PARAMETRIC MODELING OF TIMBER LIGHT-FRAME SHEAR WALLS USING OPENSEES: PRELIMINARY RESULTS

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Abstract

This contribution illustrates the main features of an original parametric Finite Element (FE) model developed using OpenSEES in order to study the response of timber light-frame shear walls under earthquake. Within the proposed FE model, the framing system and the sheathing panel are modeled as elastic elements while the connections are simulated through zero-length non-linear elements. In particular, it is assumed that the overall nonlinear seismic response of the wall rests on the cyclic behavior of the connections. The presence of openings has been taken into account, as well as the use of more than one panel to brace the wood frame in case of walls with low aspect ratios. An exemplification numerical analysis is proposed at the end.

Keywords: Energy dissipation, Finite element model, Openings, Sheathing-to-framing connections, Timber light-frame shear wall.

1. Introduction

Timber light-frame shear walls are structural members typically employed within medium- or high-rise platform framing buildings in order to withstand in-plane lateral actions, such as wind or seismic forces. In particular, they are widespread in Northern Europe, North America and New Zealand in 90% of residential buildings with one or two storeys. The typical layout of these walls (considering the structural part only) consists of an assembly of vertical studs and horizontal joists, which are connected at their ends with internal constraints. The latter, in turn, are typically assumed as hinges (Figure 1). Sheathing panels are connected by means of metal fasteners (e.g., nails, screws or staples) in order to sheathe one or both sides of the main frame. The dimensions depend on the size of the sheet, which can be realized using different materials, such as Oriented Strand Board (OSB), plywood, gypsum, fibreboard. Commonly, as pointed out in Ref. [1], the size of a shear wall is 1.22 m × 2.44 m or 2.44 m × 2.44 m, whereas the framing elements (studs and joists) cross-sections are about 38 mm × 89 mm and 38 mm × 140 mm for internal and external wall studs, respectively.

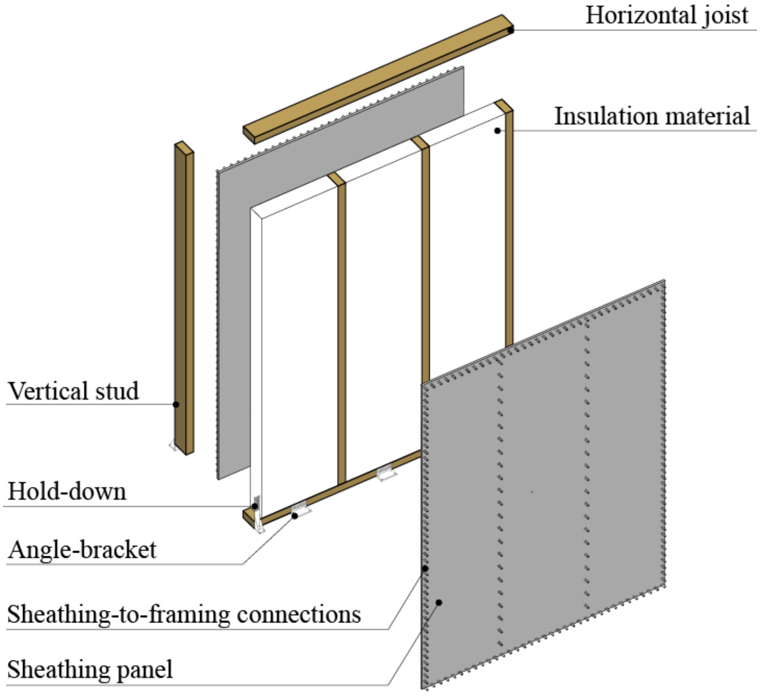

Figure 1. Typical structural configuration of a fully anchored timber light-frame shear wall sheathed on both sides.

The cross-section size of external framing elements is often chosen to accommodate minimum building requirements for thermal insulation (see Figure 1).

Generally, common fasteners (6D, 8D and 10D) with thick shank that gives greater strength, are employed for framing connections. The fasteners are placed both on the perimeter studs (typically with spacing equal to 50, 75, 100 mm) and on the intermediate studs. In the latter case, they are two or three times spaced with respect to the fasteners placed on the perimeter studs, only to prevent buckling of the sheathing panel [2]. Experimental tests have demonstrated that timber has, in general, a poor dissipative capacity whereas the steel connections – such as sheathing-to-framing joints [3][4][5], base [6] and stud-joist joints [4] – ensure a good amount of energy dissipation and cyclic ductility notwithstanding their significant pinching, strength degradation and softening. These pieces of evidence are well reflected in the numerical models available in the literature, where the non-linear wall response is basically related to the load-deformation relationships of the connections [7][8]. In general, elastic beams are implemented in order to represent the behavior of the framing elements whereas sheathing panels are modeled with plane-stress elements, assuming an elastic behavior in compression and an elastic-brittle behavior in tension [9]. Sheathing-to-framing connections and base connections are usually modeled with non-linear springs [10]. Because of the lack of extensive parametric analyses of timber light-frame shear walls [11][12], an original parametric FE model has been developed within OpenSEES [13] in order to assess the influence that geometric variables have on the global seismic performance of the wall. The main features of this parametric FE model are illustrated in the following.

2. Model implementation within OpenSEES

The original FE model developed using the open-source software OpenSEES [14] herein presented is, to the best authors' knowledge, the first attempt of modeling a timber light-frame shear wall within the TCL environment. The software OpenSEES was chosen for its capability to obtain in a simple environment a parametric model of a timber light-frame shear wall and because it's opensource software freely available to the community.

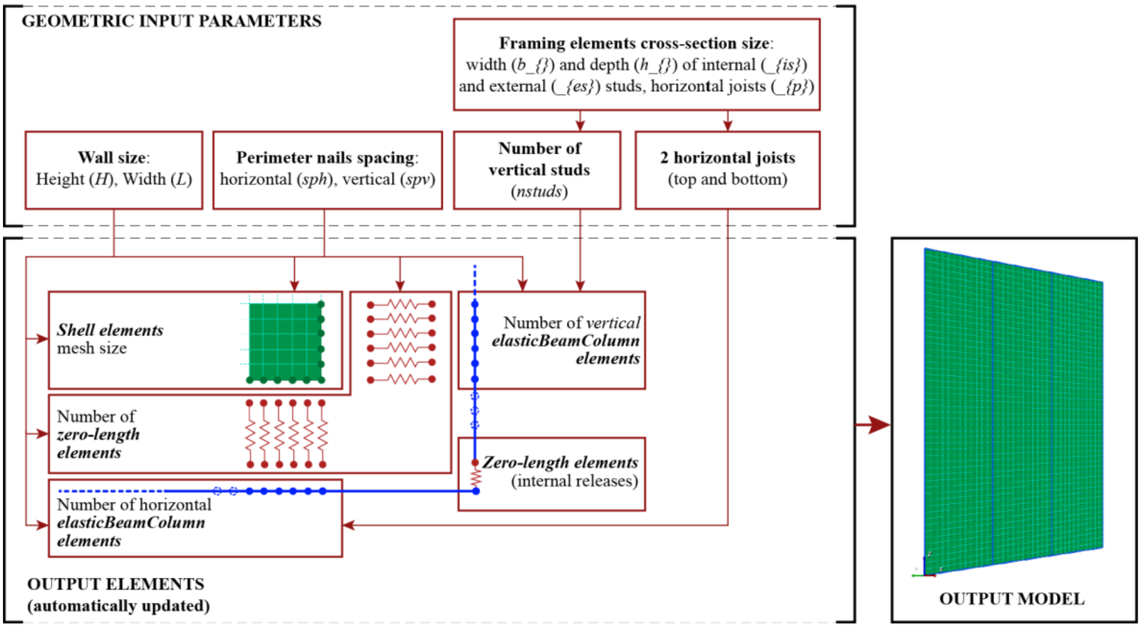

Figure 2. Overall process to build the parametric FE model of the wall without openings.

2.1 FE model without openings

A common way to simulate efficiently the dissipative behavior of timber light-frame shear walls is to model framing system and sheathing panel as elastic elements while representing the connections as zero-length non-linear elements. This approach has been adopted previously in different studies [7][8] and is implemented herein. The developed parametric model requires the following geometric parameters (see Figure 2): panel size (panel height *H* and panel width *L*), horizontal and vertical nails spacing (*sph* and *spv*), number of vertical studs (*nstuds*) and framing elements cross-section size for internal studs (b_{is} and h_{is}) and boundary elements (i.e., b_{es} and h_{es} for external studs, b_p and h_p for horizontal joists).

The nodes are created on a regular grid according to the nails spacing *sph* and *spv*. They are labeled as follows: the first digit indicates the layer they belong to, whereas the two next couples of digits indicates the *i*th (in the *x* direction) and *j*th (in the *z* direction) position of the node on the grid, respectively (Figure 3). Two layers are employed for the nodes. Layer *2* includes the fictitious nodes used to insert the internal releases between the end of vertical studs and the horizontal joists. Layer *4* includes the perimeter nodes belonging to the frame. An example of the FE model generated for 5 nails along the horizontal direction and 3 nails along the vertical direction is illustrated in Figure 3, where base and height are aligned with the *x* axis and the *z* axis, respectively. Once the nodes are placed, the elements are generated. The framing elements have been modeled using *Elastic Beam Column Elements* whereas the sheathing panel is modeled by means of *ShellMITC4 Element*s whose mesh size is adjusted automatically based on the nails spacing. In order to consider the framing joints acting as hinges [10], two *ZeroLength Elements* are inserted at both ends of the vertical studs, with zero stiffness for the rotation along the *y* direction and infinite stiffness for the remaining degrees-of-freedom. Finally, *CoupledZeroLength Elements* have been employed in order to represent the non-linear behavior of the sheathing-to framing connections. In this way, the overestimation of stiffness and force of the nail is avoided because, under non-linear loading, the yielding of the element occurs on a circular surface [15]. All these elements are labeled by considering the layer they belong to (first digit), together with first and second nodes of the element itself along *x* and *z* directions (subsequent couples of digits) as illustrated in Figure 3.

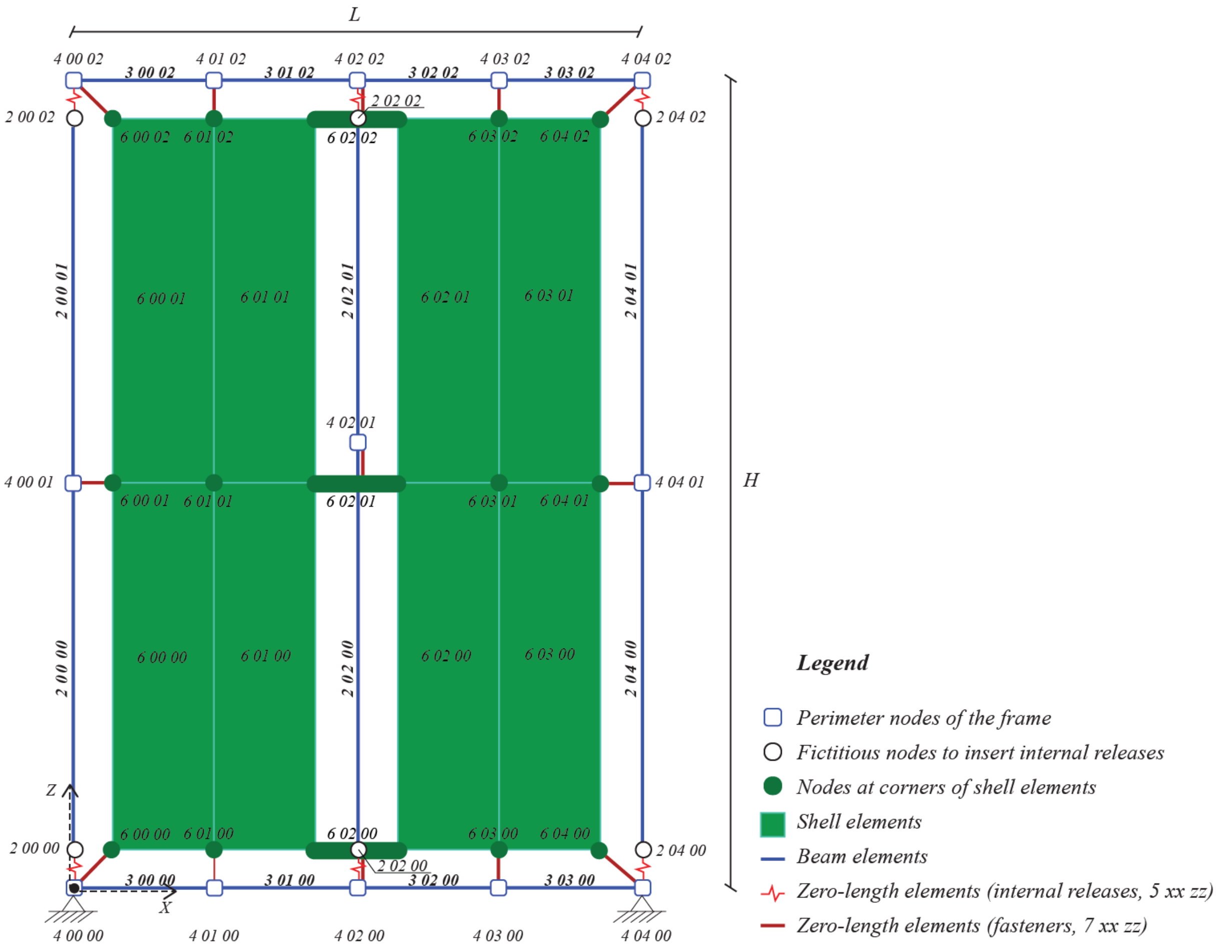

Figure 3. Layout of the shear wall FE model implemented in OpenSEES (in this example, it includes 5 and 3 nails along the horizontal and vertical direction, respectively).

Layers *2*, *3*, *5*, *6* and *7* refer to vertical studs, horizontal joists, hinges within the frame, panel (together with its nodes) and sheathing-to-framing connections, respectively. Finally, since the frame is double sheathed (Figure 1), the symmetric shell and zero-length elements are included in Layer *8* and Layer *9*, respectively.

The SAWS mechanical model – originally proposed in Ref. [16], then developed in Ref. [17] and modified in Ref. [18] – is employed to represent the mechanical behavior of a single nail using the *CoupledZeroLength Element*. The 10 parameters that define the SAWS model have been identified considering the experimental data of a single ring nail Φ 2.8 provided in Ref. [9] by means of the non-classical identification techniques presented in Ref. [19]. For more details about the FE model and its validation, the interested reader can refer to Ref. [20].

2.2 FE model with openings

A parametric FE model of the shear wall able to take into account the presence of openings has been also implemented (see Figure 4). By setting the dimensions of the openings (*bdim* and *hdim*) and their distance from one edge (*dist*), the position of the vertical studs around them is automatically updated. Nodes and shell elements at the opening are then deleted by means of the command *remove*. Moreover, the header of the opening is inserted with internal releases for the connection with the intermediate studs, in order to represent the real behavior of the joints connecting framing members (that behave like perfect hinges). To validate the accuracy of the FE model for a wall with openings, experimental data provided in Ref. [21] for specimen 2 have been considered.

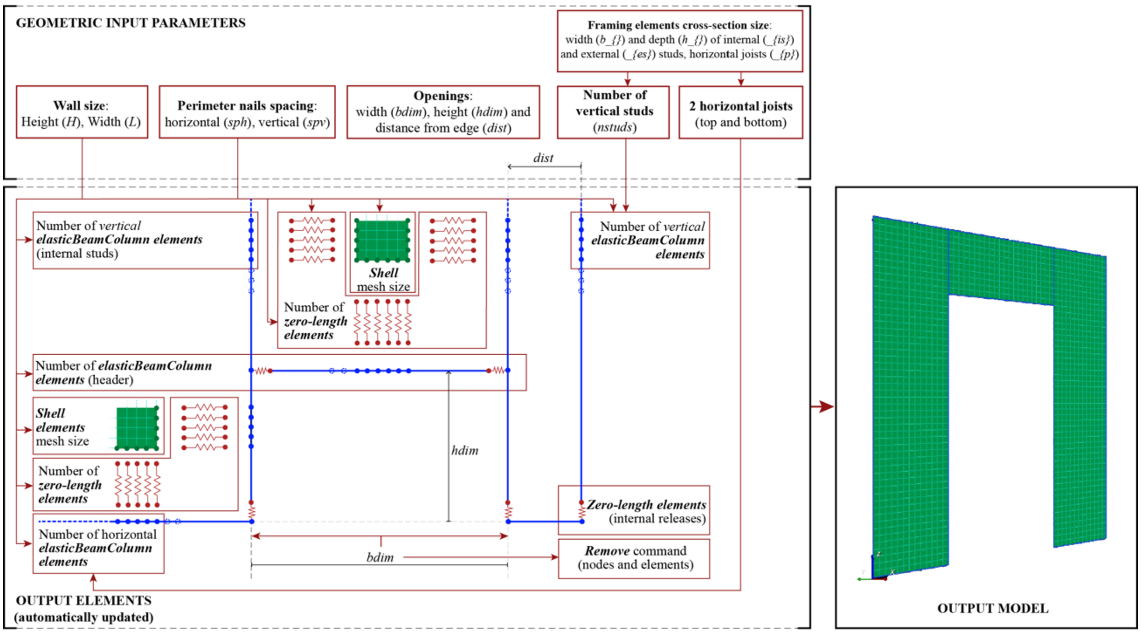

Figure 4. Overall process to build the parametric FE model of the wall with openings.

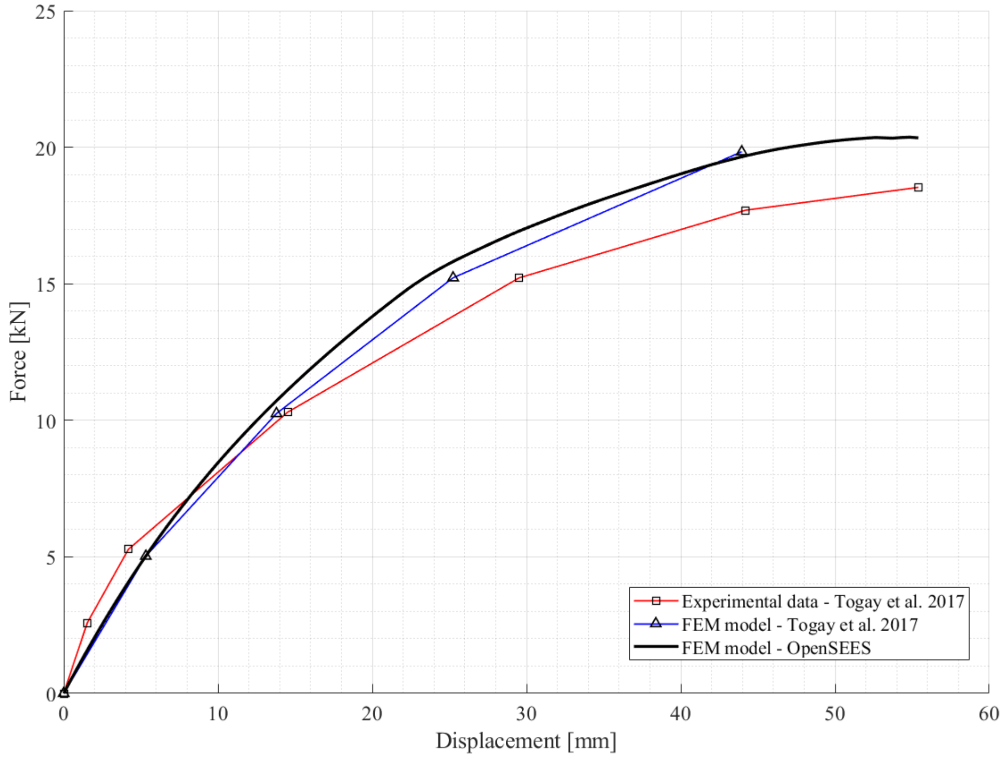

Figure 5. Comparison between experimental and predicted force-displacement curves for the reference wall configuration (specimen 2 in Ref. [21]).

As it is shown in Figure 5, the predicted force-displacement curve (black line) is in good agreement with the experimental data (red line) and the numerical results (blue line) provided in Ref. [21]. In the adopted model, the shell elements have size equal to 50 mm × 50 mm whereas nails spacing – according to Ref. [21] – is 100 mm and 300 mm on the external edges and on the horizontal elements of the central section, respectively. It is remarked that different (finer) mesh sizes have been also used, and no significant variations have been observed. Actually, nails Φ 3.1 /80 (mm) have been used to connect the OSB plates and timber framing elements. Without an experimental load-displacement curve for this nail size, the performances related to a single fastener have been obtained by multiplying times 1.08 the ordinates of the Φ 2.8 ring nail force vs. displacement curve, following the procedure in Ref. [9]. Specifically, the amplification factor has been estimated as mean value between the stiffness ratio and the resistance ratio of the two nail types, by exploiting the simplified analytical relationship proposed by EuroCode 5 [22] to predict the stiffness for timber-to-timber connections, considering nails without pre-drilling:

$$K_{ser} = \frac{\rho^{1.5}{}_m \cdot d^{0.8}}{30} \Rightarrow \frac{K_{ser,\phi 3.1}}{K_{ser,\phi 2.8}} = \left(\frac{\phi 3.1}{\phi 2.8}\right)^{0.8} \qquad (1)$$

where ϕ is the nail diameter. The difference between the experimental and the numerical curve can be explained because of the amplification factor (i.e., Eq. 1) is not fully capable to catch the mechanical response of the nail.

3. Analysis of walls with low aspect ratio

As it was pointed out in Ref. [11], the response of non- or partially-anchored timber shear walls strongly depends on the aspect ratio (i.e., height-to-width ratio). The relative rigid rotation of the sheathing panel with respect to the frame mostly stresses the nails near the corners (Figure 6). As it can be inferred from the experimental tests presented in Ref. [23], a flexural behavior of the timber shear wall can be observed if the width is significantly less than the height (aspect ratio equal to or larger than 3). Otherwise, the contribution of shear deformation to storey displacements increases, with a growth of stiffness and racking capacity. This is due to two factors, namely: i) a higher number of vertical studs is required (and thus the whole system is stiffer); ii) the wider the base of the wall, the higher the number of horizontal nails. Due to the available size of sheathing panels, a timber light-frame shear wall with low aspect ratio could be comprised of more than one panel to brace each side of the timber frame. In order to quantify the difference in terms of wall response, the parametric FE model has been developed to take into account this condition (Figure 6). The results show that the racking capacity for a single- and multi-panel wall is fairly constant whereas the decrement of the panels inertia for in-plane actions led to a reduction of the global secant stiffness.

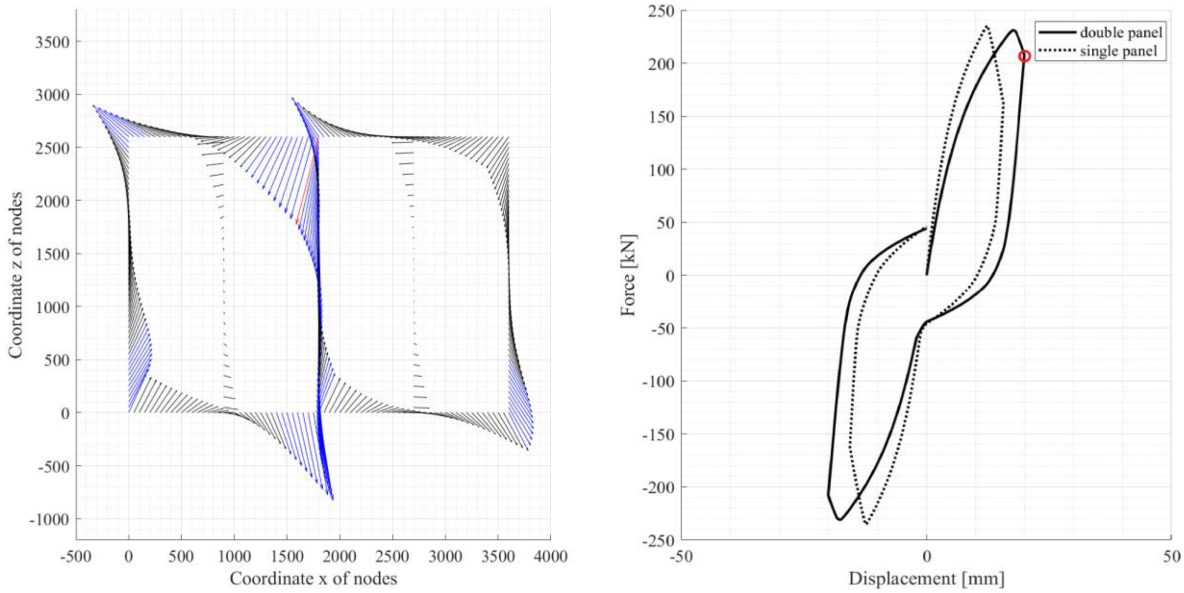

Figure 6. Global force-displacement curve of a wall with aspect ratio equal to 0.7 (right) considering two adjacent panels for both sides of the wall.
The displacement field of the nails is magnified by a scale factor equal to 100 (left); black arrow: fastener

displacement smaller than the one corresponding to peak force; blue arrow: fastener displacement exceeding the peak force; red arrow: fastener displacement at failure.

4. Conclusions

An original parametric FE model for timber light-frame shear walls implemented within OpenSEES has been described in this work. First, the numerical model of double-sheathed timber light-frame shear wall without openings has been presented. Then, a parametric FE model taking into account the presence of openings has been illustrated and, finally, further considerations about walls with low aspect ratio have been provided. Preliminary results and validations have demonstrated the reliability of the model, which can be employed to perform extensive sensitivity analyses and to support the search for optimal configurations.

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