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Research on the Connection Design of Steel-Bamboo Combined Prefabricated Rural Housing

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Abstract

With the advancement of global sustainable development, prefabricated buildings have become a direction for the construction industry due to their efficient and energy-saving characteristics. The steel-bamboo combined structure integrates the strength of steel and the sustainability of bamboo, but the design of its connection remains a technical challenge for widespread application. Through literature review and theoretical analysis, this study explores the application potential and design challenges of steel-bamboo combined structures and proposes innovative connection design ideas.

Keywords

Steel-Bamboo Combined Structure; Prefabricated Construction; Connection Design; Rural Housing.

1. Introduction

Against the backdrop of globalization and environmental crises, sustainable development has become a core issue of global consensus. The construction industry, as one of the main contributors to global energy consumption and environmental pollution, faces unprecedented pressure for green transformation. In this context, prefabricated construction, with its characteristics of high efficiency and energy saving, is widely recognized as a key direction for the transformation of the construction industry. According to a World Bank report, by 2030, the global construction industry's growth rate is expected to reach 3.9%, and prefabricated construction is one of the key factors driving this growth. Prefabricated construction can reduce construction waste by up to 70% and shorten the construction period by about 30-50%. In China, prefabricated construction is considered an important way to achieve the green transformation of the construction industry. Data from the China Building Energy Conservation Association shows that compared with traditional construction, prefabricated construction can save energy by about 20% and reduce construction waste by more than 80%. Especially in the field of rural housing, prefabricated construction can not only improve the quality of buildings, shorten the construction period, but also significantly reduce the negative impact on the environment.

Steel-bamboo combined structures, as an innovative form of prefabricated construction, integrate the high strength of steel structures and the sustainability of bamboo, showing unique advantages and great potential. As mentioned in "Prefabricated Steel-Bamboo Composite Structure Construction Technology and Engineering Application," this structure uses bamboo plywood and cold-formed thin-walled steel as the main materials, bonded together with epoxy resin, which not only gives full play to the advantages of both materials but also complements their respective shortcomings. For example, the addition of bamboo plywood improves the stability of thin-walled steel and enhances the overall performance of the structure, while the easy processing of steel also allows components to be customized into various shapes to meet different engineering needs.

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However, steel-bamboo combined structures face a series of challenges in connection design, which directly relate to the safety, economy, and sustainability of the structure. The rationality of connection construction is the key technical issue for the widespread application of steel-bamboo combined structures. Therefore, this study focuses on the connection design of steel-bamboo combined prefabricated rural housing, aiming to explore and propose innovative connection design ideas and methods through literature review and theoretical analysis. We hope that this study can provide theoretical support and practical guidance for actual projects, promote the application of steel-bamboo combined structures in rural housing construction, and achieve green development in the construction industry.

2. Development of Prefabricated Construction Technology

2.1 Development of Prefabricated Steel Structure Construction

The development of prefabricated steel structure construction is an important sign of technological progress in the construction industry. Prefabricated steel structure construction has been widely applied globally due to its fast construction speed, high strength, and excellent seismic performance, occupying an important position in the construction market. The application of prefabricated steel structure construction has expanded from simple industrial plants to commercial centers, residential buildings, and public facilities. This construction method, which uses factory-prefabricated components, achieves dual improvement in construction efficiency and quality. In Europe, the standardization and serialization of prefabricated construction are particularly prominent, with the German Syspro High-Quality Alliance being a leader in promoting the innovative development of prefabricated construction technology. Research shows that prefabricated steel structure construction can effectively reduce energy consumption and construction waste during the construction process, becoming an important way for sustainable development in the construction industry. The "Steel Structure Design Manual" detailedly discusses the advantages of prefabricated components in improving construction precision and reducing on-site workload, which is of great significance for environmental protection and resource conservation.

2.2 Research Progress on Prefabricated Bamboo Structure Construction

Bamboo, as a renewable resource, is gradually receiving attention in the field of construction. Its fast growth, strong environmental adaptability, and superior material performance make it an ideal substitute for traditional timber.

Mechanical Properties and Durability:

The mechanical properties of bamboo are detailed in "Modern Bamboo Structures" (Xiao Yan, Dan Bo, China Architecture & Building Press). The tensile and compressive strength of bamboo along the grain make it promising in structural applications. At the same time, research on the durability of bamboo is also progressing, with special treatment processes such as anti-corrosion, anti-mold, and fireproofing improving the durability of bamboo.

Application of Engineered Bamboo Lumber (BFL):

Engineered Bamboo Lumber (BFL) is processed and reorganized from bamboo to meet various structural needs. The emergence of BFL enables bamboo to be better applied in both load-bearing and non-load-bearing structures, enhancing its practicality in modern construction.

2.3 Potential and Challenges of Steel-Bamboo Combined Structures

In-depth discussion on the potential and challenges of steel-bamboo combined structures not only reveals the application prospects of this innovative structural system in modern architecture but also identifies key technical issues that need to be overcome in the design and construction process.

The design of steel-bamboo combined structures integrates the high strength of steel structures and the lightness and environmental friendliness of bamboo structures, showing unique architectural potential. Firstly, the lightweight and high-strength characteristics of this structure mean that under

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the same load, material usage can be reduced, the structure's self-weight can be lowered, thereby reducing foundation costs and improving seismic performance. According to research in "Modern Bamboo Structures" (Xiao Yan, Dan Bo, China Architecture & Building Press), the tensile and compressive strength of bamboo can be comparable to some light steel materials, making bamboo an ideal supplementary material to steel structures. In addition, the addition of steel provides extra support and stability, making the entire structure more reliable. In terms of environmental protection, bamboo, as a rapidly growing renewable resource, its use in construction helps reduce dependence on forest resources and lower the carbon footprint of buildings. At the same time, the recyclability of steel further enhances the environmental friendliness of steel-bamboo structures. In terms of economic benefits, the fast construction speed and low maintenance costs of steel-bamboo combined structures are particularly important for resource-limited rural areas.

Despite the significant potential of steel-bamboo combined structures, they also face a series of challenges. Material compatibility is a key issue, with differences in thermal expansion coefficients and durability between steel and bamboo potentially leading to stress concentration and material fatigue at connections. The connection of different materials requires special attention to material compatibility to ensure the long-term stability of the structure. Mechanical performance matching is also a challenge, as the mechanical properties of bamboo are affected by its growth conditions and processing techniques, while the mechanical properties of steel are relatively stable. "Principles of Structural Design" (Pan Jinglong, Zhu En Chun, China Architecture & Building Press) emphasizes that designers need to fully consider the differences in mechanical properties between the two materials to ensure the safety performance of the structure under various loads. Durability issues cannot be ignored, as bamboo is susceptible to microbial erosion and natural environmental impacts, especially in humid environments, where the durability of bamboo becomes a challenge. "Durability Design in Construction" discusses the anti-corrosion, anti-insect, and fireproof treatment technologies for bamboo, which are crucial for improving the durability of bamboo. Finally, in-depth research on connection construction is lacking, with current research on steel-bamboo combined structures mainly focusing on material performance testing and basic structural form exploration, with less in-depth research on connection construction. "Steel Structure Connection Technology Manual" (China Steel Structure Association, China Architecture & Building Press) provides detailed technical guidance on steel structure connections, but further research and development are needed for the connection technology of steel-bamboo combined structures.

3. Design Theory of Steel-Bamboo Combined Structures

The design theory of steel-bamboo combined structures is an interdisciplinary research field, involving materials science, structural engineering, and environmental science, among other aspects. This chapter will delve into the theoretical foundations of the design of steel-bamboo combined structures and propose innovative connection design ideas.

3.1 Material Compatibility and Mechanical Performance Matching

Material compatibility is the primary issue in the design of steel-bamboo combined structures. Steel structures are known for their high strength and good ductility, while bamboo is favored for its lightweight and rapid regeneration capabilities. The combination of different materials requires consideration of their physical and mechanical properties to ensure the integrity and stability of the structure. In steel-bamboo combined structures, this involves how to achieve effective integration of steel and bamboo through connection design.

Mechanical performance matching is another key point. Designers need to analyze the performance differences in load-bearing capacity, stiffness, and durability between steel and bamboo and design connection nodes that can balance these differences. This requires not only familiarity with the mechanical properties of the materials but also an understanding of how to effectively utilize these properties in structural design.

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3.2 Durability and Maintenance

The durability of steel-bamboo combined structures is crucial for ensuring their long-term performance. "Principles of Structural Design" (Pan Jinglong, Zhu En Chun, China Architecture & Building Press) discusses the durability issues of different materials under various environmental conditions and how to improve the durability of structures through design and material selection. In addition, reasonable maintenance strategies are also important for ensuring the long-term stability of structures, including regular inspection of connection nodes, anti-corrosion treatment, and timely repair of damaged parts.

3.3 Construction Efficiency and Environmental Impact

In the construction process, construction efficiency is an important economic factor. "Building Construction Technology and Management" (China Architecture & Building Press) mentions that prefabrication and modular construction can significantly improve construction speed and reduce costs. The design of steel-bamboo combined structures needs to consider the prefabrication, transportation, and on-site assembly of materials.

At the same time, assessing the environmental impact of steel-bamboo combined structures throughout their life cycle is also part of the design theory. It emphasizes the environmental assessment of construction projects, including the environmental impact during the production, construction, and demolition stages of materials.

3.4 Innovative Ideas for Connection Design

For the connection design of steel-bamboo combined structures, this study proposes the following innovative ideas:

Modular Design: Adopting a modular design concept allows connection nodes to be prefabricated and quickly assembled on-site, improving construction efficiency. This design method, mentioned in "Modern Construction Technology" (China Architecture & Building Press), can reduce on-site workload, lower construction costs, and enhance the reliability of structures.

Multi-functional Connection Nodes: Designing multi-functional connection nodes that can meet both structural and enclosure needs reduces material usage and construction complexity. This design approach, reflected in the "Steel Structure Design Manual" (China Steel Structure Association, China Architecture & Building Press), emphasizes the integration and multifunctionality of structural design.

Adaptive Design: Considering the differences in regions and environments, designing adaptive connection structures to meet the performance requirements under different conditions. It emphasizes that architectural design needs to consider regional characteristics and environmental factors.

Intelligent Construction: Utilizing BIM and IoT technologies to achieve intelligent construction management of connection structures, improving construction accuracy and efficiency. The "Building Information Modeling (BIM) Application Guide" (China Architecture & Building Press) provides a detailed introduction to the application of BIM technology in improving construction management efficiency.

4. Conclusion

The connection design of steel-bamboo combined prefabricated rural housing is an interdisciplinary research field involving materials science, structural engineering, environmental science, and more. The conclusions and suggestions of this study aim to promote further development in this field and provide scientific basis and practical guidance for achieving green, economical, and sustainable rural housing construction. We look forward to future research building on this foundation to bring more innovation and breakthroughs to rural housing construction.

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