A	4.53×10^4	4.22×10^4	5.29×10^4	5.87×10^4	1.99×10^5
CN-56-40-B	4.27×10^4	4.29×10^4	5.12×10^4	——	1.37×10^5
CH-56-20-A	4.19×10^4	4.11×10^4	5.05×10^4	1.17×10^5	2.51×10^5
CH-56-20-B1	4.36×10^4	4.24×10^4	2.25×10^4	——	1.08×10^5
CH-56-20-B2	4.41×10^4	4.12×10^4	5.16×10^4	1.24×10^5	2.61×10^5



(a)

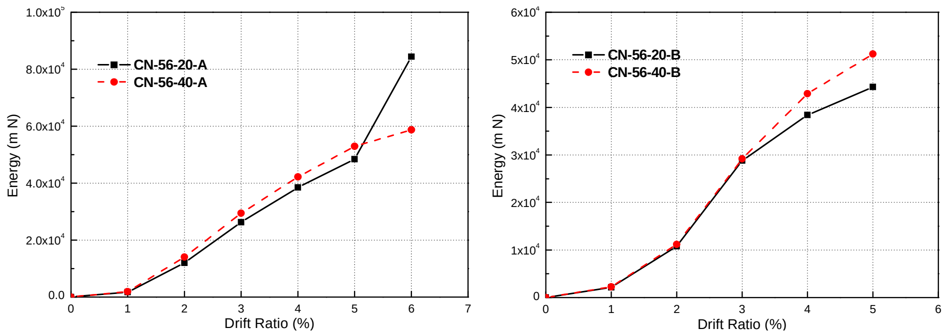


(b)



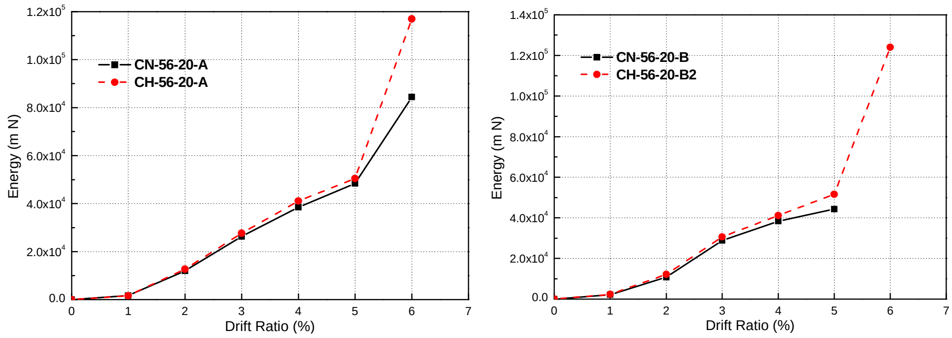
(c)

Fig. 7 Effect of load program on dissipated energy



(a) (b)

Fig. 8 Effect of axial compress ratio on dissipated energy



(a) (b)

Fig. 9 Effect of strength on dissipated energy

4. CONCLUSIONS

The ratio of diameter to thickness and the material properties strongly affect the seismic behavior of CFT columns. Better performance can be observed for CFT columns with smaller tube diameter to thickness ratio and higher material strengths.The failure modes and the length of failure zone of core concrete are related to the loading path. The loading path is an important parameter affecting the cyclic energy dissipation of CFT columns. Axial compression ratio has an impact on energy consumption and seismic performance of concrete steel tube within a certain range.

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REFERENCES

Knowles, R.B., Park, R. (1969), “Strength of concrete filled steel tubular columns,” *Journal of structure division.*, **95**(ST12), 2565-2587.

Schneider, P. (1998), “Axially loaded concrete-filled steel tubes,” *Journal of Structural Engineer.*, **124**(10), 1125-1138.

Johansson, M., Gylltoft, K. (2002), “Mechanical Behavior of Circular Steel–Concrete Composite Stub Columns,” *Journal of Structural Engineering*., **128**(8), 1073-1082.

Hu, H.T., Huang, C.S. and Wu, M. H. et al. (2003), “Nonlinear Analysis of Axially Loaded Concrete-Filled Tube Columns with Confinement Effect,” *Journal of Structural Engineer*, **129**(10), 1322-1329.

Sakino, K., Nakahara, H., and Morino, S. et al. (2004), “Behavior of Centrally Loaded Concrete-Filled Steel-Tube Short Columns,” *Journal of Structural Engineering*, **128**(8), 181-188.

Yu, M., Zha, XX., and Ye, JQ. et al. (2010), “A unified formulation for hollow and solid concrete - filled steel tube columns under axial compression,” *Journal of Engineering structures*, **32**(4), 1046-1053.

Yu, M., Zha, X.X., Ye, JQ. et al. (2012), “A unified formulation for circle and polygon concrete - filled steel tube columns under axial compression,” *Journal of Engineering structures*, **49**(1), 1-10.

Sakino, K., Tomii, M. (1981), “Hysteretic Behavior of Concrete Filled Square Steel Tubular Beam-Column Failed in Flexure,” *Transactions of the Japan Concrete Institute*, 3, 439-446.

Nakanishi, K., Kitada, T. and Nakai, H. (1999), “Experimental study on ultimate strength and ductility of concrete filled steel columns under strong earthquake.” *Journal of Constructional Steel Research*, **51**(3), 297-319.

Elremaily, A., Azizinamini, A. (2002). “Behavior and strength of circular concrete-filled tube columns.” *Journal of Constructional Steel Research*, **58**(12), 1567-1591.

Zhang, G.W., Xiao, Y. and Kunnath, S. (2009), “Low-cycle fatigue damage of circular concrete- filled-tube columns,” *ACI Structural Journal*, **106**(2), 151-159.

Zubydan, A. H., ElSabbagh, A. I. (2011), “Monotonic and cyclic behavior of concrete-filled steel-tube beam-columns considering local buckling effect.” *Thin-Walled Structures*, **49**(4), 465-481.

Moon, J. C., Roeder, W. and Lehman, D. E. et al. (2012), “Analytical modeling of bending of circular concrete-filled steel tubes.” *Engineering Structures*, 42, 349-361.

Rolando,C., Enrique, M. and Esther, R. (2012), “Strength and ductility of concrete-filled tubular piers of integral bridges,” *Journal of Engineering Structures*, 46, 234-246.

Qin, P., Xiao, Y. (2012), “Behavior of CFRP Confined Circular Concrete-Filled Steel Tube Columns.” *Proceedings of the 10th International Conference on Advances in steel concretes composite and hybrid structures Congress*, Singapore.

Zhu, D. S., Pang, B. (2013), “Experimental Study on Hysteretic Behavior of Circular Concrete-Filled Steel Bridge Piers,” *Applied Mechanics and Materials*, 256, 1640-1647.