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Research Prospectsof Seismic Performance of Bamboo Plywood Wood Structure System

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Abstract. With the rise of bamboo as an engineering material, bamboo plywood is becoming a potential alternative to the traditional oriented strand board (OSB). However, the essential differences in mechanical properties and pin connection behavior between the two make it difficult to directly apply the design method and numerical model of the OSB system. This paper systematically reviews the mechanical properties of OSB and bamboo plywood cladding materials, the mechanical behavior of nail joints, and the applicability and limitations of three nail joint modeling strategies in finite element analysis. It is found that the theoretical model and numerical simulation parameters of the OSB gauge timber system are relatively mature, while the experimental data of bamboo plywood nail joint foundations are seriously scarce; research on hysteretic characteristics under reciprocating load is insufficient, and there is a lack of a standardized load slip curve library and finite element parameter system. The common bottleneck of the three modeling methods is that the parameter basis is rooted in the OSB system, and it faces the dilemma of "no parameters available" when turning to bamboo plywood. Based on this, the future directions of establishing the bamboo nail connection test database, developing the theoretical model of bamboo nail joints, and exploring the multi-scale modeling strategy are proposed in order to provide a theoretical reference for the research on the seismic performance of bamboo plywood clad wood structure system.

Keywords: Wood structure cladding system, Oriented particleboard, Bamboo plywood, Nail connection, finite element analysis

1. Introduction

Wood structures have a high strength-to-weight ratio, light weight, and rich elasticity and toughness, which is an important construction method in seismic zones. Light wood structures have excellent seismic performance, and their seismic performance largely depends on the nail connection between the cladding and truss. The nail connection transfers shear force and dissipates energy, which determines the bearing capacity and deformation capacity of the wall. The failure is often concentrated in the nail connection area. The traditional cladding panel is multi-purpose OSB with stable performance, uniform specifications, and mature nailing parameters. With the promotion of forest protection and the goal of "double carbon", bamboo has become an alternative material for

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cladding due to its fast growth, high strength, low carbon, and renewability. In recent years, research on bamboo plywood cladding used in wood truss and shear wall has increased. The test shows that its seismic performance is good, and the shear capacity of a cold-formed thin-walled steel bamboo plywood composite wall is even higher than that of a similar wall [1, 2]. However, the strength of OSB is low, the pull-out resistance of round nails is poor, and the edge of the plate is easy to tear; Although the bamboo plywood avoids tearing, there are still a large number of nails pulled out, and the lateral resistance has not been significantly improved [3, 4]. It can be seen that there are essential differences in material properties, nail connection behavior, and failure mode between the two, which is the weak link in current cognition. Nail connection is the key bridge between material differences and structural performance. Monotonic and repeated loading tests have revealed the failure mode, stiffness degradation, and bearing capacity [5, 6], but the nailed connection is often regarded as an independent node, especially in the context of "cladding material replacement". In the numerical simulation, the requirements of the three main nail connection modeling methods are different, but the applicability is highly dependent on the constitutive parameters, and the existing parameters are almost all from the OSB system. Bamboo anisotropy, nail hole bearing strength, and failure mode are significantly different from OSB. The rationality and error of direct application of OSB parameters still lack systematic evaluation.

To sum up, at the material level, mechanical differences are not fully translated into design parameters; At the node level, the nail connection model is mostly based on OSB, and its applicability to bamboo plywood has not been tested; At the level of numerical simulation, the parameters of the three methods are rooted in OSB, and the simulation of bamboo plywood cladding faces the dilemma of no parameters available. This paper systematically reviews the mechanical properties of OSB and bamboo plywood cladding materials, the behavior of nailed joints and the applicability and limitations of three modeling strategies, and explores the bamboo nailed connection test database, theoretical model, and multi-scale simulation path, in order to provide a reference for the seismic performance research of bamboo plywood cladding wood structure.

2. Comparison of material properties between OSB and bamboo plywood

Table 1. Comparison of material properties between OSB and bamboo plywood

Index Material	OSB	Bamboo plywood
Density(g/cm³)	0.66~0.68	≥0.90
Moisture content(%)	4%~10	\
24h water absorption thickness expansion rate(%)	About10~20	Low water absorption and low expansion, far lower than OSB
Internal bonding strength(MPa)	About0.38~0.48	\
Static bending strength(MPa)	>21; Finish OSB up to 40	≥90; It can be increased by 12.80% vertically and 14.75% horizontally
Elastic modulus(MPa)	≥3500; Finish OSB up to 4500	Significantly higher than OSB
Nail holding force(N)	\	≥2000N
Mechanical anisotropy	High strength and stiffness in both vertical and horizontal directions, directional pavement, and great variability [7]	The vertical and horizontal differences are obvious, and the anisotropy is stronger [8-10]

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Table 1. (continued)

Nail connection failure mode	The board edge is torn, and the nail is pulled out [3, 4]	The nail cap is pulled through, the bamboo board is broken, and the block shear is damaged [3, 4, 11]

It can be seen from Table 1 that the density of bamboo plywood is ≥ 0.9 g/cm ³, which is higher than 0.66~0.68 g/cm ³ of OSB; Static bending strength is≥ 90 MPa, much higher than OSB; Screw holding force ≥ 2000 N, low water absorption, small expansion rate, and better dimensional stability. OSB has a moisture content of 4%~10%, a thickness expansion rate of 10%~20% in 24 hours, and an internal bonding strength of 0.38~0.48 MPa, which is low in strength, high in variability, and easy to tear the plate edge and pull out nails [3, 4, 7]. It can be seen that the strength, stiffness, and nail-holding performance of bamboo plywood are better, but the anisotropy is stronger, and the nail connection and failure mechanism are also different. Therefore, OSB material properties and connection parameters cannot be directly applied, and an independent parameter system needs to be established [8, 9, 11].

3. Mechanical behavior of bolted joints

3.1. Failure mode

The failure mode of a nail connection is the primary index to evaluate its bearing capacity. OSB gauge material system mainly includes nail yield (M-c1), cladding fracture/shear damage, gauge material tearing, and nail penetration under monotonic load, and M-c1 yield is an ideal ductile failure [5]; Superposition of low-cycle fatigue under reciprocating load leads to more complex failure and more significant degradation of stiffness and strength [5, 6]. After the replacement of materials, the failure mechanism is obviously changed: the strength of OSB cladding is low, and the pull-out resistance of round nails is poor, which is prone to plate edge tearing and nail pull-out [3, 4]; Bamboo plywood can avoid tearing at the edge of the board, but the nail cap is pulled through and protrudes in the self-tapping screw connection, and the double shear screw connection turns into the screw-bamboo board cooperative bearing, which may be accompanied by brittle failure such as block shear and splitting [3, 4]. Bamboo Glulam nail joints also show local buckling of Bamboo under the nail cap, bearing of pin groove, double hinge, and splitting failure [11]. It can be seen that the failure path and energy consumption mechanism of OSB and bamboo nail connection are different and cannot be directly applied.

3.2. Load slip characteristics

The load slip curve is the core basis for characterizing the non-linearity of the pin connection and the finite element spring parameters. Its typical characteristics are: high initial stiffness, nonlinear behavior with the development of screw rod bending and hole wall local crushing, and a falling section after the peak value [5, 6, 12]. OSB gauge timber system has accumulated relatively systematic monotonic and repeated loading curves and established the Foschi index model, domestic nail two-way skeleton model, etc., with a relatively mature parameter basis [6, 12]. The research on bamboo nail connection is still dominated by monotonic loading, and the laws of reciprocating hysteresis, stiffness degradation, and strength degradation are insufficient. A standardized load slip curve library and finite element parameter system have not yet been formed [10, 11]. At the same time, the anisotropy of bamboo is stronger, and the shape of the curve is significantly affected by the

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parallel and transverse grain, nail species, plate thickness, and edge distance. Direct use of OSB parameters will produce large errors [10, 13].

3.3. Key influencing factors

Nail edge distance is one of the most important factors affecting the bearing capacity and deformation of nail joints. With the increase of the edge distance, its influence on the mechanical performance of the joint tends to be stable. The low-cycle repeated load test further shows that the nail edge distance not only affects the failure mode of the nail joint, but also improves the bearing capacity, energy consumption, and deformation capacity of the joint, and gradually reduces the rate of strength degradation.

Panel thickness is also a key parameter. The plate thickness is the core parameter that affects the mechanical properties of nail joints. The results show that the thickness of the plate has a great influence on the relative relationship between the bearing capacity of the specimens with parallel grain stress and the bearing capacity of the specimens with transverse grain stress. In the bamboo plywood system, the mechanical properties of bamboo Glulam self-tapping screw connection are mainly determined by the thickness of the board [11].

The relationship between the direction of load and the direction of wood texture has a significant impact on the performance of nail connection. The ductility and energy dissipation capacity of the specimens subjected to longitudinal load are worse than those subjected to transverse load. This phenomenon is more prominent in bamboo. The nail holding performance of bamboo Glulam is closely related to the angle between the force direction and the grain direction [10].

The influence of nail type and nail diameter can not be ignored. The connection strength of domestic ordinary round nails mainly depends on the failure mode [5]. Using self-tapping screws instead of ordinary round screws can significantly improve the stiffness and ultimate bearing capacity of the connection [4]. In bamboo Glulam, the shear capacity of nail joints increases with the increase of nail diameter, number of columns and rows [11].

3.4. Research progress of bamboo nail connection

With the popularization and application of bamboo in the field of wood structures, the research on the mechanical properties of bamboo nail joints has attracted more and more attention. The current research mainly focuses on two kinds of materials: Glulam and plywood.

In the aspect of Glulam nailing, the research has been more systematic. A study has conducted pull-out tests on 260 specimens of bamboo Glulam nail joints. Taking the nail type, nail diameter, effective anchorage length, and the angle between the direction of force and the direction along the grain of bamboo Glulam as parameters, the failure mode and nail holding performance have been systematically studied [10]. In terms of shear performance, studies have conducted monotonic static loading tests on 125 double-sided shear specimens of nailed joints and found that the failure modes of bamboo Glulam nailed joints mainly include local buckling of Bamboo under the nail cap, bearing failure of the pin groove, double hinge failure, and splitting failure of bamboo Glulam [11]. In addition, previous studies have carried out monotonic and low-cycle repeated loading tests on bamboo Glulam nail joints and found that there are obvious differences in failure modes under different loading modes [11].

In terms of bamboo plywood nail connection, Zheng Wei and others studied the bearing performance and failure mechanism of double shear screw connection with the background of plywood shear wall with conventional wood-based structural plates as plywood, using bamboo

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plywood as the central plywood and self-tapping screws instead of conventional nail connectors [4]. Research shows that using bamboo plywood as cladding can effectively avoid the common edge tear and nail pull-out damage of traditional OSB cladding [3, 4]. In addition, studies have conducted special tests on the pull-through performance of bamboo plywood self-tapping screw cap, which provides data support for the application of bamboo plywood in reinforcement connection [3]. In the research on the new type of reinforced light wood structure shear wall, some scholars selected the reconstituted bamboo board as the cladding plate, made the specimens according to the ASTM D1761 test method, and carried out the monotonic loading test on the new type of panel nail joints.

However, compared with the OSB specification system, the research on bamboo nail connection is still in its infancy. The existing research mostly focuses on the bearing capacity and failure mode under monotonic loading, but the research on hysteretic characteristics, stiffness degradation, and strength degradation under reciprocating loading is not sufficient; The parameter system of different bamboo species and nail species has not been unified; Systematic research on the structural parameters such as nail spacing and edge distance is also relatively lacking.

4. Finite element modeling difference analysis and bamboo applicability dilemma

Table 2. Difference analysis of three kinds of finite element modeling

Method name	Advantage	Limitations	Pain points in bamboo simulation
Binding constraints	It has the advantages of simple modeling, a small amount of pretreatment, good convergence, and high efficiency; Elastic stage or modal analysis is acceptable.	Completely eliminates the slip and energy consumption of the nail connection, overestimates the structural stiffness, the hysteresis loop is close to zero, and the internal force of the member is distorted.	The material and connection differences between OSB and bamboo plywood are smoothed, and the performance of the bamboo plywood and OSB models is not different, so it cannot be used for seismic performance comparison.
Nonlinear spring element	High flexibility and moderate computing cost; Monotonic and reciprocating constitutive models can be defined, and pinching4 can simulate pinching, stiffness, and strength degradation, which is the most widely used [1]	The accuracy depends on the spring constitutive parameters; Nail group equivalence and layout influence results.	Almost all spring parameters come from the OSB specification material system [5, 6, 14]; The bearing, anisotropic, and self-tapping screw connection stiffness and ultimate bearing capacity of bamboo pin groove are significantly different from OSB [3, 4]; the direct transplantation error cannot be ignored, and the hysteresis parameters of bamboo are scarce [11, 13]
3D contact model	Theoretically, it has the highest accuracy and can capture contact pressure, local crushing, nail Bending Yield, and friction.	The mesh size is huge, the contact nonlinearity is strong, convergence is difficult, and the calibration of contact parameters is complex.	The gradient density of bamboo, the difference between along-grain and transverse-grain, and the viscoelastic constitutive model are not yet mature; It is difficult to effectively simulate fracture damage such as nail cap pull-through, block shear, and plate edge tear, and there are no standards for contact parameters.

Although the accuracy and efficiency of the three methods are different, the common bottleneck is that the parameter basis is rooted in the OSB system (Table 2). OSB specification nail connection has accumulated systematic monotonic and repeated loading data, which can provide failure mode,

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stiffness degradation, and skeleton curve parameters [5, 6, 14]. Bamboo plywood is faced with "no parameter available": the pressure of the bamboo pin groove is different from OSB, and the difference between parallel and transverse grain is greater; The connection stiffness and ultimate bearing capacity of self-tapping screws are significantly higher than those of ordinary round screws [4]; The failure mode has changed from the common edge tearing and nail pulling of OSB to the cooperative bearing of screw-bamboo board, nail cap pulling, and block shear [3, 4]. The existing research on bamboo nail connection mostly focuses on monotonic bearing capacity and failure mode. The data on reciprocating hysteresis, stiffness degradation, and strength degradation are scattered [11, 13], and the standardized load slip curve library and finite element parameter system have not yet been formed. Therefore, the binding constraint "smoothes out the difference" without parameters, the spring model "has no parameters to rely on" due to the lack of constitutive parameters, and the three-dimensional contact "has legal difficulties" due to the lack of bamboo constitutive and contact parameters. The key obstacle to the numerical comparative study of bamboo plywood cladding is not the modeling method itself, but the "no parameter available" dilemma that OSB parameters cannot translate to bamboo.

5. Conclusion

In this paper, the research progress of seismic performance of OSB and bamboo plywood wood truss cladding system is systematically reviewed from three aspects: the mechanical properties of cladding materials, the mechanical behavior of nailed joints, and the finite element modeling method. At the material level, bamboo plywood is significantly better than OSB in density, static bending strength, and nail holding force, but its stronger anisotropy puts forward special requirements for nail connection design. At the joint level, the theoretical model of the OSB gauge timber system has been relatively mature, while the research on the hysteretic characteristics and stiffness degradation of bamboo plywood nail joints under reciprocating loads is seriously insufficient. At the modeling level, the parameter bases of the three finite element methods are all rooted in the OSB system, and face the fundamental dilemma of "no parameters available" when turning to bamboo plywood.

To sum up, it can break through the dilemma of "no parameters available" for bamboo plywood nail connection from the following three aspects in the future: first, establish a standardized test database for bamboo nail connection, systematically cover bamboo plywood, Glulam, and other bamboo materials and different nail combinations, and obtain complete parameters such as failure mode, load slip curve, stiffness degradation, and strength degradation under monotonic and reciprocating loading, forming a standardized curve library that can be directly used by finite elements.

A theoretical model of nail joints suitable for bamboo was developed. The unique failure mechanisms, such as the difference between bamboo along and across grain, the bearing strength of the pin groove, and the pull-through of the nail cap, were incorporated into the constitutive framework, and a parametric hysteretic model with both accuracy and efficiency was constructed. Thirdly, the gradient structure of bamboo is incorporated into the constitutive description by using the theory of functionally graded material mechanics for reference; On this basis, the multi-scale framework of "representative volume element (RVE)+progressive homogenization+macro finite element" is adopted. The gradient equivalent elastic parameters are quantified by RVE modeling and transferred to the macro model, which breaks through the double bottleneck of the three-dimensional contact model in terms of bamboo constitutive deficiency and calculation efficiency. The promotion

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of the above work will provide a scientific basis for the popularization and application of bamboo plywood in the wood structure cladding system.

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