EXPERIMENTAL AND NUMERICAL ANALYSIS OF A NEWLY PROPOSED STRUCTURAL TIMBER WALL (TRAROM)

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Abstract

Romanian traditional architecture is a cultural identity asset. Although the skilled carpenters cannot easily be found anymore, efforts are being done to not lose this asset. Thus, within TRAROM project, a structural wall is proposed, inspired by traditional timber houses, to build houses according to the new requirements: wider spaces, energy efficient, seismic safe, etc.

After testing several layouts to check which one is better from the structural point of view, the authors decided one of the layouts as satisfying all the requirements, thus a numerical analysis was done to try to capture the envelope curve of that wall.

In this paper, the experimental test result is presented for the wall, and further a numerical model is described. The model was done by the structural engineer in the project team, in a commercial software, so it can be as easy and understandable as possible to be presented to other engineers, who may want to use the same structural system, but with different openings. The model was adapted by inverse-fitting method to match the experimental results, and the hypothesis taken into account are presented hereby.

Keywords: timber; internal stiffeners; external planks; traditional; modelling

1. Introduction

Within the TRAROM project, a structural wall was proposed to be used for new residential houses. The system was made of timber, with sections that are easily found everywhere (at least in Romania) and can be connected easily by screw nails (threaded annular ring nails), so highly skilled workmanship is not necessary when manufacturing such a house [1].

After testing several layouts, the best one was selected as having a high capacity under lateral loading, not showing many damages for high displacement, and having a reasonable execution cost. The test setup is presented hereby and results are shown for the best wall.

A simple numerical model was made in Allplan SCIA professional, a commercial software for structural design, and it was matched with the envelope curve of the wall test by inverse-fitting method. The results and hypothesis are presented further, and the model can be easily reproduced by engineers.

The purpose of the model was to be a tool that can be used by practitioners, not only by researchers, so when owners chose to build their houses with this new system, the designers can easily adapt their proposals according to the desired lengths and other requests.

2. Description of the wall experiment

The main timber frame was made of timber posts with 50x150 mm dimensions, connected by screw nails (6x140 mm) to two horizontal timber beams with the same dimensions, at the upper part and at the bottom part (Fig. 1). On this frame thus created, wooden planks with the dimensions of 20x120 mm were arranged in different layouts. The connections between the wood planks and the frame were made with screw nails 5x70 or 5x80 mm, two per connection (plank to post or plank to beam) (Fig. 2). The connections between the posts, beams and internal stiffening elements were done with same type of screw nails, but with 5x140 dimensions (Fig. 3).

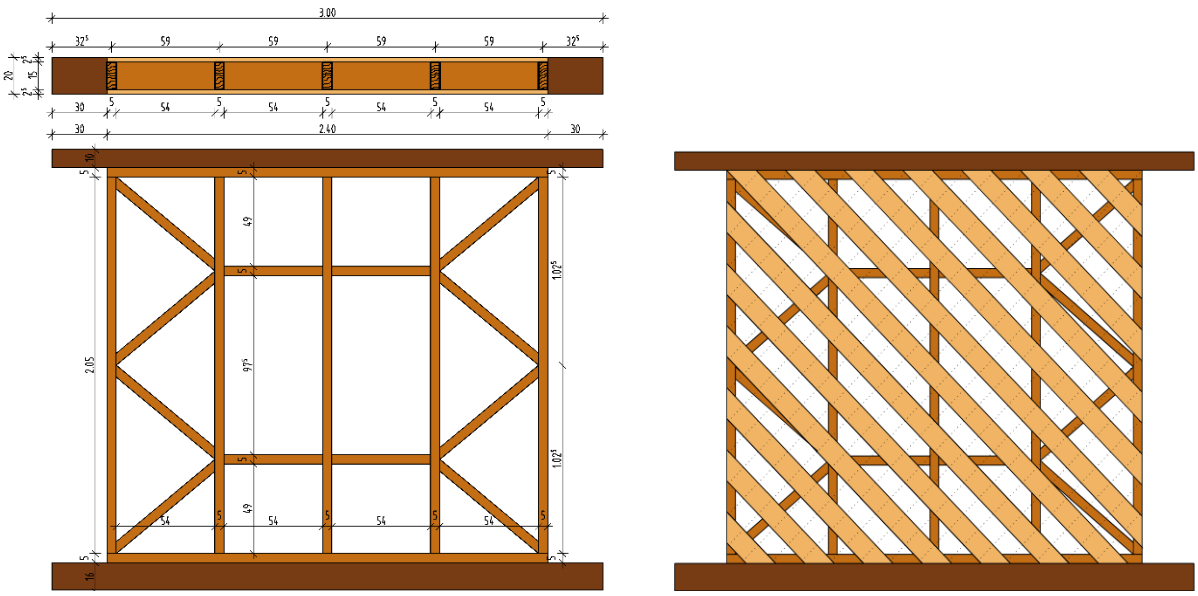

Fig. 1 – Dimensions of the main frame (left) and the layout of the exterior planks connected to the internal main frame (right)

Fig. 2 – Screw nails used for the connections

Fig. 3 – Screw nails 5x140 mm were used for the bottom marginal connections (inserted oblique)

The setup is shown in Fig. 4. A vertical force of 19 kN/m was applied at the top of the wall, being kept constant (± 20%) during the experiment. The loading scheme simulates just the behavior of the wall panel, so the loading beam should be strongly connected to the upper beam of the specimen. Same situation was for the bottom beam, simulating the mud sill on the foundation. The loading protocol was according to EN 12512 [2], for timber joints (Fig. 5). The yield displacement was considered 20 mm, according to [3].

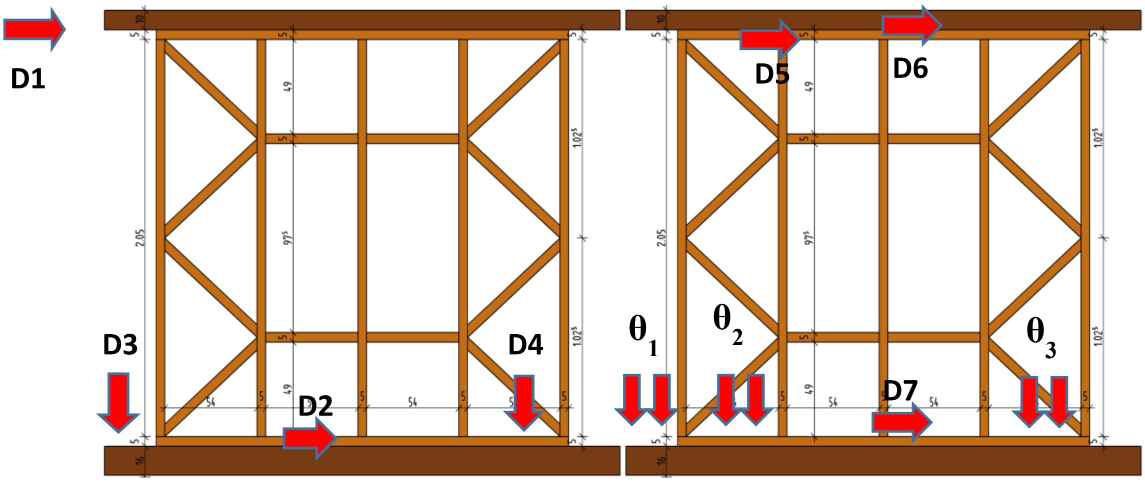

Fig. 4 – Test setup [4]

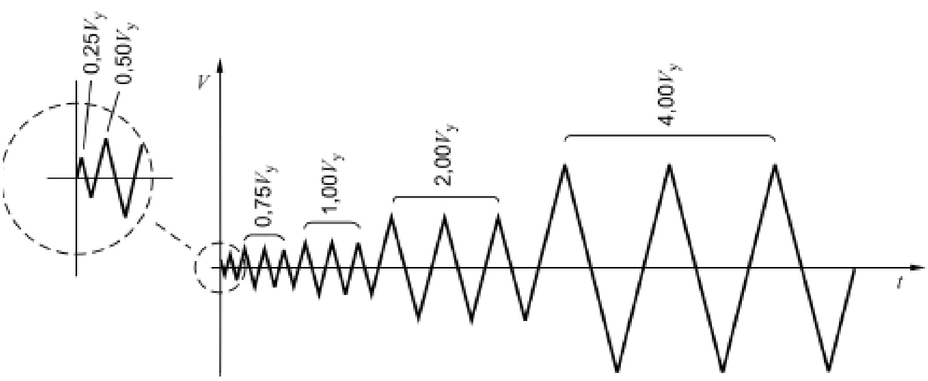

Fig. 5 – Loading protocol [2]

Input/control deformation of the protocol, shear angle, δ, was used to cancel the rocking as a rigid body (measuring the uplift in the bottom connections) and slippage, by subtracting them from the displacement at the top of the wall. This allows to observe the pure shear behavior of the wall. δ was calculated based on the following formula:

$$\delta = \frac{D_1 - D_2}{H} - \frac{D_3 - D_4}{L} \tag{1}$$

where D1, D2, D3, D4 = measured displacements (Fig 2).

The testing system is pantograph type, not allowing the rotation of the steel loading beam. The specimen was fixed at the base to the reaction plate by steel bolts, and at the upper part it was fixed in the same way to the steel loading beam.

The hysteresis curve (Fig. 4) shows a maximum capacity of 75.5 kN, corresponding to δ=0.05 rad.

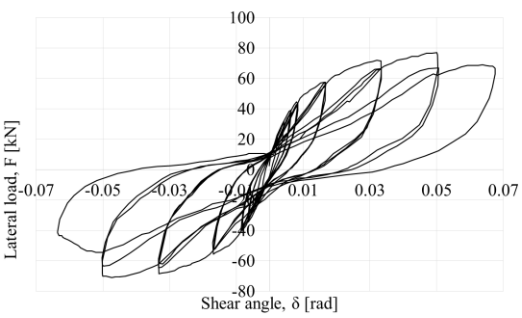

Fig. 6 – Hysteretic curve

Fig. 7 – Deformed specimen at 0.06 rad

After δ=0.0167 rad deformation, rotation was observed in the bottom connections. At δ=0.05 rad a significant detachment of the panel from the top timber loading beam and also from the bottom (Fig. 8, Fig. 9) was observed. The bottom beam showed bending due to the screw nails connected to the panel's bottom beam pull-out force. The diagonal elements forming the truss detached (Fig. 10). Due to the load path through the trusses' elements, the marginal joints both upper and lower were subjected to sliding (Fig. 11), breaking the timber fiber around the screw nails' holes [4].

Fig. 8 – Significant detachment of panel from the timber loading beam at δ=0.0501 rad [4]

Fig. 9 – Uplift in the marginal bottom joint at δ=0.0501 rad [4]

Fig. 10 – Detachment of diagonals at δ=0.0501 rad [4]

Fig. 11 – Failure of the upper marginal joint at δ=0.0501 rad [4]

Connection tests were also conducted for all types of joints that can be found in the wall, and an example of pull-out test on a joint between a post/beam and a plank is shown in Fig. 12. Results of these tests are described in detail in [4].

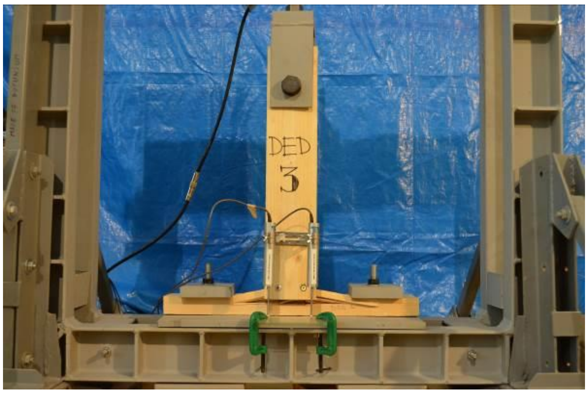

Fig. 12 – Pull out test on a connection between a plank and a post/beam

3. Numerical model

The numerical analysis was done in a commercial software, SCIA, in order to be more accessible for engineers and practitioners. The overall model scheme is shown in Fig. 13. The analysis was push-over type, simulating the wall experiment.

The static scheme considers six types of connections between elements as follows:

a – The connection between the top of the wall panel to the steel loading beam (Fig. 14). It allows translation in the X direction (in-plane) and also in the Z direction (to allow settlement from the vertical loading). It also allows rotation along Z axis, because in the experiment was observed rotation of the columns.

b – The connection between the bottom of the wall panel to the reaction floor (Fig. 15). It was fully restrained.

c – The connection between the exterior planks and the posts/beams (on the edges of the wall panel) (Fig. 16 and Fig. 17). This type was modeled using a spring with an assigned stiffness of 0.3 kN/mm (corresponding to the yielding force) [4], as resulted from connection tests. This value was the lowest obtained among the three tested joint specimens.

d – The connection between the exterior planks and the posts (along the height) (Fig. 16 and Fig. 18). These was also modeled as springs with the same stiffness as the previous one (0.3 kN/mm).

e – The connection between the beams and the posts. It was modeled also as a spring with an assigned stiffness of 2.5 kN/mm, as resulted from connection tests [4] for the lowest value of the yielding force among the three specimens.

f – The connection between the internal diagonal stiffeners and the posts/beams. This was modeled also as a spring, with an assigned stiffness as 2.5 kN/mm [4], as connection type “e”.

The material was chosen as strength C16 (EN 338) with an elasticity modulus of 8 GPa, being close to the value of Young’s modulus obtained by bending tests on beams from the same material (8.9 GPa). The value of the bending strength was used as obtained in the tests, 1.6 GPa. The rest of the properties were left as corresponding to the selected strength class.

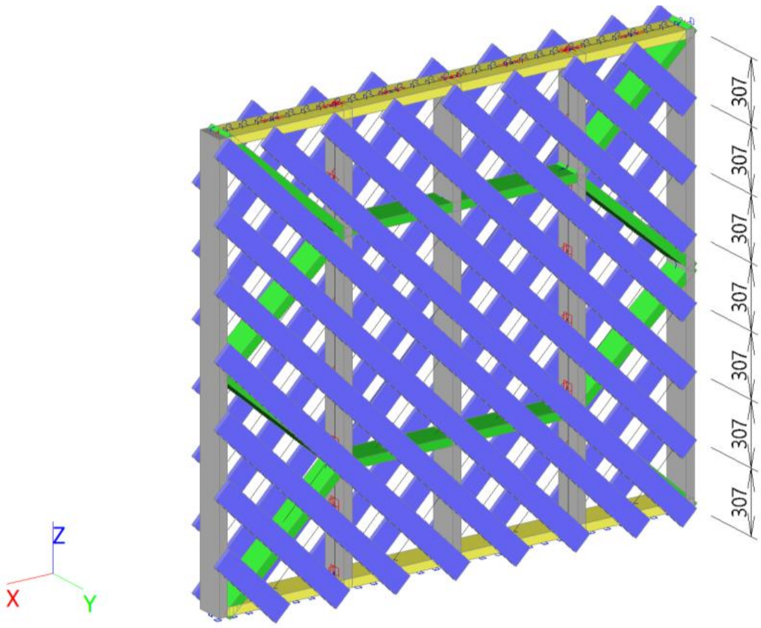

Fig. 13 – The model built in SCIA

The representations of the connections show bars, circles and squares in X, Y and Z directions. The bars indicate the direction in which the translation or the rotation is blocked. The circle means that the translation is blocked in the direction of the bar, while the square means that the rotation is blocked in the direction of the bar.

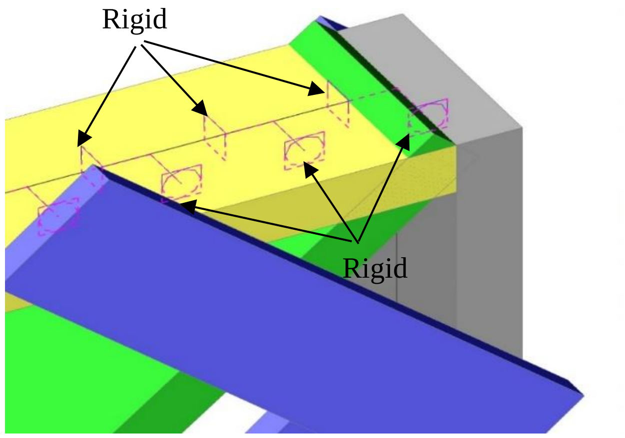

Fig. 14 – Details of the set DOF at the top part of the wall (connection a)

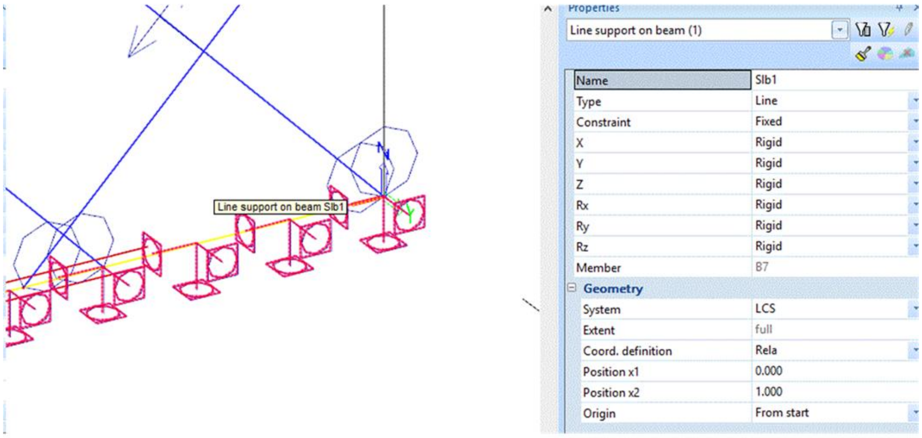

Fig. 15 – Details of the set DOF at the bottom part of the wall (connection b)

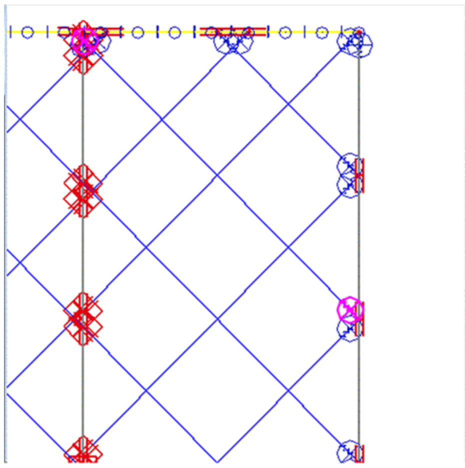

Fig. 16 – Representation of the connection between exterior planks and beams/posts: (c) on the edges of the wall panel – blue and (d) pink circles and intermediate connections along the posts' height – red squares

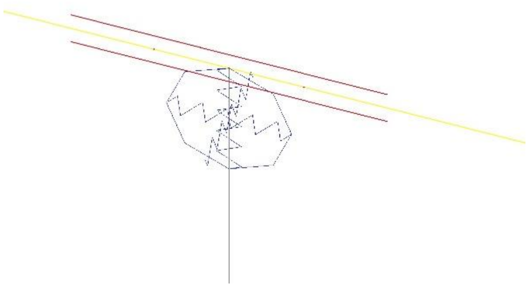

Fig. 17 – Details of the intermediate connections between planks and posts, on the edges of the wall panel (connection c)

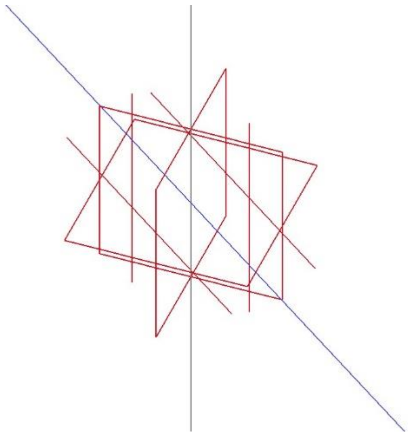

Fig. 18 – Details of the intermediate connections between planks and posts, along the posts' height (connection d)

The vertical load was considered uniformly distributed at the top part of the wall and self-weight was also taken into account (about 90 kg mass) (Fig. 19). The lateral load was applied in increments of aprox. 7 kN at the top of the wall.

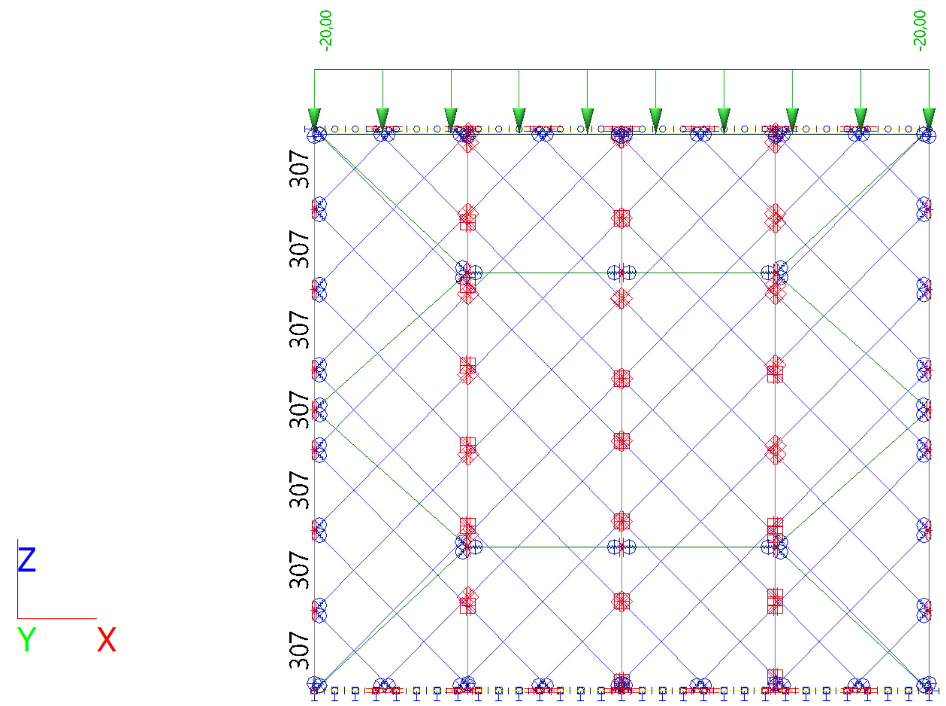

Fig. 19 – Application of the vertical load

The results in terms of Force-Displacement are shown in Fig. 20. The internal efforts and deformed shape of the wall are shown in Fig. 21 and Fig. 22, respectively. The deformation was similar to the one observed in the experiment.

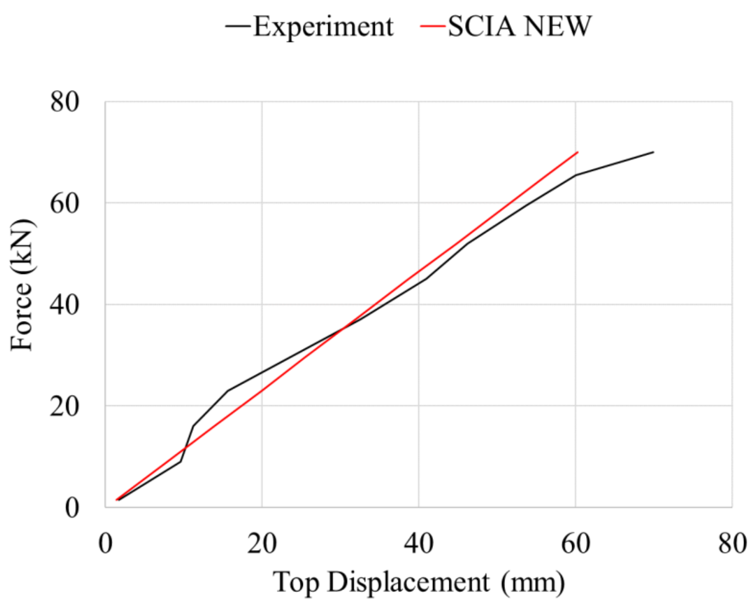

Fig. 20 – Comparison between the experiment's envelope and numerical model in SCIA

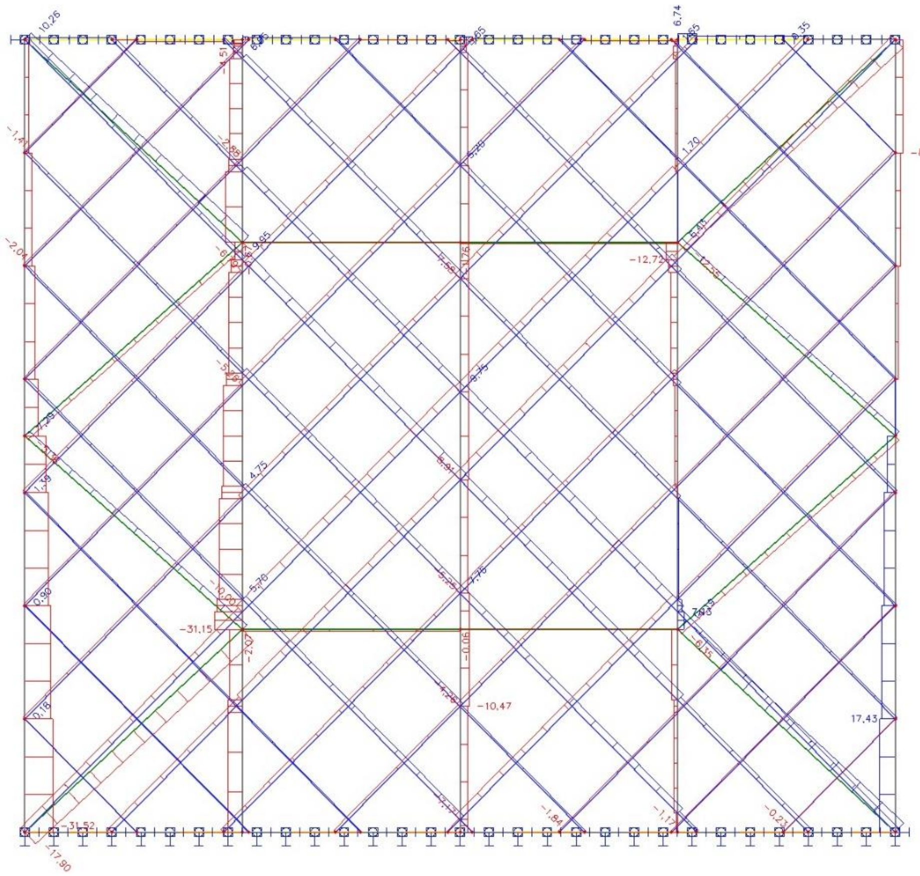

Fig. 21 – Axial force in the elements of the numerical model at 70 kN lateral load

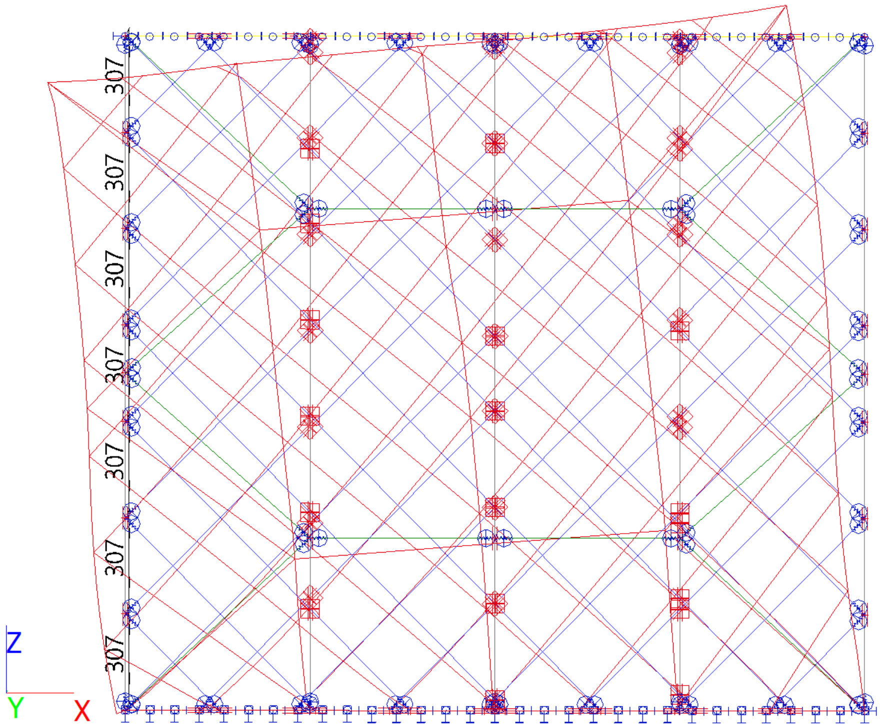

Fig. 22 – Deformed shape of the numerical model at 70kN lateral load

4. Conclusions

The paper presented a numerical analysis of an experimental test of a timber wall subjected to combined lateral and vertical loading. The model showed good matching results with the experimental envelope curve, and can be easily reproduced by engineering professionals due to its simplicity.

The timber wall presented, which was proposed as a good solution for new residential houses, aims at reducing as much as possible the human error in manufacture, and thus has very simple and effective details that can be built by unskilled workers.

5. Acknowledgements

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6. References

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