

Properties of Wood Shear Walls Connected by Wood Nails

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The performance of a wood wall connected by wood nails and twist nails was tested. It was found that during the monotonic load testing, the wood nails connected to the shear panel and stud at the column bottom broke when the deformation reached 12.1 mm. However, the primary failure mode was that the twist nails bent and the head cap became dented in the shear panel. For reciprocating loads, it was found that the wood nails experienced local fracture on the tensile side. The skeleton curve of the wood wall connected by twist nails showed a good trend of bearing capacity changes in both tension and compression sides. Based on the properties of the standard wood wall, a new T-shaped fastener was designed for the midply wood wall. The lateral performance of the reinforced standard wood shear wall and midply wood shear wall were tested. By adding T-shaped pull-up fasteners, sandwich wall structure and double row nails, the strength, stiffness, and ductility of the midply wood wall were substantially better than those of standard walls connected with twist nails using conventional pull-up fasteners.

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INTRODUCTION

Twist nails are widely used in the joints of wood structure. Several researchers have studied the properties of the joint connected by twist nails. Dong *et al.* (2015, 2019) tested the strength of three types of joints, including the coil nails, paper row nails, and twist nails with the diameters 2.8 mm, 2.5 mm, and 3.1 mm, respectively. The strength of the joints connected by these three types showed the same positive correlation with the diameters. At the same time, it was found that the strength of the joint was considerably affected by the pull-out resistance, but less effected by the bending yield strength (Dong *et al.* 2015, 2019). The failure mode of the joints was studied. The thickness of the oriented strand board (OSB) and Spruce-Pine-Fir (SPF) was not an important influencing factor. While the new or old OSB and SPF materials had a significant impact (Zhang *et al.* 2019). In the study by Yao *et al.* (2019) the thickness of the OSB showed important impact on the nail-holding power. In contrast, the diameter of the nails has only little influence. The same conclusion was obtained from other research (Gao *et al.* 2017). In the field of light wood structure shear wall, the gypsum board was replaced by the phosphogypsum board. The failure mode of the joints was the splitting failure under nail hole, horizontal fracture failure at the nail hole, and mixed destruction mode (Bai *et al.* 2023). Chen *et al.* (2023 a, b) found that under monotonic loading, the failure mode of the joints mainly manifests as a “double hinge” mode of iron nails and the fiber crushing failure at the bottom of the nail rod. However, under low cycle loading, most iron nails showed fatigue fracture failure caused by repeated

bending deformation. However, this failure phenomenon rarely occurred in shaking table tests and actual earthquakes. This may be because during low cycle loading, the joint was connected by only 1 to 2 nails. By contrast, in actual buildings, because of the thousands of nail joints, it is possible to avoid fatigue failure caused by concentrated bearing capacity on a single nail.

There is currently limited research progress on the connection of wooden nails. Zhou *et al.* (2022) used wooden nails to fix glued wooden boards around the bolt holes of glulam, to enhance the local strength of the bolt holes. Wang *et al.* (2021) used wooden nails to connect SPF at multiple angles. When the nail insertion angle was 60°, the bearing capacity, stiffness, and ductility coefficient of the joint were the highest in the shear tensile state. Li *et al.* (2020) used bamboo wood pins to connect double-layer specification composite beams. In the research of the authors' previous study, wood nails could be used to connect laminated timber with excellent performance instead of twist nails (Xue and Zhu 2020; Zhu *et al.* 2023).

In the studies of wood structure shear walls, Chen *et al.* (2023) found that the failure of bamboo wood shear walls often began with the failure of the nail joints between bamboo laminated timber and oriented particle board under wind and earthquake loads in their study. Using bamboo laminated timber (LBL) as the stud, the edge distance of the nails of OSB and LBL has the greatest impact on the failure mode. In cases where the structural requirements were not met, the specimens are prone to premature brittle failure. Bai *et al.* (2023) used gypsum panels as wooden wall shear panels. They found that boundary studs have little effect on the shear bearing capacity of gypsum panel lightweight wood structure shear wall walls, but shear stiffness could be improved. When using boundary double studs, the proportion of skeleton shear force distribution can be increased, delaying the failure of panel nail connections, and thus improving the shear performance of shear walls. Liu *et al.* (2022) found that small diameter wood composite wall studs can be used instead of SPF in wood frame shear walls, and considerable lateral bearing capacity can be achieved. A reinforced wooden shear wall was designed. The load-bearing capacity of the shear walls was improved by reducing nail spacing, increasing the number of end studs, and lengthening the length of anti-uplift fasteners (Xavier *et al.* 2020). In contrast, a midply wood shear wall was designed (Erol *et al.* 2006, 2007).

The lateral resistance performance of the midply wood shear wall was studied. The lateral stiffness and shear strength of the midply wood shear walls were almost twice and three times that of ordinary wood shear walls, respectively (Zheng *et al.* 2016a,b). Furthermore, the midply wood shear wall was filled in the beam column frame. The maximum bearing capacity 148.3 kN was reached (Zheng *et al.* 2019). Based on the midply wood shear walls, Guo *et al.* (2020) designed a full-length screw anti pull-out fastener (ATS). Compared with ordinary midply wood shear walls, the load-bearing capacity, energy consumption, and lateral stiffness were increased 154%, 427%, and 93%, respectively. Bagheri and Doudak (2020) and Chu *et al.* (2020) also obtained similar conclusions.

Based on the above research, wood nails were used to connect the wood shear walls including the standard walls, and midply walls instead of twist nails. Meanwhile, a new uplift resistant fastener was designed. To study the feasibility of wood structure shear walls using wood nails, the wood nails were used as connectors to study the lateral resistance performance of shear walls in this paper.

EXPERIMENTAL

Materials

The stud materials were spruce-pine-fir (SPF) of grade II (Crownhomes, Jiangsu, China). The section dimensions of them were 89 mm (width) $\times$ 38 mm (thickness). The density was 495 kg/m³ when the MC was 9.7%. The thickness of the OSB was 11 mm. The diameter and length of the twist nails with surface galvanizing used to connect studs and OSB were 2.8 mm and 63 mm, respectively. In contrast, the diameter and length of twist nails connected the top or bottom beam slab and studs were 3.2 and 82 mm, respectively. All the SPF and twist nails were provided by Suzhou Crownhomes Co., Ltd. The diameter and length of wood nails were 4.7 mm and 76 mm. The wood nails were made of compressed beech. All the wood nails were provided by BECK from Austria. The relevant metal connectors were processed by Suzhou Andali Co., Ltd.

Experimental Design

Specimen prepared

For the pretest, the standard wood shear walls with the dimension 1200 mm $\times$ 2400 mm were made of studs and OSB (Fig. 1).

According to the pretest, the reinforced standard wood shear wall and midply wood shear wall with dimension 2400 mm $\times$ 2400 mm were designed (Fig. 2). For the reinforced standard shear wall, the traditional anti uplift fastener is shown in Fig. 3. The new anti-uplift fastener is presented in Fig. 4 for midply wood shear wall.

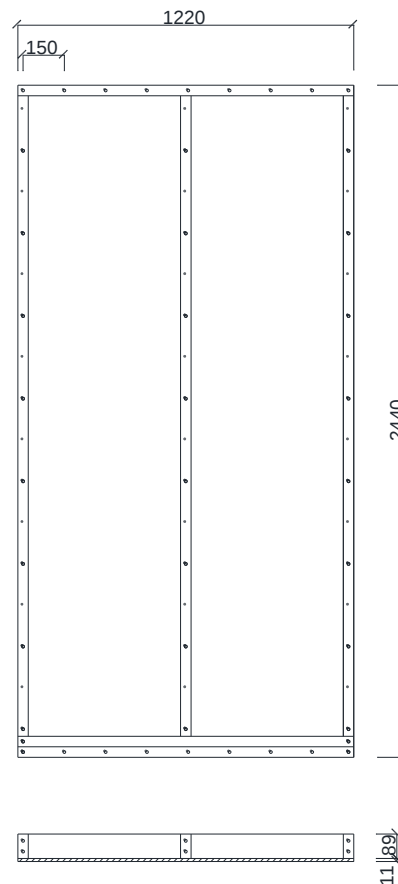
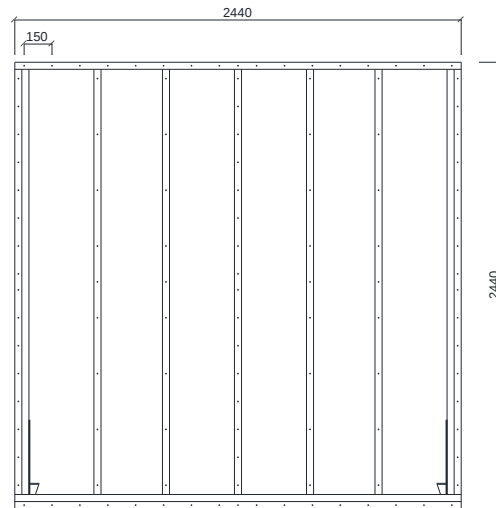
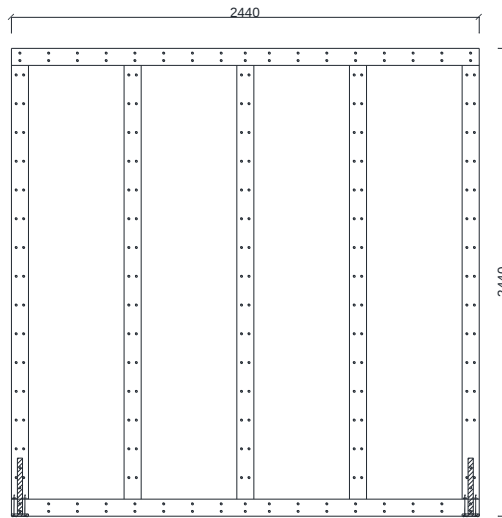


Fig. 1. The standard wood shear wall



(a)



(b)

Fig. 2. The reinforced standard wood shear wall (a) and midply wood shear wall (b)

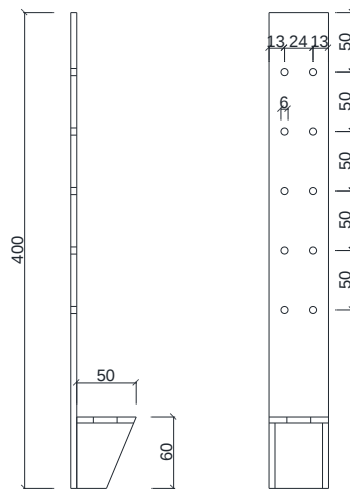


Fig. 3. The traditional anti uplift fastener

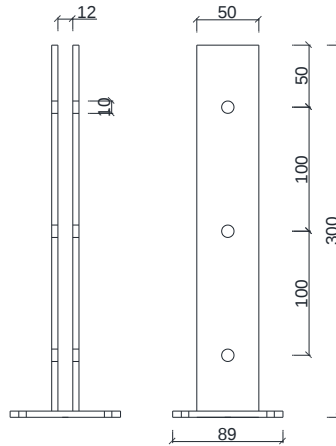


Fig. 4. The new anti-uplift fastener

Lateral load resistance test

The shear wall testing system (YAW-100J; Jinan Popwil, Jinan, China) was used to test all the shear wall specimens according to the national standard China GB/T 37745 (2019). The shear wall fixed to the testing system is shown in Fig. 5.



Fig. 5. The shear wall fixed to the testing system

RESULTS AND DISCUSSION

Standard Wood Walls Connected by Wood Nails and Twist Nails

The normal standard wood shear wall was mainly composed of top and bottom beams, studs, and shear panels connected by nails. The 82-mm twist nails were used for connecting routine studs and beams. The 63-mm twist nails were used to connect the shear panels to the studs. In contrast, wood nails were used to connect composite studs and shear panels in this paper. No anti-pull-out fasteners were installed at the column base.



Fig. 6. The bent (a) and indentation (b) of the wood nails



Fig. 7. The pull out of the studs



Fig. 8. The wood nails fractured and the shear panel separated from the stud



Fig. 9. The studs separated from the bottom beam of the shear wall connected by twist nails



Fig. 10. The head caps of the twist nails dented in the shear wall connected by twist nails

Through observation of the experimental phenomenon, it can be seen from Fig. 6(a) that the wooden nails were bent and broken at the base of the wall stud, indicating poor ductility and easy breakage of the wooden nails. Figure 6(b) shows the indentation of the wooden nails on the cover panel. Due to the lack of nail caps for protection, the indentation of the wooden nails was more obvious, and some were even completely separated from the cover panel. Figure 7 shows the pull-out of the composite studs, and the fibers of SPF were pulled out on the surface of the wood nail, indicating that the wooden nail not only had compression effect but also partial welding effect during the insertion process. As the reciprocating horizontal lateral force increased, the wall performed noticeable deformation, as shown in Fig. 8. The wooden nails at the edge of the wall were basically completely broken under the reciprocating force, with the covering panel and studs detached. The wall studs connected by wood nails showed no obvious damage throughout the whole testing process. In contrast, as a comparison, the studs were also separated from the bottom beam in the wall connected by twist nails, as shown in Fig. 9 (Farshid *et al.* 2023). However, when the wall deformation was large, the stud was separated from the bottom beam, the twist nails on the shear panel were bent, and the head caps of the twist nails were partially concave, but still partially connected with the bottom beam (as shown in Fig. 10).

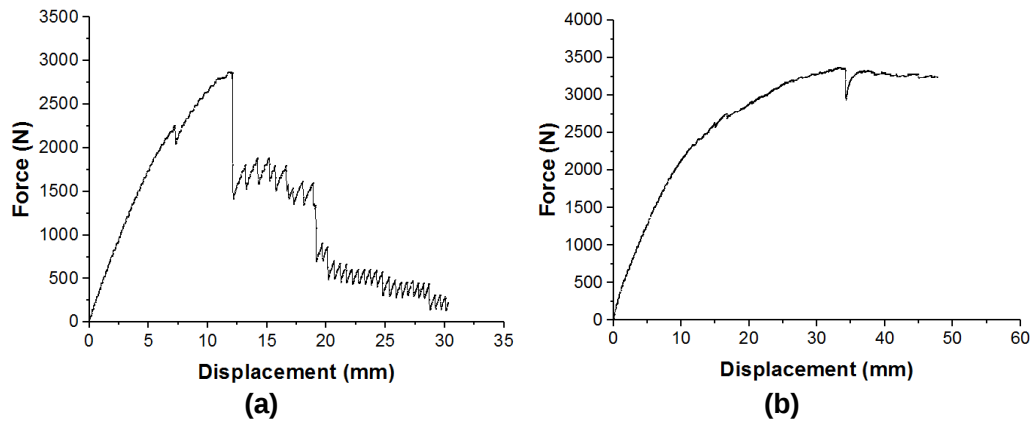


Fig. 11. The displacement and force curves of wood walls connected by wood nails (a) and twist nails (b)

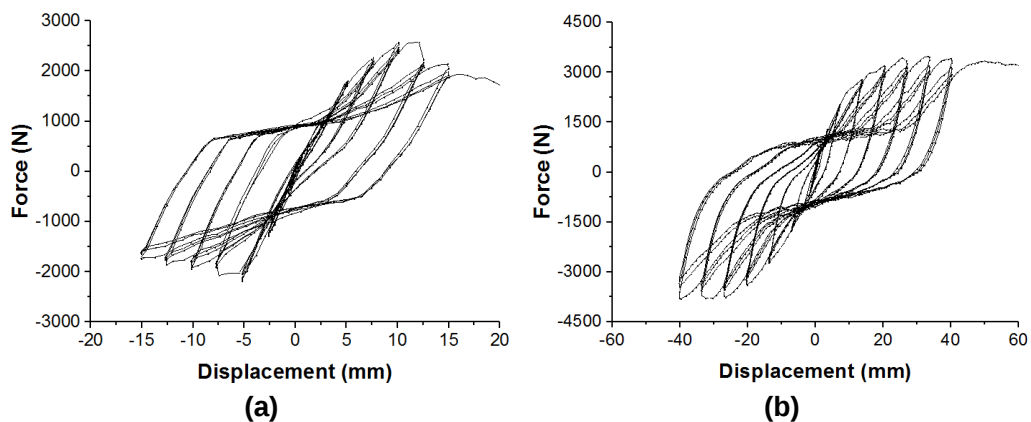


Fig. 12. The hysteresis curves of wood walls connected by wood nails (a) and twist nails (b)

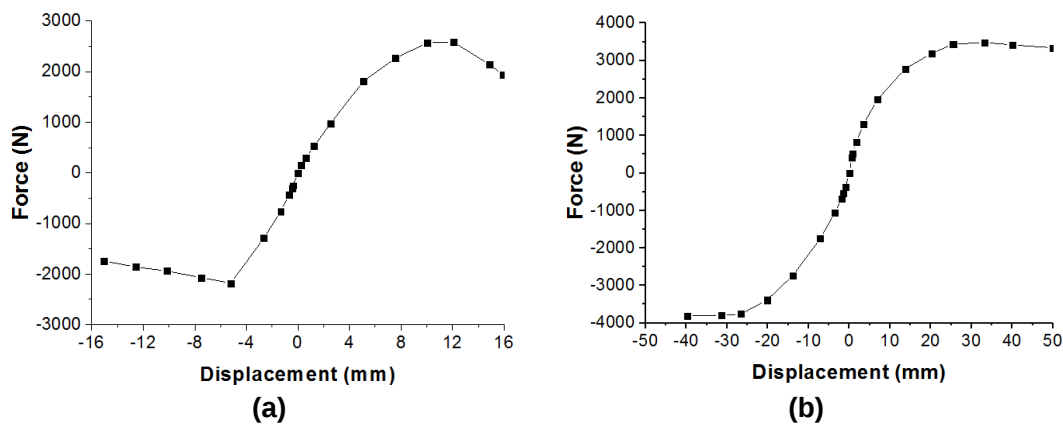


Fig. 13. The skeleton curves of wood walls connected by wood nails (a) and twist nails (b)

It can be seen from Fig. 11 that the maximum force of monotonic loading of the shear wall connected by wood nails and twist nails were 2870 and 3290 N, respectively. And the initial stiffness were 345 and 221 MPa, respectively. However, there was a noticeable difference in deformation between them. The shear wall connected by wood nails suffered serious damage only at 12.1 mm. According to experimental observations, the fracture occurred between the shear panel and studs in the column. The bearing capacity of the shear wall connected by twist nails began to decline slowly after 30 mm, which was

mainly caused by the head caps of twist nails that fell into the shear panel and the bent of the twist nails. For reciprocating load, the wood nail group and twist nail group basically showed the same change rule as monotonic load (as shown in Fig. 12). However, from the skeleton curve in Fig. 13, it can be clearly seen that the load-bearing capacity of the wood nail group increased first and then gradually decreased on the tensile side, but it showed a substantial decrease on the compressive side, indicating that the wood nails had undergone local fracture after being subjected to force on the tensile side, and cannot provide sufficient stiffness and strength on the compressive side. The skeleton curve of the twist nail group showed a good trend of bearing capacity changes in both tension and compression sides, and the ductility and stiffness degradation capacity were better than that of the wood nail group.

Reinforced Standard Wood Shear Wall and Midply Wood Shear Wall

Due to the large deformation, the breakage of the wood nails could easily happen. A new T-shaped anti-pull fastener was designed in this project (as shown in Fig. 4). Adopting the form of sandwich walls, the traditional connection method of nailing the narrow edges of the edge columns to the cover panels was changed to a wide face and cover panel connection. Firstly, the number of wood nails can be doubled, especially at the corners where the original single row single nail stress changed to multiple rows and multiple nails stress, effectively reducing the phenomenon of local nail compression damage or nail bending of the covering panel at the corners. In addition, due to the increase in the moment of the wide cross-section, the lateral resistance of the side studs will be remarkably improved, the deflection will be reduced, and thus the overall shear strength and stiffness of the shear wall will be improved. The application of new T-shaped anti-pull fasteners with internal filling further enhanced the connection performance at the column of the wood wall, avoiding the phenomenon of detachment between the edge columns and bottom beams during the usage of conventional walls. At the same time, the placement method of T-shaped steel plates was also able to bear lateral forces on a wide surface. Compared with the narrow surface bearing lateral forces of conventional pull-out fasteners, the overall shear strength and stiffness of shear walls have been greatly improved.



Fig. 14. The midply shear wall connected by wood nails

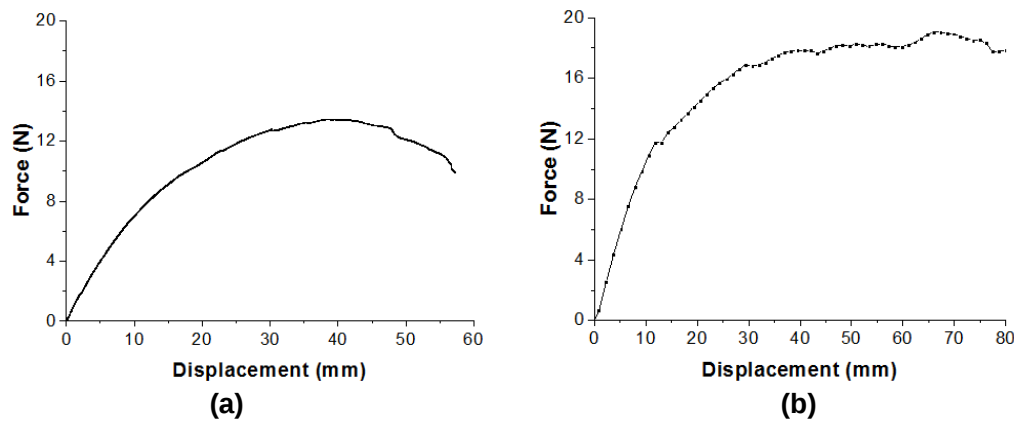


Fig. 15. The displacement and force curves of the reinforced standard wood shear wall (a) and midply wood shear wall (b)

The lateral resistance performance of the strengthened midply wood wall connected by wood nails (Fig. 14) and the standard wall strengthened with conventional pull-up fasteners connected by twist nails were compared in the same size of 2400 mm × 2400 mm. In Fig. 15, the maximum monotonic loading force of the wood wall connected by twist nails was 13.5 kN, and the stiffness at the elastic stage was 695 MPa. The maximum monotonic loading force of the wood wall connected by wood nails was 19.0 kN, and the stiffness in the elastic stage was 1030 MPa, which were higher than the properties presented by Zhang *et al.* (2023). During all the testing process, no obvious damage occurred in the bottom of the column. At last, the break was found in the shear panel connected to the studs by wood nails.

CONCLUSIONS

1. During the pretest process, for monotonic load, the wood nails connected to the shear panel and stud at the column bottom had been broken when the deformation reached 12.1 mm. However, the primary failure mode was that the twist nails bent and the head cap dented in the shear panel.
2. For reciprocating loads, it was found that the wood nails experienced local fracture after being subjected to force on the tensile side and could no longer provide sufficient stiffness and strength on the compressive side. The skeleton curve of the wood wall connected by twist nails showed a good trend of bearing capacity changes in both tension and compression sides, and the ductility and stiffness degradation capacity were stronger than that of the wood wall connected by wood nails.
3. The lateral performance of the reinforced standard wood shear wall and midply wood shear wall were tested. Through adding T-shaped pull-up fasteners, sandwich wall structure, and double row nails, the strength, stiffness, and ductility of midply wood wall were substantially better than those of standard walls connected with twist nails using conventional pull-up fasteners.

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