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A numerical study of coupled timber walls with slip friction damping devices

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HIGHLIGHTS

- Coupled timber walls with slip-friction connections were introduced and numerically modelled.
- The response of the system to quasi-static and time-history dynamic loading was studied.
- The efficiency of the proposed system is compared with a similar system with equivalent nailplates.
- Timber coupled walls with slip friction connections enhance the ability of walls to absorb the seismic energy.
- Timber coupled walls with slip friction connections represent a feasible low damage solution for rocking timber structures.

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ABSTRACT

In rocking timber structures, the traditional connections such as nailplates may need to be replaced by damping devices to provide the required lateral resistance and dissipate the seismic energy. This study seeks to investigate the seismic behaviour of coupled timber walls with slip friction connections. Slip friction connections present a low damage solution as they do not suffer from stiffness degradation and can be used after a seismic event. The seismic response of the described system is compared to those with equivalent nailplates. Displacement control quasi-static and also dynamic time-history analyses showed that the performance of the systems with friction devices is significantly improved under seismic loading compared to similar systems with equivalent nailplate connections. The systems with nailplates incurred significant inelastic damages while the systems with friction devices exhibited superior performance in terms of strength degradation and absorbed seismic energy. The introduced concept presents a feasible solution for timber structures when a low damage design is targeted.

1. Introduction

The potential for structural systems with prefabricated members in seismic applications has significantly increased in the last two decades. This was mostly due to the introduction of jointed ductile connections in precast concrete. In the United States in the early 1990's, the PRESSS (PREcast Seismic Structural Systems) program was initiated in order to develop design recommendations for precast construction in seismic zones and also to introduce novel concepts and technologies in precast concrete structures [1]. As an important outcome of the program, precast concrete walls were recognised as being significantly effective lateral load resisting members. Later, in order to minimise the observed residual damage during the experiments, a coupled wall system with energy dissipative devices was introduced as another part of the program [2].

In a typical coupled wall system, two or more prefabricated walls are connected to each other with special energy dissipative connectors along the vertical edges. In a seismic event, the walls are allowed to rock restrictedly at the base and then return to their initial position. The vertical joints dissipate energy by experiencing inelastic deformations under lateral forces. The system can accommodate large lateral drifts while residual damages are minimised. This concept has later been adapted to timber structures by Palermo et al. [3]. Iqbal et al. [4] further developed the concept and tested coupled timber walls with mild steel U-shaped Flexural Plates (UFPs) as the vertical joints. They concluded that the U-shaped plates offer an effective energy absorption mechanism through metal yielding during rocking of the walls.

Passive friction-based energy dissipater devices were originally utilised for steel structures. Popov et al. [5] introduced the

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symmetric slotted bolted connection which dissipates energy through friction during equilateral tension and compression cycles. It consists of a main plate sandwiched by two outer plates connected together by bolts. The connection is designed such that at a predestined force, sliding will be initiated. The slippage force is function of both the clamping force of the bolts and the coefficient of friction of the surfaces enclosed by the two outer plates.

Clifton et al. [6] proposed the *Asymmetric* sliding hinge joint for steel moment resisting frames which had non-rectangular yet stable hysteretic behaviour. In the asymmetric assembly, when the applied force rises above the frictional resistance of the first surface, sliding will be triggered while the bottom plate remains still for a short period of time. Subsequently, the bottom plate starts to slip and the sliding shear and the stiffness of the connection will be doubled. Therefore, bolts are forced into a double curvature state and the joint renders a pinched hysteretic behaviour [7]. This is advantageous for minimising the post-seismic residual drifts but it is not beneficial for stiffness retention after a seismic event. Khoo et al. [8] developed the design models for asymmetric slotted bolted connections based upon numerous experiments and also rigorous analyses.

For timber structures, Most of the proposed seismic solutions were based on energy dissipation through deformation and yielding of the fasteners (such as nails or screws) and crushing of the wood fibres [9–12]. Filiatrault [13] utilised friction dampers for timber sheathed shear walls. The analytical studies demonstrated a noticeable improvement in the hysteretic behaviour of the walls compared to traditional timber shear walls. Large amount of dissipated energy was also observed at different lateral drifts up to 1.5%. Loo et al. [14,15] investigated the application of slip friction connections as a replacement of traditional hold-downs for timber Laminated Veneer Lumber (LVL) walls. Their experiments showed significantly improved seismic performance compared to traditional systems in terms of hysteretic behaviour stability and residual deflections [16]. Additionally, and most importantly, the timber wall remained in the elastic region after several quasi-static and dynamic numerical analyses that was also confirmed by experimental tests.

This study seeks to investigate the application of sliding frictions passive dampers (slip friction connections) in coupled timber walls. Towards this purpose, a new configuration is proposed. The slip friction connections developed and tested by Loo et al. [14,15] are used as hold-down connectors. Additionally, a new type of slip friction connector for vertical joints inspired by previously proposed slip friction hold-downs is presented. A symmetric configuration is considered for both hold-downs and vertical joints between the adjacent walls. Nonetheless, the asymmetric concept undoubtedly has the potential for further studies in timber structures. General arrangement of the proposed system is shown in Fig. 1.

In order to determine the slip force which triggers the rocking movement in the system, a numerical simulation has been conducted on the timber walls. Henceforth, the efficiency of the proposed coupled wall system is investigated through displacement control quasi-static and dynamic time-history analyses. To compare the seismic performance of the introduced concept with the conventional systems, similar numerical models with equivalent nailplate connections in lieu of slip friction devices are developed and analysed.

2. Lateral resistance of Cross Laminated Timber (CLT) and Laminated Veneer Lumber (LVL) walls

Cross laminated timber is a new generation of engineered wood product which was firstly developed in Europe in the 1990s and then adopted in other parts of the world [17]. It consists of typically three, five, or seven layers of dimensioned lumber oriented orthogonally to each other and then glued to create a structural panel. It is a strong, sustainable and dimensionally stable wood product. It offers almost similar characteristics to that of a precast concrete panel yet has a much more advantageous strength to weight ratio. More than that, efficient planning during construction and a high level of prefabrication are the two key advantages which significantly accelerate the construction process. Thus, CLT has been notably gaining popularity among the building owners and the designers around the world and numerous CLT buildings have been built in different countries during the last decade.

Generally, in all low damage timber structural systems, the key point is that timber elements must remain in the elastic region and any possible pinching phenomena in the connections which may cause non-recoverable plastification in the wood should be avoided. Thus, the first step in design and modelling of CLT shear walls with slip friction connections is to decide on a rational method to determine the maximum tolerable lateral force (and the consequent overturning moment) at which the wall can remain in the elastic region (F_E). If a lateral force is applied to the top of a rocking CLT wall (see Fig. 3(b)), the movement should be initiated before the stress in any of the timber boards exceeds the allowable characteristic strength. Loo et al. used a similar approach to specify the slip threshold for a rocking LVL wall with slip friction hold-downs [15].

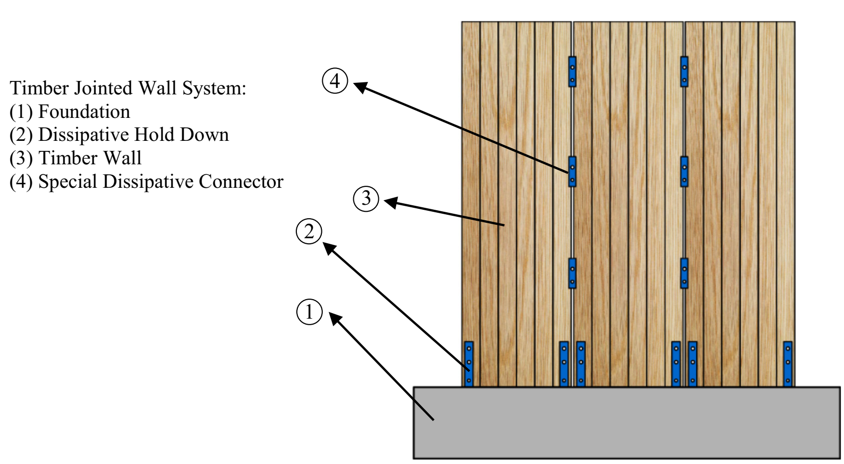

Fig. 1. The concept of coupled timber walls with slip friction connections.