

# Application Prospect of Shear key Built in Steel Pipe Sleeve Grouting Connectors

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## Abstract

The research team studied a steel pipe grouting connection method with favorable application scenarios and mechanical properties. By installing three types of shear key—annular, parallel spiral and cross spiral—inside the steel pipe sleeve grouting connector, the problem of limited application of traditional connection methods was solved. Based on experimental research, finite element simulation and theoretical analysis, this paper summarizes relevant research results at home and abroad, verifies the feasibility of this connection method, and analyzes its mechanical advantages. It is concluded that this connection method is suitable for the complex stress requirements in multiple fields, with convenient construction and controllable cost, boasting broad engineering application prospects and providing technical support for the high-quality development of steel structures.

## Keywords

Shear key, steel pipe, Composite stress, Connection joint.

## 1. Introduction

Steel pipe structures are widely used in construction, bridges, marine engineering, wind power facilities and other fields due to their advantages such as light self-weight, high bearing capacity, excellent seismic performance, high construction efficiency and environmental protection. They have become one of the core structural forms promoting the industrialization of the construction industry and green low-carbon development. As the core stress components of steel structures, the performance of connection joints directly determines the safety and durability of the entire structure. With the increasing complexity of engineering scenarios, the limitations of traditional steel pipe connection methods have gradually become prominent.

Among traditional connection methods, welded connection features high strength but strict construction requirements, poor adaptability to special environments and environmental pollution; flange connection allows convenient disassembly but consumes more materials, has high cost and limited application scope; bolted connection offers flexible construction but low stiffness, weak resistance to composite loads and poor durability; ordinary sleeve connection lacks effective shear components and is only applicable to simple axial stress scenarios. In addition, the traditional stiffening ring connection cannot adapt to the composite stress conditions of axial force, bending moment and torque, making it difficult to meet the needs of high-end engineering.

In response to the above limitations, the research team has developed a steel pipe sleeve grouting connection method with built-in shear key. Integrating the convenience of sleeve connection, the integrity of grouting connection and the shear advantage of shear key, this method can bear composite loads simultaneously and adapt to various special environments, providing a new path for the high-quality development of steel structures. Based on domestic and foreign research and the experimental results of this project, this paper systematically

analyzes the feasibility and application prospects of this method, providing support for its engineering promotion.

## **2. Research on Connection Methods of Concrete-Filled Steel Tubes by Scholars Worldwide**

Concrete-filled steel tube (CFST) structures combine the excellent properties of steel and concrete, and their connection methods have long been a research focus of scholars at home and abroad. Relevant research results have laid a solid foundation for the research and development of shear key-type grouting connections, and also highlighted the deficiencies of current research.

Foreign research started early, focusing on the connection optimization for complex engineering scenarios. Paul Dallyn et al. [1] found through monitoring that the grouted connections of large-diameter ordinary pipes for offshore wind power in Europe have axial displacement and severe wear, providing a practical basis for the setting of shear key; Ziquan Dai et al. [2] verified the good bending stiffness and ductility of shear key-controlled grouting sleeves under bending loads, which are suitable for steel modular buildings. Domestic research, combined with engineering practice, has achieved fruitful results. Zhong Weiqiu et al. found that shear keys can significantly improve the connection bearing capacity, and triangular and rectangular shear keys bear forces more evenly; Huang Liwei et al. proposed that double-sided shear keys can reduce the slip amount, bottom grouting method can improve compactness, and recommended the optimal size of shear keys as 6~8mm in height and 10~15mm in width; Li Wei et al. confirmed through comparative tests that the bearing capacity and ductility of specimens with shear keys are far superior to those without shear keys, and the failure mode changes from bond slip to grout crushing.

Xian Wang, Tao Chen et al. [3] pointed out that water intrusion will deteriorate the fatigue performance of grouted connections; Chen Tao et al. studied the failure modes of grouted connections for offshore wind turbines and clarified the influence of manufacturing quality on performance; Wu Liwei et al. verified the reliability of sleeve grouting connections in precast CFST composite shear walls, whose mechanical response is equivalent to that of cast-in-place structures; Chen Jianwei et al. studied the seismic performance of CFST shear walls, providing a basis for the design of similar structures. Chen Dejin, Zha Xiaoxiong et al. [4] carried out research on the bending performance of internal and external flange connection joints of CFST, optimized the structural design of flange connection through experiments and theoretical analysis, improved the bending bearing capacity of joints, and provided a reference for the performance optimization of traditional flange connection. Meng Fulei, Li Xiong et al. [5] studied the rapid assembly connection technology of CFST column ring beam joints, focusing on the improvement of construction efficiency, and providing technical support for the industrial construction of steel pipe connections in prefabricated buildings; Ye Dan, Huang Ling et al. [6] developed corresponding anti-seismic devices and their application methods for the anti-seismic needs of deck-type CFST arch bridges, involving the optimal design of steel pipe connection joints, which further expanded the application scenarios of steel pipe connection methods.

Chen Baochun, Mu Tingmin et al. [7] systematically summarized the research progress and engineering application of steel-concrete composite structure bridges in China, pointing out that CFST structures are increasingly widely used in bridge engineering, the performance optimization of connection joints is the key to promoting their development, and emphasizing the important significance of the research and development of new connection methods for the high-quality development of steel structures; Liu Wei [8] carried out research on the working

mechanism of CFST under local compression, providing a theoretical basis for the stress analysis and structural design of steel pipe connection sections.

In summary, existing research has fully affirmed the role of shear keys, but most focus on axial compression and eccentric compression conditions, with insufficient research on the composite stress of compression-bending-torsion. In addition, most shear key are annular, and the stress mechanism and design method of spiral shear keys still need to be improved, which provides a clear research entry point for this project.

### **3. Feasibility of This Project**

This project focuses on the research and development of a new connection method with shear key built in steel pipe sleeve grouting connectors. In response to the problems of limited application and insufficient composite stress performance of traditional connection methods, three connection forms are proposed: annular shear keys, parallel spiral shear keys and cross spiral shear keys. Through systematic experimental research, finite element numerical simulation and theoretical formula derivation, the feasibility of this new connection method is verified, its mechanical performance advantages are clarified, and solid technical support is provided for engineering application. The feasibility of this project is mainly reflected in four aspects: technical feasibility, experimental feasibility, theoretical feasibility and engineering application feasibility, with specific analysis as follows.

#### **3.1. Technical Feasibility**

The three shear key connection forms proposed in this project are all optimally designed based on the existing research results of steel pipe sleeve grouting connection technology and shear key, combined with actual engineering needs, with a mature and feasible technical route. As a widely used form of shear connector at present, the annular shear key has the advantages of simple structure, convenient manufacture and clear force transmission, and has been applied in many engineering scenarios. The relevant design methods and construction technologies are relatively mature, which can provide a reliable technical foundation for the project research.

Parallel spiral shear keys and cross spiral shear keys are new types of shear key optimized and developed on the basis of annular shear keys in this project, whose core advantage is simple manufacturing process and effective adaptability to complex composite stress scenarios. Among them, the parallel spiral shear key is arranged with a single spiral line, featuring a symmetrical structure, which can transfer loads evenly and reduce stress concentration; the cross spiral shear key is arranged with double spiral lines crossing each other, which further enhances the shear and torsion resistance of the connection section and can better adapt to the working conditions bearing axial force, bending moment and torque at the same time. The manufacture of the two types of spiral shear keys does not require complex processing equipment and can be realized through conventional mechanical processing. They have good adaptability to sleeves and steel pipes during construction and can form a firm whole with grout, ensuring the integrity and stability of the connection.

In addition, this project adopts a multi-dimensional analysis method integrating experimental research, finite element numerical simulation and theoretical formula derivation. Among them, the finite element simulation uses mature numerical analysis software, which can accurately simulate the stress state, deformation law and failure mode of connection joints under different load conditions, effectively making up for the limitations of experimental research; the theoretical formula derivation is based on the basic principles of material mechanics and structural mechanics, combined with the deformation coordination relationship of steel pipes, sleeves and grout, which can construct a scientific and reasonable bearing capacity calculation model and provide theoretical support for the design of connection methods. The above

technical methods are all maturely applied in the industry, which can ensure the smooth progress of the project research and fully reflect the technical feasibility of this project.

### 3.2. Theoretical Feasibility

Based on the results of experimental research and finite element simulation, and according to the deformation coordination relationship of steel pipes, sleeves and grout in the grouted connection section, this project constructs a theoretical calculation model of bearing capacity suitable for steel pipe sleeve grouting connections under axial compression, eccentric compression and compression-bending-torsion composite stress states. The theoretical derivation process is scientific, reasonable and logically rigorous, with strong theoretical feasibility.

At present, the calculation formulas for the bearing capacity of sleeve grouting connections in foreign codes are mostly obtained based on experimental regression, with great application limitations, making it difficult to adapt to complex composite stress scenarios and restricting the popularization and application of steel pipe grouting sleeve connections. The theoretical calculation model of this project breaks through the limitations of traditional formulas, fully considers the stress mechanism of shear keys, the stress state of grout, and the interaction between steel pipes, sleeves and grout. Combined with the constitutive relationship of materials and deformation coordination conditions, the bearing capacity calculation formula is derived through theoretical derivation, which can accurately predict the bearing capacity of connection joints under different stress forms.

At the same time, this project verifies and optimizes the theoretical calculation model combined with the finite element simulation results to ensure the accuracy and applicability of the model. Finite element analysis can accurately simulate the internal stress distribution, strain change and crack propagation process of connection joints, providing important numerical support for the derivation of the theoretical model; by comparing the theoretical calculation results with the experimental results and adjusting the model parameters, the theoretical calculation values are in good agreement with the experimental values, further improving the theoretical calculation model. In addition, this project also proposes connection design processes and methods for different stress conditions, providing clear theoretical guidance for engineering design and fully reflecting the theoretical feasibility of this project.

## 4. Conclusions

Based on the research results of scholars at home and abroad on the connection methods of CFST, as well as the experimental research, finite element simulation and theoretical analysis of this project, this paper systematically discusses the application prospects of shear key built in steel pipe sleeve grouting connectors, and draws the following conclusions:

First, the connection method with shear key built in steel pipe sleeve grouting connectors effectively breaks through the limitations of traditional steel pipe connection methods, solves the problem of limited application of traditional bolted connection, flange connection, welded connection and other methods in complex stress scenarios and special environments, and has excellent mechanical properties and wide applicability. By installing three types of shear key—annular, parallel spiral and cross spiral—inside the connector, this method can significantly improve the bearing capacity, shear resistance, slip resistance and ductility of the connection section, bear composite loads such as axial force, bending moment and torque at the same time, and adapt to the stress requirements of various complex engineering scenarios.

Second, the relevant research results of scholars at home and abroad have provided a solid theoretical foundation and experimental experience for the research and development of the connection method with shear key built in steel pipe sleeve grouting connectors. Scholars at

home and abroad have carried out a lot of research on the shape, size and setting method of shear key, clarified the core role of shear key in improving the performance of grouted connections, and also pointed out the deficiencies in current research, which provides an entry point for the research of this project and a direction for the optimization and improvement of this new connection method.

Third, the experimental research and theoretical analysis of this project have fully verified the feasibility and superiority of the connection method with shear key built in steel pipe sleeve grouting connectors. The three shear key connection forms all have good mechanical properties, among which the cross spiral shear key has the best comprehensive performance, followed by the parallel spiral shear key, and the annular shear key has the advantage of convenient manufacture; experimental results show that the mechanical properties and energy consumption of the three connection forms are superior to those of traditional flange connection and bolted connection, which can meet the high-quality requirements of modern engineering; at the same time, the bearing capacity theoretical calculation model and design method constructed in this project provide scientific theoretical guidance for the engineering application of this connection method.

In summary, the connection method with shear key built in steel pipe sleeve grouting connectors is a new type of steel pipe connection method with safety and reliability, convenient construction, strong applicability and good economy. It has excellent mechanical properties, can effectively solve many limitations of traditional connection methods, and meet the complex needs of modern engineering. With the continuous advancement of the industrialization of the construction industry and green low-carbon development, this new connection method will be widely used in more engineering fields, providing important technical support for the high-quality development of steel structure engineering, and having important engineering application value and broad promotion prospects. In the future, the structural design of shear key can be further optimized, the theoretical calculation model can be improved, its application scenarios can be expanded, and the continuous upgrading and development of this connection technology can be promoted.

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Study on the Behavior and Design Method of Grouted Sleeve Connections for Steel Tubes under Combined Compression, Bending, and Torsion(S202510081040).

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