Engineering Structures 111 (2016) 275–284

Contents lists available at ScienceDirect

Engineering Structures

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

Simplified modelling of timber-framed walls under lateral loads

Katja Vogrinec [a,*], Miroslav Premrov [b,1], Erika Kozem Šilih [b,2]

[a] Lumar IG d.o.o., Limbuška cesta 32a, SI – 2000 Maribor, Slovenia
[b] University of Maribor, Faculty of Civil Engineering, Smetanova ulica 17, SI – 2000 Maribor, Slovenia

ARTICLE INFO

Article history:
Received 21 June 2015
Revised 10 December 2015
Accepted 17 December 2015
Available online 6 January 2016

Keywords:
Prefabricated timber structures
Timber-framed walls
Calculation model
Fictive diagonal element
Tensile and compressive support
Openings

ABSTRACT

In the current paper a simple mathematical model with a fictive diagonal for a quick and accurate determination of the racking stiffness of composite timber-framed wall elements is developed. The stiffness of the timber-framed wall is determined through the analytical calculation of the wall element, taking into account the bending and the shear flexibility of the composite wall element, the flexibility of the fasteners between the timber frame and the sheathing board along with the flexibility of the tensile and compressive support at the foundations. The model furthermore allows for consideration of the walls with door and window openings in addition to that of tensile cracks appearing in the fibre–plaster sheathing boards, with the stiffness of the wall element being reduced. By varying the fictive diagonal cross-section of the numerical model according to the presented facts, the appropriate stiffness of the timber-framed wall can be obtained and used in the 3D static model. The model is suitable for any three-dimensional modelling with the analysis of the lateral load impact (wind, earthquake) on the building being carried out by using simple 3-dimensional FEM software, which is extremely useful for engineering application.

1. Introduction

Modern frame–panel construction systems originate from the American balloon-frame and platform-frame constructions. As mentioned in Kolb [1], Europe has witnessed a major replacement of the two construction types with the frame–panel construction, owing to its numerous advantages. The benefits to be pointed out lie in factory prefabrication assuring the so called “ideal weather conditions”, in addition to careful design of the structural elements and details with computer-run supervision over the manufacturing process whose precision allows for perfect fitting of the contact areas. The elements are then transported to the construction site where their assembly takes place storey by storey. The on-site assembly is usually fast with a maximum period of three days needed for a two-storey house.

In the frame–panel structures the required stability of the building to withstand horizontal loads is attained with the timber-framed walls and the anchorage of the wall elements. Timber-framed walls can be produced as single-panel systems (Fig. 1a) or as the recently more commonly used macro-panel systems, as shown in Fig. 1b. The wall elements consist of a timber frame and single-sided or two-sided sheathing boards, attached to the timber frame with mechanical fasteners (usually staples). The fasteners are spaced at regular intervals of a maximum of 75 mm. Timber-framed walls have a standard width of $b = 1250$ mm and a height $h = 2500–2800$ mm, while the thickness of the wall depends on the type of wall (internal or external). In the macro-panel systems considered as an upgrade of the single-panel systems, wall element units with the width of $b = 1250$ mm are connected together to make a single element with a maximum length of 13 m (transportation limit).

The timber frame consists of three timber studs and two timber plates (top and bottom), with the thermal insulation placed between timber elements (Fig. 1a). As sheathing material, different types of boards can be used. They differ in their bearing capacity and fire safety. In North America, wood-based sheathing boards are frequently used (oriented strand board (OSB), plywood, particle boards, etc.), with the most commonly used boards in Europe being fibre–plaster boards (FPB). In Premrov and Dobrila [2], an extensive numerical analysis is presented analysing the influence of OSB and fibre–plaster boards (FPB) on the racking resistance of timber-framed wall elements. The results of the developed semi-analytical model evidently demonstrate higher racking stiffness of the wall elements with FPB, while the racking resistance proves to be evidently higher in the case of using OSB boards. The authors indicate an important dilemma of using the best sheathing board with regard to the height and location of the building and

* Corresponding author.
E-mail addresses: katja.vogrinec@outlook.com (K. Vogrinec), miroslav.premrov@um.si (M. Premrov), erika.kozem@um.si (E. Kozem Šilih).
[1] Tel.: +386 (2) 229 4300; fax: +386 (2) 252 4179.
[2] Tel.: +386 (2) 229 4330.

http://dx.doi.org/10.1016/j.engstruct.2015.12.029
0141-0296/

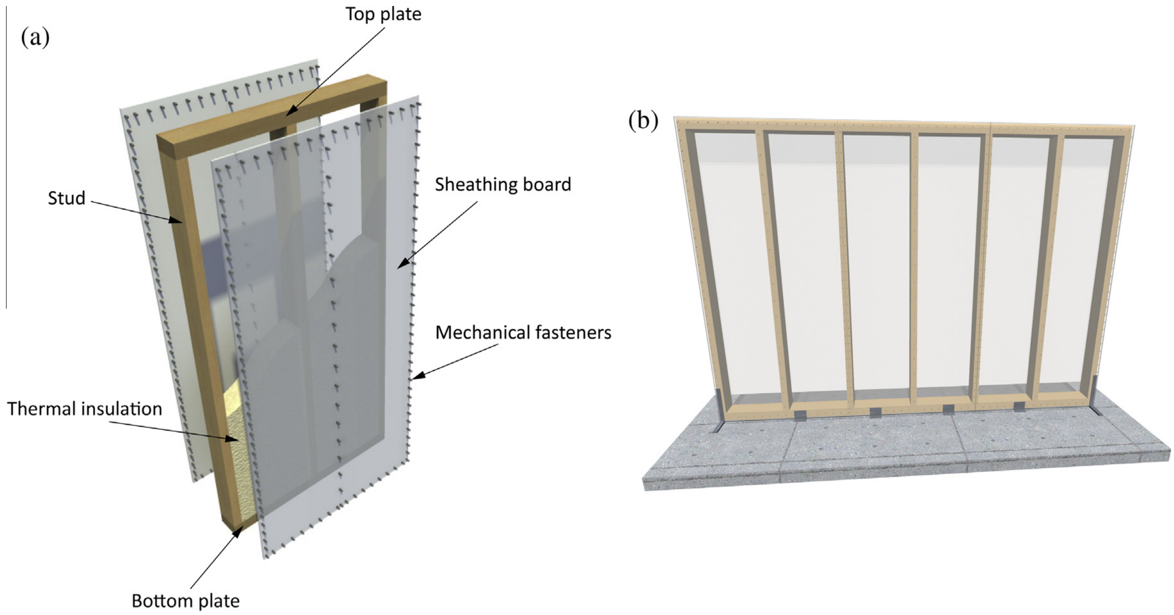

Fig. 1. (a) Composition of the single-panel wall element. (b) Macro-panel wall with anchoring.

recommend using OSB sheathing boards instead of fibre–plaster boards in extremely windy or seismic areas.

To transfer uplift and shear forces from the timber-framed wall to the foundation, the walls must be anchored to the concrete ground slab or the foundations. As given in Kolb [1], the anchorage is achieved by bolts through the bottom plate of each element, steel angles, or welded steel components. In Tomasi and Sartori [3], different types of connections systems for shear and hold-down anchoring of the timber-framed wall were experimentally investigated in order to derive their stiffness and strength parameters. In reference to wood-based sheathing boards where the anchors are not directly attached to the timber stud but through the sheathing board, authors showed that in the case of OSB plates the interposition of the OSB does not affect the behaviour of the connections and the OSB plate can be ignored when calculating the bearing capacity of a hold-down anchor. Detailed explanations of anchoring timber-framed walls, including the installation of the anchors and experimental investigations are also available in Kessel [4]. The anchoring of the timber-framed wall with hold-down anchors to the concrete slab is schematically presented in Fig. 1b.

2. Semi-analytical development of the calculation model

2.1. Basic design approaches

The most common approach to calculate timber-framed walls is to consider the wall element as a vertical cantilever beam, fixed at the bottom and free to deflect at the top, in the case of which the wall cantilevers from the foundation and is subjected to the lateral force at the top. The presented calculation model is used in Eurocode 5 [5] and applied by many different authors, such as Breyer et al. [6], Faherty and Williamson [7], Prion and Lam [8], Schulze [9] and Kessel [10]. According to the presented method, each macro-panel wall element is composed of separate segments acting as individual cantilevers, where one segment is determined with the width b of the sheathing board. Lateral forces acting at the top of the element are uniformly distributed across the length of the wall to each segment with the width b ($F_H = F_{H,tot}/n$, where n is the number of full height wall segments with the width b), based on the assumption that all the segments are the same full height walls without window and door openings. This design assumption is shown in Fig. 2.

According to the presented cantilever model, a moment is induced in the wall which is resisted by a couple applied to the wall members in contact between the wall and the foundation, as shown in Fig. 2. On the tensile side, the tensile force F_t appears while the compressive force F_c appears on the compressive side, where

$$F_t = F_c = F_H \cdot \frac{h}{b} \tag{1}$$

with h being the height and b the width of the wall element according to Fig. 2.

These forces are undertaken by adequate anchorage of the walls. As written in Faherty and Williamson [7], due to the static equilibrium of the timber-framed wall it is necessary for the wall to have tension anchorage at the uplifting end. In practice this means that such anchorage will be needed at each end of the wall (and also at door and window openings, as shown in Fig. 2), since the lateral load can be imposed in either direction of the wall. More details considering the anchorage of the timber-framed walls can also be found in Kessel [4,11].

Most of the timber-framed walls in the structure have windows and door openings which interfere with the uniform distribution of the horizontal force along the wall (Fig. 2). In relation to this problem, different calculation approaches have been suggested. As presented in Eurocode 5 [5], wall panels which contain a window or door opening should not be considered as contributors to the racking load-carrying capacity of the wall. These segments should be ignored and only the full height wall segments ought to be taken into account and analysed as separate cantilever walls. In Breyer et al. [6], two additional methods in addition to the segmented shear wall method, where only sections of full height walls between the doors and windows are designated as shear wall segments, are discussed. These two methods involve the design of the entire wall, including the opening. Yasumura and Sugiyama [12] proposed a simplified approach for stiffness calculation of timber-framed walls which can be used for wood-based sheathing boards where the effective shear strength and stiffness ratio is computed with the following equation: