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Optimized Application of Steel-Wood Materials in Large-Span Spatial Structures

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Abstract. With the continuous development of society and the increasing progress of science and technology, the construction industry has higher and higher requirements for the form and material properties of large-span spatial structures. Under this background, the application of steel-wood structures in large-span spatial structures brings new technical design principles and more possibilities for modern architectural engineering. In this paper, the application of steel-wood materials in large-span spatial structures and case model analysis are deeply studied. Firstly, the design theory of steel-wood materials used as main building materials in long-span spatial structures is analyzed from the aspects of stability and strength of building structures. Then, the rationality, safety and economy of steel-wood materials in application are discussed. Finally, the application cases and effects of the dome-shaped cloud structure model are analyzed, and the application advantages of steel-wood materials in specific large-span spatial structures are illustrated. The results show that the steel-wood structure has good structural strength and stability, can effectively cope with various static and dynamic loads, and improve the functionality and safety of the building. At the same time, it can reduce the construction cost and reduce the pollution to the environment. The steel-wood structure can show excellent versatility and flexibility in the large-span spatial structures, so as to achieve efficient space utilization.

Keywords: Steel-Wood Materials; Large-Span Spatial Structures; Dome-Shaped Cloud Structure Model.

1. Introduction

With the acceleration of the global urbanization process and the development of social economy, the housing construction industry is facing unprecedented challenges and opportunities, and the progress of building technology and design has become a key factor to achieve sustainable development and improve the quality of urban life. In this process, as an important part of modern architecture, the large-span space structure carries more and more functional and cultural significance. Such structures not only need to meet the requirements of functionality and aesthetics, but also need to have good structural stability, economy and sustainability. Large-span spatial structures are those with a larger span (usually more than 30 meters) and a smaller proportion of height. This type of structure is usually used in places that require large space coverage without internal support columns, such as stadiums, exhibition halls, conference centers, airport terminals, large commercial centers. As people all know, the materials used in traditional large-span spatial building structures are mainly steel and concrete [1, 2]. However, with the continuous pursuit of sustainable development and the emergence of new material technology, steel-wood composite structure, as a new material system, is gradually attracting attention and application in the field of architectural design. Steel-wood structures combine the advantages of steel with the lightweight and environmentally friendly properties of wood, providing superior mechanical properties and design flexibility to effectively address the challenges of large-span spatial structures.

Under the above background, this paper aims to explore the application of steel-wood materials in large-span spatial structures, contribute new ideas and practical experience to the sustainable development of construction engineering, and promote the construction industry towards a more environmentally friendly, efficient and sustainable direction.

2. Design Theory of Steel-Wood Materials in Large-Span spatial Structures

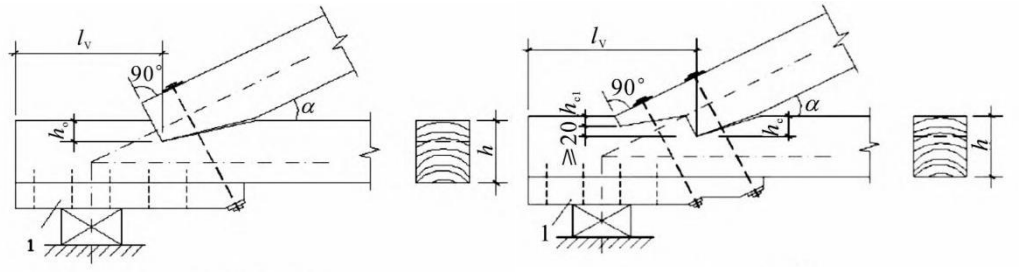
The optimization of the large-span spatial structure is the key to ensure the stability and aesthetics of the structure. Through precise optimization, the self-weight of the structure can be reduced, the load transfer path can be optimized, and the overall efficiency of the structure can be improved [3].

2.1. Stability and Strength of Building Structure

In the design of large-span spatial structures, the shape design should not only share the load effectively, but also ensure sufficient stability and strength while minimizing the structure's self-weight. In steel-wood structures, rigid joints and wood components are usually used [4]. Wood is usually used as a pressure rod, and its stability design needs to consider its cross-section shape, length, support type and other factors. Steel provides high tensile and compressive strength, while wood provides lightweight and flexible properties. Through the combination of the two materials, the bending and torsional ability of the whole structure is improved.

According to the analysis of the mechanical properties of wood, wood is a viscous and elastic material, and natural wood has two characteristics, namely, high anisotropy and dispersion. Moreover, wood is affected by many factors and will undergo obvious plastic deformation under long-term load. In modern building structures, the combination of steel and wood joints is usually used, and metal components with good mechanical properties such as bolts, pins, steel plates or steel bars are usually used to strengthen the wooden joints to a certain degree. The joint performance of the combination of wood and steel structure is specifically analyzed, and the connection modes of the two are divided into tooth connection, pin connection and tooth plate connection [4].

The tooth connection is applied to the relevant node part of the pressure transfer, which is usually applied to the lower chord hinge node of the wooden truss structure (Fig. 1) [4]. Pin connection is one of the most commonly used joint forms in wood structure, which is simple, safe and reliable. The specific operation is to drill holes in the wood structure, and the load is transferred through the fasteners such as pins and bolts of the wood structure. Tooth plate connection is the connection between wood and stamping at the junction, which is usually used in lightweight frames and truss structures (Fig. 2) [4].



(a) Single Tooth Joint (b) Double Tooth Joint

Figure 1. Tooth Joint [4]

(a) Tooth Plate Connects Roof Truss Structure (b) Tooth Plate

Figure 2. Tooth Plate Connection Joint [4]

In summary, the comprehensive application and optimization of steel-wood materials can effectively improve the stability and strength of large-span spatial structures, while maintaining the structural characteristics of light weight and high efficiency. This structural design strategy not only helps to achieve superior structural performance, but also plays an important role in practical engineering.

2.2. Spatial Efficiency and Functionality of Building Structures

The combination of steel-wood materials can flexibly design more efficient section shapes, such as cantilever structure, arch structure, to maximize the available space inside the space [5]. Moreover, the flexibility and strength of steel-wood structures can also be utilized to design multi-functional space layout, such as open space, multi-level space, to achieve diversified use of space [5]. By optimizing the application of steel-wood materials, the diversified use of space and functional flexibility can be achieved, so that the large-span spatial structure not only has excellent mechanical properties, but also provides an efficient and comfortable environment in practical applications. This design strategy not only improves the efficiency of space use, but also enhances the functionality and adaptability of the building.

3. Analysis of Steel-Wood Materials in Large-Span Spatial Structure

The large-span spatial structure of steel-wood materials needs in-depth analysis from multiple angles of building structure design to ensure the rationality, safety and economy of the structure.

3.1. Rationality of Building Structure

The rationality of large-span spatial structure first considers the influence of structure layout and material selection on structure performance [6]. By optimizing the use of steel-wood materials and the design of structural components, the structure can be optimized in load bearing and other aspects. The combination of steel-wood materials can provide greater adaptability and flexibility in the design, and can be used for a variety of structural forms, such as beams, columns, trusses, to meet different architectural needs and space design requirements. Moreover, steel and wood materials are easy to prefabricate in the factory, achieving rapid on-site assembly. It not only improves quality control, but also reduces site construction time and environmental impact.

3.2. Safety of Building Structure

Safety is a crucial consideration in the design of large-span spatial structures. The introduction of steel-wood materials must ensure the stability and safety of the structure under various load conditions. Through advanced structural analysis and simulation technologies, such as finite element analysis and wind tunnel test, the seismic and wind resistance of the structure can be evaluated, potential structural weaknesses can be found and solved in time, and safe and reliable operation of the structure can be ensured within the design life [2, 7].

3.3. Whole Process Cost of Building Structure

When selecting and applying new materials, the whole process cost of the structure must be considered comprehensively, including the economy of design, construction, maintenance and demolition. Especially in large-span spatial structures, the effective use of the advantages of steel-wood materials can reduce the building's weight and material waste to a certain extent, reduce the whole life cycle cost of the structure, and improve the return on investment. The renewability and recyclability of steel and wood also give steel-wood structures the potential for sustainability in the construction industry, maximizing their contribution to environmental protection and sustainable development.

4. Structural Model Application Case Analysis

4.1. Structural Model Case

Japan designed dome-shaped cloud structure model after introducing prestressing technology into steel-wood structure, as shown in Fig. 3 [4]. Due to the abundant wood resources in Japan, after the introduction of glulam technology, steel-wood structures have been applied in a large number of building structures. The dome-shaped has a span of 143 meters and is the first large-span steel and wood structure in Japan to exceed 100 meters [4]. In the structural system of this model, from the perspective of the wooden arch, the main body of the model is 36 main ribs in a radioactive arrangement, which is the main compression member of the dome [4]. Each arch frame fits the curve of the dome with a broken line, which is convenient for the processing of wood parts. The structure adopts steel tie rod to strengthen the bending stiffness of the shell surface in the form of tension string. Diagonal steel cables and three ring steel cables were used to fix the dome, restrain its expansion deformation and out-of-plane instability, and the 36 arches were connected as a whole.

Figure 3. Dome-Shaped Cloud Structure [4]

4.2. Application Effect

The dome-shaped cloud structure model combines steel, wood and film in materials, and gives full play to the advantages of each material. In the form of structure including arch, truss, cable film, etc., 36 radiation-arranged wooden arch, steel pressure ring, wood pull ring together to form a self-balancing system, reduce the thrust on the column and foundation, with good mechanical performance. Due to its unique appearance and unique traditional design concept, the structure provides a significant promotion effect in the application of steel-wood materials in large-span spatial structures.

5. Conclusion

This paper mainly studies the application of steel and wood materials in long-span spatial structures, and draws the following conclusions:

(1) According to the role of steel and wood materials in the structure and the connection mode of the two materials, the optimization design theory of steel and wood materials in the long-span space structure is expounded. In the future, further research could leverage the strengths of both materials to achieve more efficient and aesthetically pleasing structural solutions.

(2) Through in-depth analysis of its technical characteristics, economic benefits and environmental impact, the paper discusses how steel and wood materials promote the transformation of the construction industry to the direction of sustainable development, and provides theoretical support for the design and implementation of future residential construction.

(3) This paper introduces the structural system, node details and construction methods of the concrete dome cloud structure model, and shows the successful application of steel and wood materials in the long-span space structure and the possibility of innovative design.

(4) In the future, with the needs of science and technology and the needs of society, there are still many directions for steel and wood materials to be further explored and improved. The sustainability of the structure can be improved by studying composite materials with higher strength and lighter weight. More accurate and optimized designs are achieved through more advanced modeling and

simulation techniques. It is believed that in the future, not only steel and wood materials, but also more new materials can meet the needs of building construction and promote the sustainable and innovative development of the construction industry.

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