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High-capacity hold-down for mass-timber buildings

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HIGHLIGHTS

- Mass-timber products enable the use of timber as structural material in tall buildings.
- Experimental studies on a novel high-capacity hold-down solution were conducted.
- A modified HSK assembly provides high initial stiffness and predictable capacity.

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ABSTRACT

Engineered mass-timber products such as cross-laminated timber enable the use of timber as structural material in tall buildings. One of the advantages of using timber is the reduction in weight and the resulting reduction in foundation costs. A lower structural mass, however, will also lead to less inherent resistance to overturning forces caused by lateral loads such as wind. This paper summarizes the experimental studies on a novel high-capacity hold-down solution for tall timber structures. The connection assembly consists of a modified Holz-Stahl-Komposit (HSK)™ application: perforated steel plates that are adhesively bonded into the timber panel with duct tape being used to cover some rows of the holes in the perforated plate. This arrangement allows the perforated steel plate to yield inside the timber which prevents lateral buckling of the hold-down. A total of 54 tests at material, component and full-scale hold-down level were conducted using quasi-static monotonic and reversed cyclic loading. The results demonstrated that the modified HSK hold-down assembly provides high initial stiffness as well as the required capacity and ductility for seismic applications in tall mass-timber buildings.

1. Introduction

1.1. Tall and mass-timber structures

Production and subsequent use of timber in commodity products for residential light-frame construction up to six storeys is an important part of the North American construction sector. While timber as a structural material is increasingly being used in non-residential construction, taller timber buildings remain relatively rare due to the building height limitations in the codes. However, a large number of mid-rise timber structures were built across North America at the beginning of the 20th century. Fire incidents during that period were the main reason for classifying the construction materials into combustible and non-combustible categories and placing area and height restrictions on buildings made of combustible materials [1]. Nevertheless, recent examples from around the world show that timber has the potential to expand into construction market segments that are currently dominated by steel and concrete structures. Publications, such as the ‘Technical Guide for the Design and Construction of Tall Wood Buildings in Canada’ [2] and ‘Use of Timber in Tall Multi-Storey Buildings’ [3], address the renewed interest in using timber for tall buildings. Tall timber building systems have been embraced by developers and architects around the world to meet the growing demand of living and working space with a sustainable building material [4].

Over the last decades, several innovative materials, connectors, and systems were developed that contributed to resurgence in the use of timber as a structural material. On the material level, the introduction of cross-laminated timber (CLT) has been a game changer. CLT is a plate-type engineered timber product which can be used as structural walls or floors [5]. Recent research provided guidance for designing CLT shear-walls [6] and CLT connections [7]. On the system level, multiple innovative hybrid systems were

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proposed for the use of timber in large-scale construction such as pre-stressed systems [8], steel moment resisting frames with CLT panels [9], balloon-framed mass-timber systems with steel link beams [10–12], the jointed-frame concept [13] or timber-concrete hybrid systems as implemented in the Life-Cycle-Tower [14].

1.2. Hold-downs for timber structures

To provide resistance against the overturning moments caused by lateral loads such as wind or seismic action, anchors or “hold-downs” are installed to transfer the vertical uplift forces to the foundation. Compared to steel and concrete, timber is a light material, leading to possible reduction in foundation costs, and lower lateral seismic forces. Low self-weight of timber structures, however, provides less inherent resistance to overturning forces due to strong winds and can of tall timber buildings is to provide adequate anchors able to take the larger uplift forces.

Different types of anchorage systems are available. For low-rise timber structures, steel straps that emerge from the foundation are nailed to end studs of the shear walls. Others options include foundation bolts or threaded rods. Usually, the capacity of such traditional hold-downs is around 50 kN [15]. For multi-storey timber-framed structures, systems such as the Simpson Strong-Tie® Strong-Rod™ [16] that consist of rods, coupler nuts, bearing plates and shrinkage-compensation devices, create a continuous load path to the foundation and can transfer loads of up to 120 kN.

A novel connection, consisting of hollow steel tubes placed inside mass-timber panels was tested under quasi-static monotonic and revised cyclic loading and demonstrated its potential with high initial stiffness while providing high ductility [17]. This connection is easily to manufacture and install, inspect and replace, but the maximum uplifting force that can be resisted is still limited.

1.3. HSK-System

Another option is the Holz-Stahl-Komposit-System (HSK-System)™, which is based on adhesively bonded perforated steel plates (Fig. 1a). The plate holes are filled by adhesive after insetting it into the timber, forming so-called “adhesive dowels” (AD). The “bond capacity” is based on the sum of the individual AD capacities. The steel links (SL) between the plate holes determine the ductile plate capacity. The capacity of an HSK connection is governed by the minimum of: (i) the steel plate, (ii) the adhesive bond, and (iii) the timber capacity. Previous research showed that the connection is stiff, ductile and can be designed to produce a ductile steel failure under static as well as fatigue loading [18,19].

The HSK system has been applied as hold-down for tall buildings such as the Wood Innovation Design Centre in Prince George, Canada, is currently North America’s tallest contemporary pure timber building [20]. Fig. 1b shows the HSK hold-down design with the perforated steel plates welded to section-reduced steel side plates which provide the ductile fuse for capacity design. Other prominent examples where the HSK system was applied include the free-floating cantilevered solid timber staircase of the Earth and Ocean Science Centre in Vancouver, Canada, [21] and the wooden wind-mill tower project in Hanover, Germany, with a height of 100 m [22].

1.4. Hold-down using modified HSK system

For high-rise timber structures, the hold-downs must be strong and stiff to resist the large uplift forces caused by strong winds, but also provide ductility and energy dissipation in seismic events, if designed for such action. The HSK hold-down provides high stiffness and strength, but so far has only been applied in tall timber structures located in low seismic areas, partially due to the lack of knowledge to quantify its performance under reversed cyclic loading, a situation where the section-reduced steel side plates that have been used in previous designs could easily buckle.

The objective of the research presented herein was to design a modified HSK hold-down that avoids this risk of buckling. To achieve the objective, material, component mid-scale, and full-scale hold-down tests were conducted under quasi-static monotonic and reversed cyclic loading. The HSK system was modified by attaching the perforated plates to a steel profile which is not section reduced, as illustrated in Fig. 2. The yielding fuse is provided by a section of the plates where rows of holes in the perforated steel plate are covered by duct-tape such that in these rows no adhesive bond can form. This modification allows for a yield mechanism to develop inside the connection assembly which is restrained from buckling.

2. Experimental investigations

2.1. Materials

The perforated steel plates had a uniform pattern, with hole diameters of 10 mm, length of the SL portion between holes of 5 mm and thickness of the plate of 2.55 mm. The steel grade was S275 with specified yield stress of 275 N/mm^2 [23]. The tests were conducted with two engineered timber products, Glued-laminated Timber (GLT) and Cross-laminated timber (CLT). Series 1-3a and series 1-4 were fabricated using Douglas-Fir (*Pseudotsuga menziesii*) 20f-E grade GLT. Series 1-3b,c,d and series 2 to series 4 were fabricated using CLT panels, grade V2M1, supplied by Structurlam Products Ltd. and fabricated according to ANSI/APA PRG 320-2012 [24]. The wood species was SPF No.1/No. 2, with an average apparent density of 450 kg/m^3 (based on weight and volume of the CLT panels); the moisture content of the timber products was determined by means of handheld electric resistance meters as 10% (±2%). 3 M Scotch Cloth 220 duct tape was selected to cover

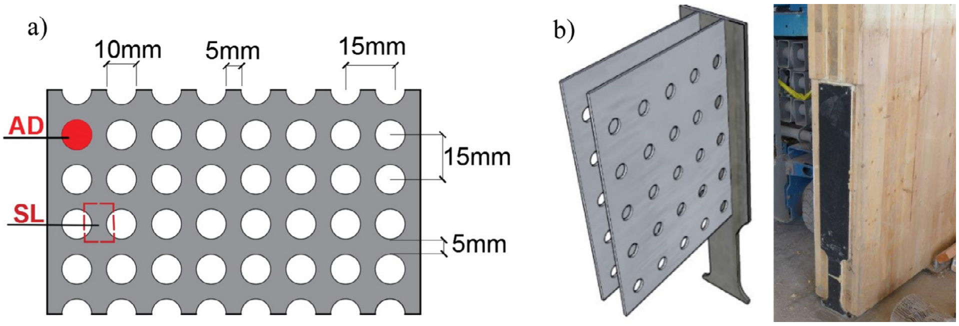

Fig. 1. HSK connection: (a) Geometry of perforated steel plate; (b) Conventional HSK hold-down.