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Experimental results on the role of sheathing-to-frame and base connections of a European timber framed shear wall

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HIGHLIGHTS

- The nail's surface feature affected the mechanical properties of the connections.
- The vertical load did not influence the behavior of the full-scale shear walls.
- The shear walls failed at 2.5% drift due to the low cycle fatigue fracture of nails.
- The contribution of each connection to the wall's total displacement was evaluated.
- The sheathing-to-frame connections dissipated more than 80% of the total energy.

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ABSTRACT

In platform timber frame buildings the horizontal forces (wind, earthquake) are carried by the shear walls, whose hysteretic behavior is mainly governed by the sheathing-to-frame connections, if hold-downs and shear angle brackets at the wall base are designed with an adequate overstrength.

The paper presents the experimental results obtained from tests both on connections between the sheathing panel and a timber stud and on full-scale prefabricated timber frame shear walls, with or without vertical loads. The results of monotonic and cyclic tests on nailed and stapled connections showed the importance of the surface feature of nails on initial stiffness and ductility of the connection. The full scale tests evidenced that the vertical load did not significantly influence the behavior of the walls, whose hysteretic response depended on the sheathing-to-frame connections which were able to dissipate more than 80% of the total energy. Furthermore, a dissipative hysteretic behavior of the shear wall was guaranteed up to 2.0% drift with the collapse governed by the low cycle fatigue failure of the steel nailed connections.

1. Introduction

Timber frame structures are common construction systems for multi-storey residences, low-rise commercial and industrial buildings especially in North America, New Zealand and Northern Europe. These structures are gaining increasing significance in the building industry and also in European seismic prone areas owing to their sustainability, cost effectiveness, short construction time and reduced inertial forces.

The modern European platform frame constructions consist of a modular wall system in which the elements are interrupted at each storey. Unlike the light wood frame walls of North America, which are assembled on site, in most of Europe the shear walls are usually prefabricated elements. They consist of a timber frame, with hinged connections, sheathed by wood-based panels (e.g. Plywood, Oriented Strand Boards, Particleboard). The connection between the frame and the sheathing panels is guaranteed by metal fasteners such as nails, screws or staples fixed to the frame along the panel edges. Hence, the shear walls are in-plane diaphragms able to counteract lateral loads such as wind or seismic actions. The structural continuity among modular elements is restored by means of outer metal connections such as angle brackets and hold-downs, able to transmit shear forces and overturning moment respectively (from floor diaphragm to walls, from one level to another level, and from walls to foundations). As a result, the hysteretic behavior of timber frame constructions is governed by the local behavior of sheathing-to-frame connections, angle bracket and hold-down connections, which are responsible for the structure's dissipative capacity. Among these joints, the behavior of the local joint between the timber frame and sheathing panel

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is one of the most relevant as confirmed by the expressions of main standards [1–4], by analytical models [5–7] and by numerical Finite Element Modelling of wood-frame walls [8,9].

Several experimental studies performed over the past 15 years [10–12] showed the degradation of wall strength, stiffness and ductility of timber framed walls for drift of about 2.0% during quasi-static cyclic or dynamic loading tests, as well as the wall damage, characterized by the fatigue failure with pull-out of sheathing nails. If the monotonic loading was applied, the shear walls experienced higher displacement (up to 5% drift) and maximum shear force compared to the results of cyclic tests, depending on the cyclic loading protocol adopted [12].

More recently, an extensive survey of the literature was published by Kirkham et al. [13], who focused on the design requirements, seismic modeling, as well as on experimental results of quasi static and dynamic tests on single shear walls or full-scale wood-frame structures. As an alternative to the relative simple and economic cyclic quasi-static test methods, a handful of shake table tests were also carried out within several recent research projects [14–19]. These studies showed that the overall seismic performance of timber frame structures is adequate and nonstructural finishes significantly contribute in increasing the strength and the stiffness of the system [14,16]. The structures suffered substantial costly damage [16], but more often visual damage limited to non-structural elements was observed, despite the fact that shear walls reached inter-storey drift greater than 2% under severe simulated earthquakes [18].

Nevertheless, even though these full-scale dynamic tests showed the excellent performance of multi-storey light frame buildings during major earthquakes, they did not provide experimental results which allow a critical discussion on the contribution of each connection type on the overall building performance.

Moreover, in multistory wood frame structures the importance of the vertical load could become significant and its influence on the racking strength of shear walls with or without hold-down was experimentally investigated by several authors [20–23]. In the case of shear walls fixed to the foundation with hold-downs, a vertical load of 25 kN/m increased the shear strength by up to 30% and the lateral stiffness by about 80% with respect to the case with no vertical load [20,21]; likewise, partially anchored walls, in particular without hold-downs, gained a greater improvement in performance from dead load application compared with fully anchored ones [22]. Recent monotonic tests have shown that frame shear walls can exhibit large drift levels (up to 7%) without losing stability for vertical loading greater than 40 kN/m [23]; contrary to the results of previous studies, the maximum lateral load has not been affected by the value of the vertical load.

Although the shear performance of wood-framed building has been widely investigated, there is still a need to better understand the influence of all the joints (sheathing panel-to-timber frame connections, angle steel bracket and hold-down ones) on the overall behavior of shear walls in terms of strength, ductility and energy dissipation. To this aim several experimental monotonic and cyclic tests have been carried out on sheathing-to-frame connections with different types of nails having the same nominal shank diameter or with staples. The results of the local tests on the connection allowed addressing the choice of the nail type to be used in the shear walls.

Finally, two full-scale experiments were performed on fully-anchored timber-framed walls, by applying quasi-static cyclic horizontal displacements. The tested walls are representative of seismic-resistant prefabricated elements of conventional European timber framed buildings. The results allowed the influence of the vertical load and the contribution of each connection on the shear wall response to be assessed.

2. Sheathing-to-frame connections

2.1. Test program and test set-up

Four series of push-out tests were performed on sheathing-to-frame connections, aimed at investigating the effect of different types of steel connectors on the stiffness, strength and ductility of the joints. Each series consisted of at least two cyclic tests and a monotonic reference one. Different specimen configurations were arranged by varying the sheathing thickness (18 or 22 mm) and the type of metal fasteners (both nails and staples were employed as depicted in Fig. 1)

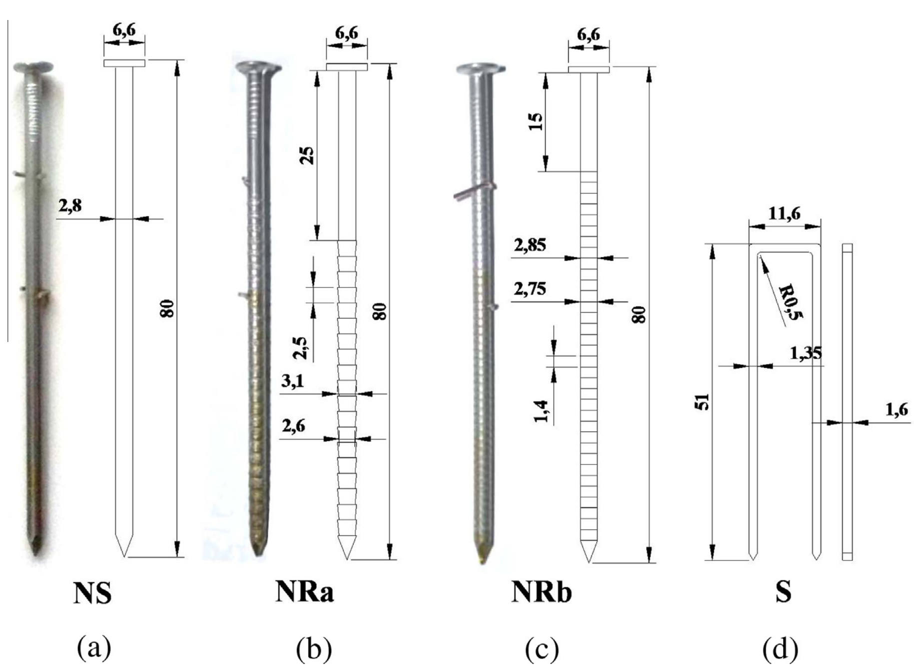

Fig. 1. Metal fasteners: smooth nails (a), ring nails type a (b), ring nails type b (c) and staples (d).