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Mechanical characterization of a pre-fabricated connection system for cross laminated timber structures in seismic regions

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ABSTRACT

This paper focuses on the point-to-point X-RAD connection system for the construction of cross laminated timber buildings in earthquake prone areas. Tests on X-RAD connectors subjected to "shear-tension" and "shear-compression" loading configurations are presented as supplement to the experimental data provided in previously published research. Tests aimed at characterizing the behavior of timber walls assembled with the system and loaded by lateral force are also reported. A capacity domain that allows for quick safety checks for any given load combination on the connector was derived from the experimental outcomes and is presented herein. An extremely simplified, yet effective numerical approach (the connector behavior is reproduced by 3-link elements) is proposed and compared with the experimental evidence. The 3-link model was able to reproduce with sufficient accuracy both, the elastic and post-elastic response of the walls. In the discussion section, particular attention is given to the system capability of dissipating energy and exhibiting ductile behavior.

1. Introduction

Cross Laminated Timber (CLT) panels are a class of engineered timber products composed of orthogonal layers of boards introduced into the Central European market about twenty years ago. They are becoming increasingly popular structural components of walls and floors in multi-storey buildings. Multi-storey buildings made of CLT usually feature several typologies of connection systems whose mixed use can often be found within the same structure [1,2]. Recently, innovative connection solutions have been studied in order to create panel-to-panel joints or joints between panels and other structural components. Solutions based on point-to-point connections have been proposed by several authors in [3–5], as an alternative to the traditional connection systems [6,7] that use nailed plates as shear and hold-down anchors. From a structural design and analysis perspective, point-to-point connections between CLT panels or between CLT and other materials can reduce ambiguity in definition of load paths and forces on connectors within them. Point-to-point connections are ones that transfer in-plane shear and tension forces between panels in load paths. Conversely, hold-downs and angular brackets, which can be subjected to forces different from the design forces (e.g. when angular bracket are loaded in tension), can lead to uncertainty when it comes to determining the analysis load distribution [8–13]. Several research works that are available in literature [13–16] have demonstrated the adequacy of adopting CLT structures in seismic areas by conducting large experimental campaigns aimed at studying the behaviour of full-scale CLT structures.

The X-RAD system, presented in [17,18] can be included in the category of point-to-point connection systems. This connection system, intended to be pre-assembled, is fastened to the corners of the CLT panels by means of fully-threaded self-tapping screws. A key advantage is that relatively few fasteners need to be installed during assembly of the panels that constitute the seismic force resisting system. In order to maximize the capacity of the connection system for manifold load configurations, the fully-threaded screws, which are intended to be mainly loaded in tension/compression, are installed at two different angles of inclination.

Experimental campaigns were performed at the CNR-IVALSA institute of San Michele all'Adige, at Graz University of Technology (TU Graz) and at the University of Trento. In particular, the tests were aimed at characterizing the X-RAD connector under different loading conditions [18] and evaluating the response under lateral loading of walls where the CLT panels are fixed to each other or to the foundation by means of X-RAD connectors. This paper presents an analytical

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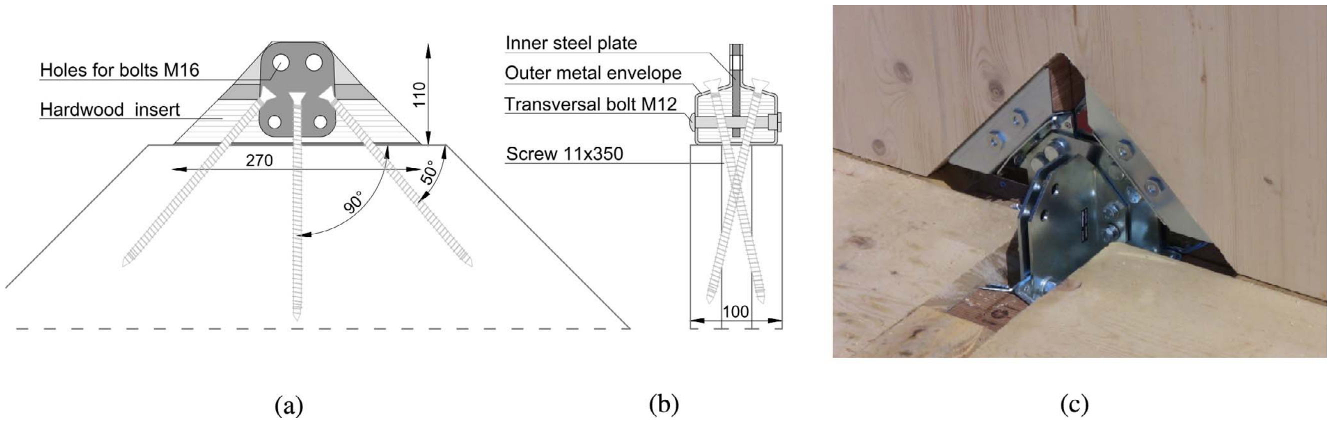

Fig. 1. X-RAD connection system: (a) and (b) connector schematics; (c) close-up on intersecting panels jointed with X-RAD connectors.

formulation predicting the capacity of X-RAD connectors for various loading configurations based on observation of experimental failures. A safety-checking method based on a derived capacity domain is proposed, together with a simple Finite Element Analysis method for estimation of force flows in CLT structures assembled using X-RAD connections. Analytical and numerical predictions are compared with the experimental data.

2. Description of the X-RAD connection system

2.1. The X-RAD connector

The X-RAD system is a mechanical connection system designed to be positioned at the corners (or in case of large panels at intermediate positions) of CLT panels; see the illustration in Figs. 1(c) and 2(b). The X-RAD connector itself [19] has three main components: (1) an outer metal envelope combined with an internal steel plate, (2) a core made of hardwood laminated veneer lumber (LVL), and (3) six fully-threaded self-tapping screws (11 × 350, nominal diameter [mm] x length [mm]) inserted at two different angles of inclination in order to optimize the connector capacity (Fig. 1). In the X-RAD system, connectors fixed to adjacent or intersecting CLT plates are joined together using steel bolts and steel linking plates; see Fig. 1(c).

The double inclined fully-threaded self-tapping screws permit X-RAD connectors to engage the full capacity of both the CLT panels (load is transferred to several CLT layers) and the screws (primarily subjected to axial loading).

The X-RAD connector is designed and intended for pre-assembling. Therefore, the connectors can be used as lifting hooks during loading/unloading of the CLT panels on/from the trucks and also during the assembling operations on-site. Once transported to the building site, the CLT wall panels pre-assembled with connectors can be positioned on special steel plates anchored to (or cast-in) the foundation. Then, just few standard steel bolts are required for connecting the anchoring plates to the X-RAD units and for securing the panels in their final position. The result of this is that any on-site nailing/screwing operation is avoided [18].

The X-RAD system is characterized by building tolerances designed to exploit the precision of the CNC cutting machines (e.g. bolt-hole clearances of 2 mm). Several panels have already been assembled by using X-RAD without tolerance issues being reported, mainly thanks to the anchoring plates that guide the panel installation. However, it is evident that the adoption of the X-RAD system requires a continuous quality control of the construction process as the system cannot accommodate onsite corrections of overlooked design errors.

2.2. Application of X-RAD connection system in CLT structures

Although CLT panels are large dimensional elements, a multitude of panels can be present in a building requiring numerous fasteners to realize panel-to-panel connections. Wall and floor panels are usually connected to each other by metal elements consisting of thin plates nailed to the timber elements. The function of such nailed plates is to transfer the shear forces (angular brackets) and uplift forces (hold down elements), originating from wind and earthquake actions, to the foundations (see Fig. 2(a)). Nail plates are not the only type of fasteners utilized in CLT structures. Self-tapping screws are commonly used to connect the floor panel longitudinal edges in order to create diaphragm continuity in the direction transversal to the panel orientation. Inclined screws are also often used to create a box-like response by joining cross wall elements along their vertical edges.

Using different connectors featuring different typologies implies a certain degree of ambiguity in the definition of the load path. This results in fasteners that can be subjected to a combination of forces different from the design load configuration [8–10,12].

The X-RAD connection system is suitable for joining both coplanar and perpendicular panels, creating wall-to-wall, floor-to-floor and wall-to-floor connections. However, at the current stage of technical

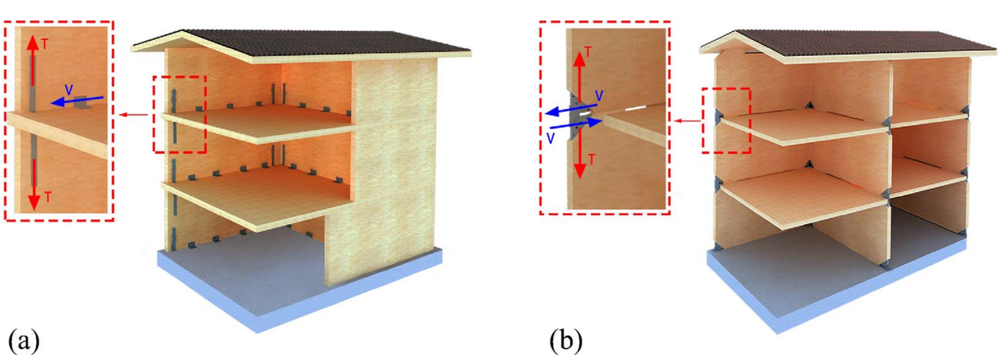

Fig. 2. Schematic representation of CLT buildings assembled by using: (a) standard connections; (b) X-RAD connection system.

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