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Summary of Research Status of Concrete Filled Steel Tubular Truss Structure

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Abstract. With the development trend of industrialization of building, truss structure is more and more widely used as a simple force structure in engineering applications because of its advantages of light weight, large span, low steel consumption and so on. The key to improve the overall stability, ultimate bearing capacity and seismic performance is to make use of the mechanical advantages of the new materials. This paper expounds the characteristics of concrete-filled steel tubular trusses, introduces its application in bridge engineering and building roof structure, and systematically summarizes the design theories and research results in the field of truss at home and abroad. The feasibility of a new epoxy resin concrete material in the application of concrete-filled steel tubular truss is discussed, and further research work is expected.

1. Introduction

A truss is a geometrically invariant structure in which the bars are hinged to each other at both ends. The truss is like a hollow beam. The rod is mainly subjected to axial tension or pressure, so that the strength of the material can be fully utilized. When the span is large, the truss can save material compared with the solid web, which can reduce the self-weight of the structure and increase the structural rigidity, and is economical to use. Steel pipe structure refers to the hollow steel pipe structure which is used in all or part of the steel structure. Steel pipe structure has the following characteristics: the steel pipe structure has good geometrical characteristics, the pipe wall is thin, the cross-section material is evenly distributed around the centroid, and the section has a large radius of gyration, so it has good torsional stiffness. Steel pipe as a compression, bending and biaxial bending member, its bearing capacity is higher. The steel pipe has a beautiful appearance, especially a pipe truss composed of steel pipe members, without redundant node connections, and has a strong visual effect. The circular tube section has good anti-hydrodynamic characteristics, which can greatly reduce the effect of wind and water flow. The steel pipe is a closed section. When the average thickness and cross section area are the same, the exposed surface area is about 50% to 60% of the opening interface, which is beneficial to corrosion prevention and can save the material used for coating. The joints can be welded directly without passing through other connectors. It is possible to pour concrete in the pipe and form a composite member[1]. Due to the above advantages of the steel pipe structure, the



concrete-filled steel tubular truss structure is widely used in civil and industrial buildings, and the design of concrete filled steel tube truss structure is becoming more and more fully studied both at home and abroad.

2. Domestic and foreign application examples of steel pipe trusses

2.1. Foreign application examples

The application of steel pipe structure was originally in the offshore platform. The first modern offshore platform built in the Gulf of Mexico in 1947 made people aware of the superiority of steel pipe construction. Subsequently, the American Welding Association included the welding specification for the pipe structure, and the pipe truss structure began to be widely used in engineering practice. The terminal of Stuttgart airport in Germany uses the tree-shaped support structure of steel pipe members cast steel joints, which has the characteristics of novel shape, simple and light weight. The Oval-Lingotto stadium has a construction area of approximately 26,500m², an ice rink of 400m and a width of 12.60m. The ceiling of the venue is made of space steel truss structure, completely suspended, without any support in the field, creating an independent free space. Kansai International Airport, Japan, uses inverted triangular space tubular truss structure as the roof truss. It is considered to be one of the most outstanding buildings at that time because of little damage under the action of the 7.2-segment earthquake Osaka-Kobe in 1995. The seismic superiority of space pipe truss structure is verified. The World Trade Center, built in New York in 1972, the Silst Tower, built in Chicago in 1974, the Royal Stock Exchange in Toronto in 1974, the Republican Square Building in Denver in 1978, and the DeLaGauchetiere in Montreal in 1991 is a practical example of steel-concrete composite truss structure in engineering.

The design, fabrication and installation of steel pipe truss are simple, and its adaptability span is very large, so it is also widely used in the field of bridges[2], such as Boulonnais Bridge in France, Kinokawa Bridge in Japan, Dreirosenbridge Bridge in Basel on the Rhine River in northwest Switzerland and White Warehouse Highway Bridge in Japan.

2.2. Domestic application examples

The steel pipe structure started late in our country, but in recent years, the steel output has increased year by year, and the relevant technical standards required for steel structure have been matured. The steel pipe truss structure has been greatly developed during this period, and is often used in long-span roof structures, the roof of industrial plants, as well as bridges, etc.

Concrete-filled steel tube girder bridges have few application cases and are mainly made of circular steel tubes. The typical ones are Zidong Bridge, Xiangjiaba Bridge, Wanzhou Bridge and Ganhaizi Bridge. Guangdong Nanhai Zidong Bridge is the first bridge with concrete filled steel tube space truss composite beam structure in China, Xiangjiaba Bridge in Zigui County, Hubei Province is the first bridge project to use concrete filled steel tubular composite trusses in continuous rigid frame construction. Wanzhou Bridge in Wanxian County, Sichuan Province, another up-combined truss system with concrete-filled steel tube space truss, is adopted after Xiangjiaba Bridge. Sichuan Ya'an Ganhaizi Bridge is currently the largest bridge of its kind in the world. At present, rectangular steel tube concrete is only widely used in building structures. The application of rectangular steel tube concrete to bridge structures is an innovation in cross-section form. Commonly used rectangular steel pipe truss application examples: Wuhu Yangtze River Bridge, Dongguan Dongjiang Bridge, Wuhu Yangtze River Bridge, Wuhan Yangtze River Bridge, Nanjing Yangtze River Bridge, Luokou Yellow River Railway Bridge, Dongguan Dongjiang Bridge[3-5].

Since trusses are mostly used in roof structures of buildings, trusses are often referred to as roof trusses. [6]Guangzhou New Baiyun International Airport terminal building adopts triangular arc-shaped truss structure with square and round tube space. The truss span is 76.9m, the spacing is about 18m, and the variable-section steel-tube herringbone column is used as the supporting member. The shape is light and beautiful, and the force is reasonable and reliable, saving material. The roof of

the second floor exhibition hall of Nanjing International Convention and Exhibition Center adopts an arc inverted triangular space tubular truss with a span of 75m and an upper chord radius of 125m as the supporting structure, and the arch frame is suspended at 14m, forming a large exhibition space with novel structure and magnificent atmosphere without intermediate columns. The steel shed of Sanmenxia Culture and Sports Center Stadium adopts space ortho-triangle truss structure with a height of 29.3m and a cantilever length of about 30m. Considering the tension of the upper chord of the shed and the bending characteristics of the lower chord, at the same time, the two chords of the lower chord are combined into one at the root of the support, so that the steel truss looks like feathers, and the shape is novel and beautiful.

3. Research status of Steel Pipe Truss

3.1. Research Status of Steel Truss with Circular Section and Rectangular Section

According to the section form of steel tube, hollow steel pipes can be divided into two types: round pipes and rectangular pipes. From 2007 to 2009, Liu Yongjian, Zhou Xuhong et al.[7-9] studied the design method of rectangular concrete-filled steel tubular truss joints, and completed the experimental research on the bearing capacity of 37 rectangular steel tubular concrete trusses X, T, Y and K joints. Combined with the nonlinear finite element numerical simulation calculation and parameter analysis, their paper further studies the bearing capacity of the concrete-filled steel tubular truss joints, the calculation of the length coefficient of the joints and the eccentricity of the joints, and gives the method of calculation of the rectangular concrete-filled steel tubular trusses and node loads.

In 2010, Liu Yongjian and Liu Junping[10] conducted a comparative study on the bending behavior of concrete rectangular and circular steel tubular trusses filled in the main pipe. In contrast to the failure mode, the node rupture occurs in the rectangular section truss, the empty pipe truss is the drum side failure of the pressure-bearing main pipe, and only the concrete trusses filled by the pressure-bearing main pipe and the main pipe of the tension and pressure are damaged by punching and shear. The tube truss with shaped section and the concrete truss filled with concrete only under compression occurred the bulging failure of the main side wall at the joint of the pipe, and the concrete truss filled with concrete in the pipe under tension and compression was the tensile fracture failure of the pipe under tension.

In 2013, Liu Liang[11] of Chang'an University studied the design of rectangular concrete filled steel tube composite truss continuous beam bridge. The research shows that the rectangular concrete filled steel tube composite truss continuous beam has obvious technical and economic advantages over the concrete box girder. After being popularized, it will bring remarkable social and economic benefits, and has a broad application prospect.

In 2018, Huang Yiqun, Yin Yue, Wang Zhen et al.[12] put forward a practical design method for the overall stability of rectangular section space steel pipe trusses. The upper string of the truss is used as the lattice-type axial compression member to calculate the stability of the space steel pipe truss in order to determine the overall stability bearing capacity of the space steel pipe truss.

To sum up, in the study of truss bearing capacity, there is no obvious difference in bearing capacity between the two kinds of section empty pipe trusses, but after filling concrete in charge, the overall and joint bearing capacity of circular section trusses is higher than that of corresponding rectangular section trusses. Square tube is a special form of rectangular tube. Under the same cross-sectional area, the bending performance of circular pipe is worse than that of square pipe, and the torsional performance of circular pipe is stronger than that of square pipe. Concrete-filled steel tube with circular cross-section is widely used in bridge structures because of its remarkable hoop effect. At the same time, the curve of the circular tube is smooth, and the effect of wind load and fluid load on the pipe is small, and the processing of the intersecting line is more complex than that of the square tube. With in-depth research, the overall stability of the steel pipe truss in rectangular cross-section space depends on the lateral stability of the winding, which has obvious technical and economic advantages and has broad application prospects.

3.2. Research Status of Rectangular Truss and Inverted Triangle Truss

According to the section of truss, the steel pipe truss can be divided into two types: rectangular truss and inverted triangular truss. In 2000, Liu Dianzhong and Liu Canjun[13] of Jilin University of Architecture studied the application of triangular steel pipe trusses. The research shows that the triangular space truss structure is developed on the basis of the grid structure, and compared with the grid structure, it has its unique advantages and practicability. The steel used in the structure is not large, and the structural rigidity and safety are large.

In 2009, Cai Jian, Chen Guodong et al.[14] conducted a comparative test on the models of long-span prestressed rectangular steel pipe truss, prestressed rectangular steel pipe truss and rectangular steel tube concrete truss. The results show that the ultimate bearing capacity of the truss with prestressed and filled concrete is increased and the deformation is reduced, and the local buckling of the compressed steel pipe is prevented by the filled concrete.

In 2014, Zhao Siyuan, Guo Yanlin and others[15] studied the out-of-plane stability performance of two-truss arch with inverted triangular section and fixed truss arch and the influence of member deformation on the out-of-plane overall stability performance of truss arch. The influence is reflected in the design equation of stable bearing capacity through two correlation coefficients, and according to the numerical results of finite element method, the design equations of axial force and bending moment bearing capacity of truss arch under full-span average cloth load or half-span water distribution load are proposed.

At present, most of the research on the overall stability of steel pipe truss structures focuses on the inverted triangular space steel tube truss. The ductility of the circular steel tubular truss with inverted triangular section and the performance of the steel capacity of the unit are the best. The space steel tube trusses used for long span trestle and pipe support are usually rectangular section, which has greater lateral stiffness and better overall stability compared with the inverted triangular section space steel tube trusses commonly used in civil buildings. However, because the lateral support can not be set up and needs to bear a certain lateral wind load, the rectangular section space steel pipe truss used in long-span trestle and pipeline support may still fail due to the loss of overall stability. In recent years, with the increase of structural span, the overall stability of spatial steel pipe trusses with rectangular section has been paid more and more attention.

4. Deficiencies and prospects of research on concrete-filled steel tubular trusses

The research and application of steel pipe structure in our country started relatively late, at the same time, there are few innovations in steel truss type selection in our country. The static performance of steel pipe truss structures is much studied, but the seismic performance under earthquake is less studied. More attention should be paid to the study of truss joints and stability, such as the study of intersecting joints[7]. The application of concrete-filled concrete reinforced concrete trusses for new polymer concrete is yet to be explored.

In this paper, a new type of concrete material, epoxy resin concrete, is applied to concrete-filled steel tube truss. Epoxy resin concrete[16] not only has the advantages of high strength, good toughness and high impact strength, but also has strong wear resistance, water resistance, chemical corrosion resistance and frost resistance. The bond strength with metal and non-metallic materials is high and the electrical insulation is good. It can be seen that epoxy resin is feasible in the application of concrete-filled steel tube trusses, which can be further studied and tested.

As the materials of steel pipe trusses are continuously updated and introduced, a growing number of scholars have conducted more in-depth research on their performance, and the factors perplexing their development will be gradually solved and perfected. Because the steel pipe truss has light weight, good mechanical properties and various shapes, it will have wider application prospects in the large-span spatial structure.

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