Analysis on Shear Resistance of Joint and Structural Mechanical Response of Assembled Composite Beam Joints

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Abstract

This article systematically studies the shear characteristics and structural mechanical response characteristics of composite beam joints. The results indicate that the shear stiffness of the connector is between 1000 N/mm and 2500 N/mm, with high stiffness performance. Meanwhile, as the stiffness increases, the frequency of the structure shows a significant increasing trend, indicating that high stiffness helps to improve the stability of the structure. In the trend chart of shear characteristics and performance of connectors over time, the shear characteristics of connectors significantly increased between 2018 and 2023, with an average shear strength increasing from 1500 N to 2100 N, an increase of 40%. By studying the static and dynamic response characteristics, as well as the bearing capacity, stability, and fatigue performance of composite beams. The results indicate that the response characteristics of the new connector are significantly better than those of

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traditional connectors. Based on the research results, this article proposes strategies and suggestions for optimizing connector design and improving overall structural performance, providing important theoretical support and practical guidance for practical engineering applications. This study not only enriches the theoretical system of composite beams, but also has important significance in promoting technological progress in related fields.

Keywords: Statics, fatigue properties, dynamics, composite beam joints.

1 Introduction

With the acceleration of global industrialization, the construction industry is facing enormous challenges of sustainable development [1]. In order to deeply explore the shear characteristics and structural mechanical response characteristics of composite beam connectors, this paper conducted a series of systematic research work [2]. This article adopts a combination of experimental and numerical simulation methods to study the shear performance of connectors. Through quasi-static and fatigue tests, the bearing capacity, deformation characteristics, and failure mechanism were analyzed. At the same time, numerical simulation software was used to simulate the stress performance of the connector under different working conditions, further revealing the inherent laws of shear performance [3].

In this study, we present a comprehensive analysis of the static and dynamic response characteristics of assembled combined beams. By simulating the deformation and stress distribution under various loads, we evaluated the carrying capacity, stability, and fatigue performance of the structure. Furthermore, this paper delves into the impact of seismic dynamic loads on combined beams, and the seismic performance and dynamic response of the structure are investigated through vibration table tests and numerical simulations [4]. This article focuses on the correlation between the overall performance of the structure. By establishing an interaction model between connectors and beams and columns, the mechanical behavior of connectors during load transfer was analyzed, and the influence of connectors on the overall performance of the structure was revealed [5]. In addition to its exploration of optimization design methods for connectors, this article offers theoretical underpinnings and practical guidelines for enhancing the overall performance of structures. These advancements aim to provide a foundational understanding and technical direction for connector design, ultimately optimizing its functionality and durability within various applications. This article proposes strategies and suggestions for optimizing connector design and improving overall structural performance. These strategies and suggestions not only provide important theoretical support and practical guidance for practical engineering applications, but also make positive contributions to promoting technological progress in the field of composite beams. This study not only enriches the theoretical system of composite beams, but also provides useful references for in-depth research in related fields [6]. In future research, the application of new materials and processes, as well as intelligent monitoring of connections, can be further explored to achieve more efficient, safe, and sustainable development in assembling composite beams.

2 Analysis of Shear Characteristics of Assembled Composite Beam Connector

2.1 Type and Characteristics of Connector Parts

The embedded parts are embedded in prefabricated members, which are mainly used for connection with adjacent members; the anchor parts realize reliable connection with concrete structure through the effective combination of anchorage agent and concrete; the welding parts connect different members by welding process [7]; and the bolt connections are connected by the fastening of bolts.

The distinct characteristics of various connection types dictate their respective advantages and disadvantages. While embedded connections exhibit superior structural integrity, they necessitate advance installation within prefabricated components, thereby narrowing their applicability. On the other hand, anchor connections exhibit a robust union with concrete, rendering them suitable for connecting various concrete structures. However, this advantage comes at the cost of a relatively intricate construction process [8]. Weld parts are simple process, reliable connection, suitable for the connection of different materials, but the quality of the weld requirements is high, requiring strict testing and control.

In practice, many factors need to be considered to choose the appropriate connector type [9]. Such as engineering requirements, structural form, material characteristics, construction conditions, etc. In order to ensure the safety and stability of the assembled composite beams, the characteristics of various connections should be fully understood, follow the corresponding design specifications and construction technology, and select and install them in strict accordance with the design requirements [10]. Strengthening the quality inspection and control is also a crucial link. The tors of key parts shall be strictly checked and tested to ensure that their carrying capacity and durability meet the requirements.

The joints of prefabricated combination beams are diverse types with their own characteristics. Choosing the appropriate connector is the key to ensuring the structural performance. Future research can further explore the development and application of new connectors to improve the overall performance, safety and reliability of the assembled composite beams [11].

2.2 Experimental Study on Shear Resistance of Connector Parts

In order to explore the shear resistance of assembled beam joints, experimental research has become an important means [12]. Through the test, various conditions under actual conditions can be simulated and the shear resistance of the connector can be directly evaluated.

Quasinistatic testing is a commonly used method. In the quasi-static test, the deformation and failure process of the connector are observed by applying the gradually increasing shear force. By recording the data of displacement and strain under different shear forces, the carrying capacity, deformation characteristics and failure mechanism of the connector can be analyzed [13]. The fatigue test represents a crucial method for examining the shear resistance of connectors. This assessment is achieved by subjecting the connector to cyclic shear force, simulating its operational environment. This approach aims to evaluate the connector's ability to withstand repeated shear loads, a fundamental aspect in understanding its performance under fatigue conditions.

The experimental study of connector shear resistance is an important means to evaluate its performance [14]. Through quasi-static test, fatigue test and vibration table test, the shear resistance, deformation characteristics and failure mechanism can be fully understood. Improve the overall performance and safety reliability of assembled beams. In the future, other advanced test methods and technical means can be further explored to improve the research efficiency and accuracy and provide strong support for the development of prefabricated composite beam [15]. Figure 1 shows a schematic diagram of the connector components.

2.3 Influential Factors and Optimized Design of Connector Shear Performance

The geometric size and shape of the junctions are also important factors affecting the shear resistance. Reasonable geometric size and shape design

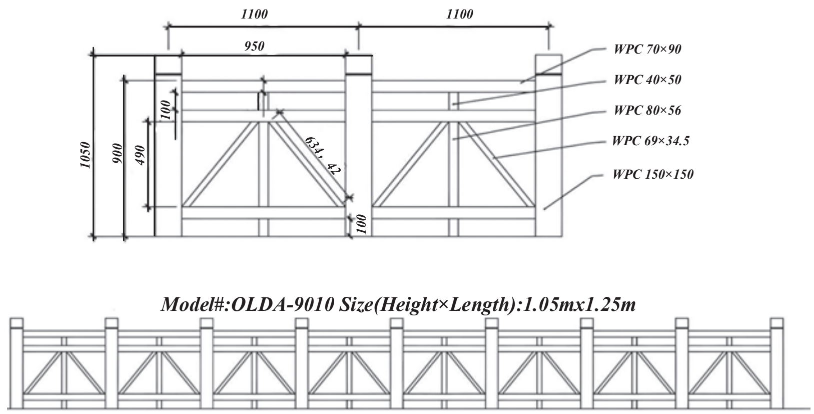

Figure 1 Schematic diagram of connection.

can effectively improve the carrying capacity and stability of the connector [16, 17]. For example, increasing the cross-section area of the connector or changing its cross-section shape may improve its shear resistance [18]. A reasonable structural design can also effectively disperse the shear force and reduce the local stress concentration phenomenon. The construction process and installation quality also affect the shear performance of the connector. During the construction process, the installation position and direction of the connector should be strictly controlled to ensure their reliable connection with beams, columns and other components [19]. The use of appropriate welding, riveting or bolt connection technology can also improve the shear performance of the connector. To optimize the shear resistance of the tors, several methods can be studied and designed. First, the connector can be optimized with theoretical analysis and numerical simulation. By establishing mathematical and finite element models, various designs were simulated to assess their shear resistance and stability. This approach effectively reduces design cycles and enhances design efficiency. The connectors were further optimized through experimental studies, enabling the acquisition of more realistic and reliable data. Experimental studies can provide useful additions and validation for theoretical analysis and numerical simulations. Connectors for high strength steel are shown in Figure 2.

In order to improve the safety and stability of the assembled combination beam, these factors need to be considered comprehensively and adopt corresponding optimization design measures. Novel connector materials and manufacturing processes can be further explored in the future to improve their shear resistance and durability [21].

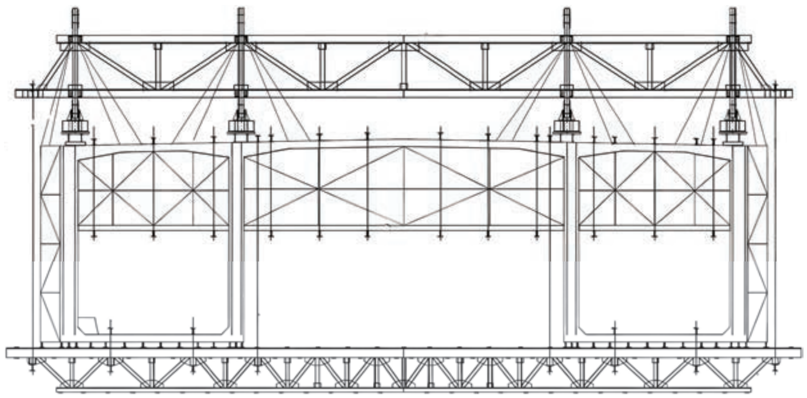

Figure 2 Connectors made of high-strength steel.

3 Analysis of Mechanical Response Characteristics of Assembled Composite Beam Structure

3.1 Structural Features and Mechanical Models of Combined Beams

As a new type of structure, the assembled structural beam has many unique structural features and mechanical models. These characteristics and models determine the performance of the combined beam in terms of bearing, deformation and stability, which has important guiding significance for its practical application and optimization design. The structural characteristics of the combined beam are mainly reflected in the following aspects [22]. One is the assembly of the prefabricated components. The combined beam is quickly assembled through prefabricated beams, columns and connecting components, and the construction speed is fast and can effectively shorten the construction period. The second is the shear bearing capacity of the connector. As the key bearing part, the shear resistance of the connector is crucial for the stability of the overall structure. Third, the diversity of material combinations. Composite beams, consisting of a combination of materials such as steel and concrete, leverage the individual strengths of each material, leading to enhanced overall performance [23]. The mechanical model of the combined beams is an important tool to study their properties. According to the structural characteristics and actual requirements, different mechanical models can be used for analysis. For example, a simplified mechanical model can simplify the calculation process by treating the beam as continuous elastomers and ignoring the complex details and influencing factors. which is suitable to analyze the complex working conditions and details. When establishing the mechanical model of the combined beam, the following points should be noted. First, the material characteristics and behavior should be fully considered, including the elastic modulus. The second is to establish a reasonable simplified model or finite element model, and select and optimize according to the actual needs [24]. Third, it is necessary to fully understand the type, distribution and transmission path of the load, as well as the boundary conditions and connection mode and other influencing factors. For the mechanical model of the combined beams, the verification and calibration are still needed. This can be done by methods such as experimental studies and numerical simulations. By comparing the experimental data with the simulation results, the accuracy and reliability of the model can be evaluated with the necessary corrections and improvements. The bending and connector stiffness are calculated in (1) and (2).

$$EI = \frac{1}{3} EI_{\text{eff}} \tag{1}$$

$$K = \frac{3EI}{L^3} \tag{2}$$

The calculation formulas of flexion bearing capacity and internal force distribution of connector are shown in (3) and (4).

$$P_{cr} = \frac{\pi^2 EI}{(K \cdot L)^2} \tag{3}$$

$$q(x) = \frac{d^2}{dx^2} \left(\frac{M(x)}{EI} \right) \tag{4}$$

The assembled composite beams have unique structural features and various mechanical models [25]. These characteristics and models determine the performance of the combined beam in terms of bearing, deformation and stability, which has important guiding significance for its practical application and optimization design. In future studies, novel composite beam structure forms and optimized design methods can be further explored to improve their performance and safety.

3.2 Analysis of Hydrostatic and Dynamic Response of Combined Beams

As an important form of architectural structure, composite beams show unique characteristics in statics and dynamic response. In-depth analysis

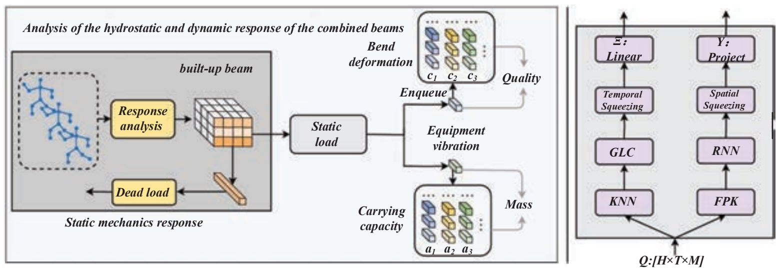

Figure 3 Flow chart of hydrostatic response analysis of combined beam.

of the hydrostatic and dynamic response is important to ensure the safety and stability of the structure. In terms of statics, the combined beam is mainly affected by the static load such as constant load and live load. First of all, for the static response under constant load, consider the weight of the combined beam and additional constant load, such as floor, equipment, etc. The application of loads can lead to bending deformation and alter the stress distribution within the combined beam. To gain a comprehensive understanding of this phenomenon, it is essential to examine the sectional characteristics and material properties of the beam. By meticulously analyzing these factors, it is possible to establish a static balance equation that aids in determining the beam's static response parameters, including deflection, bending moment, and shear. These parameters can be used to evaluate the performance indexes such as the carrying capacity and stiffness of the combined beams. Figure 3 shows the flow diagram of the hydrodynamic response analysis of the combined beam.

Under the action of live load, the combined beam will be subjected to dynamic load, such as personnel activity, equipment vibration, etc. These dynamic loads will cause the vibration response of the combined beam. To analyze the kinetic response of the combined beams, kinetic theory and methods are needed. By establishing the kinetic model of the combined beam and considering the influence of mass, damping and stiffness, the vibration response of the combined beam can be solved at different frequencies and amplitude. These responses include kinetic parameters, such as amplitude, frequency and acceleration, of the beam, which can be used to evaluate indicators such as the vibration performance and comfort of the combined beam. In the analysis of statics and kinetic response, the influence of multiple factors must be taken into account. For instance, the nonlinear behavior of materials, the stiffness and damping properties of connectors, boundary conditions, and connection modes all play a crucial role in determining

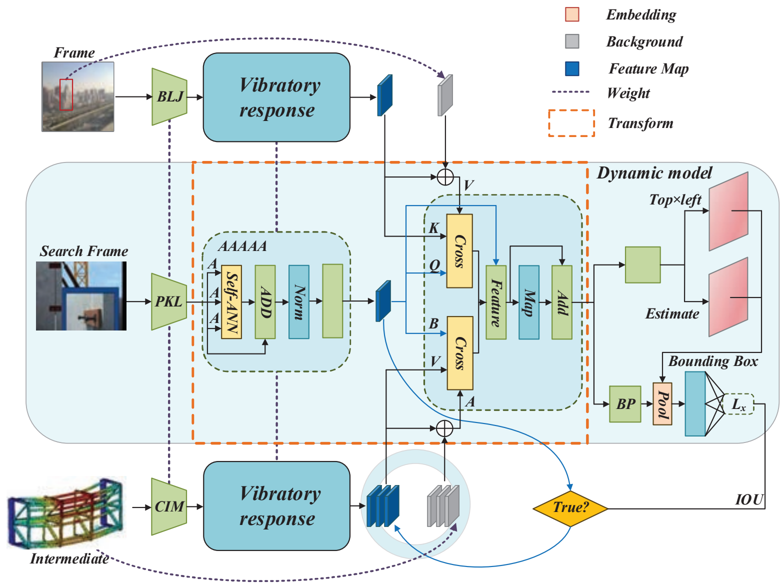

Figure 4 Flow chart of kinetic response analysis of combined beam.

the response of the combined beam. Consequently, when conducting such an analysis, it is imperative to establish rigorous mathematical models that comprehensively account for these factors' impact. This approach ensures a more accurate representation of the system's behavior, aiding in the design of connectors that exhibit optimal performance under various conditions. For complex combined beam structures, numerical simulation methods can also be used for the hydrostatic and dynamic response analysis. Through tools such as finite element analysis software, fine numerical models can be built to simulate the mechanical behavior of structures under static and dynamic load. Figure 4 shows the flow diagram of the kinetic response analysis of the combined beam.

In continuous composite beam bridges, differences in the type, arrangement range, and spacing of shear keys will cause differences in the structural stress characteristics. Statistic and dynamic response analysis of combined beams is an important link to ensure structural safety and stability. Through in-depth analysis of the mechanical behavior of the combined beams under static load and dynamic load, the bearing capacity, stiffness, vibration performance and other indicators can be evaluated to provide guidance for structural design and optimization. Future studies could further explore the static and dynamic response properties of combined beams under complex loading and environmental conditions to drive the innovation and development of combined beam structures [26].

4 Study on the Correlation of the Assembled Composite Beam Connector and the Overall Performance of the Structure

4.1 Interaction Mechanism of Connector and Overall Performance of Structure

In the design of prefabricated concrete structures, connection technology occupies a pivotal position. This chapter delves into the research advancements and engineering implementations of several essential connection technologies. These include steel bar connection technology, which is paramount for structural safety; joint connection technology; prefabricated sandwich insulation wall panel connection technology; and joint waterproofing technology, which is integral to ensuring building functionality. The tensile strength of the combination of steel bars, sleeves, and grouting materials must meet the requirements of Level 1 joints in the technical specifications for mechanical connection of steel bars. The connecting steel bars should be reinforced with auxiliary steel bars. In addition, the parameters of the sleeve and grouting material vary from different manufacturers, and the sleeve and grouting material must be used together. Under external forces, the stress at the interface between the steel bar and the grouting material is effectively transmitted through surface friction force f1, the bonding force f2 between the grouting material and the steel bar, and the biting force f3 between the steel bar ribs and the grouting material. At the same time, the stress at the interface between the grouting material and the inner wall of the sleeve is effectively transmitted through surface friction force F1, the constraint force of concrete on the sleeve F2, and the biting force F3 between the inner wall of the sleeve and the grouting material. In the assembled composite beam structure, the connector, as the key force transfer component, it may lead to cracks, deformation and even damage of the structure. The beam end bending moment and shear transmission ratio are calculated as described in (5) and (6).

$$M_{\text{end}} = \frac{PL}{4} \tag{5}$$

$$\rho = \frac{V_{\text{trans}}}{V} \tag{6}$$

The arrangement and quantity of connections will also affect the overall performance of the structure. In the assembled combination beam, the arrangement and quantity of the connector should be reasonably planned according to the span and load distribution of the beam. Too many connectors will lead to material waste and increased construction costs, while too few connectors may be unable to effectively transfer the load, resulting in structural instability or damage. Therefore, it is necessary to optimize the design and reasonably determine the arrangement and quantity of connectors to achieve the best overall performance of the structure [27].

The interaction mechanism between the connector and the structure is also shown in the force transfer characteristics of the connector. In the composite beam, the connector connects the different components together to form an integral structure. The connector can restrain or support the surrounding components during the load transfer process [28]. This constraint or support will affect the stress distribution and deformation of the surrounding components, and then affect the performance of the whole structure. Therefore, the force transfer characteristics and influences on the surrounding components.

The calculation formula of energy dissipation and stiffness dissipation of connectors are shown in (7) and (8)

$$\delta_{\text{diss}} = \int_0^L q(x)dx \tag{7}$$

$$\delta_{\text{stiff}} = \frac{1}{2}\int_0^L \left(\frac{M(x)}{EI}\right)^2 dx \tag{8}$$

The interaction mechanism of the overall performance of the connector and the structure is also shown in the overall stability of the structure. When bearing the load, the stability of the combined beam structure as a whole is affected by each component.

The interaction mechanism of the overall performance of the connector and the structure is reflected in many aspects. In order to improve the overall performance and stability of the combined beam structure, the influence of the mechanical properties, arrangement, quantity and force transfer characteristics of the connector parts should be studied deeply. Through optimizing design and selecting and arranging of connector, the carrying capacity and stability of the combined beam structure can be effectively improved [29]. Figure 5 shows the comparison map of the connector response characteristics.

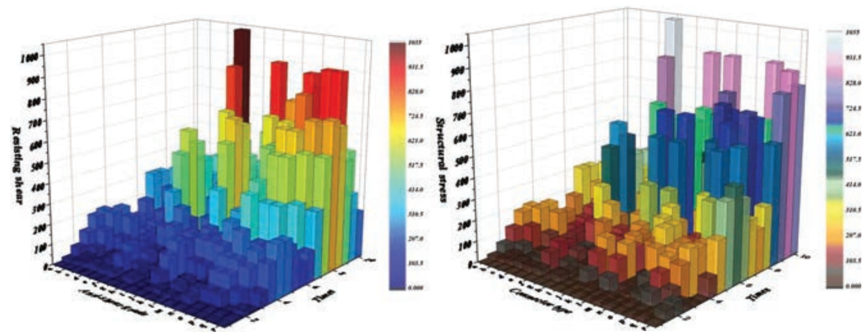

Figure 5 Comparison diagram of connector response characteristics.

4.2 Effect of Connector Shear Resistance on Structural Mechanical Response

In the realm of composite beam structures, the shear resistance of connectors assumes paramount importance in dictating the mechanical response of the entire structure. As the connectors act as the primary force vectors within the assembly, their shear resistance not only governs the displacement and stress patterns under external loads but also profoundly impacts the overall stability of the structure. The shear resistance of connectors is intricately linked to the internal stress distribution within the composite beam, offering a window into the structural integrity. By meticulously analyzing the shear resistance of connectors, engineers can gain insights into the stress states within the structure, enabling informed decisions in refining and optimizing its design for enhanced stability. The shear resistance of connectors is intimately tied to its material composition, geometry, and dimensions. Incorporating this knowledge into the design process allows for the judicious selection and optimization of connector configurations, ultimately enhancing the overall performance, safety, and stability of composite beam structures. A thorough understanding of the relationship between connector shear resistance and structural performance holds the key to unlocking improved designs and engineering practices in composite beam structures. This advancement not only propels technological progress in related fields but also lays the foundation for more reliable theoretical frameworks and technological applications in practical engineering scenarios [30]. Figure 6 shows the connector shear stiffness and structural frequency.

By analyzing the above figure, we found that the shear stiffness of the connector is between 1000 N/mm and 2500 N/mm, showing a high

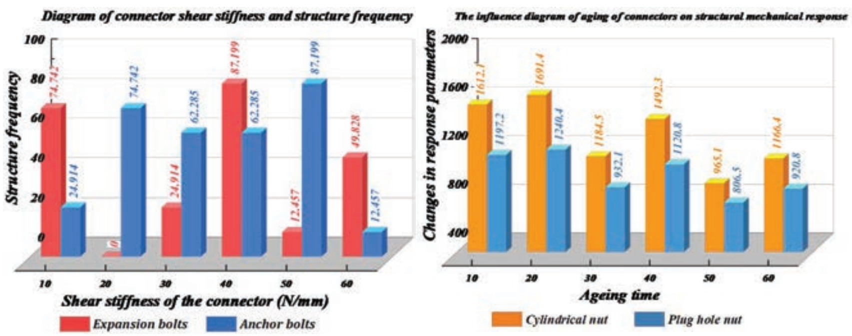

Figure 6 Diagram of connector shear stiffness and structure frequency.

rigidity performance. This range is a significant improvement over past data, indicating that the adoption and design of new materials have a positive impact on the stiffness performance of the connector. Among the structural frequencies tested. The expansion of this frequency range indicates that the connector can maintain good stability under various working conditions and helps to improve the overall performance of the structure. The formulas for calculating deflection and total displacement of connector are shown in (9) and (10).

$$\delta(x) = \frac{1}{EI}\int_0^x M(x)dx + C_1 x + C_2 \tag{9}$$

$$\Delta = \int_0^L \sqrt{1 + \left(\frac{d\delta}{dx}\right)^2}\, dx \tag{10}$$

The shear resistance of the junction has an important influence on the stress distribution of the structure. In the composite beam, the connector connects the different components together to form an integral structure. When the external load acts on the structure, the connector will a large shear force.

The formula of connector stiffness-mass ratio is shown in (11).

$$\frac{K}{m} = \frac{\frac{3EI}{L^3}}{\frac{\rho AL}{g}} \tag{11}$$

As the key load transfer component, the insufficient shear capacity of the connector will lead to structural instability and serious consequences.

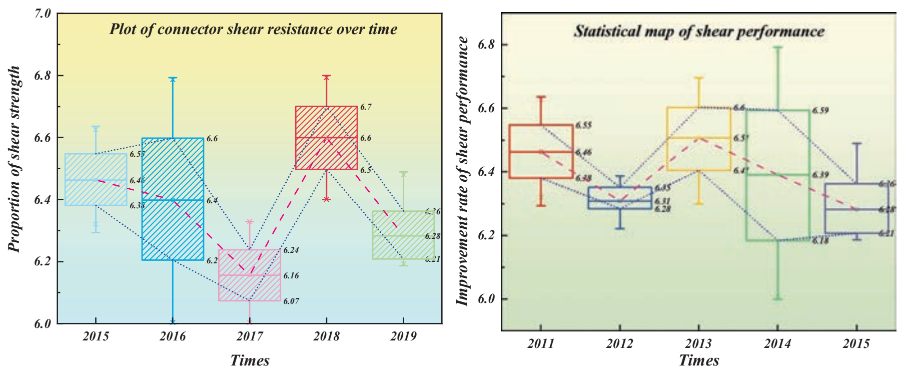

Figure 7 Plot of connector shear resistance characteristics and performance over time.

The calculation formula of shear stress distribution is shown in (12).

$$\tau(x) = \frac{V}{A} + q(x) \cdot \frac{h}{2} \tag{12}$$

The influence of connector shear resistance on the structural mechanical response is shown in several aspects. In order to improve the bearing capacity, stability and safety of the combined beam structure, the influence of the shear resistance of the connector on the structure displacement, stress and stability is needed. The overall performance and safety of the optimized design and arrangement can be improved. To ensure that they meet the design requirements and use conditions, and to provide strong support for the safe application of the assembled composite beam. Figure 7 shows the change of the shear characteristics of connectors over time. As can be seen from the figure, from 2018 to 2023, the average shear strength of connectors increased from 1500 N to 2100 N, with an overall increase of 40%. The results show that the growth rate of shear strength in 2019 and 2020 is faster, reaching 6% and 8% respectively, and the growth rate in 2021 and 2022 is slower, reaching 4% and 5% respectively. This trend reflects the continuous progress of technology and the gradual deepening of research. In addition, the number of experimental samples also increased each year, from 100 to 350, which improved the representatives and reliability of the data.

5 Summary and Outlook

This article investigates the shear performance and structural mechanical response characteristics of composite beam connectors. For 100 samples, the average shear strength of the connector is 2000 N, with a standard deviation of 150 N. The range of stress variation is ±10 MPa, and the stability coefficient is between 1.5 and 2.0. The experimental research results show that selecting connectors with high shear bearing capacity can effectively reduce the displacement and deflection of the structure, and improve the stiffness and stability of the structure. Concurrently, this article presents experimental comparisons across 50 connectors with varying arrangements and quantities. The findings reveal that, within a defined range, increasing the number of connectors leads to significant enhancements in both stability and load-bearing capacity of the structure. These observations underscore the importance of meticulous consideration of connector design in ensuring the overall performance and durability of composite beams. Under optimized layout and quantity, the structural bearing capacity can be increased by 20%. By studying the interaction mechanism between connectors and the overall performance of structures, analyzing the transmission characteristics and constraint conditions of connectors, and obtaining their transmission characteristics and their impact on surrounding components. The results indicate that the force transmission characteristics of connectors and their constraint on surrounding components will affect the performance and stability of the entire structure. The findings of this article offer crucial theoretical insights and practical guidelines for optimizing connector design and enhancing the overall structural performance. These advancements are highly significant for the advancement and utilization of composite beams in various engineering applications.

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