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# Proposal of an analytical procedure and a simplified numerical model for elastic response of single-storey timber shear-walls

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## HIGHLIGHTS

- Behavior of timber buildings subjected to horizontal forces.
- Stiffness of timber shear-wall.
- Numerical modelling of timber shear-wall.
- Hold-down effect on the behavior of timber shear-walls.

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## ABSTRACT

A simplified and reliable tool for the elastic analysis of one-storey timber shear-walls under simultaneous horizontal and vertical loads is presented. This approach is suitable for the analysis both of light timber-frame walls and CLT walls. The analytical expressions to determine the horizontal displacement and the elastic stiffness of a single wall are provided, these expressions are then extended to walls placed in series. A simplified numerical model suitable for F.E. analysis is also developed. In the last part of the paper a comparison between an analytical example and the results of a laboratory test is shown.

## 1. Introduction

The structural analysis of timber buildings subjected to horizontal forces (wind, earthquakes, etc.) may require the use of Finite Element Models with the aim of evaluating the design actions of the structural members and mechanical connections. These models should well describe the structural behaviour of the timber buildings, but their complexity should be related to the design purposes as well. Simplified models, in most cases, can ensure suitable and reliable results with the added benefits of being less time-consuming and much more manageable.

This paper is the first stage of a research work concerning the seismic study of the timber buildings from the analytical point of view. It supplies a numerical process, called UNITN model, with the goal to provide designers and researchers a simplified but powerful tool to evaluate the elastic response of light timber frame (TF) shear-walls and cross laminated timber (CLT) shear-walls.

In Europe TF and CLT constructive systems are preferred, see Fig. 1; respectively TF walls are made by a pinned-frame, which is a mechanism, braced by OSB (Oriented Strand Board) or GFP (Gypsum Fiber Panel) sheathing panels whereas CLT walls are solid-timber walls composed by layers of timber planks glued together. Following the increase in the use of this type of buildings, a great amount of research has been conducted on timber shear walls, with a particular focus on their behaviour when subjected to a horizontal load. Numerous experimental tests have been performed in order to characterize this type of wall [1–3]. Push out

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tests and cyclic tests on the singles components of the walls have been also carried out [4,5]. Several closed-form models have been proposed in standard or in literature, often based on energy methods or strain–displacement relationship. A quite wide review of some of these models was presented in [6]. In Conte et al. [7] the approaches proposed in the Commentary (Erläuterung) of DIN 1052 [8], in New Zealand Standard NZS 3603:1993 [9], in Canadian Standard CSA 086-01:2005 [10], and by Källsner and Girhammar [11] have been analysed.

Most of these models neglect some elastic components (like deformation of angle brackets), and give more importance to other elastic components which could be neglected (like compression deformation and deformation of timber frame). In all proposals analysed the main deformation contribution, according to UNITN model, is attributed to the nail slip, on the contrary the effect of the vertical load is generally disregarded (not in the UNITN model).

The UNITN model (UNified Iterative TreNto model) has been developed to provide a simplified equation to describe the elastic behaviour of timber shear-walls through the use of a equivalent stiffness for each shear-walls. Four deformation contributions are taken into account as well as the role of the vertical load (this key concept has no investigated before). The model arises from the large campaign research (see [12,4,13,14]) made by the Timber Research Group of University of Trento.

The model is characterized by generality because the same approach can be adopted for TF and CLT shear-walls, and by the fact that it takes into account the variation of the wall stiffness when the hold-down is activated, entails inevitably an iterative procedure to find out the real force distribution between multiple shear-walls. A parametric study of the hold-down stiffness contribution demonstrates that the wall elastic stiffness cannot be considered linearly proportional to the wall length as is usually assumed nowadays by designers. The use of the UNITN model is presented in this paper only to analyze single-storey buildings, whereas, its use for multi-storey timber buildings is already under investigation by the authors and it will be presented in a future paper.

## 2. Elastic horizontal displacement of a timber shear-wall

The elastic horizontal displacement (Point C, Fig. 1) of a light timber frame wall subjected to a horizontal force can be obtained by adding the contributions of deformation from various sources, viz. the sheathing-to-framing connection ($\Delta_{sh}$), the rigid-body rotation ($\Delta_h$), the rigid-body translation ($\Delta_a$) and the sheathing-panels ($\Delta_p$), as stated by the following equation:

$$\Delta = \Delta_{sh} + \Delta_h + \Delta_a + \Delta_p \tag{1}$$

Some other contributions (such as compression perpendicular to the grain between studs and bottom rails, bending deflection etc.) could be taken into account. However, according to [7] for the wall typologies tested (see [13,14]), and considering the authors' intention to develop a simplified approach, these contributions can be neglected.

These contributions are considerably smaller compared to the others, therefore according to the intention of the author to develop a simplified approach, they are neglected according to [7]. The final expression of the horizontal displacement of a light timber frame wall, which components will be illustrated in the following subsections, is:

$$\Delta = \frac{\lambda \cdot F \cdot s_c}{l \cdot n_{bs} \cdot k_c} + \left[\frac{h}{\tau \cdot l \cdot k_h} \cdot \left(\frac{F \cdot h}{\tau \cdot l} - \frac{q \cdot l}{2}\right)\right] + \frac{F \cdot i_a}{k_a \cdot l} + \frac{F \cdot h}{l \cdot G_p \cdot n_{bs} \cdot t_p} \tag{2}$$

Eq. (2) has been developed by considering also the presence of a uniformly distributed vertical load $q$.

The length and the height of the wall are respectively assumed equal to $l$ and $h$. Each deformation contribution is obtained by means of the mathematical calculations reported from Sections 2.1–2.4. In the case of a CLT wall, Eq. (2) can be modified by substituting the sheathing panel contribution with the CLT panel contribution and removing the term for the sheathing-to-framing connection, to obtain:

$$\Delta = \left[\frac{h}{\tau \cdot l \cdot k_h} \cdot \left(\frac{F \cdot h}{\tau \cdot l} - \frac{q \cdot l}{2}\right)\right] + \frac{F \cdot i_a}{k_a \cdot l} + \frac{F \cdot h}{l \cdot G_{CLT} \cdot t_{CLT}} \tag{3}$$

In Eqs. (2) and (3), as shown in Section 2.2, the term $\Delta_h$ concerning the wall rigid-body rotation must be taken into account only if it is positive or equal to zero, i.e. hold-down in tension, otherwise it must to be removed.

There is the uncommon chance to have vertical concentrated force instead of vertical distributed load or even in addition to it. In this event, Eqs. (2) and (3) are not valid; a specific equation will be developed by authors. The equations can be anyway use

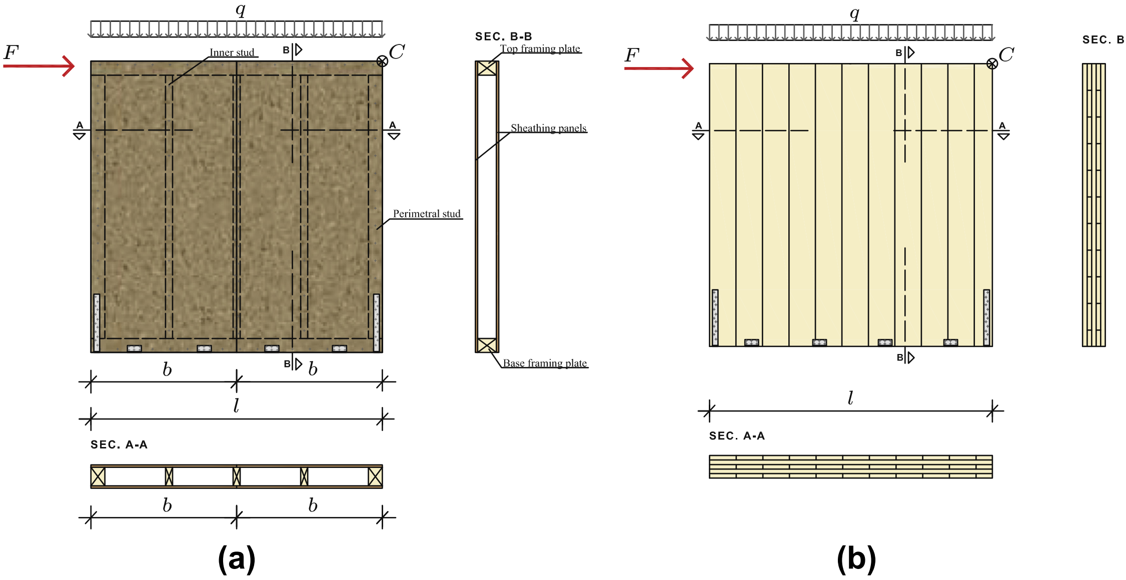

Fig. 1. (a) TF (timber framed wall); (b) CLT (cross laminated timber wall).