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# SEISMIC DESIGN OF A MID-RISE BUILDING IN CHILE USING RADIATA PINE CROSS LAMINATED TIMBER

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**ABSTRACT:** This paper describes some relevant aspects of a research and development project that introduces the use of CLT panels in buildings in Chile. The primary objectives of this project were to fabricate and test CLT panels using local radiata pine, and to design a mid-rise building prototype for a social housing solution in Chile. The main challenge for this project was to adapt the Chilean building code and standards to the seismic design of a building using CLT as the main structural system. American and Canadian standards and guidelines were adopted with some modifications to a CLT based on typical Chilean radiata pine. A four-story building structured with CLT panels was designed and used to demonstrate de technical feasibility of a building with CLT panels in Chile. Information on basic steps of this project and the procedure of the seismic design process adopted for a CLT building in Chile are presented in this document.

## 1. Introduction

Cross Laminated Timber (CLT) has been used for more than 20 years for making floor and wall panels in Europe, and over the last decade in the USA and Canada (Brander, 2013, and Schickofer, 2010). CLT is a prefabricated element based on common sawn wood grouped in layers joined by adhesives on their faces (Fig. 1). This kind of fabrication can achieve panels of different thicknesses depending on the number of layers and the thickness of each timber element, with good resistance to loads outside and within the plane of the panel. The excellent mechanical properties of CLT have allowed its use for the construction of different kinds of buildings, from low buildings with a large surface to towers more than 10 floors high. Fig. 2 shows a type building based on CLT in the city of Vancouver, British Columbia. Many of these buildings have been built in low seismicity areas, but nowadays there is a tendency to develop these kinds of projects in high seismicity zones, e.g., Italy and the west coast of Canada and the USA (Ceccotti, 2008).

In Chile there is still no information on the manufacture and use of CLT in buildings. The Materials Research Laboratory (Laboratorio de Investigaciones de Materiales, LIMUS) of the Universidad de

Santiago de Chile, with financial support from the Corporación de Fomento, CORFO, and the logistic support of the Technological Development Corporation (Corporación de Desarrollo Tecnológico) of the Cámara Chilena de la Construcción, has taken the initiative of introducing CLT in the national market through a research and development project whose objectives are 1) to study the technical and economic feasibility of using CLT in buildings in Chile, and 2) to promote the use of CLT in Chile. The technical part of this project studies the use of local lumber (radiata pine) as the basis for CLT, testing CLT panels and its connections, and production and design of a building based on CLT for social housing in Santiago, Chile. The present document will be focused on the technical aspects of this project with emphasis on the structural design of a typical social housing building in Chile.

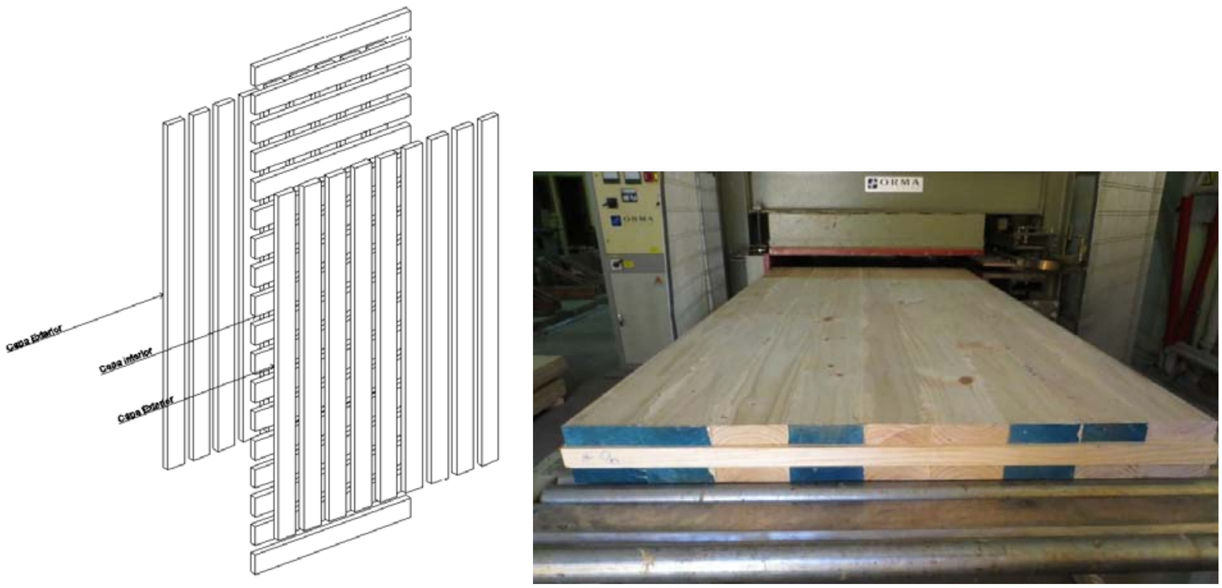


**Fig. 1 –CLT panel and detail of its layers and components.**

## 2. CLT in Buildings

Gradually, CLT is becoming an alternative building material in different parts of the world, and it is one of the most emblematic products derived from wood for the construction of medium height buildings in developed countries like Canada, New Zealand, the USA, and the European Community (Brander, 2013, and Schickofer, 2010). CLT has the advantage of excellent heat and sound insulation characteristics that increase the well-being of the inhabitants and reduces energy expenses in heating systems (Gagnon and Pirvu, 2011). This material allows the massive construction of medium sized housing solutions due to its high earthquake resistance, and moreover it favors the reduction of atmospheric $CO_2$.

These projects have been backed by a number of research projects that have included tests on components subject to dynamic loads (Popovski et al., 2011) and full scale tests on buildings (Pei et al., 2010). These tests have led the authorities of some districts to allow the use of CLT as the main earthquake resistant system in buildings, and the use of wood in tall buildings. Several guides have been developed on the design of wood and CLT buildings (ANSI/APA, 2012, and FP Innovations, 2013), allowing architects and engineers to use CLT in buildings.

The growing demand for CLT has also allowed the creation of a new industry and the use of new construction techniques, with clear advantages over concrete or steel structures. Some companies have implemented their own standards for their panels and have produced design guides that optimize the use of CLT and improve the quality of the projects (eg. Structurlam, 2014). Table 1 gives information provided by the manufacturers on the mechanical properties of CLT panels that are commonly used in buildings in British Columbia.

**Fig 2. – Building under construction with CLT structural components in Vancouver, BC.**

## 3. CLT in Chile

### 3.1. Manufacturing Process

CLT panels were manufactured entirely in the Material Research Laboratory at the Universidad de Santiago de Chile using local radiate pine as the main component. The lumber was classified visually and mechanically and then grouped according to its corresponding classification (Fig. 3a). Finger-joints were used (Fig. 3b) to connect lumber pieces in order to remove knots and to achieve the required length of the panels.

Once the members were oriented in plan, they were glued together on their lateral edges to form individual layers, as shown in Fig. 3c. Three layers were stacked crosswise on top of each other and glued together under high pressure to form the final CLT panel as shown in Fig. 3d.

**Table 1 – Properties of CLT panels provided by manufacturers for use in structural design (adapted from Structurlam, 2014)**

| Characteristics | | Maximum span in mm for live load on floor, kPa (kgf/m2) | | | | | In-plane shear strength |
|---|---|---|---|---|---|---|---|
| Panel type | Thickness mm | Residential 1.9 (194) | Office 2.4 (245) | Mechanical 3.6 (367) | Storage 4.8 (489) | Library 7.2 (734) | Vr kN/m (kgf/m) |
| SLT3 | 99 | 3490 | 3490 | 3220 | 2980 | 2650 | 95 (9687) |
| SLT5 | 169 | 4920 | 4920 | 4920 | 4730 | 4220 | 190 (19375) |
| SLT7 | 239 | 6200 | 6200 | 6200 | 6200 | 5720 | 285 (29062) |
| SLT9 | 309 | 7370 | 7370 | 7370 | 7370 | 7180 | 380 (38749) |

### 3.2. Testing of boards and connections

The in-plane and out-of-plane tests were carried out based on the requirements of Chilean codes (NCh 801, 2003, NCh 802, 1971, and NCh 803, 2003) using loading and unloading cycles to get the lateral displacements under different load level and the residual displacements (Fig. 4a). A total of eight loading and unloading cycles were applied, with load increments of 500 (kg) in each cycle. In some shear tests the connector failed before the panel (Fig. 4b), showing the high resistance of this kind of system. The panels were also tested under four-point-bending (Fig. 4c), resulting in typical bending failures due to breakage of the lower layers of the panel (Fig. 4d).

### 3.3. R factor estimation.

Since the construction system based on CLT panels is relatively new and is not considered under the Chilean building code NCh433 (2010), it is necessary to calculate it experimentally. This factor is the ratio of the maximum horizontal displacement at the upper end of the panel to the displacement recorded at its yield point. Fig. 5 shows the degree of deformation reached for the load protocol defined for this test. According to the data obtained from these tests, a factor R equal to 3, and an over-resistance factor of 2 for the connectors were recommended. Currently, a series of tests are under development to have a better representation of the loading cycles to resemble the true hysteretic behaviour of CLT panels and a proper estimation of energy dissipation mechanism between the panels and connectors.

**Fig. 3 – Manufacturing process of a radiata pine CLT panel showing a) a sample of sawn lumber used for the panel's layers; b) connections of sawn lumber (typical finger-joint); c) pressing of a layer, and d) final CLT panel.**

## 4. CLT Building Project in Chile

The design of a CLT building in Chile was only part of the project for the introduction of CLT as a building material in Chile. The following subsections provide some of the main aspects considered during the building's structural design process. The project considered the preparation of detailed guidelines for the design and calculation of CLT buildings in Chile that have been distributed to the Chilean professional community within this year.

### 4.1. Project Description

The main scope of this project was defined based on the indicators for social housing in Chile of the Ministry of Housing (Ministerio de Vivienda y Urbanismo in Spanish). The projected building has four floors with a height of 2.6 m each. The length, width and height of the building are 20.55 m, 7.05 m and 10.4 m, respectively, with floors, walls and beams made of CLT, with two apartments in each level (55 m2 per apartment). The staircase that provides access to the apartments is located in the middle. It was assumed that the building will be built on a typical soil type in the city of Santiago (equivalent to a Canadian code-based Site Class C). Fig. 6 shows a perspective view of the building, a typical elevation, and a first floor plan.

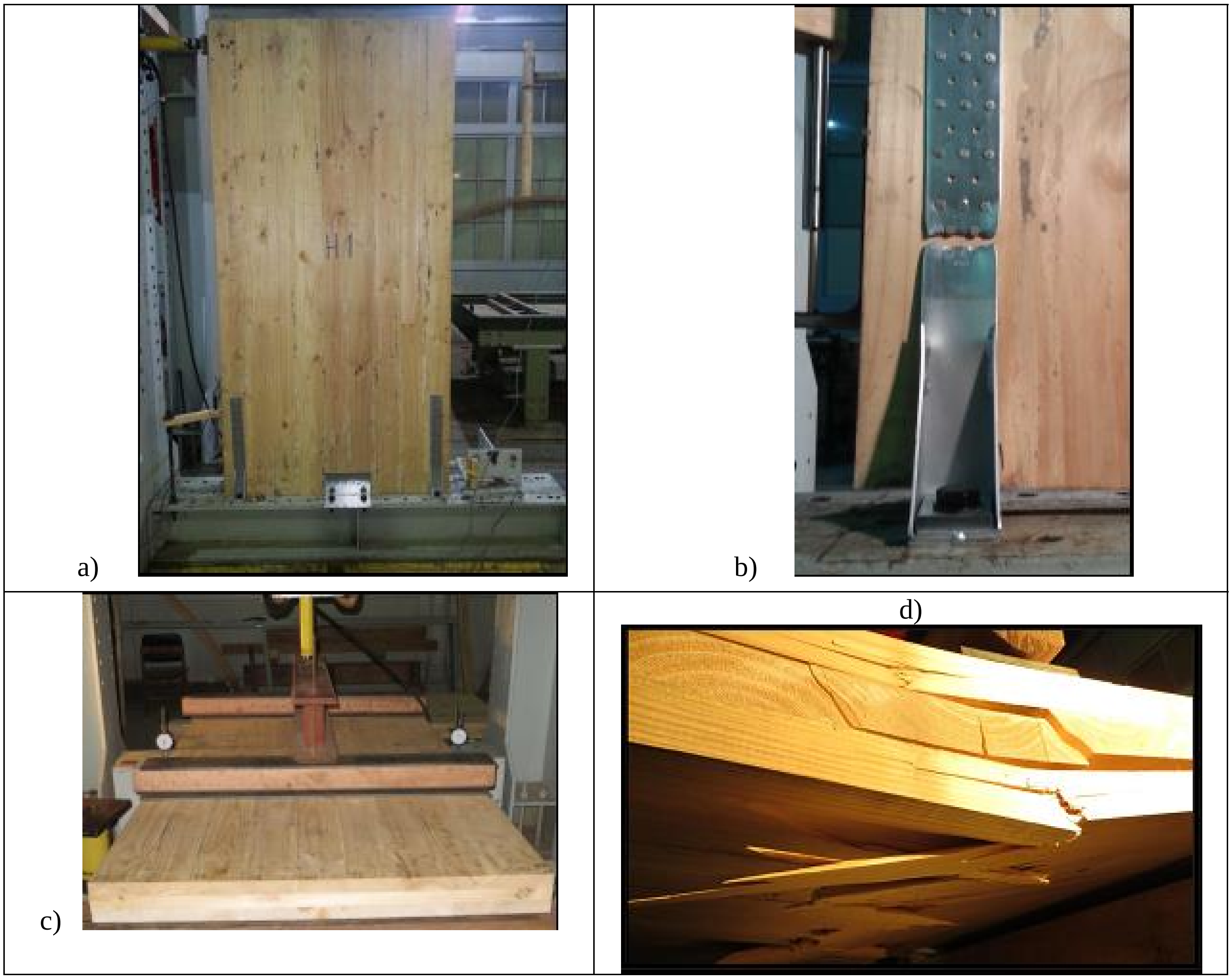


**Fig. 4 – CLT panels to be tested under vertical and horizontal loads according to the requirements of Chilean code NCh801 (1971), showing a) the original panel; b) failure of a connection during a test; c) applied load during the bending test; and c) typical out-of-plane failure.**

The project was designed mainly according to the limitations of the panel dimensions, their manufactured sizes and location of the main seismic resistance components. The idea of the design was to optimize the number of panels and windows, which in each floor change places, and to keep the same size of each module to optimize the manufacture of panels, achieving lower costs and speeding the assembly process.

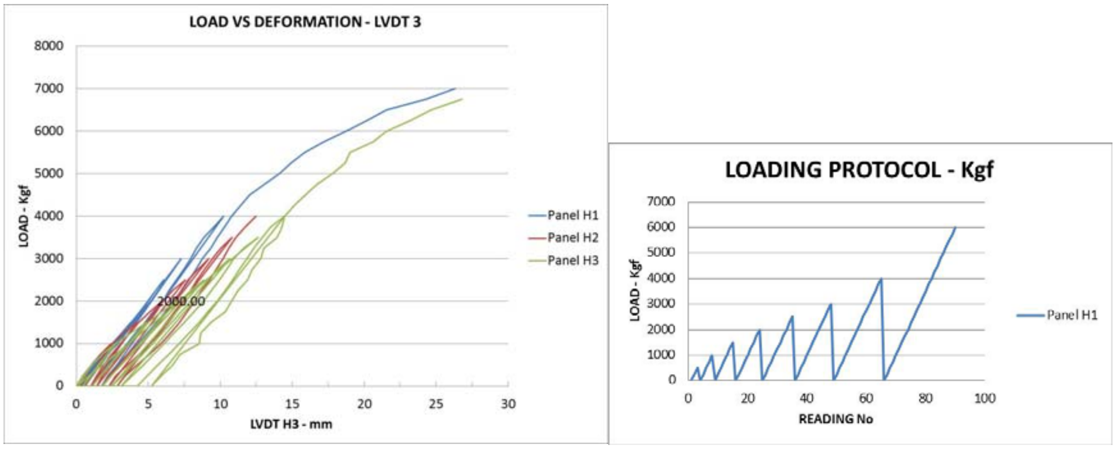


**Fig. 5 – Results of the lateral load loading and unloading test of three CLT panels.**

**Fig. 6 – Four story building based on CLT projected for social housing in Santiago, showing a) a perspective view; b) a typical elevation; and c) the floor plan of the first story.**

### 4.2. Structure and Modeling

The architectural project is based on partition walls made of CLT panels, representing the resistant structural axes of the building. The inertial forces are transferred from flexible diaphragms based on CLT floor panels to each vertical CLT panel through metallic connections. The inertial loads are transferred from walls to the concrete foundations through hold-downs and anchoring bolts.

The building's structure is modeled with linear elastic elements in floors and walls. Fig. 7 shows the 3D modeling, the elevation, and the floor plan of the structure of the four-story building. Several load cases with their corresponding load combinations are defined according to the requirements of the Chilean load combination code NCh3171 (2010). The seismic load was defined according to the requirements stablished by the Chilean seismic design building code NCh433 (2010). Table 2 summarizes the loads and load combinations used in the building´s structural analysis and design.

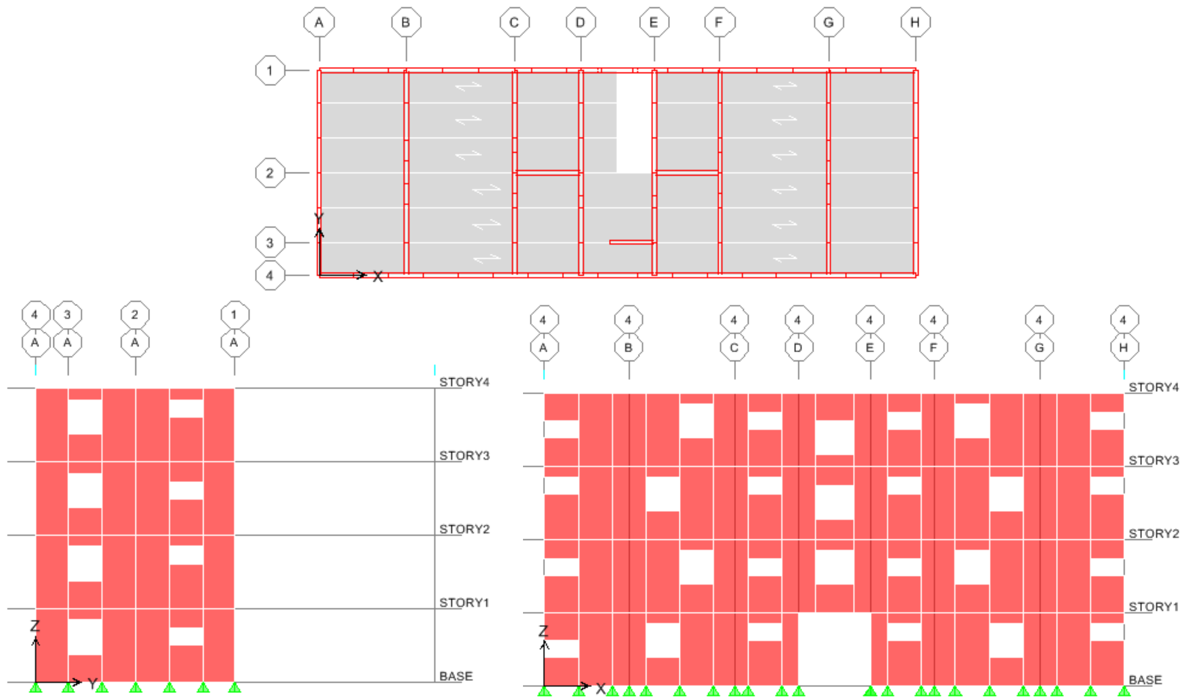


**Fig. 7. – Model of the structural system of the four-story building based on CLT panels projected in Santiago.**

The properties of the panels were based on recommendations coming from the North American and Canadian standards (ANSI/APA, 2012, and FP Innovations, 2013) calibrated to the values obtained from tests carried out on the CLT panels with radiata pine. Table 3 shows the properties used for the analysis and design of the structure of this building.

**Table 2. Summary of the loads used in the building's structural analysis and the corresponding load combinations according to the Chilean code for load combinations, NCh 3171 (2010).**

| | | | | Factors for Load Combinations | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Load** | | **Quantity** | **Units** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| Dead | D | 450 | kgf/m3 (density) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Live | L | 200 | kgf/m2 | | 1 | | 0.75 | | | 0.75 | 0.75 |
| Reduced Live | Lr | 100 | kgf/m2 | | | 1 | 0.75 | | | | |
| Wind | W | 70 | kgf/m2 (pressure) | | | | | 1 | | 0.75 | |
| Earthquake | E | 24 | % Seismic Weight | | | | | | 1 | | 0.75 |

## 4.3. CLT wall design

A detailed design was carried out for each panel with the minimum thickness requirements to resist the lateral loads in each floor. The panels were verified for the lateral shear and compression loads. A pre-dimensioning was defined based on the design data delivered by the manufacturers in Canada (see

Table 1) and then they were verified by design methods recommended by the Chilean code for testing NCh1198 (2006). The details of the final dimensions are given in Fig. 8a.

## 4.4. CLT floor design

All the floors were made of CLT panels. In this case the panels were designed to take the vertical loads (dead and live loads) and in-plane shear loads (diaphragm loads). Fig. 8b shows the assumed load distribution on the floor panels subject to lateral loads.

**Table 3. Mechanical properties of the CLT panels for the analysis and design of the four-story building (adapted from ANSI/APA, 2012)**

| | Direction with largest resistance (kgf/cm2) | | | | | | Direction with smallest resistance (kgf/cm2) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CLT Grados | $F_{b,0}$ | $E_0$ | $F_{t,0}$ | $F_{c,0}$ | $F_{v,0}$ | $F_{s,0}$ | $F_{b,90}$ | $E_{90}$ | $F_{t,90}$ | $F_{c,90}$ | $F_{v,90}$ | $F_{s,90}$ |
| E1 | 137 | 119,522 | 97 | 127 | 9 | 3.2 | 35 | 84,368 | 18 | 46 | 9 | 3.2 |
| E2 | 116 | 105,460 | 72 | 120 | 13 | 4.2 | 37 | 98,430 | 23 | 54 | 13 | 4.2 |
| E3 | 84 | 84,368 | 42 | 98 | 8 | 2.5 | 25 | 63,276 | 11 | 33 | 8 | 2.5 |
| E4 | 137 | 119,522 | 97 | 127 | 12 | 3.9 | 40 | 98,430 | 23 | 58 | 12 | 3.9 |
| V1 | 63 | 112,491 | 40 | 95 | 13 | 4.2 | 37 | 98,430 | 23 | 54 | 13 | 4.2 |
| V2 | 62 | 98,430 | 32 | 81 | 9 | 3.2 | 35 | 84,368 | 18 | 46 | 9 | 3.2 |
| V3 | 69 | 112,491 | 39 | 102 | 12 | 3.9 | 40 | 98,430 | 23 | 58 | 12 | 3.9 |

(a) Definition of Terms:
$F_{b,0}$: Bending allowable stress parallel to the fibre
$E_0$: Modulus of elasticity parallel to the fibre
$F_{t,0}$: Tensile allowable stress parallel to the fibre
$F_{c,0}$: Compression allowable stress parallel to the fibre
$F_{v,0}$: Flexural shear allowable stress parallel to the fibre
$F_{s,0}$: In-plane shear allowable stress
$F_{b,90}$: Bending allowable stress perpendicular to the fibre
$E_{90}$: Modulus of elasticity perpendicular to the fibre
$F_{t,90}$: Tensile allowable stress perpendicular to the fibre
$F_{c,90}$: Compression allowable stress perpendicular to the fibre
$F_{v,90}$: Flexural shear allowable stress perpendicular to the fibre
$F_{s,90}$: Out-of-plane shear allowable stress
(b) Tabulated values are for allowable stress design and shall not be modified by the size modification factor. These values should be used along with section properties provided by the CLT manufacturer.
(c) Use of values in Section 7.2.1 of PRG 320 CLT can be also adopted for different grades.

## 4.5. Connections design

The design of the connectors was carried out using the loads obtained from the structural analysis and the strength defined by the manufacturer. Ductile connectors were assigned at the bottom of the vertical panels. Other connectors, such as those from panel to panel, were considered as having a brittle behavior and were amplified by an over-resistance factor. Some examples of connections are shown in Fig. 9.

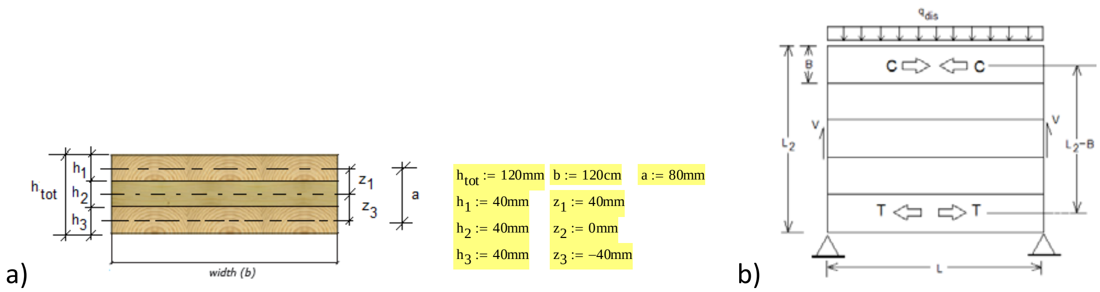


**Fig. 8: a) Dimensions of the CLT panels used for the building's walls and floors; and b) distribution of the loads on the floor panels (diaphragms).**

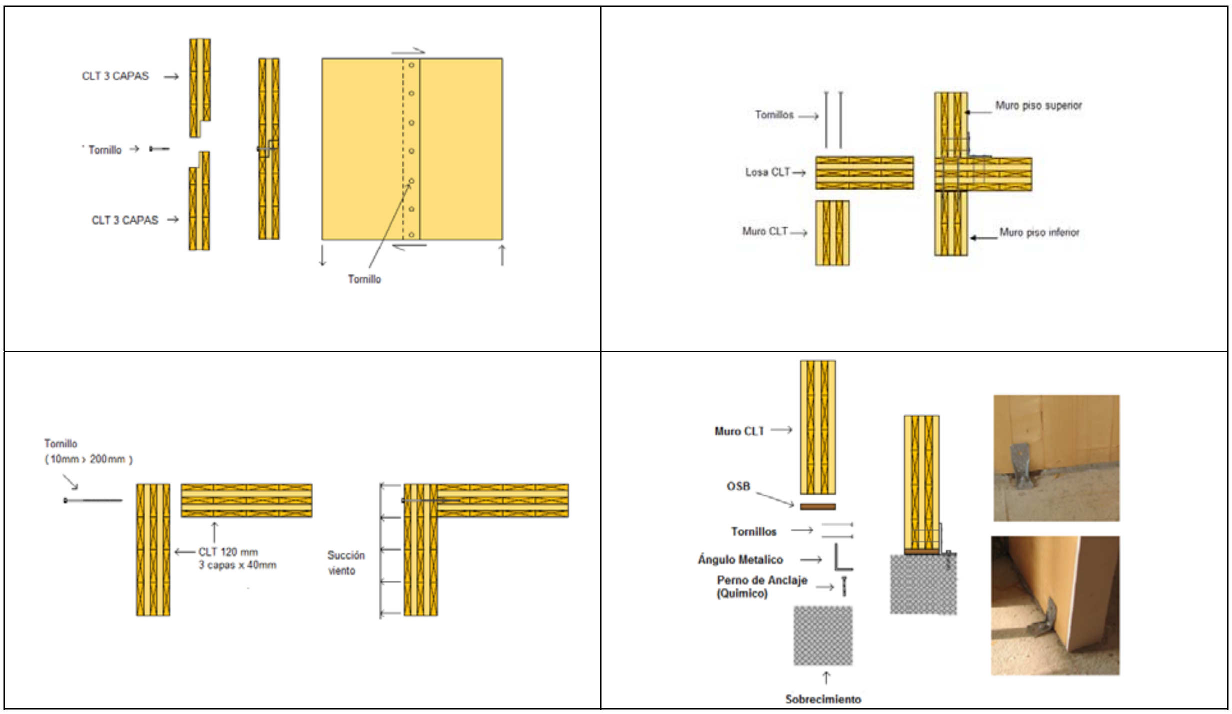


**Fig. 9 – Examples of connections adopted in the design of CLT panels showing the connection between a) vertical panels; b) perpendicular panels (corners); c) horizontal and vertical panels; and d) vertical panels and the foundations.**

## 5. Final Comments

This document presents details of the technical part of a research and development project that introduced the CLT for buildings in Chile using local radiate pine. The results from the manufacturing and testing of CLT panels in Chile were used to design a four-story building for social housing in Santiago

This project pioneers the manufacture and testing of CLT panels and their use in the design of wood buildings in Chile. It falls within the framework and limitations of Chilean national codes and includes design recommendations along with mechanical properties adopted from North American codes. The structure of buildings was based on CLT floors and walls and allowed a design within the limitations of the Chilean national standards.

Some mechanical properties of CLT as well as of the connections were taken from the data recommended by foreign standards. However, the project considers future stages to study more deeply the properties of CLT manufactured with local timber, as well as the testing of a larger number of connectors.

CLT turned out to be feasible for use in housing building projects in Chile, presenting great advantages from the standpoint of livability, construction process, and use of modular solutions.

Several other results produced by this project, such as fire resistance, testing of connections, manufacturing details, and economic feasibility studies, will be presented in other documents during this year.

## 6. Acknowledgements

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