

Research Status and Development Prospect of Steel Truss Bridge Joints

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Abstract. In recent decades, with the increasing demand of long-span bridges and the continuous progress of construction technology, steel truss bridges have been more and more widely used. In general, the joint form of steel truss bridge can be divided into two types: splice joint and integral joint. The selections of the joint forms in steel truss bridges have gradually become the focus of the designers and researchers. Based on the engineering cases of steel truss bridges, this paper introduces the characteristics and advantages of the splice joint and the integral joint, respectively. The engineering performances of these two kinds of joints are compared under the same working condition. The corresponding conclusions on joint selection are obtained, and the prospect of joint design for steel truss bridges is proposed.

Keywords: Steel Truss Bridge, Splice Joint, Integral Joint.

1. Introduction

Truss bridge refers to the bridge with truss as the main bearing component of the structure. It is innovated from the simplest girder bridge. The bridge types developed from truss bridge include cantilever bridge and truss arch bridge, which play a very important connecting role in the development of modern bridge technology. Steel truss bridge is mainly composed of upper chord, lower chord, web member, longitudinal and transverse beam, upper horizontal longitudinal connection and bridge portal frame. It has the advantages of simple joint form and simple structure shape; High stiffness and good geometric characteristics; good compression and torsion resistance; simple construction and material saving; conducive to rust prevention, cleaning, maintenance, repair and other work. The pipe truss structure with circular pipe section has the advantages of good hydrodynamic characteristics [1]. As a result, it is widely used in railway and highway construction.

The development of steel truss bridge in China can be traced back to the 19th century. In 1894, the Luanhe River Bridge, Chinese first railway bridge, was constructed under the auspices of engineer Zhan Tianyou. However, at that time, owing to the limitation of technical conditions, its structure used rivets, and the process was also extremely simple. In the first half of the 20th century, standardized steel truss bridges and long-span continuous truss bridges appeared one after another, and steel truss bridges began to enter the stage of history. In the 1990s, the technology of welding integral joints and splicing outside joints was first adopted in the construction of Sunkou Yellow River Bridge on Beijing Kowloon Line in China; The unequal thickness butt welding of main truss members is realized for the first time; the steel beam is manufactured by finish machining with the edge is no longer machined for the first time as well. Benefit from the dedication of technical workers and manual workers, these new technologies were born and widely used in many projects. The Sidu River Bridge, Dongxin Ganjiang bridge, Zhengxin Yellow River Bridge and Hutong Yangtze River Bridge under construction all adopted these technologies. Especially, the Wuhu Yangtze River Bridge was constructed under these technologies and it was regarded as a landmark building. By the way, Wuhu Yangtze River Bridge is the largest highway railway dual-purpose bridge with the largest span and scale built at the end of this century [2]. The famous steel truss bridges in China are shown in Table.1.

Table.1. Famous steel truss bridges in China

Year	Name of bridges	Length / m
1894	The Luanhe River Bridge	670.6
1966	The Qushui Bridge	300
1995	Sunkou Yellow River Bridge	3556
2000	Wuhu Yangtze River Bridge	6078.4

In the development and application of steel truss bridges in China, joint welding technique is particularly important. The joint types of steel truss bridges are mainly divided into splice joint and integral joint. There are many complex steel truss structures and truss members, so the bridge structure should be fully considered [3]. The joint of steel truss bridge is not only the place where the main truss members meet, but also the place where the longitudinal members and beams are connected with the main truss. It plays an essential role in the mechanical performance of the whole steel truss bridge. Choosing the appropriate joint does great contribution to reduce the cost and optimize the construction of steel truss bridge. Recently, profit by the popularization of computer technology, more and more kinds of finite element software were born, and the joint technique of steel truss bridge also made continuous progress. Under the joint action of experience summary and modeling analysis, the joint technology of steel truss bridge has been improved to a new level.

Based on the analysis of the splice joints and integral joints in steel truss bridges, this paper mainly compares the structural design, mechanical properties, and economic benefits of the two joints, and the results show that the comprehensive performance of the integral joints is better than that of the splice joints.

2. The joint technology

2.1 Splice joint technology

Splicing technology is that the main truss member and the welded integral joint are connected into one outside the joint through high-strength bolts. Splice joint is to set gusset plates on both sides of the member, and then splice the web member and chord to the gusset plate with high-strength bolts. The splice joint has the advantages of simple structure, convenient splicing, no special requirements for welding process, less processing difficulty and less influence on the joint rigid region. In construction, splice joints have the advantages of convenient operation, fast construction speed, less on-site construction operation and less environmental pollution, which meet the requirements of the concept of sustainable development. Although its operation is simple and greener, in the actual construction process, affected by the accuracy of torque wrench, the discreteness of bolt quality, human operation error or negligence, the real preload of bolt may not reach the installation requirements, which is bound to affect the stress of each plate of joint splicing joint. The schematic diagram of splice joint is shown in Figure 1.

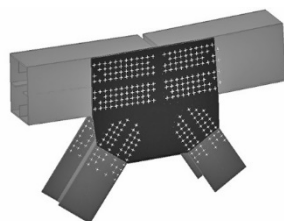


Figure 1. The splice joint

Because the construction quality of splice joints is difficult to be effectively guaranteed, many steel truss buildings often fail to meet the requirements of relevant technical standards in manufacturing and construction, and cannot ensure the safety, applicability and durability of the structure at the same time [4-5]. During the construction of steel truss bridge, the weld line produced by splice joints often becomes the weak link of steel structure. At present, the domestic team led by Professor Wang Yuanqing and foreign Yi Liu and Liam Gannon have done some research on welding

and strengthening steel beams under load. However, there is little research on welded splice joints strengthened by welding under load at home and abroad. As a result, more and more attention has been paid on the reinforcement and reconstruction of splice joints. How to reduce the reinforcement construction cost and improve the construction efficiency while ensuring the structural safety, applicability and durability has become the goal of the scientists.

2.2 Integral joint technology

The integral joint of truss bridge means that the gusset plate is welded with the chord at one end to form a whole, and its main truss gusset plate becomes a part of the chord [6]. The integral joint is to weld the plate connecting the web member and chord into a whole in the factory at first, weld the chord and web member with the gusset plate or splice them on the gusset plate with high-strength bolts. The integral joint bolt is few, the structural appearance is simple and beautiful, easy for industrial production, easy for on-site construction. And it can also ensure the construction quality, improve construction conditions and labor intensity. The application of integral joint technology improves the industrialized manufacturing degree of steel beams, facilitates on-site installation and improves on-site working conditions. According to statistics, the use of integral joints saves 34% of high-strength bolts compared with normal bolt welded structural steel beams, so as to obtain better economic benefits [7]. Its advantage is that the steel section can be fully utilized by increasing the plate thickness of the gusset plate; for the butt joint connection between the integral joint and other members, the size of the small point plate can be reduced; both ends of the weldment are butt jointed on the thick gusset plate of the main truss, which reduces the material length of the rod and is convenient for ordering and transportation from the steel factory. The integral joint structure of steel truss can not only improve the industrialized manufacturing degree of steel girder, facilitate site installation, but also have good economic benefits. Compared with the traditional splice joint, the integral joint has advantages in the distribution of joint stress and the workload of site assembly, and has been widely used in the design of steel truss bridges. The schematic diagram of integral joint is shown in Figure 2.

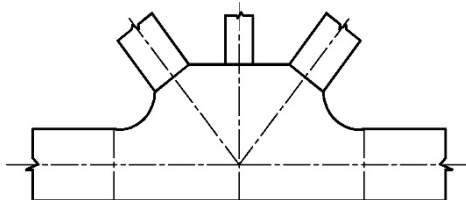


Figure 2. integral joint

The integral joint has obvious advantages in industrial production, connection structure, on-site construction, appearance aesthetics and so on. Due to its material saving and good integrity, it is gradually favored by engineers. In China, more and more integral joints appear in the design and construction of steel truss bridges. However, the integral joint also has its disadvantages [8-10]. The integral joints are mostly welded structures with complex structures and dense weld lines, including various butt weld lines and fillet weld lines. For the long-span steel bridge with integral joints, since it bears large dynamic load and the structural stress is complex, the joints are prone to fatigue problems [11-12].

The analysis of the mechanical properties of the integral joint is a complex work as well. Recently, the model test method is generally used to evaluate the integral joint resistance [13]. Solid model test is helpful to grasp the actual stress condition of weld lines and geometrically complex parts, but the test costs a lot, the period of the test is long, and it is greatly limited by the surrounding situation and equipment. The space finite element simulation calculation has no these limitations, and can provide a theoretical basis for the test. At present, the theory of using ABAQUS to establish solid model for analysis is becoming more and more perfect. Taking some long-span steel truss bridges as the engineering background, this paper studies the modeling, analyzes the stress and strain of the integral

joint under different loads, and analyzes its antifatigue load performance, so as to provide a theoretical basis for future construction [14].

Overall, it can be clearly seen that in a large number of steel truss bridge engineering cases, the research results show that the integral joint stiffness has little effect on the axial force and deflection of steel truss members in the construction stage. Besides, it has a great influence on the combined stress at the end of the member and the secondary bending moment at the end of the member, especially on the flexural member. As a result, in the process of dragging construction of steel truss bridge, the influence of integral joint stiffness on the mechanical performance of steel truss bridge should be fully considered. Further optimizing the structure of the integral joint, optimizing the algorithm of modeling and analysis, and looking for lighter and higher strength materials may become a new direction of the application of the integral joint [15-16].

3. Discussion and Conclusion

Combined with engineering cases and theoretical analysis, the engineering performance of splice joints and integral joints is compared and analyzed from the following three aspects.

(1) In terms of structural design: the structure of spliced joints is simple, and high-strength bolts are mainly used as connections, resulting in greater uncertainty in the construction quality of steel truss bridge, which is restricted by operating tools, bolt quality, human operation and other uncertain factors. On the integral gusset plate, the section webs of all members are integrated in the joint area, and the whole joint is directly spliced and butt welded with the full section of chord or web member to become a part of the members, which is the main structural feature of the integral joint different from the splice joint. The number of bolts required for the integral joint is less, and the welding technique is widely used, which reduces the labor intensity and is easier for construction, production and quality assurance.

(2) In terms of mechanical properties: compared with the splice joint, the spliced section between the integral joint and the member is far from the complex joint stress area, the fatigue strength of the welded joint is easy to be guaranteed, and the material strength of the chord and web section plate can be brought into full play. In the numerical simulation of a large number of steel truss bridge engineering cases, the maximum stress and maximum bending moment at the spliced joint are significantly higher than those at the overall joint. Therefore, the overall joint is more reasonable in stress distribution and is more conducive to the durability of truss structure.

(3) In terms of economic benefits: because the splice joint needs larger plate size and more high-strength bolts; the integral joint benefits from more and more sophisticated welding technology, which effectively saves the required member length and the cost of plate surface with high-strength bolts. In addition, when order and transport materials from the factory, it can also reduce the freight and raw material consumption to a certain extent. From these two aspects, the use of integral joints can improve economic benefits effectively.

However, splice joint is not useless. The use of splice joint in some specific steel truss structures can also facilitate the operation of constructors and speed up the construction speed. Besides, the price of integral joint is more expensive and the mechanical performance of it is more difficult to study. In conclusion, compared with traditional splice joint, welded integral joint have obvious advantages. In design and construction of steel truss bridge, the use proportion of integral joint should be appropriately increased, so as to optimize the stress distribution of steel truss as much as possible while saving construction materials and reducing costs, which is conducive to future maintenance and repair. On account of the rapid progress of integral joint technique, the steel truss bridges in China are more and more stable and durable.

In the joint design of steel truss bridge in the future, it is an irreversible trend to use a large number of integral joints. More finite element software can be combined to simulate and optimize the joint design of steel truss bridge, so as to make its seismic and other mechanical properties more stable. Searching for more easily available high-strength materials is also a practical way to further reduce

costs and save raw materials. So as to meet the requirement and development of steel truss bridges in China.

At last, some suggestions on the research of joints are put forward:

(1) Based on the actual engineering cases, aiming at the quality problems of steel truss beam splice joints caused by weld construction, a feasible welding reinforcement scheme is proposed. The number of welds should be controlled as small as possible.

(2) The finite element software should be used to simulate and analyze the mechanical performance of the joints of in strengthened steel truss beam. Doing such simulation in advance can help to avoid stress concentration on joints.

(3) Compare and analyze the numerical simulation data of finite element software with the measured data of strain gauge at the welded joint of steel truss beam, and select a more reasonable method to weld and strengthen the welded joint of steel truss bridge.

References

- [1] Wang Tianliang. Test study of integral panel points of steel truss girder [J]. *Bridge Construction*, 1999(4): 32-40.
- [2] Guo Zhaoqi, Li Junping, Wang Suili, Ma Lifen. The fabrication of steel girders with integral joints for Wuhu Yangtze River Bridge [J]. *Steel Construction*, 2001, 16(51): 31-33.
- [3] Zhu Ming . Construction technologies of a large span steel truss [J]. *Steel Construction*, 2006, 21(4): 84-87.
- [4] J. A. Packer. Concrete-filled HSS connections [J]. *Journal of Structural Engineering*, ASCE, 1995, 121(3): 458-467.
- [5] Liu Yongjian. Experiments on ultimate bearing capacity and research on design method of joints of concrete-filled rectangular steel tube truss [D]. Changsha: Hunan University, 2003.
- [6] Cheng Shuai, Wang Huili, Han Jialun, Zhang Junlin, Ma Xingliang, Huang Zhou. Review of the study of integral panel points of steel truss girder [J]. *Steel Construction*, 2009, 27(6): 1-4.
- [7] Huang Yong-hui, Wang Rong-hui, Gan Quan. Experiment on welding residual stress of integral joint for steel truss bridge [J]. *China Journal of Highway and Transport*, 2011, 24(1): 83-88.
- [8] Volkhard Angelmaier. Tubular steel bridges with cast steel nodes innovative solutions in modern bridge design [D], Germany: 2004.
- [9] Alistair Grieg, Susana Rivas. Welding automation in space-frame bridge construction [D]. London: Department of Mechanical Engineering, University College London, 2001.
- [10] Van Bogaert. Stability and node-detailing of tubular steel arch bridges [D]. Belgium: Ghent University, Civil Engineering Department, 2007.
- [11] Ying Shuhui, Wang Huili, Qiu Wenliang. Numerical simulation analysis of fatigue property of steel truss integral joint [J]. *Steel Construction*, 2013(05), 15-18.
- [12] Liu Gao, Wu Wenming, Tang Liang, Wang Tianliang. Fatigue test on integral joint of the main truss of the Baling River Bridge [J]. *Highway*, 2010, 3(3): 96-100.
- [13] Qiao Jinfei, Li Feng-qin. Study and design of integral joints and detailed structures of steel truss girder [J]. *Journal of Railway Engineering Society*, 2009(8): 68-72.
- [14] Pan Zhe. Fatigue properties analysis of the overall node of steel truss bridge [D]. Dalian: Dalian University of Technology, 2012.
- [15] Zhang Jianmin, Gao Feng. Optimum analysis of steel truss integral joints [J]. *China Railway Science*, 2011, 22(5): 89-92.
- [16] Li Zhaoxia, Li Aiqun, Tommy Chan Hungtin, Guo Li, Zhou Taiquan. Finite element modeling for health monitoring and condition assessment of long-span bridges [J]. *Journal of Southeast University*, 2003, 33(5): 563-572.