Stress on Steel-concrete Composite Truss Joints Research Status and Application Overview

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Abstract: Based on the comprehensive analysis of various stress research schemes for steel-concrete composite truss joints, the current research status of steel-concrete composite truss joints and epoxy resin concrete at home and abroad are systematically elaborated. The existing problems in the current composite truss joints are analyzed, and possible solutions are proposed. At present, the research on epoxy resin concrete has been very extensive. Epoxy resin concrete has high strength, good toughness, high impact strength, good chemical corrosion resistance, wear resistance, water resistance, frost resistance, tensile resistance and compressive resistance, which make it widely used in engineering. The problem of using epoxy resin concrete instead of ordinary concrete in steel-concrete composite truss is put forward, analyzed and discussed.

1 Introduction

With the continuous development of our country's economy and building technology, people's requirements for buildings are also gradually increasing. Among them, long-span space is also very important in structural design. If long-span structural members are not carefully planned, it will cause great waste and affect the use of building space. Steel trusses are often used in large-span spaces such as industrial plants, but their high cost will cause unnecessary waste to a certain extent. Therefore, steel-concrete composite trusses will be used in some large-span spaces. The steel-concrete composite truss organically combines two different materials of steel and concrete by shear connectors. On one hand, the upper chord and lower chord, which are mainly under pressure, are of concrete structure. The composite truss can reasonably utilize materials and exert the respective characteristics of materials. Compared with steel structures, it can greatly reduce the amount of steel products. At the same time, the structural rigidity is significantly higher than that of steel truss beams, which greatly reduces the engineering cost of truss beams. Moreover, only the web members are of steel structure, and the steel web members are alternately subject to tensile and compressive stresses. The maintenance and repair after use are also simpler and more convenient. On the other hand, adopting the form of combined truss can effectively reduce the height of the cross section and make its application range wider. At the same time, due to adopting the dragging construction scheme, the construction of combined truss is relatively simple [1,2]. The composite truss has better integrity and shear resistance, and enhances the overall stability and ductility. In the steel-concrete composite truss, the joint area is the key connection area of the members in its structural

system, connecting chords and web members, etc. Typical joint forms include lug plate type, external connection type and steel box type joints, each of which has its own advantages and disadvantages. In order to ensure the effective connection of the joint area, its internal force transmission path and failure mode are much more complicated than those of reinforced concrete joints or pure steel structure joints, and the mechanical properties of joint strength and stiffness have important influence on the overall stiffness, structural strength and stability of the structure. Therefore, the design of nodes is a key link. After years of development, the tensile and compressive properties of epoxy resin concrete are much higher than that of ordinary concrete. Under certain conditions, epoxy resin concrete can replace ordinary concrete in composite trusses, which not only can further reduce the engineering cost, but also can optimize the complex stress situation in the joint area of composite trusses. Therefore, the author discusses the stress situation of joints of steel-epoxy resin concrete composite trusses by replacing ordinary concrete with epoxy resin concrete.

2 The current research situation in this field at home and abroad

2.1 Research Status of Steel-Concrete Composite Truss Joints Abroad

Nodes of truss structures are divided into two categories according to the connection modes at the nodes: direct nodes and indirect nodes. Direct node refers to the connection of all members by welding, while indirect node refers to the connection with node plates without direct contact between all members [3]. The key of steel-concrete composite truss is to organize steel and concrete,

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two materials with different mechanical properties, to work together, and the node plays an important role. Nodes are the intersection of forces in the structure [4], and are the "joints" of composite trusses. Therefore, it is very important to ensure reliable performance of nodes. In the actual structure of steel-concrete composite truss joints, it is emphasized that the failure of the joints often leads to the failure of the structural members connected with the joints, which in turn leads to the failure of the whole structure.

Composite trusses have the advantages of high bearing capacity, good ductility and convenient construction, but the research on joints is relatively lagging behind. Many foreign scholars have carried out experimental research on steel-concrete composite truss joints and used them in some engineering practices, but their understanding of their working performance is relatively limited. At present, Japan has carried out systematic experimental research on the stress of composite truss joints, and there are many engineering examples of composite trusses, and many important results and conclusions have been obtained. Yoshihiro Nishiko [5] has carried out fatigue tests, static failure tests, etc. on a steel box joint, and obtained mechanical indexes such as ultimate bearing capacity, joint failure mode, load-displacement curve. of this type of joint. Toshio Nomura [6] conducted experimental research and theoretical analysis on an ear-plate joint, and adopted a new connector-PBL shear key. This type of node has been successfully applied to the construction of Ape Lany Bridge and Batuan Bridge. In contrast, there is less research in this field in our country at present, and the research on steel-concrete composite truss is still in the initial stage. It should be said that composite truss has broad research and application value.

2.2 Research Status of Steel-Concrete Composite Truss Joints in China

At home and abroad, there are generally three methods for joint research: experimental research, theoretical analysis and numerical simulation analysis. Static test and model test are usually used for joint test. The loading equipment required for static test is relatively simple, and some tests can be directly loaded with heavy objects. Model tests are often used to verify test results and infer design parameters of prototype structures or safety degree of structural design.

In the composite truss, the upper chord node at its support is in a very complicated stress state due to the intersection of internal forces of members and the staggered material interfaces. The key to the structural design of the whole truss is to effectively transfer the axial pressure of the concrete upper chord to the connected diagonal web members [7]. In order to obtain the stress situation of the upper chord joint of the composite truss, it is often necessary to study the failure process and characteristics of the joint under static load, so as to obtain the failure load, failure mode and distribution of stress and strain of the joint and then comprehensively analyze the stress.

In 2012, Zhou Lingyu and others [1,8,9] conducted experimental and theoretical research on the bearing capacity of the most critical upper chord end node in the composite truss to explore the reasonable structure and bearing capacity of the new composite node. It is believed that under static load, increasing the plate thickness of the node can effectively improve the bearing capacity of the node, while chord has relatively little influence on the bearing capacity of the node. He Guichao [10] found that the failure modes of the two main types of K-shaped composite truss joints are different after in-depth research on the force transmission mechanism and ultimate bearing capacity of the composite truss joints. The failure modes of external joints mainly include the following: (1) concrete cracking at the free end of chord; (2) Cracks appear in the bottom surface concrete of chords connected with the front end of the gusset plate due to stress concentration; (3) Slippage occurs at the joint of the tension web rod and the node plate bolt; (4) The joint plate at the joint between the rear end of the exposed joint plate and the compression web member is buckled and deformed. The failure modes of lug-plate gusset plate include: (1) concrete cracking in the middle of chord side; (2) Cracks appear in the concrete at the corner contact parts of chord and tension and compression web members; (3) There is a through crack in the concrete at the bottom of the chord between the tension and compression web members. Moreover, it puts forward the formula for calculating the shear bearing capacity of the joint under horizontal load, analyzes the force transmission path of the joint, obtains the correlation law between the shear distribution of PBL shear key group of steel-concrete composite connection and the slip of the joint plate and concrete, and analyzes the parameters affecting the bearing capacity.

2.3 Summary and Analysis of Current Situation

Based on the above analysis, it is concluded that the static bearing capacity of steel-concrete composite truss joint is an important index for joint design and analysis. The composite truss joint has good ductility and sufficient strength. The failure modes of external joints in the main composite truss joints are tearing failure of joint plates at tension web members and buckling deformation of joint plates at compression web members. The main failure mode of lug plate joint plates is cracking failure of chord concrete under bending and shearing, and the failure mode is mainly compression web members. From the failure forms of the joints, it can be analyzed that there is a certain degree of stress concentration in both types of K-joints. Through appropriate structural improvement, stress concentration can be reduced, but it is difficult to completely eliminate. It can also be seen from the failure mode of the joint that the intuitive characteristics of the stress analysis of the composite truss joint include large cracks in concrete members and large deformation of steel members, which is convenient for qualitative analysis of the joint stress.

3 Research Status of Epoxy Resin Concrete at Home and Abroad

3.1 Research Status of Epoxy Resin Concrete

Epoxy resin concrete is a kind of polymer concrete. Different from ordinary concrete, its cementing material is synthetic resin. In the 1930s, Cresson, an Englishman, applied natural latex materials to the modification of road materials. In the 1950s, foreign countries began to study the performance of epoxy mortar, and the United States used this kind of polymer concrete to repair and reinforce buildings in practical projects. In the 1970s, polymer concrete was used to repair Portland cement concrete components, mainly highway and bridge components. The United States, Europe and Japan have been at the forefront of research in the field of polymer concrete standardization, and have done a lot of experimental and theoretical research on the material properties related to epoxy resin concrete. In contrast, the research work in this field in our country is still very little, and the research on epoxy resin concrete is still in the initial stage, so the research and application prospect of epoxy resin concrete are still very wide. At present, there are mainly five research directions for epoxy resin concrete.

- (1) Research on epoxy resin concrete in structural reinforcement, renovation and repair:
- (2) Study on gradation of epoxy resin concrete under different design strength requirements:
- (3) Research on various physical and chemical properties of epoxy resin concrete under the influence of different factors:
- (4) Research on epoxy resin materials:
- (5) Economic research on epoxy resin concrete.

At present, the research on epoxy resin concrete in our country focuses on its application in bridge and road repair. In recent years, the state has vigorously promoted fabricated buildings, and epoxy resin concrete has attracted much attention due to its excellent material properties. Zhou Mei et al. [11] from the Department of Soil and Wood of Liaoning University of Engineering and Technology have explored the influence of filler types and dosage on the strength of epoxy resin concrete. Through experiments, they have studied the influence of different types of fillers and their dosage on the shear strength of epoxy resin concrete, and on this basis, they have studied the influence of different fillers on the tensile strength and compressive strength of epoxy resin concrete. Zuo Lian et al. [12] of Northwestern Institute of Nuclear Technology perfected the preparation method of high-strength epoxy resin concrete, analyzed the influence law of different material dosage on the strength of epoxy resin concrete, and obtained the mix proportion of epoxy resin concrete with relatively high compressive strength.

Huang Yutong and others from the School of Civil Engineering and Communications of South China University of Technology [13] have studied the early-age compression performance of epoxy resin concrete. Through the quasi-static compression performance test method, they believe that the elastic modulus of epoxy resin concrete increases continuously and the stiffness

increases gradually during curing. For epoxy resin concrete of different ages, the shape of the stress-strain curve is similar as a whole. Elastic modulus is an important mechanical property of concrete, which reflects the relationship between stress and strain of concrete and is an important design parameter in concrete structure design. The elastic modulus of concrete affects the results and rationality of structural design, which is also one of the necessary parameters for calculating the deformation, cracks and temperature stress of mass concrete structures. Under the same compressive strength of epoxy resin concrete and ordinary cement concrete, the elastic modulus of epoxy resin concrete is smaller than that of ordinary cement concrete. Therefore, under the same load, the deformation of epoxy resin concrete is larger than that of ordinary cement concrete, that is, the toughness of epoxy resin concrete is better than that of ordinary cement concrete [14-16]. In the test of Huang Yutong et al. [13], it is found that the compressive strength of epoxy resin concrete increases with the increase of curing time. In the first 24 hours, the strength increases faster, and the compressive strength reaches 91% of the strength after curing (curing for 72 hours). When curing for 72 hours, the compressive strength of epoxy resin concrete reaches 55.2MPa.

3.2 Application Status of Epoxy Resin Concrete

In recent years, epoxy resin concrete has been widely used in various engineering fields, especially in structural reinforcement.

The application of epoxy resin concrete in building reinforcement is mostly to quickly repair cracks and the like in concrete buildings, or to replace common concrete with epoxy resin concrete to reinforce and fix components with enlarged cross sections, and also to rectify floor defects. According to different construction technologies, epoxy resin concrete materials are divided into scraping type and pouring type [17,18].

Another important application field of epoxy resin concrete in engineering is bridge engineering [19]. Bridge is a civil engineering subject to great stress. A large amount of prestressed reinforced concrete is used in the manufacture of the bridge. Due to long-term vibration, gaps will occur between adjacent prestressed reinforced concrete on the bridge foundation. In order to prevent this situation, epoxy resin concrete with high initial adhesive strength can often be used to bond the bridge into a whole. At the same time, it can be used for the construction of bridge expansion joints. Because epoxy resin concrete has the characteristics of high strength and high impact strength, when epoxy resin concrete is used for filling between the beam body and the rubber expansion body, it can better solve the "bump" phenomenon of vehicles passing through the bridge expansion joints.

In the actual application process of epoxy resin concrete, it is often necessary to select different filling materials according to the construction requirements. The main function of filler is to improve the performance of epoxy resin concrete, reduce the amount of epoxy resin and reduce the cost. For example, the strength can be

improved by adding quartz powder, etc. See Table 1[20] for the specific filler and its effect.

Table 1 List of Common Fillers

Packing name	Effect
Quartz powder, porcelain powder, iron powder, cement, carborundum	Increase hardness
Asbestos powder, quartz powder, stone powder	Reduce shrinkage
Emery and other abrasives	Improve wear resistance
Asbestos fiber, glass fiber	Increase toughness and impact resistance
Alumina, porcelain powder	Increase adhesion and mechanical strength
Aluminum powder, copper powder, iron powder and other metal powders	Increase thermal conductivity and electrical conductivity
Mica powder, porcelain powder, quartz powder	Increase insulation performance
Various pigments, graphite	Have color

3.3 Summary of Current Situation of Epoxy Resin Concrete

Epoxy resin concrete has high strength, good toughness, high impact strength, good chemical corrosion resistance, wear resistance, water resistance and frost resistance. The cured epoxy resin concrete has strong resistance to atmosphere, humidity, bacteria and chemical media. Moreover, the epoxy resin concrete has short strength forming time and high early strength, and is suitable for repairing cement concrete pavement, engineering rush repair and the like. Epoxy resin concrete has become one of the building materials with the fastest development in research and application due to its remarkable application effect in recent years, the problem of forming steel-epoxy concrete composite trusses by replacing common concrete in steel-concrete composite trusses with epoxy concrete will be discussed.

4 steel-epoxy resin concrete composite truss

4.1 Advantages of Steel-Epoxy Resin Concrete Composite Truss

The connection status of steel-concrete composite truss determines the overall performance of the composite structure, and the treatment of joints is the key point in the design of the composite structure. In steel-concrete composite trusses, concrete chords and steel web members are connected by metal connectors such as gussets and studs, which have more advantages over pure reinforced concrete structures and steel structures, but it is difficult to overcome some inevitable disadvantages. For example, metal shear connectors are easy to induce

internal cracks in concrete, and excessive welding between metal connectors and steel will affect the fatigue performance of composite trusses. In addition, due to the discontinuous transmission of interaction between steel and concrete caused by metal connectors, theoretical analysis will be difficult. There is a certain degree of stress concentration at the joints of composite trusses, which will also affect the stability of the joints. Therefore, the author hopes to use the excellent adhesive property of epoxy resin concrete to improve this.

Different from traditional composite trusses, steel-epoxy concrete composite trusses using epoxy resin concrete can be bonded and combined with steel web members by using the adhesive property of epoxy resin concrete to play an integral role. This connection mode has more advantages. On the one hand, large-volume bonding layer can make the transfer of shear force between steel and concrete become continuous, the distribution of bonding stress is more uniform, and the stress on the interface layer is more reasonable. On the other hand, there will be no stress concentration at the joint of the composite truss. In recent years, scholars at home and abroad have carried out some theoretical and experimental studies on some "glued" composite structures. A.Si Larbi[21] et al. found through push-out tests and finite element analysis that the glued joint composite structure has very high rigidity, and the application of low elastic resin can reduce the brittle behavior of concrete without greatly reducing the strength. B.Jurkiewicz[22]] et al. found through three-point bending static load test that the glued concrete composite beam can have larger plastic strain without shear failure under the condition of reasonable design. Wang Yuqiang et al [23] established a three-dimensional nonlinear finite element model by using spring elements to simulate the adhesive interface layer, studied the bonding stress and failure process of adhesively connected steel-concrete composite beams, and found that the adhesive with small elastic modulus is beneficial to shear force transmission. However, the elastic modulus of epoxy resin concrete is lower than that of ordinary concrete, which also provides a basis for the application of epoxy resin concrete in composite trusses to optimize the joint stress.

Epoxy resin concrete also has more excellent tensile and compressive properties than ordinary concrete, so the number and size of reinforcement can be appropriately reduced when making chord, which can save cost and has certain advantages in economy.

4.2 Further Prospect of Steel-Epoxy Resin Concrete Composite Truss

Steel-epoxy resin concrete composite truss will still have many problems in future practical application, mainly reflected in the following aspects:

(1) In this paper, the joint is taken as the research object, but the analysis of the steel-epoxy resin concrete joint is not sufficient. The stress and deformation of the joint are complicated, which needs further research and analysis.

(2) There are many factors that affect the bearing capacity at the joint, including the diameter of the penetrating steel bar, the discharge position, the concrete tenon area, the joint plate aperture size, the epoxy resin concrete strength, etc. As the stress at the joint is complex, the stress relationship after the joint is connected by gluing needs to be further determined.

5 Conclusion

Epoxy resin concrete has high tensile, compressive and adhesive properties. If the concrete is applied in the steel-epoxy resin concrete composite truss, the stress concentration phenomenon at the joints can be reduced to a certain extent, so that the integrity of the composite structure is stronger, the usage amount of steel can be reduced, and the cost can be saved to a certain extent. Epoxy resin concrete has high strength, good toughness, high impact strength, good chemical corrosion resistance, wear resistance, water resistance, frost resistance and other properties, which can also improve the overall stability of the composite truss. Therefore, the research value and application prospect of steel-epoxy resin concrete composite truss are very extensive.

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