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Stress distribution among sheathing-to-frame nails of timber shear walls related to different base connections: Experimental tests and numerical modelling

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HIGHLIGHTS

- Numerical investigation on the in-plane performances of nailed timber shear walls.
- Dissipative capacities concentrated in the connections among the components.
- Validation of the models by comparison with experimental tests.
- Investigations on the distribution of the shear among the sheathing nails.
- Focus on the different arrangements of the base connections.

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ABSTRACT

The performances of nailed timber shear walls subjected to in-plane horizontal actions are numerically investigated in the paper. In particular, it focuses on the different behavior that the vertical diaphragm may perform if the wall base steel devices are connected to the timber frame with or without the interposition of the sheathing. Nonlinear static analyses were performed and the dissipative capacity is concentrated in the connections among the components (nails, hold-down, angle brackets, stud-joist node), whose behavior is calibrated by means of experimental tests and numerical simulations on connections. The reliability of the numerical model was proved by comparing the numerical results with the findings of five full-scale experimental tests performed on shear walls subjected to in-plane horizontal cyclic loads. It emerged that the different arrangements of the base connections influence significantly the distribution of the shear among the sheathing nails and, when the base steel devices are applied with the sheathing interposed and/or the panels are nailed to a base timber plate, the force distribution among the fasteners significantly differs from those suggested by the analytical methods proposed in the literature.

1. Introduction

Modern Platform Frame timber buildings are able to exhibit good performances when subjected to horizontal actions, due to wind or earthquakes, as the lateral forces are transferred from the horizontal diaphragms to the vertical bracing system and then to the foundation. In such a structural type, each storey is framed independently and connected to floors and roofs. Horizontal and vertical diaphragms are typically assembled from wood-based sheets fixed by means of widespread mechanical fasteners (such as nails or screws) to a light timber frame. The shear walls (Fig. 1) are connected to the floors and foundation through steel bolts, angle brackets, hold-downs or tie-downs.

The diaphragm action of shear walls provides the vertical and lateral load-carrying capacity of a Platform Frame building; thus, for a correct structural design, a good accuracy in the prediction of the force and displacement capacities of these resisting elements is necessary.

Extensive experimental campaigns concerning in-plane tests on full-scale shear wall specimens were performed to investigate on the main mechanism that influences the overall behavior of the diaphragms. The most varied geometrical and mechanical characteristics (of the frame, the sheathing, the fasteners...) and the influence of the openings and of the vertical load were

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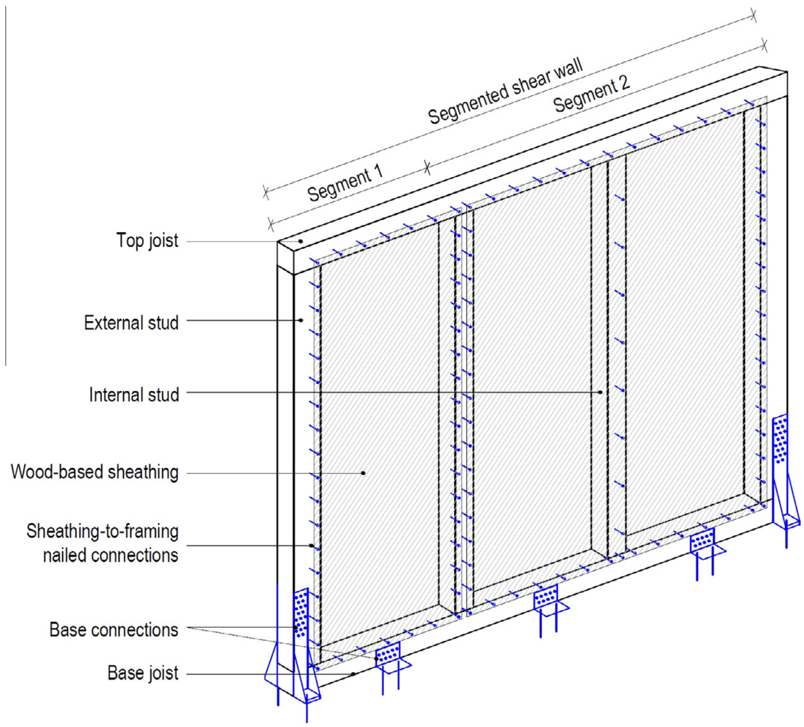

Fig. 1. Example of a segmented timber shear wall.

investigated, referring, in particular, to the shear walls typologies typically employed in the residential timber housing in Italy and Alpine areas [2,22,27,14].

As the results of the full-scale experimental tests are limited, a variety of numerical models were developed to investigate on a wider range of possible wall configurations. The models range from linear to nonlinear analysis and from strain energy approaches to finite element analysis (e.g. [25,17,19]). As the structural behavior of the shear walls is mainly influenced by the connections, several experimental campaigns focused on the characterization of the behavior of the sheathing-to-framing joints, on the base joints and on the stud-joist joints, allowed to calibrate the behavior of the different components of the model [20,1,23,24,12,14].

It may be observed that the overall lateral performances of a shear wall are significantly influenced by the behavior of the sheathing-to-framing connections, thus an accurate modelling at this level is needed. The different approaches adopted in the literature concern mostly the introduction of nonlinear spring elements connecting the sheathing to the frame, both assumed to be linear elastic. But, because of the non-uniformity of the fasteners loading direction, this methods may lead to some limitations in the applicability and reliability of the results [16].

A different method, assumed in the paper, consists in modelling such a connection by means of nonlinear beams, perpendicular to the sheathing, able to automatically account for their different loading direction and accounting for their actual resistance.

The aim of the paper is to evidence, by means of numerical simulations (nonlinear static analyses), the actual distribution of stresses among sheathing nails considering the influence of the mechanical base connections of shear walls subjected to in-plane horizontal load.

In particular, the scope is to face a type of shear wall that is very common in Italy and Alpine areas, as it presents some important constructive advantages. In fact, the prefabricated shear wall, made with a light timber frame and particle board sheathings nailed on both sides of the frame, is placed on a fixed base timber element; the base steel devices are then applied to the timber frame through the interposition of the panels, which are also nailed in the field to the base plate. This type, however, presents some critical aspects, as a significant change in the loading direction path of the nails of the sheathing-to-frame connection occurs, with respect to the case of a direct connection of the base steel devices to the timber frame. The actual shear load distribution significantly differs from that assumed in the analytical relationships available in the literature (eg [17,18]) due to the higher nails concentration at the base of the sheathing, in correspondence of the hold-down and of the base plate. Therefore, it is important to develop a model that can correctly predict the actual performances of such a shear walls.

The nonlinear behavior of the different connections was derived from specific experimental tests and numerical simulations and the reliability of the model was checked by comparing the numerical capacity curves with the experimental results of five in-plane cyclic tests performed on shear wall samples of different characteristics.

2. Experimental tests on timber shear walls and connections

Five shear wall specimens were subjected to in-plane horizontal cyclic load. Different geometrical and mechanical characteristics of the timber components and of the connections were considered. The specimens characteristics and the experimental results are reported in the following.

Moreover, the setup and the results of some specific experimental tests carried out on connections (hold down and stud-joist node) were presented.

2.1. Shear walls configurations and material characteristics

The main characteristics of the five considered shear walls, marked by the identifier PLS, are summarized in Table 1 and illustrated in Fig. 2. The main features of the specimens reflect the most common shear wall configurations used in the Platform Frame building practise in Italy and in Alpine area Countries. Different techniques to fix shear walls with the foundation were tested. The most common considers the timber frame directly connected to the foundation by means of steel devices which contrast the wall uplift (hold-down) and the sliding (angle brackets). Differently, the bottom joist of the wall could be placed over a timber member fixed