RESEARCH ON CCRST COLUMNS USED IN SEISMIC REGIONS

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ABSTRACT :

Concrete columns reinforced with concrete filled steel tube (CCRST) is a kind of steel-concrete composite column, which consists of an ordinary reinforced-concrete column with a steel tube designed to be put in the core additionally. Owing to the steel tube, the column is effective in improvement of the ductility, as well as in decrease of the column section size due to the enhancement of the bearing capacity. It is used quite extensively in high buildings in recent years in seismic regions in China. In this paper, a review of the practice application and research work carried out on the CCRST columns is given. The review lays emphasis on the experimental study work on its composite action under axial load, its seismic performance under cyclical lateral load, and a kind of unique RC beam-CCRST column joint.

KEYWORDS: Columns, Steel tube, Seismic

1. INTRODUCTION

High strength concrete (HSC) has become a major aspect in the development of concrete. It has been used successfully in a number of building construction projects. HSC offers much structural efficiency, such as high strength, better endurance, and improved stiffness, especially when used in columns of multistory buildings. However, the application of HSC in high seismic regions has lagged behind its application in low seismic regions. One of the primary reasons has been the concern over the lack of ductility of HSC columns subjected to cyclic forces.

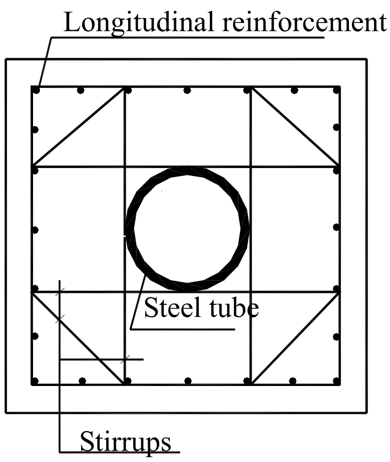


Fig. 1 Column cross section

Based on design practices, a new type of HSC columns reinforced with concrete filled steel tube (CCRST) was developed to improve the ductility of HSC columns by Liaoning Provincial Building Design & Research Institute (Liyan Lin, 1995, 1997, 1998). Fig. 1 shows the cross section of this type of composition columns. It can be seemed as a superposition of the inside steel tube concrete with outside reinforced concrete. The different 2 parts of the column can be constructed in different time or in same time. If being constructed in different time, the construction steps will be: 1.set up the steel tube and cast the concrete inside the steel tube, thus inside steel tube concrete column comes into being; 2. continue the construction of upper beams and slabs to make the inside steel tube concrete column support a certain amount of vertical loads; 3.if the vertical loads reach 0.3~0.6 times of the ultimate compression strength of the inside steel tube concrete column, then cast the outside reinforced concrete, upon that, CCRST column is finished. If being constructed in same time, the inside steel tube concrete and outside reinforced concrete is cast at a same time. CCRST columns have been used quite extensively in high buildings in recent years in seismic regions of China owing to its effectiveness in the improvement of the ductility, as well as in the decrease of the column section size.

With the increased use of CCRST columns, a great deal of theoretical and experimental work has been carried out. This paper presents a literature review focusing on: (1) design concepts in practice application, (2) composite action under axial load, (3) performance under cyclical lateral load, and (4) RC beam-CCRST column joint.

2. DESIGN CONCEPTS IN PRACTICE APPLICATION

There are 4 design concepts developed in the design of CCRST columns to improve its bearing capacity and seismic performance: strengthening, composite, confinement, and superposition (Liyan Lin, 2000,2008).

2.1. Strengthening

Strengthening here means to use materials with higher strength. Nowadays, high strength concrete with high elastic model, lower shrinkage, and lower creep is widely used in practice. In addition to it, the steel tubes with higher strength and bigger thickness are also widely available. They can offer more powerful confinement for the inside concrete. CCRST columns use the high strength concrete in the inside steel tube to get a higher bearing capacity.

2.2. Composite

CCRST column is a kind of composite column of steel and concrete, depending mainly on the concrete to support the axial compression. The concrete used in the inside steel tube is usually high strength concrete from C60 to C100, while the outside reinforced concrete is common one from C40 to C60. With the composition of steel tube, high strength concrete, steel reinforcement, and common concrete in this way, the resistance mechanism in CCRST column is much reasonable. The steel tube and inside concrete will mainly resist compression and shear force, while the outside concrete and outside steel reinforcement will resist mainly flexural force and partial compression. In the CCRST column, the steel tube is used mainly for confinement for the inside concrete. Therefore, the steel consumption in CCRST column is less than that in concrete-filled steel tube column and that in steel reinforced concrete column (SRC) when designed under same loading.

2.3. Confinement

There are 2 kinds of confinement be active in the CCRST column. One is the confinement of the steel tube for the inside concrete. Another one is the confinement of outside reinforced concrete for the inside steel tube concrete. On the confinement of steel tube in improving the strength and also seismic performance of the inside concrete, there have been many discussions available (Shangtong Zhong, 1994, Shaohuai Cai, 2002).

For the confinement of the outside reinforced concrete, it is likely to delay or prevent the buckling of the inside steel tube, thus improve the stability of the inside steel tube concrete in compression. In addition to it, the confinement of the outside reinforced concrete can also improve the effectiveness of the confinement of the steel tube for inside concrete.

2.4. Superposition

With the superposition of the inside steel tube concrete and outside reinforced concrete, the CCRST column can get a rational distribution of compression loading between the two parts. When the two parts are constructed at same time, the inside steel tube concrete can share most of compression loading due to its high elastic module. If the two parts are constructed in different time, the inside steel tube concrete can share far more compression loading, for it has supported almost 0.3~0.6 times of its ultimate compression strength (as mentioned in 1.Introduction) before the compression loading be distributed between the two parts in proportional to their elastic modules. The bigger of the difference between compression strength of the inside concrete and outside concrete, the less of the compression loading will be shared by the outside reinforced concrete.

As we know, failure of the columns under eccentric compression is usually caused by the crush of the outside concrete owing to high compression stress. Constructed in this superposition way, the CCRST column can get better ductility, for the compression stress in the outside concrete can be lower under service loading.

3.COMPOSITE ACTION UNDER AXIAL LOAD

As a kind of composite column, the ratio of steel area to total cross-sectional area of the CCRST column is usually quite large. It is a very important issue for CCRST column if the inside steel tube can work in a good cooperation with the outside reinforced concrete in the columns. Tests were conducted on the short CCRST columns under axial compression by Jian Cai (2002), Yongjuan Lin (2002), and Zhou-yi Chen (2005). It was concluded that under axial compression, the outside reinforced concrete can work in a good cooperation with the inside concrete-filled steel tube till the columns fail. This can be found by investigating the development of longitudinal strains of different portions of the specimen in the test. The compatibility of deformation of different portions was remarkable in low stress stage. After that, with the increasing of stress, the divergence of strain between different portions increased gradually. But till the applying load closed to ultimate load, there was no completely splitting between different portions being found.

4. PERFORMANCE UNDER CYCLIC LATERAL LOAD

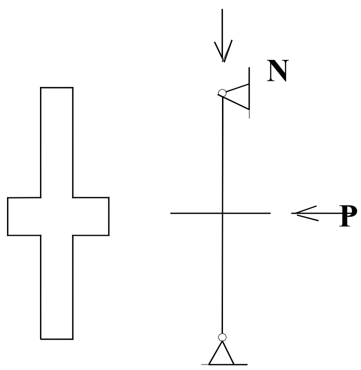


Fig. 2. Simplified models of test specimens and loading arrangement

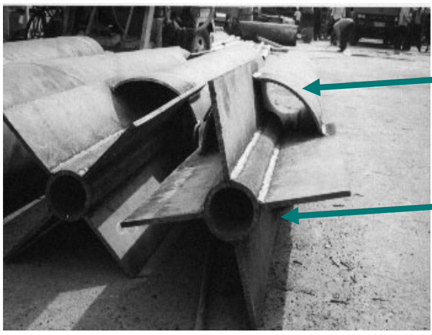
The behavior of CCRST columns subjected to cyclic lateral forces with a constant axial load was examined by Guo-fan Zhao (1996,2001) and Hui Li (1998,1999). In the test carried out by Guo-fan Zhao, total 38 specimens were investigated. They are the kind of CCRST column that the both inside steel tube concrete and outside reinforced concrete were cast in the same time. Test parameters included concrete strength（C60 and C80）, axial compression ratio(0.5~0.8), volume stirrup ratio, longitudinal reinforcement ratio, and area ratio of steel tube. Fig. 2 shows the simplified models of the specimens and loading arrangement of the tests. Both ends of the column specimens were the middle points (points of inflection) of column. A horizontal corbel to model the connecting beam was located at the middle of the specimen, where the repeated horizontal loads to model the earthquake action was applied. Most of the columns were under high axial compression, but the damage characteristics of these specimens were flexure-compression damage rather than shear-compression damage. Though the compression reinforcement yielded at first, the crushing of the concrete in compression zone was after the yielding of tensile reinforcement. Thus, the failure of these columns in brittle manner was forbidden. The rotate ability of compressive plastic hinge was increased and the ductility of this kind of column was improved. It is believed that the existence of inside concrete filled steel tube plays an important role in improving the performance of the CCRST columns under cyclic lateral load. The resulting hysteretic loops of these specimens indicated a stable response with considerable amount of energy dissipation.

Hui Li conducted test on 6 CCRST column specimens, with inside steel tube concrete and outside reinforced concrete were cast in different time for 4 specimens, while rest 2 ones in same time. The same result was reached as mentioned above. The CCRST column is effective in improving its ductility and seismic performance. It is also reported that the ductility of the CCRST columns with inside steel tube concrete and outside reinforced concrete cast in different time are better than those cast in the same time when other design parameters are same.

5. RC BEAM-CCRST COLUMN JOINT

The design and detailing of beam-column joints is important in achieving satisfactory performance of RC frames. There are various kinds of RC beam-CCRST column joints being used in practice. Here a type of new and unique joint is discussed.

Fig. 3 shows the construction detail of this kind joint. At the beam-column joint, the steel tubes of the up column and the following column are connected by the small steel tube and 4 steel plates. In this way, the longitudinal reinforcement bars of the beam can easily pass through the steel plates instead of passing through a big steel tube.



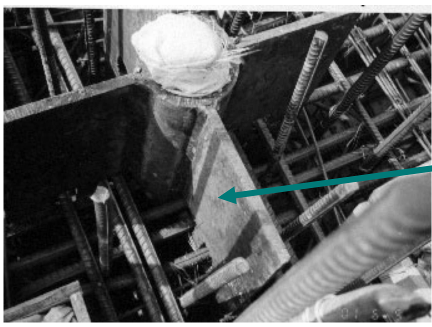


Fig. 3 RC beam-CCRST column joint

Due to the significant contribution of joint failures to the collapse of buildings during earthquakes, the design methods should be able to upgrade the joint's capacity, in order to prevent a brittle shear failure and, instead, shift the failure towards a beam flexural hinging mechanism, which is a more ductile type of behavior. Zhihui Huang (2001) carried out test on shear behavior of this kind joint. The beams of the joint specimens were strengthened intended to get the shear failure at the joint. The calculation method of this kind joint was presented based on the test results. It is reported that these joint specimens show substantial deformability and energy-dissipation capacity even in shear failure mode.

6. DESIGN CODE

Over ten years, based on various experiments and analysis, the design code for the CCRST columns have been formulated. As one of the engineering construction standards in China, "Technical specification for steel tube-reinforced concrete column structure" (CECS 188:2005) was published in the year 2005. In this design code, the ultimate compression strength is calculated by superimposing the strength of both the inside steel tube concrete and outside reinforced concrete with a strength reduction according to the slenderness ratio. The way for calculating the strength interaction between axial and flexural is the same as those for reinforced concrete column, with the axial load being taken as that act on outside reinforced concrete.

7. CONCLUSION

CCRST columns represent an innovative approach to high strength concrete composite columns by taking advantage of the design concepts such as strengthening, composition, confinement, and superposition. The presented research developments show that the design method of this kind of columns is effective in improvement of the seismic performance of HSC columns as well as feasibility in design practice, which promises a good future for the application of CCRST columns in seismic region.

REFERENCES

Guofan Zhao, Dejuan Zhang, Chengkui Huang (1996). Study of earthquake resistant behavior of high strength concrete column reinforced with concrete filled steel tube. *Journal of Dalian University of Technology* **36:6**, 759-766.

Guofan Zhao, Dejuan Zhang, and Zhou-yi Chen (2001). Behavior and design of high-performance concrete columns under cyclic loading. *Proceedings of ICCMC/IBST 2001 International Conference on Advanced Technologies in Design, Construction and Maintenance of Concrete Structures*, Hanoi, Vietnam, 230-236

Hui Li, Bo Wu, Liyan Lin (1998). Study on seismic properties of laminated column high strength concrete containing steel tube. *Earthquake Engineering and Engineering Vibration* **18:1***,* 45-53.

Hui Li, Zhen-yu Wang, Bo Wu (1999). Experimental research on mechanism and seismic performance of laminated column with steel tube filled with high- strength concrete. *Earthquake Engineering and Engineering Vibration* **19:3***,*27-33.

Jian Cai, Xiaofeng Xie, Chun Yang, et al (2002). An experimental research on the composite column with core of high strength concrete filled steel tube under axial compression loading. *Journal of South China University of Technology (Natural Science Edition)* **30:6,** 81- 85.

Liyan Lin et al (1995). Design review and discussion on HSC columns. *Proceeding of second symposium on high strength concrete and its application.*

Liyan Lin et al (1997). High strength concrete columns reinforced with concrete-filled steel tube. *Proceeding of 7th China-Japan building structural symposium.*

Liyan Lin et al (1998). Application of HSC columns reinforced with concrete-filled steel tube in the LiaoNing Post Building. Symposium of high strength concrete engineering practice, QingHua University publish house, Beijing.

Liyan Lin et al (2000). Theory and design method of HSC columns reinforced with concrete-filled steel tube. Engineering Mechanic, extra edition.

Liyan Lin et al (2008). Design concept and analysis of technical economy for steel tube reinforced concrete column. *Building Structure* **38:3,** 17-21.

Liyan Lin (2002). Experimental and Study of Steel Reinforced Concrete Column with Steel Circle Pipe. Southeast University, Nanjing.

Shaohuai Cai(2003). Modern Steel Tube Confined Concrete Structure, China Communications Press, Beijing.

Shangtong Zhong (1994). Concrete-filled Steel Tube Structure, Heilongjiang Scientific Press, Haerbin.

Zhihui Huang, Lirong Cheng, Jiaru Qian, Liyan Lin (2001). Experimental study and finite element analysis on shear behavior of steel tube fill high strength concrete composite column core area. *Industrial Construction* **31:7**,50-53.

Zhou-yi Chen, Guo-fan Zhao, Wei-jian Yi, Li-yan Lin (2005). Experimental research on behavior of high strength concrete column reinforced with concrete-filled steel tube under axial compression. *Journal of Dalian University of Technology* **45:5,** 687- 691.

Zhou-yi Chen, Wei-jian Yi, Guo-fan Zhao, Zheng-ping Sha, Li-yan Lin (2005). Ultimate strength of high strength concrete columns reinforced with concrete filled steel tube under axial compression and their reliability analysis. *Journal of Hunan University (Natural Science Edition)* **32:4,** 6-11.