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Application on Concrete-filled Steel Tube Composite Structure in the Field of Civil Engineering

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Abstract. In recent years, as the construction technology tends to mature, the engineering field has higher and higher requirements for structures in engineering, and the composite structure has gradually become a hot spot. This paper focuses on the study of concrete-filled steel tube (CFST) structures in composite structures. By studying the development process of CFST structure and the production process in the actual project, it is proved that the composite structure of CFST has more research prospects than the traditional structure. Then, it is analyzed that CFST has many advantages, and the application prospect in the future practical engineering is more extensive than the traditional structure. Then the existing cases of CFST structure in various aspects of engineering are listed, the role of using CFST structure in Nanchang Shengmi Bridge is analyzed. The conclusion is drawn that the composite structure including CFST has the tendency to replace the traditional structure. This paper aims to provide a possible reference for the future research of CFST.

Keywords: Concrete-filled steel tube; Composite structure; Civil engineering.

1. Introduction

Chinese architecture has a long history, and the structure of ancient buildings is usually composed of bricks made from clay, straw or wood cut from trees. Then with the development of science and technology, steel, concrete, cement and other building materials have emerged and gradually become indispensable components of building structures. However, the single structure composition of the traditional structure has its different advantages and disadvantages, such as the reinforcement structure itself has a strong compressive ability, but the bending ability of the side is weak. With the continuous advancement of modernization, the requirements for the structural components of the combination are also increasing. Combined structure refers to the combination of two or more materials in civil construction on the premise of ensuring that the material plays a role in the structure [1]. Compared with the traditional structure, the combined structure has many advantages, such as strong bearing performance, good seismic performance, strong fire performance, material saving and structural weight reduction advantages. Concrete-filled steel tube (CFST) structure is a kind of composite structure. CFST structure refers to the structure formed by adding concrete to the steel tube, which can be classified according to the different shape of the steel tube section and the different stress state. Therefore, CFST structure is widely used in modern engineering, among which Nanchang Shengmi Bridge is famous.

This paper mainly studies the CFST structure in the composite structure, and analyzes the application and role of the composite structure in it by combining the actual concrete cases. Finally, the author puts forward some thoughts on the future research direction of combinatorial structure based on his own understanding, and provides reference for future research.

2. Development and Production of CFST Structure

2.1. Development History

CFST is evolved and developed based on rigid reinforced concrete and spiral reinforced concrete [2]. In 1879, the piers of the Severn Railway Bridge in England were first made of CFSTs to better withstand pressure and prevent corrosion. Since then, CFST structure has been widely used. At the end of the 19th century, Americans invented Lally columns by injecting concrete into circular steel pipes, which were mainly used for bearing weight in house structures [3]. At the beginning of the 20th century, France built a deck arch bridge with CFST structure in Ibis, a suburb of Paris. Then the CFST structure was really applied to arch Bridges in the former Soviet Union. In the former Soviet Union, a 110m through arch bridge across the Neva River was built in Leningrad region in 1937 with a CFST structure as the arch rib. In 1939, a deck arch bridge was built in Siberia with a CFST structure as the girder rib [4]. Although CFST structure was applied to arch bridge in this period, due to the relatively backward pouring technology, the construction process was more complicated and the construction cost was higher than that of ordinary steel structure. Therefore, CFST structure has not been widely used. Until the end of the 1980s, the emergence and development of pumping concrete technology has effectively solved the problem of CFST structure, and CFST structure has been widely used. Such as Japan's Aoba Bridge, Sydney's Market city project and so on.

CFST structures were first introduced in China in the 1960s [5]. In 1965, China started the construction of Beijing Metro Line 1, in which CFST structure was used as the load-bearing column of two stations [6]. In the 1980s, CFST structure was included in the national development plan, and then there were many researches on CFST structure in our country successively. With the maturity of CFST (CFST) technology, there have been a large number of projects using CFST structures in China. In terms of Bridges, in 1991, China completed the Wangcang East River Bridge in Sichuan Province, which was the first CFST arch bridge in China. In addition, in recent years, there are also Nanchang Shengmi Bridge, Wanzhou Yangtze River Bridge, Wujiang Bridge and other CFST Bridges. The Wujiang Bridge is currently the world's largest overspan CFST arch bridge. In terms of construction, CFST structures have been mainly used in high-rise buildings in recent years. For example, the Seg Square building in Shenzhen, all its columns are CFST columns, and it is also the highest building in the world that adopts all CFST columns so far. Because of the many advantages of CFST structure, it will continue to be widely used in future projects.

2.2. Production and Construction Process

The production of CFST structure is usually made of steel tube first. Determine the length of the steel pipe according to the project needs. Then cut to remove excess parts, process the steel plate indenter, weld and butt the coil. Then the steel pipe column is installed to complete the production of the concrete-filled steel pipe column. The process of installing the steel pipe column is to measure the size of the steel pipe, install the base section of the steel pipe, and weld the steel pipe. Concrete is poured after inspection. After the CFST structure is made, check valves are installed first, and then transferred to the construction site after adapting to the concrete. After that, the reinforced concrete is poured again, and the sealing steel plate is welded after the conveyor pipe and the stop valve are removed [7].

3. Structural Characteristics

CFST structure is a kind of composite structure, that is, concrete is poured into the inner space of the steel tube to form a composite structural member. Fig. 1 shows the classification of CFSTs. Its classification can be classified according to the section shape of the steel pipe, which is roughly divided into rectangular, square, polygon and circular CFST structures. It can also be classified according to the action state of the forces received in the project, that is, it can be divided into collaborative stress structures. Initial stress CFST structure. Concrete structure with steel tube restraint [5]. CFST has the following advantages:

(1) High bearing capacity

Due to the interaction between steel pipe and concrete, steel pipe improves the compression capacity of concrete, and the effect of concrete on steel pipe delays the time of local bending of steel pipe. Therefore, CFST structures have the characteristics of higher bearing capacity than each single structure [8].

(2) Stronger corrosion resistance

Because concrete is poured inside the steel pipe, the steel structure has stronger corrosion resistance during operation, and the corresponding anti-corrosion coating workload is smaller [9].

(3) Better plasticity and toughness, seismic performance

The restraint effect of steel pipe on concrete changes the elastic properties of concrete, so the shape and toughness of concrete are stronger [8]. Through repeated loading experiments on square CFST columns, Lu et al. [10] concluded that CFST structures have better local instability resistance and therefore stronger seismic performance.

(4) Convenient construction

Because the CFST structure can be processed directly in the factory, the process of binding steel bars can be removed from the construction site, so the construction efficiency is higher and the construction is more convenient.

(5) Good fire resistance

Han et al. [11] conducted an experimental study on the fire resistance of CFST columns, drew the relationship between axial deformation and heating time, and concluded that CFST structures have better fire resistance than general structures due to the strong heat absorption effect of CFST and the complementary effect of steel tube and concrete.

(6) Cost savings

CFST structure can save material costs, compared with a single steel structure or concrete structure used less material, so it can save costs and improve economic benefits.

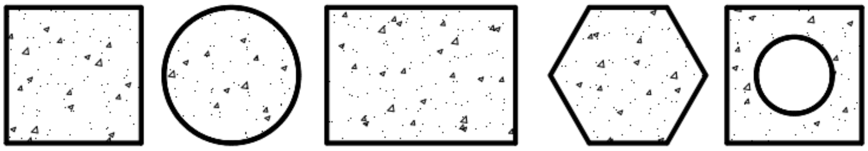

Figure 1. Common CFST section shapes [5]

4. Applications of CFST Structure

4.1. Applications in High-rise Buildings

High-rise buildings have higher requirements for technical strength of concrete, and the specification for strength is clearer. CFST columns can be used as load-bearing columns in local high-rise buildings because of their strong bearing capacity, good seismic performance and less consumables. In addition, the CFST column is stronger than the reinforced concrete column structure, and the column body is relatively thinner and more stable, and the cost of anti-corrosion work is smaller [6]. In general, the application of CFST structure in high-rise buildings improves the strength, toughness and ductility of the original building materials, improves the quality, efficiency and performance of the entire building, and also improves the entire construction landscape [12]. Examples of the application of CFST columns in the field of high-rise buildings are as follows: In 2008, the Shanghai Tower project, the bearing column of the CFST structure. In 2011, the Beijing Fund financing Center project, its outer steel frame includes a giant CFST column, and its interaction with the belt truss, waist truss, and boom truss makes the Beijing fund financing center form a multiple lateral force resistance system. In 2017, the outer frame and core tube of the Guangzhou Greenland Financial Center project used CFST structure.

4.2. Applications in Industrial Plants

CFST structure is also widely used in the construction of industrial plants. Compared with the traditional reinforced concrete industrial plant, the advantages of the CFST composite structure plant structure are more obvious. The CFST mainly adopts the design of stress control design, so there is no problem of traditional concrete cracks on the surface, and the width proportion of the bearing surface can be relatively reduced, which improves the space utilization rate. In addition, compared with ordinary concrete outer film, steel pipe is also more conducive to lifting and rotating, reducing the construction difficulty of large-span structure. The mass is also lighter, and the overall plant weight is also smaller. The pumping process of CFST is simpler than that of reinforced concrete, and the filling degree and compactness are better. The production of CFST structure is also more convenient, and the concrete can be poured after the main structure is roughly completed, and there is no need to set up additional aerial work platform for aerial work. Therefore, the construction time can be greatly reduced, the safety can be increased, and the construction of industrial plants is also more convenient [13]. Practical examples of CFST structure in industrial plants include: an open-air workshop of Shanghai Electric Machinery Factory in 1999, whose limbs were all made of CFST columns [6]. In 2000, all the columns of a main steelmaking continuous casting and rolling plant of New Steel Rolling Company of Anshan Iron and Steel Corporation were made of CFSTs. In addition, the multi-storey industrial plant of Xining Aluminum Plant also uses CFST columns.

4.3. Applications in Subway Stations

The subway station project is the first project to apply the CFST structure in China. Compared with reinforced concrete structure, the use of CFST structure can consolidate the bearing capacity of subway stations, and successfully reduce the space occupied by reducing the column section. At the same time, because there is no need to install, disassemble, split and disassemble the mold, the construction process is less, and the construction period is shorter. The practical application cases of CFST structure in subway station projects are as follows: It was first used in the Beijing Metro Line 1 project in the 1960s, and the platform projects of Beijing Station and Qianmen station used CFST columns. In 2009, CFST columns were used in the vertical support system of Baishiqiao Station of Beijing Ternary Line 4. In 2014, Shawan Park Station of Changsha Metro Line 2, its frame columns were all CFST columns.

4.4. Applications in Bridges

CFST structure is mainly used in arch bridge types, which can be divided into through arch bridge, half-through arch bridge and deck arch bridge. The CFST (CFST) through arch bridge is usually a tied arch bridge, that is, the basic structural form of beam and arch are combined with each other. It has the characteristics of beautiful design, strong adaptability to the foundation and strong crossing ability. The half-through arch bridge of CFST is usually divided into two kinds: tied arch bridge and hingeless arch bridge, which have the characteristics of novel design and convenient construction, and are usually built in canyons and other areas. CFST deck arch bridge generally adopts hinge less arch bridge, which is relatively more aesthetic value and has higher requirements for foundation [4]. Due to the characteristics of high strength, convenient construction and relatively beautiful shape of CFST arch bridge, it is widely used in practical projects in China, such as the famous Wanzhou Yangtze River Bridge built in 1997, the main span is 420m. There is also the Jianghan Third Bridge in Wuhan, whose main span is 280m. And the main span of 270m Guangxi Sanan Yongjiang Bridge, etc. This paper takes Nanchang Shengmi Bridge as an example to describe the application of CFST structure in bridge.

4.4.1. Project overview.

Nanchang Shengmi Bridge is built over the Ganjiang River, with a total field of 3880m and a width of 35m. It is a two-way eight-lane bridge [14]. It serves as an important bridge connecting Nanchang city and Changbei City [15]. The main bridge of Nanchang Shengmi Bridge adopts the form of intermediate CFST tie bar arch with multiple arches. The main span is 228m, the side span is 75m, and the bridge width is 39m [14]. Fig. 2 shows the overall layout.

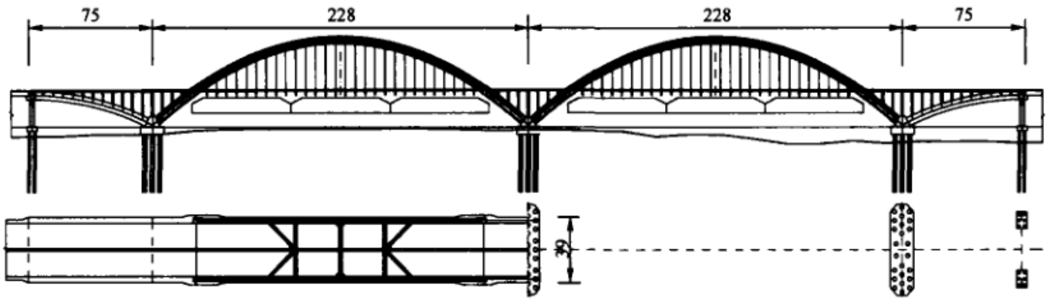

Figure 2. General layout of Nanchang Shengmi Bridge [16]

4.4.2. Main arch.

The main span of Nanchang Shengmi Bridge adopts CFST arch rib above the bridge floor, reinforced concrete arch rib below, the ratio of vector to span is F/L=1/4.5, and the arch axis adopts the quadratic parabola. The CFST arch rib section adopts 4 steel pipes with Φ=900mm to form a space truss structure. The arch rib of the main hole is 4.6m high and 2.6m wide. The four main steel pipes are connected by transverse strips, partitions and belly rods, and C50 micro-expanded concrete is poured between the strips and inside the steel pipes. Fig. 3 shows the arch rib structure. The ratio of side span to vector span is F/L=1/8.5, the arch axis adopts catenary m=1.8, and the arch rib is cast-in-place prestressed concrete with a height of 5.0m and a width of 3.0m. In order to improve the safety performance, the joint method of anchorage bolt and prestressed reinforcement is adopted at the junction of steel pipe truss arch rib and concrete arch rib in Nanchang Shengmi Bridge. In order to play the role of transverse support, two hollow steel tubular K-shaped transverse supports and one hollow steel tubular one-line transverse supports are set up on the arch rib. In addition, the fixed beam at the intersection of the arch rib and the bridge floor system also plays a role of transverse support [16].

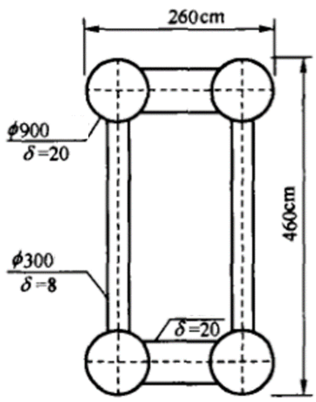

Figure 3. Arch rib structure

4.4.3. Concrete-filled steel arch rib.

Li et al. [16] calculated that when the arch rib of CFST is in the most unfavorable combination of the upper and lower chord, the axial force is 42557 kN and the bending moment is 1041kN·m, which is much higher than the axial force used by the chord calculated by the ultimate bearing capacity calculation of Shengmi Bridge in the design and construction regulations of CFST structure. Therefore, the CFST structure greatly improves the bearing capacity of arch rib and increases the sufficient safety degree.

To sum up, the shape of Nanchang Shengmi Bridge is simple and beautiful, which improves the traffic convenience of Nanchang. Its application to the CFST structure is mainly reflected in the arch rib above the main span bridge floor. The use of CFST structure improves the axial force of the arch rib on the tie rod and greatly increases the safety.

5. Conclusion

In this paper, CFST structure in steel-concrete composite structure is studied. Firstly, the development process, production and construction process and structural characteristics of CFST structure are summarized. Combined with the case of Nanchang Shengmi Bridge, the application of steel-concrete composite structure in practical engineering is analyzed. The main conclusions are as follows:

(1) CFST has many advantages. Due to the interaction between steel pipe and concrete, compared with the traditional steel structure, it has a higher bearing capacity, corrosion resistance, earthquake resistance, and fire resistance, and the construction is also more convenient and economical. Therefore, CFST structure has wide application prospect.

(2) Through the analysis of the application of CFST structure in various aspects and the actual case of Nanchang Shengmi Bridge, it shows that this structure has played a special advantage in high-rise buildings, industrial plants, subway stations and Bridges, and has a trend of gradually replacing traditional reinforced concrete structures.

(3) Although there are many advantages of CFST structure, there are also some problems. Because the internal material structure of the CFST structure is wrapped by the external material structure, there is a problem that the quality of the internal concrete or steel cannot be directly detected to avoid quality defects. Therefore, to develop a more convenient and accurate detection method can become one of the research directions. Moreover, because the CFST structure is a combination of two materials, the connection between the two may be separated. Therefore, the possible causes of separation between steel pipe and concrete, and the mechanism of connection and reinforcement of the two are still to be studied. With the advance of urban modernization, the actual engineering puts forward higher requirements for the mechanical properties and cost of composite structures. At the same time, a variety of new materials continue to emerge, so more types of combinations of materials to form a richer combination of structural types also need further research.

References

[1] W. Zheng, Analysis on construction technology of concrete-filled steel tube structure, China Construction Metal Structure 08 (2022): 26-30.

[2] L. Han, Z. Tao, W. Liu, Concrete-filled steel tube structure -theory and practice, Journal of Fuzhou University (Natural Science Edition) 06 (2001) 24-34.

[3] Y. Jiang, Z. Kou, Y. Jia, L. Ning, Development, research and Application of concrete-filled steel tube structures, Journal of Liaoning University of Technology (Natural Science Edition) 02 (2004) 62-65.

[4] Y. Zhao, Design optimization of arch rib profile of concrete-filled steel tube arch bridge, Wuhan University of Technology MA thesis, 2007.

[5] S. Luo, Study on the mechanical properties of steel tubes in concrete-filled steel tube column during concrete placement construction, Chongqing University MA thesis, 2016.

[6] S.T. Zhong, Application and Achievement of Concrete-filled steel tube structure in China, Proceedings of the 2008 National Building Steel Structure Industry Conference. Ed. Harbin Institute of Technology, 2008, pp. 5-13.

[7] C. Cui, Application of concrete-filled steel tube columns in engineering construction, Construction Mechanization 45.04 (2024) 77-79.

[8] L. Han, Theory and Practice of concrete-filled Steel Tube structure, Invited report of the 10th National Structural Engineering Academic Conference, The Tenth National Structural Engineering Academic Conference, vol. I. Ed. School of Civil Engineering and Architecture, Fuzhou University, 2001, pp. 249-274.

[9] Y. Liu, L. Sun, X. Zhou, J. Xian, N. Zhang, H. Li, Progress in engineering application and research of concrete-filled steel tube bridge tower, China Journal of Highway and Transport 35.06 (2022) 1-21.

[10] X. Lu, W. Lu, Experimental study on seismic performance of concrete-filled steel tube columns under repeated loads, Journal of Building Structures 02 (2000) 2-11+27.

[11] L. Han, J. He, H. Wu, Q. Han, Experimental study on fire resistance of concrete-filled steel tube columns, Journal of China Civil Engineering 03 (2000) 31-36+53.

[12] D. Xie, Analysis of concrete-filled steel tube construction technology in middle and high rise building engineering, Construction Materials & Decoration 36 (2017) 32-33.

[13] D. Li, X. Sun, S. Li, S. Zhang, Z. Chang, Discussion on comprehensive technology application of concrete filled steel tube in large industrial plant, Proceedings of the 26th East China Civil Engineering Construction Technology

Exchange Meeting of Six Provinces and One City (Part II). Ed. Shandong Construction Engineering (Group) Co., LTD. 2020, pp. 86-90.

[14] B. Li, L. Wu, Structural analysis of the main bridge of Shengmi Bridge, Guangdong Building Materials 26. 04 (2010) 17-19.

[15] J. Ling, H. Tang, W. Guo, X. Li, Overall design of the main bridge of Nanchang Shengmi Bridge, World Bridges 03 (2005) 5-7.

[16] Y. Li, H. Tang, W. Guo, J.G Ling, Design of Nanchang Shengmi Bridge, Proceedings of the 17th National Bridge Academic Conference (Volume 1). Ed. Architectural Design and Research Institute of Tongji University, Architectural Design and Research Institute of Tongji University, Architectural Design and Research Institute of Tongji University, Architectural Design and Research Institute of Tongji University, 2006, pp. 150-156.