Engineering Structures 173 (2018) 787–799

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

OSB sheathed light-frame timber shear walls with strong anchorage subjected to vertical load, bending moment, and monotonic lateral load

Abdollah Sadeghi Marzaleh*, Stella Nerbano, Andrea Sebastiani Croce, René Steiger

Empa, Materials Science and Technology, Structural Engineering Research Laboratory, Ueberlandstrasse 129, 8600 Dübendorf, Switzerland

ARTICLE INFO

Keywords:
Light-frame timber shear wall
OSB sheathing
Seismic analysis
Racking test
Vertical load
Bending moment
Finite element
Shear stiffness
Shear resistance
Ductility

ABSTRACT

One of the common lateral load resisting systems in multi-story timber buildings in Central Europe are reinforced concrete shear walls. The RC shear walls are not optimal for timber buildings for several reasons such as: (i) the difference in tolerance between concrete and timber construction procedures, (ii) elevated construction time caused by necessary curing of concrete, (iii) moisture of concrete affecting the integrity and mechanical properties of timber, (iv) relatively high shear stiffness resulting in increased forces in seismic design, and (v) eccentricity with regard to applied seismic forces depending on the location of the shear walls. A light-frame timber shear wall (LFTSW) with OSB sheathing stapled to glued-laminated timber framing and strong anchorages has been investigated in this research program to be used as the single lateral load resisting system being located in the perimeter of the building. Results of experiments and numerical calculations showed 20% and 37% increases in shear stiffness and shear resistance, respectively, of the investigated LFTSWs in comparison with established LFTSW configurations. In addition to the conventional racking tests, vertical loads and bending moment were applied to the edge studs in order to study their effect on the in-plane behavior of the investigated LFTSWs. A marginal decrease in shear stiffness and shear resistance was observed due to the vertical load and bending moment applied. The decrease was more significant when applying the vertical loads due to the deformation, to which the staples were exposed, before applying the lateral load. Independent from level and combination of internal forces a ductile behavior was observed experimentally on the investigated LFTSWs, where the failure was governed by ductile displacements in the stapled connection between sheathing and framing.

1. Introduction

In many multi-story timber buildings, the lateral load resistance is provided by a combination of timber walls and reinforced concrete (RC) walls, e.g. for forming the elevator shaft and/or the staircase and also for guaranteeing the safe escape in case of fire hazards. As a result of recent developments in fire research related to timber structures, regulations in many countries allow currently to build timber buildings up to 6 or even more stories without RC staircases. This together with the timber construction companies claiming major drawbacks in construction of mixed timber concrete buildings (namely differences in tolerances, elevated construction time caused by necessary curing of concrete, moisture of concrete affecting the integrity and mechanical properties of timber) made designers come to the idea of providing sufficient resistance for lateral loads to multi-story timber buildings exclusively by few but strong light-frame timber shear walls (LFTSW).

With regard to the seismic design of multi-story timber buildings, RC shear walls are not optimal because of their comparatively high stiffness, which may make the structure tend to fundamental periods in the plateau range of the acceleration spectrum. If, additionally, RC shear walls are part of staircases and elevator shafts which frequently are located asymmetric in plan, this results in an eccentricity of the seismic forces and, therefore, torsional forces in buildings. In order to address these issues, the concept investigated in a research project, recently carried out in Switzerland, was to provide the required lateral road resistance to multi-story timber buildings by a limited number of LFTSWs located in the perimeter of the building. Thus, the very high stiffness of the RC walls and the irregularity of the building in its plan are avoided.

In order to reach this goal, the LFTSWs investigated have a specific configuration as opposed to established LFTSWs (Fig. 1). In the established configuration, the bottom rail is connected to the foundation with a few hold-downs to prevent uplift caused by rocking and to

* Corresponding author.
E-mail addresses: abdola.sadeghimarzaleh@empa.ch (A. Sadeghi Marzaleh), stellanerbano@gmail.com (S. Nerbano), andreaseb91@gmail.com (A. Sebastiani Croce), rene.steiger@empa.ch (R. Steiger).

https://doi.org/10.1016/j.engstruct.2018.05.044
Received 7 July 2017; Received in revised form 7 March 2018; Accepted 14 May 2018

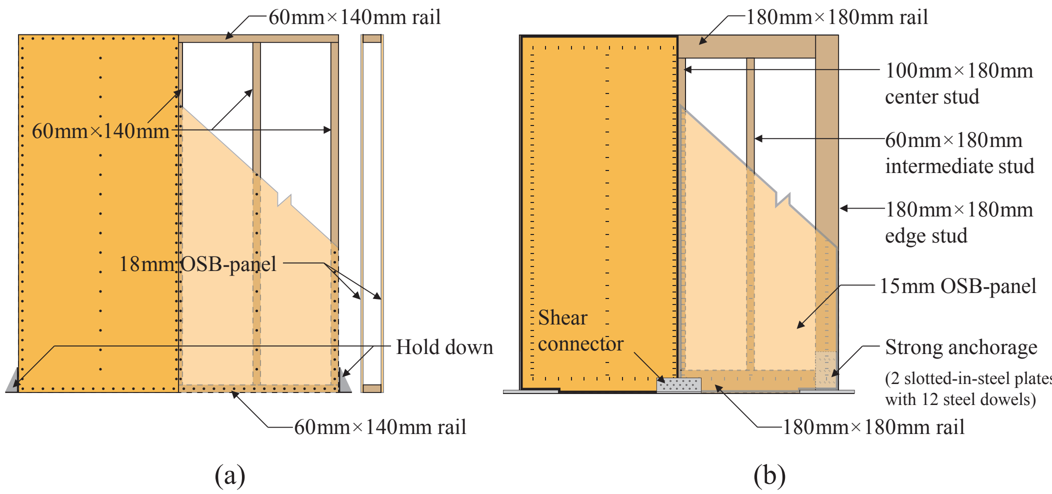

Fig. 1. Configuration and members of (a) established LFTSW (adapted from [1]) and (b) investigated LFTSW in the present study.

provide certain ductility to the system. In addition, the edge studs are connected to the bottom rail on its top surface. The connections between the framing members behave as hinges. Therefore, under a racking load, the frame has almost zero resistance and is deformed to a parallelogram. To have an optimized solution for both wind and seismic forces, the LFTSWs investigated in the study presented in this paper have been designed to be comparatively stiff. The edge studs have been rigidly connected to the foundation by means of slotted-in steel plate connections with steel dowels. The bottom rail is additionally attached to the foundation using shear connectors (steel angle connected to the bottom rail by means of annular ring nails and to the foundation by means of Hilti anchors of type HAS-TZ) to transfer the shear forces to the foundation. The shear connectors are nailed through the sheathing panel which results in constraining the panels against translation. The top rail is connected to the edge studs by a pair of screws, similar to the established configuration of light-frame timber walls forming a hinged connection. This specific configuration of the investigated LFTSWs makes them exhibit a different in-plane response compared with the established LFTSWs.

Matters of interest when testing timber-framed walls in the recent years were: resistance to combined shear and uplift forces [2], impact of openings ([3–5]), influence and performance of anchoring and hold down devices [6], influence of boundary conditions and loading protocols ([3,5,7–9]) and contribution of exterior finishing (e.g. stucco) [10]. Most studies dealt with timber structures for regions of high seismicity. In several countries – due to low-to-moderate seismicity – seismic design requirements do not play the same role. In order to get economic solutions experiments on components of light-frame timber buildings have to reflect this situation with respect to the selection of the appropriate connections and timber elements as well as the relevant loading combination. These issues will affect the structural response at connections, components, and building level and cannot be derived from previous research findings focused on timber structures for regions of high seismicity.

In any building, the shear walls located at lower stories beside vertical loads are subjected to bending moment as a result of lateral loads acting on higher stories (mass times ground acceleration). The in-plane response of LFTSWs is assessed experimentally by racking tests e.g. according to ASTM E2126 [11] and ISO 21581 [12] where the wall elements are subjected to a lateral load acting at their top but where the effect of vertical load and bending moment is not investigated. There are studies in which the effect of vertical load on the in-plane response of LFTSWs had been investigated ([13–15]). To get a more realistic experiment, however, a bending moment should be applied to the timber shear walls. In an effort to take into account the bending moment, Dujic et al. [3] studied the effect of changes in boundary conditions on the in-plane response of timber shear walls. Their experimental program was focused mainly on the case of partial anchoring of the walls to the foundation where vertical loads hindered the uplift of the walls what finally resulted in an increase of the shear resistance. To the best of authors' knowledge, there have been no tests in which a bending moment was applied to timber shear walls as a function of lateral load in a controlled way.

In the study presented in this paper, a test set-up was designed to apply a combination of vertical load, bending moment, and lateral load to LFTSWs specifically designed to be part of the timber-only lateral load resisting shear wall system as described above. The in-plane response of this specific type of LFTSW, here and after named as 'investigated LFTSW', under monotonic lateral loads was investigated and compared with established LFTSWs. The effect of vertical load and bending moment was included in the experimental study and according numerical and analytical models were developed.

2. Research methodology

2.1. Wall specifications

The global geometry of the LFTSW specimens was kept constant in all tests with length and height equal to 2.5 m and 2.8 m, respectively. The total wall thickness was 210 mm. The wall element was composed of glued-laminated timber (GLT) GL24h framing [16] and OSB/3 sheathing [17,18] on both sides of the wall. Panels of grade OSB/3 are denoted load-bearing panels for use in humid conditions. Based on the product sheets, the implemented OSB/3 panels are characterized by elastic moduli of 3,800 MPa and 3,000 MPa in the main in-plane directions and a shear modulus of 1,080 MPa. The vertical elements of the framing consisted of two edge studs, a center stud and two intermediate studs with cross-sections of $180 \times 180\,mm^2$, $100 \times 180\,mm^2$ and $60 \times 180\,mm^2$, respectively. Top and bottom rails of the frame had a cross-section of $180 \times 180\,mm^2$. The sheathing consisted of two OSB/3 panels with a width of 1.25 m and a thickness of 15 mm stapled to the both sides of the frame with a spacing of 50 mm except for the intermediate studs where the spacing was 100 mm. The implemented staples were characterized by a diameter of 1.53 mm, a crown length of 11.2 mm, a leg length of 55 mm, and an ultimate strength of $f_u \geqslant 600$ MPa. At each of its corners, the wall was strongly anchored to an RC foundation plate by means of four heavy-duty capsule adhesive Hilti® HVU anchors of diameter M16 and multiple dowelled shear connections with two slotted-in S235 steel plates (Figs. 13 and 15f). Twelve steel dowels of diameter 8 mm and steel grade $f_u \geqslant 500$ MPa were used in these slotted-in connections. The main timber components