

STORY VERTICAL POST-COMPRESSION FOR TIMBER BUILDINGS: A NEW SYSTEM FOR SEISMIC IMPROVEMENT OF CLT WALLS

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A new constructive system for multi-story timber building with CLT panels is described. A vertical post-compression of each story allows avoiding the use of traditional joints, as hold-downs and angle brackets. Reducing the number of joint elements, the new constructive system may be faster than the traditional one. The story vertical post-compression allows to improve a shear-type behavior of each story with better performances of the CLT panels. Numerical studies on a single panel and a five-story building are made performing pushover static equivalent nonlinear analyses. These studies show as the new system allows better performances, in the case of horizontal actions, in comparison to the traditional constructive use of CLT panels. Thus, the new system is very suitable, for timber buildings, in areas prone to seismic actions and wind actions.

Keywords: Seismic and wind actions, CLT panels, Pushover analysis, Single panel analyses.

1 INTRODUCTION

Timber walls with “story vertical post-compression” represents a proposed new way to design buildings in areas at earthquake risk. Timber post-compression was studied in the last two decades mainly to improve the bending behavior of beams in frames (Newcombe *et al.* 2010, Smith *et al.* 2012) or in multi-story column-panels (Sarti *et al.* 2014). The proposed solution explores the advantages to improve a shear-type behavior in each story and to eliminate the traditional joints. Cross-laminated vertical timber panels are post-compressed by vertical post-tensioned bars placed outside them and in the building corners. The constructive system is made up of two verticals coupled CLT panels, by horizontal coupled beams and by the steel vertical bars connecting the beams (Figure 1a). The coupled beams may be made of glulam or steel. The steel bars are fixed to the steel elements that couple the beams. Each bar connects only two subsequent floors; thus, its diameter and its post-tensioning may be calibrated for each story differently from the other story and according to the resultant vertical load and the horizontal shear action. The purpose of this constructive system is to substitute the connection elements between panels and the connections to the foundation (i.e., hold-downs and angle brackets) through the bars post-tensioning, in such a way to avoid damages to those connection elements, to the screws or bolts and to the CLT panels themselves (Ceccotti *et al.* 2000).

To validate the system, a single panel and a five-story building were numerically analyzed. Pushover analyses show the better behavior of the post-compressed single panel and building in comparison to the traditional connection techniques.

2 THE RESEARCH TASKS

The purpose of this work is to analyze the structural behavior of vertical post-compressed CLT panels in comparison to traditional ones, that is with traditional steel joints as hold-downs and angle brackets, with horizontal actions. The expected benefits of this constructive system are:

- the elimination of steel joints (hold down, angle brackets, ...) thanks to the post-compression;
- a better response to the horizontal actions (seismic events or wind);
- a low invasiveness into the structural elements (beams and panels), by avoiding the insertion of tension bars into them;
- an easy maintenance, thanks to the accessibility to the gaps designed for the placement of tension bars;
- better performances against buckling, thanks to the coupled CLT panels;
- the post-compression optimization for each story level, according to the dead load.

For this aim, they have analyzed a single panel and a multi-story building in terms of capacity curves, performing “pushover” nonlinear static equivalent analyses. For other examples of experimental and numerical analyses of traditional timber building with CLT panels, see also Ceccotti *et al.* (2000).

3 THE SINGLE PANEL ANALYSES

3.1 CLT Panels Orthotropy Simulation

Timber is an orthotropic material with different strengths and behaviors in relation to its fiber’s direction. A simple micro-modeling has been used to simulate CLT orthotropy using 3D isotropic finite elements in performing nonlinear analyses. Each CLT strata is made by columns of isotropic 3D elements with the wooden stiffness and strength parallel to the fibers; between two columns there is a thinner “joint” column of 3D elements with reduced stiffness and strength calibrated in such a way to simulate the wooden stiffness and strength orthogonal to the fibers. In the micro-modeling are modeled also the glued joint between the CLT strata (Figure 1b).

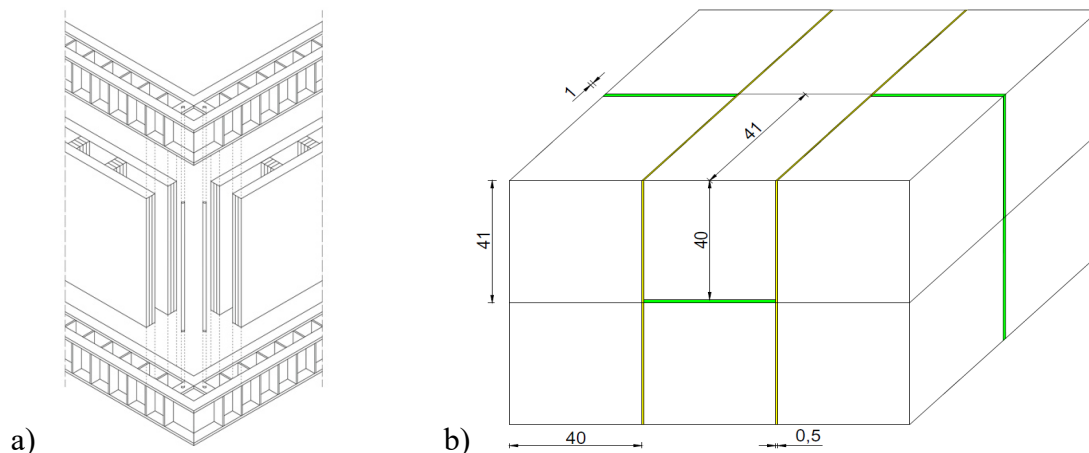


Figure 1. a) The constructive system and one-story corner solution. b) The micro-modelling of a three strata CLT: wooden 3D isotropic main elements (white), glue elements (yellow), “joints” elements to give the fiber direction (green).

3.2 Material's Mechanical Characteristics

They are chosen the WHT740 hold-downs and TTN240 angle brackets for the traditional panel and building. The steel beams used in the new system are the Ipn 500. Using Midas FEA software, the materials nonlinear behavior was simulated by the Total Strain Crack criterion. The input materials to perform the pushover analysis are:

- the laminated timber strength GL24c class for the panels;
- the polyurethane glue added in the production of the panels;
- the S460 steel for the beams, hold downs, angle brackets, and tendons;
- the C25/30 concrete for the foundation;
- E0 GL24c = 11600 MPa, $\nu_1 = 0,37$;
- E90 GL24c = 320 MPa (“simulated” by the combination of E0 and E “joints”);
- E PU glue = 586 MPa, $\nu_2 = 0,42$;
- E “joints” = 7,708 MPa.

3.3 CLT Single Panels Pushover Analyses

The panels are 3 m tall and 4 m long; in the traditional system, they have 243 mm of thickness, whereas, in the post-compressed one, each of the two coupled panels has a thickness of 121 mm. The tension bars used for post-compressed panels are about 36 mm in diameter, with a post-tension of 270 kN.

The results of the calculation software are listed below. In the Figures 2 and 3, the traditional panel with hold-downs and angle-brackets is on the left, whereas the post-compressed one is on the right to better compare their results.

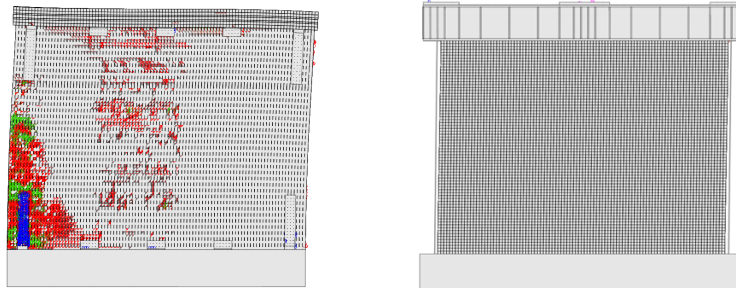


Figure 2. Traditional and post-compressed X-lam panel, crack status F=1650 kN.

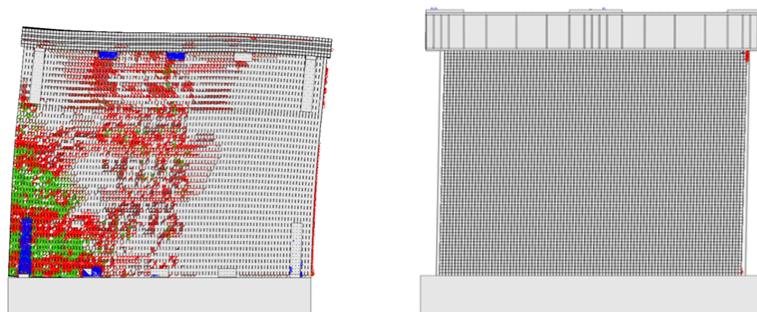


Figure 3. Traditional and post-compressed X-lam panel, crack status F = 2475 kN.

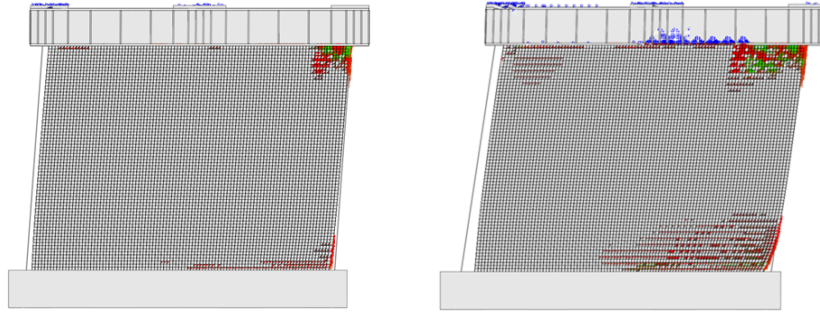


Figure 4. Post compressed panel, crack status with $F = 6600$ kN and $F = 9075$ kN.

The traditional panel shows an anticipated cracking compared to the post-compressed one, with damages in the wood, for tensile stresses, starting from the upwind hold down. The post-compressed panel works in a different way: when the horizontal force lifts the structural elements, the beams hold the panel thanks to tendons action. Likewise, the cracking happens later for compressive stresses on the opposite side (Figure 4). This also means a more ductile local and global behavior (as well shown by the capacity curves in Figure 5), as wood is more ductile in compression than in traction.

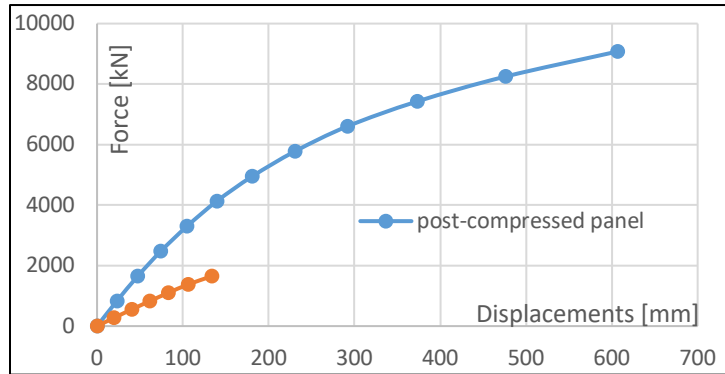


Figure 5. Capacity curve, comparison between traditional panel and post-compressed one.

4 A FIVE STORY BUILDING ANALYSES

4.1 Pushover Analyses in the Building Shorter Main Axis Direction

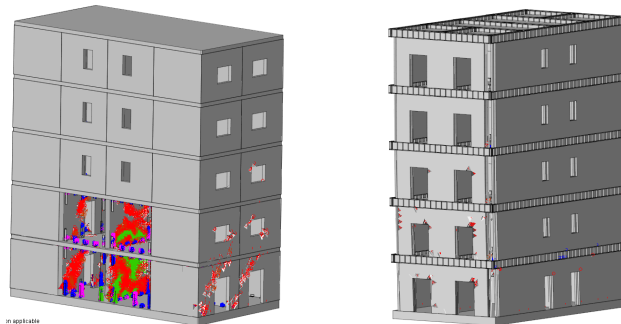


Figure 6. Traditional and post-compressed building, crack status with $F = 7000$ kN per floor.

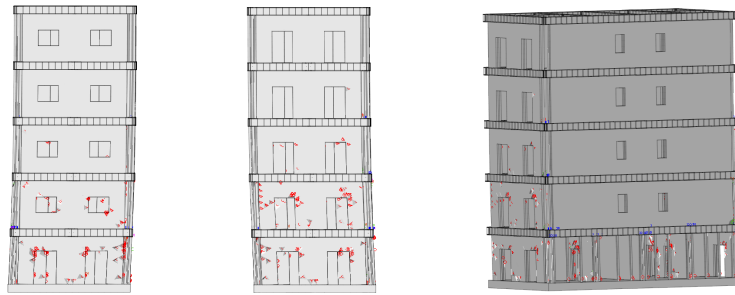


Figure 7. Post-compressed building front, rear and lateral views, crack status with $F = 11000$ kN per floor.

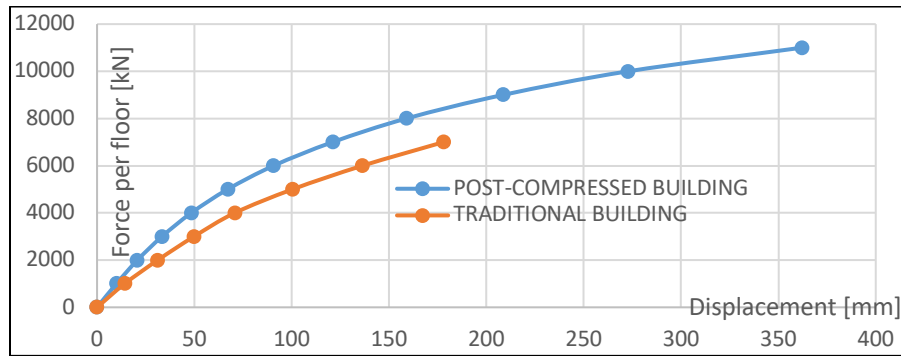


Figure 8. Capacity curves, comparison between traditional building and post-compressed one.

4.2 Pushover Analyses in the building longer main axis direction

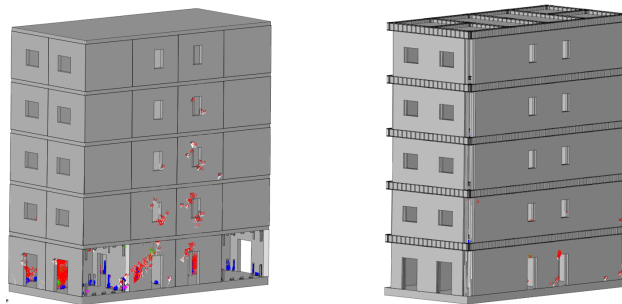


Figure 9. Traditional and post-compressed building, crack status with $F = 11000$ kN per floor.

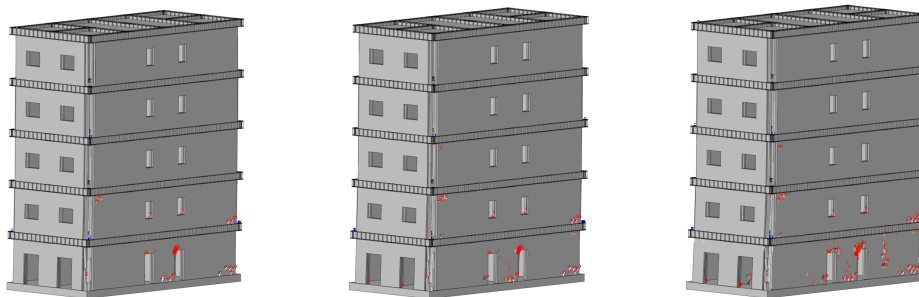


Figure 10. Post-compressed building crack status with $F = 12000$ kN, $F = 13000$ and $F = 14000$ kN per floor.

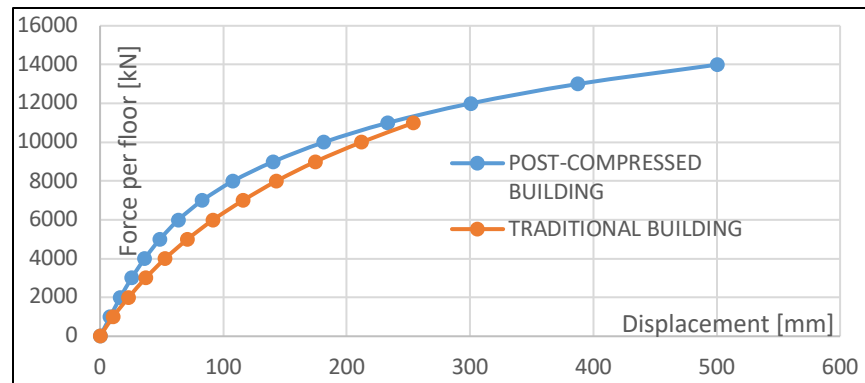


Figure 11. Capacity curves, comparison between traditional building and post-compressed one.

The models show as the vertical tendons, especially those connecting the beams on the building perimeter, impose a shear-type behavior to the building itself (Figure 7, and 10); behavior that allows a better performance of the CLT panels of each story, while the traditional building performs a global bending behavior that cause an anticipate crisis at ground level (Figure 6 and 9). The global behavior improvement is well shown by the capacity curves in Figure 11.

5 CONCLUSIONS

The pushover analyses results show how the panels with traditional joints are more vulnerable than the post-compressed ones in case of horizontal actions. The capacity curves of a single panel or of an entire building indicate a brittle bending type behavior for the traditional structural scheme and a ductile shear-type behavior for the new one. In the single panel analyses, the increment in ultimate load is 550% (from 1650kN up to 9075kN) and the increment in ultimate displacement is 450% (from 133mm to 406mm). In the building weaker direction, the increment in ultimate load is 157% (from 7000kN up to 11000kN per floor), while in the stronger direction, it is 127% (from 11000kN up to 14000kN per floor). The building increment in ductility, in terms of ultimate displacement, is 203% in the weaker direction (from 178mm to 362mm), while it is 197% in the stronger direction (from 254mm to 501mm).

The numerical non-linear analyses show as the proposed tasks of the elimination of steel joints as hold down and angle brackets (thanks to the post-compression), and the task of a better response to the horizontal actions as seismic events or wind, maybe very well obtained with the proposed structural system.

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