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Seismic resistant rocking coupled walls with innovative Resilient Slip Friction (RSF) joints

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ABSTRACT

Multi-story hybrid timber-steel structures are becoming progressively desirable owing to their aesthetic and environmental benefits and also to the relatively higher strength to weight ratio of timber. Moreover, there is an increasing public pressure to have low damage structural systems to minimize the destruction after severe earthquakes. A recent trend in the timber building industry is the use of cross laminated timber (CLT) wall systems. CLT is a relatively novel engineered wood based product well suited for multi-story structures. Latest research findings have shown that CLT buildings constructed with traditional steel connectors can experience high damage mainly because of stiffness degradation in the fasteners.

It has been proven that friction joints can provide a perfectly elastoplastic behaviour and a stable hysteretic response. Up until now, the main disadvantage of the friction joints has been the undesirable residual displacements after an earthquake. This study presents a hybrid damage avoidant steel-timber wall system using the innovative Resilient Slip Friction (RSF) joint. The proposed system includes coupled timber walls and boundary steel column as the main lateral load resisting members. RSF joints are used as ductile links between the adjacent walls or between the walls and the steel boundary columns. The efficiency of the system has been investigated by experimental joint component tests on the RSF joint followed by reversed cyclic numeral analyses and dynamic non-linear time-history simulations on the wall system. The results confirmed that the proposed system has the potential to be recognised as an efficient lateral load resisting system.

1. Introduction

Multi-story hybrid buildings built with structural timber members are becoming progressively desirable for engineers and building owners because of the aesthetic and environmental benefits of the wood and engineered wood products and further for the relatively higher strength to weight ratio of timber. Furthermore, there is an increasing public pressure to have low damage structural systems in order to minimize the earthquake destruction after moderate to severe seismic events. This is important as the building could be quickly reoccupied with minimal business interruption and repair costs.

Cross laminated timber (CLT) is a new generation of engineered wood product which was firstly developed in Europe in the 1990s and then expanded globally as a reliable construction material [1]. It is a strong, sustainable and dimensionally stable product which offers different structural characteristics similar to that of a pre-cast concrete panel, yet it has relatively higher strength to weight ratio. Additionally, CLT structures possess flexible planning and high level of prefabrication which considerably accelerate the construction process and reduce the overall cost. Hence, CLT has been notably gaining popularity among building owners and designers and as a consequence, numerous CLT buildings have been built in different countries over the last decade.

During the PRESSS (PREcast Seismic Structural Systems) program in the early 1990's, a new design approach for structural walls was introduced which was based on the application of simple joints between the prefabricated panels in order to localize the inelastic deformations in those joints [2]. In addition, unbounded post-tensioned steel members were employed to provide the self-centring behaviour. The dissipation capacity of such system is highly related to the type of the dissipaters implemented between the walls (also known as the sacrificial fuses). For timber structures, Palermo et al. adopted a similar approach and conducted preliminary experimental tests on laminated veneer lumber (LVL) walls with different types of fuses [3,4]. The results confirmed that the enhanced performance of the system was attributed to the ductile joints between the members. Smith et al. further extended the concept into coupled wall systems [5]. They proved that the design flexibility of the hybrid coupled wall systems combined with the offered speed of construction creates a significant potential for such system in multi-story buildings. Iqbal et al. studied the application of U-shaped Flexural Plates (UFPs) as supplementary damping devices in post-tensioned LVL timber coupled rocking walls [6]. The test results exhibited

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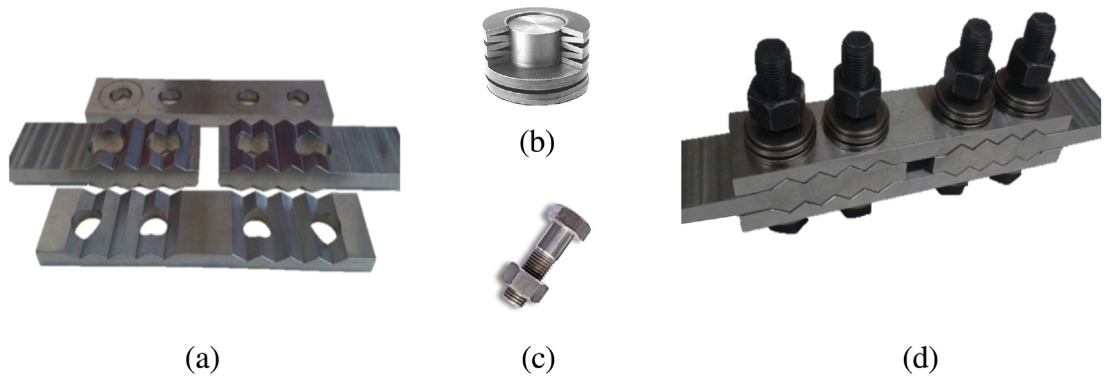

Fig. 1. RSF joint: a) Cap plates and slotted centre plates b) Belleville springs c) High strength bolts d) Assembly of the joint.

an efficient energy dissipation mechanism over the deformation of the UFPs during the earthquakes. Sarti et al. experimentally investigated the seismic performance of the hybrid rocking walls with end columns [7]. Their experimental results confirmed a notable improvement in the seismic performance of the introduced system in terms of energy dissipation and stability of the hysteretic behaviour. Iqbal et al. tested coupled post-tensioned rocking LVL walls with sacrificial nailed plywood sheets as hysteretic dissipative elements [8]. The experimental results affirmed the seismic performance of the system. Nevertheless, relatively lower hysteretic stability was observed compared to the similar systems with UFPs.

Friction based passive damping devices were originally introduced for steel structures. Popov et al. proposed symmetric slotted bolted connections which dissipate energy through friction during equilateral tension and compression cycles [9]. Popov's comprehensive experiments exhibited stable rectangle-shaped hysteretic loops. Clifton et al. proposed the asymmetric sliding hinge joint for steel moment resisting frames which had non-rectangular yet stable force-deformation behaviour [10]. Khoo et al. developed design models for the asymmetric slotted bolted connections based upon numerous experiments and rigorous analyses [11].

For the first time in timber structures, Filiatrault used friction dampers at the four corners of a traditional timber sheathed shear wall [12]. The results demonstrated a significant improvement in hysteretic behaviour of the walls while large amount of seismic energy was absorbed through friction. Loo et al. investigated the application of slip friction connections as the replacement of traditional hold-downs in LVL rocking walls [13,14]. The experimental results showed an excellent seismic performance in terms of hysteretic behaviour and the minimized residual deflections. Additionally, and most importantly, the timber wall remained in the elastic region after several non-linear dynamic numerical analyses. Furthermore, no substantial damage was observed in the timber members during the quasi-static experimental tests. Hashemi et al. introduced the application of slip friction connections in CLT coupled walls as the hold-down connections and also as ductile links between the wall panels [15,16]. The numerical results confirmed the efficiency of the introduced system in terms of seismic energy absorption and durability of the hysteretic behaviour. The proposed concept was further developed to hybrid rocking core walls in which the post-tensioned joints are used as supplementary devices in the beam-column connections to provide a self-centring system [17].

This study seeks to develop a damage avoidant CLT coupled rocking wall system which includes innovative Resilient Slip Friction (RSF) introduced by Zarnani and Quenneville [18] as the ductile links between the adjacent walls or columns. Owing to the characteristics offered by the RSF joints, this innovative lateral load resisting system is able to provide self-centring behaviour in addition to significant rate of seismic energy dissipation. A simple procedure for designing the joint is described and the results of RSF joint component tests are presented. Furthermore, a numerical model is developed to demonstrate the seismic performance of the proposed system. To investigate the efficiency of the system, the model is subjected to displacement-control quasi-static cyclic simulations and also non-linear dynamic time-history analyses.

2. Resilient Slip Friction (RSF) joint

The concept of slip friction connections using flat steel plates sliding over each other has already been recognised as an effective energy dissipating structural solution and the energy absorption mechanism of the friction joints has been known as one of the most efficient ones

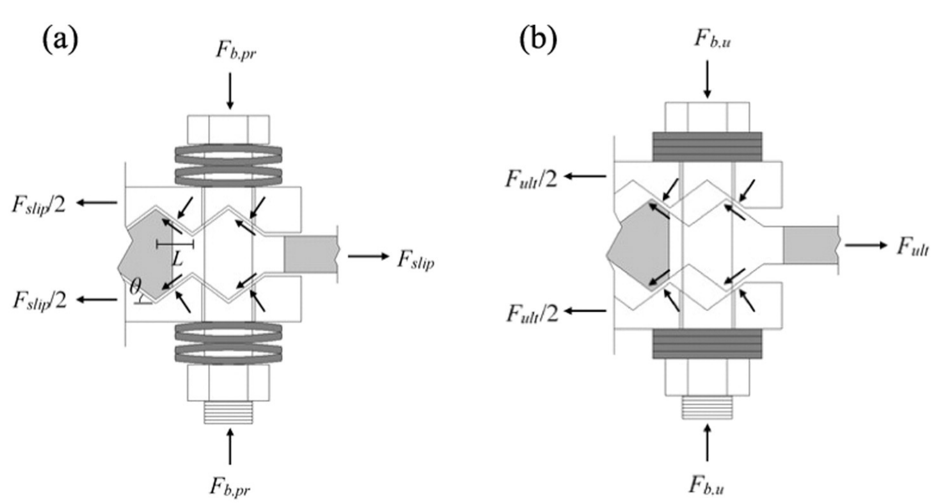

Fig. 2. Free body diagrams for a symmetric RSF joint: a) On the brink of slippage b) At ultimate deflection