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EXPERIMENTAL STUDY OF WALL JOINTS IN CROSS LAMINATED TIMBER PANELS THROUGH CYCLIC TESTS

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Abstract

Cross Laminated Timber (CLT) is one of the most emblematic and sustainable by-product from wood for the construction of mid-rise buildings. It has gained main relevance in industrialized countries in Europe, North America, Australia, and New Zealand during the last twenty years. Chile has plenty of forest resources, particularly in radiata pine, and a high housing deficit, so introducing CLT seems to be an interesting alternative for building construction. Further, Chile is located in one of the world's most active seismic region, and so, it becomes necessary to understand the dynamic behaviour of buildings structured with CLT. In the present study, cyclic tests performed in joints of CLT panels produced with radiata pine grown in Chile are presented, with the aim of determining the dynamic properties of the joint, as well as its energy dissipation capacity, among other properties. Three wall-wall joint configurations of 5-plies CLT panels were considered: vertical in the same plane (P), vertical in the perpendicular plane (T), and vertical in corners (L). The three test samples, with identical measures and characteristics, were tested following the procedure described in European code DIN EN 12512 and adapted to the laboratory conditions. Each joint is done with 5 steel screws placed in a zig-zag way. In the case of joint in the same plane (P), two kind of connectors were considered, steel screws and straps; 5 steel screws were placed in a zig-zag way and straps were placed to achieve the horizontal and 45º pattern; three samples were tested in each situation. Mode of failures of each tested joint is analysed, and their maximum resistance capacity is reported. From the test results, equivalent viscous damping and reference ductility are determined, parameters which represent energy dissipation capacity of the configurations. These values are compared with those that were obtained in similar tests previously done using 3-ply CLT samples to determine the influence of CLT panels' thickness in the dynamic behaviour of wall-wall joints.

Keywords: cross laminated timber, cyclic test, equivalent viscous damping, hysteretic behaviour.

1. Introduction

The use of Cross Laminated panels (CLT or XLAM) in building has acquired most relevance in developed countries in Europe, North America and Oceania during the last twenty years, especially in mide-rise buildings. This increase is due to the important advantages shown by this building system with respect to traditional systems, such as execution speed, cleanliness in working place, and reduction in carbon footprint which is implicit in wood [1, 2, 3]. Considering that Chile has plenty of forest resources and housing lack over 700.000 houses, lack which concerns over two million people [4], it results convenient to introduce building system with CLT as an alternative of sustainable building for mid-rise buildings [2,3]. Due to the high seismicity which affects Chile, it is essential to characterise dynamic behavior of buildings structured with CLT to generate the necessary standards which may allow the increase of use of this building system in the professional Chilean community.
Then, in the present study, it is analysed the hysteretic behaviour of joints in cross laminated timber panels materialised through metal connectors. Cyclic tests are realised in wall type samples made of five layers with the aim to determine dynamic properties of vertical joints of wall encounters. Three types of joints are considered, on its own plain (P), in the corner (in L) and perpendicular (in T). Tests are realised at the laboratory of the Pontificia Universidad Catolica de Valparaiso, which has the necessary equipment for them. Procedure of European code DIN EN 12512 [5] is used to do these studies. Laboratory equipment is described in detail, in references [6,7].

This work corresponds to the continuation of series of studies which the investigation team has been working during the last ten years [2,3, 8, 9, 10] whose aim is to generate technical record necessary to introduce the building system CLT in Chile.

2. Methodology

2.1 Code used: DIN EN 12512:2001

The objective of regulations in this code is to determine the performance of structural wooden elements and their fixing elements when subdued to a cyclic load. The resistance and behaviour of wooden structures depend mainly of fixing elements. In this code there are also stablished methods to determine ductility, resistance damage, dissipation, potential energy and equivalent viscous damping of the structural elements [5].

2.1.2 Static Tests

Yield deformation of each type of joint is determined by means of a procedure stablished by code DIN EN 12512. This procedure contemplates applying load until test sample fails. With the results gotten in this static test, curve load vs deformation is done, from which it is determined the yield point. Then, with this result maximum displacement values of load cycles are determined, which must be applied to the joint in reference to determine its dynamic properties [5].

2.1.3 Cyclic Tests

Load cycles are defined from yield deformation determined in the static test. In Fig. 1 it is shown the protocol of load in the cyclic test, which consists in a cycles series which are subdivided in groups of three of the same deformation amplitude, it must be generated in the test sample. Maximum amplitude of cycles is defined in function to yield deformation determined in the static test of test samples with the same characteristics that are subdued at the cyclic test. Maximum deformation allowed in the load protocol is 30 mm or test sample failure [5].

Finally, with the results of load and deformation gotten in the cyclic test hysteresis curves are gotten.

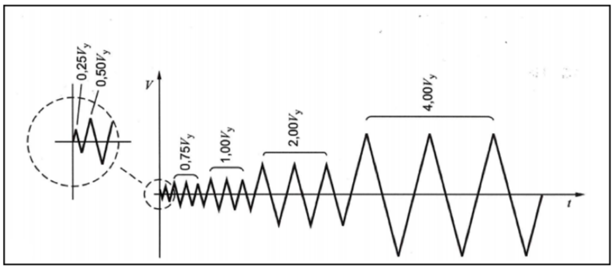


Fig. 1 –Cyclic Load Protocol [5]

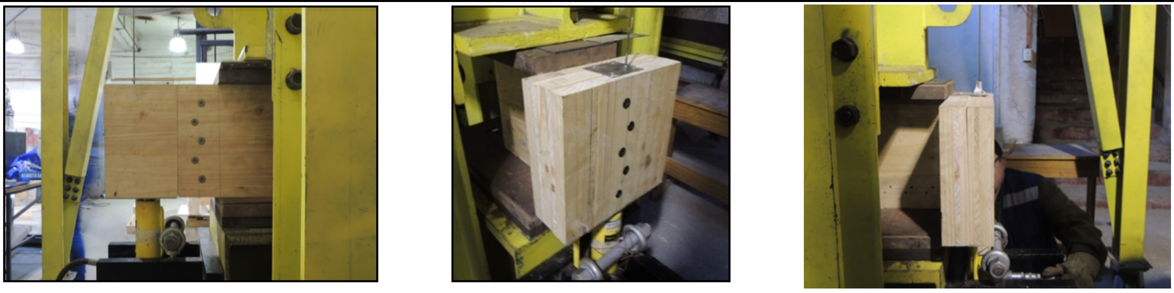
2.2 Manufacturing Test Samples

Manufacturing cross laminated wood test samples is done with Radiata pine pieces grown in Chile, with 12% average humidity content, visually classified G2 grade, according to Chilean code NCh 1207 [11], and mechanically in grades C24 y C16 according to European rule BS EN – 519:1995. Both CLT pieces, of 110x240x300 mm, that make the test samples have five plies, two to the outside and the one in the middle of 30 mm thickness, with the wood´s fibre in a longitudinal direction, two intermediate plies of 10 mm thickness with wood’s fibre across, as shown in Fig. 2.

Fig. 2 – Five plies CLT elements [6]

2.3 Assembly

In Fig. 3 it is shown assembly done for static tests of the three configurations of joints in wall encounters which are contemplated in this study. In Fig. 4 it is shown the assembly used for cyclic tests of wall joints on its own plain, that is similar for the three cases which are analysed in the present study. In Fig. 5 it is shown a diagram of the used assembly in cyclic tests of the three configurations of joints in wall encounters, which are: walls on its own plain (P), perpendicular walls (T) and corner walls (L).



(a) (b) (c)

Fig. 3 – Assembly for static tests: (a) joint P, (b) joint T, (c) joint L [6]

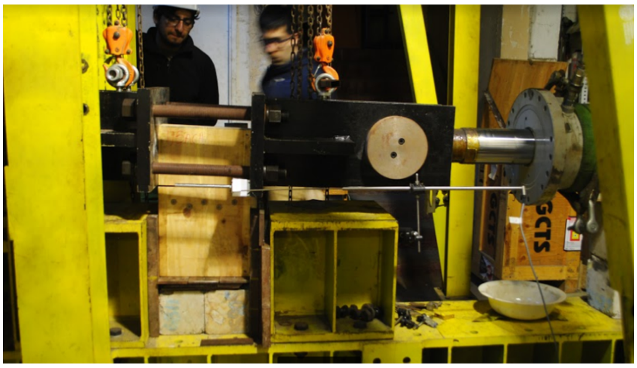
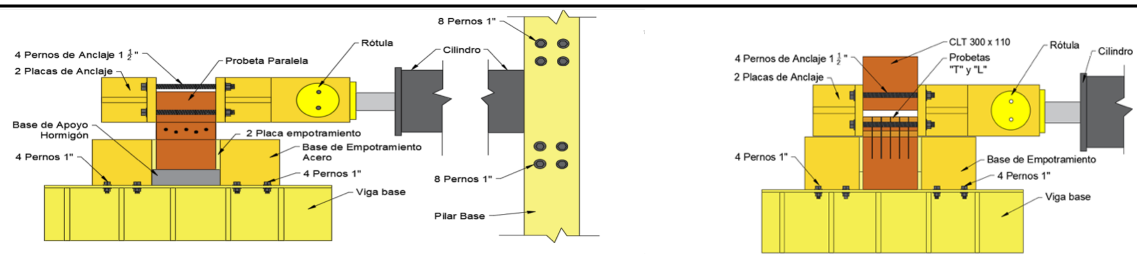


Fig. 4 –Assembly for cyclic tests of wall joints on its own plain (P) [6]



(a) (b)

Fig. 5 –Assembly diagram for cyclic tests: (a) joint P, (b) joints T y L [6]

To materialise the joint in each test sample, 5 steel screws are used, separated in vertical direction of the wall in 5 cm and 1.6 cm in the horizontal direction to comply requirements of code NCh 1198 [12] and of the catalogue supplied by the company Simpson Strong-Tie [13]. With the objective to make easier the fulfilment of cyclic tests the joint axis is placed in the horizontal direction. For the joint of walls on the plain galvanised screws SDWH19400 DB of 4” hexagonal head are used and for perpendicular joints in L and in T, SDWS22900, 9” plain head are used. Screws, which were donated by the company Simpson Strong-Tie, are shown in Fig. 6.

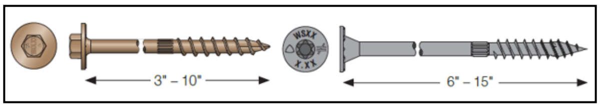


Fig. 6 – Screws SDWH y SDWS [13]

In Fig. 7 assembly of test samples of joints in walls on their own plain for static and cyclic tests is shown, with straps as joint elements. MSTA12 straps are used and galvanised nails N10 DHDG of 1 ½", donated by the company Simpson Strong-Tie.

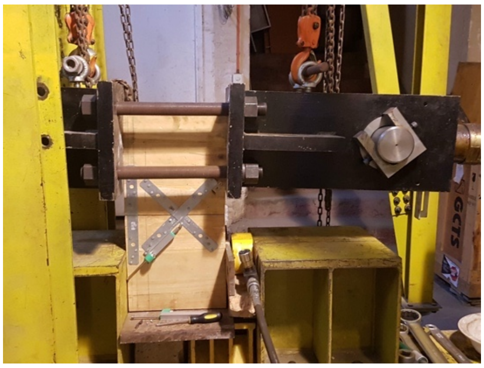


Fig. 7 –Assembly for joint tests of walls in their plain with straps [7]

3. Test results in five plies panels

Results gotten from static and cyclic tests done are shown, for each configuration of panels joint made with five plies.

3.1 Static Tests

According to dispositions in code DIN EN 12512, a static test for each kind of joint is done. In Table 1 it is shown, a summary of results gotten in each of the configurations of wall joints contemplated in the study. Including maximum deformation (Δu), the maximum strength (Fm), the yield deformation (Δy), strength of yield (Fy) and the ductility (D).

Table 1 – Results of 5-plies CLT samples static testing [6, 7]

Kind of joint	Δu mm	Fm KN	Δy mm	Fy KN	D
P (screws)	56.0	35.0	4.9	17.2	11.4
P (straps)	61.6	31,2	15.4	27.3	4.0
T	70.0	46.0	10.1	38.2	6.9
L	46.0	41.0	5.4	27.7	8.5

3.2 Cyclic tests

With the values of strength and deformation gotten in the cyclic tests, hysteresis curves are done for each test sample which are shown in Figures 8 a 11. Three repetitions for each kind of joint are done.

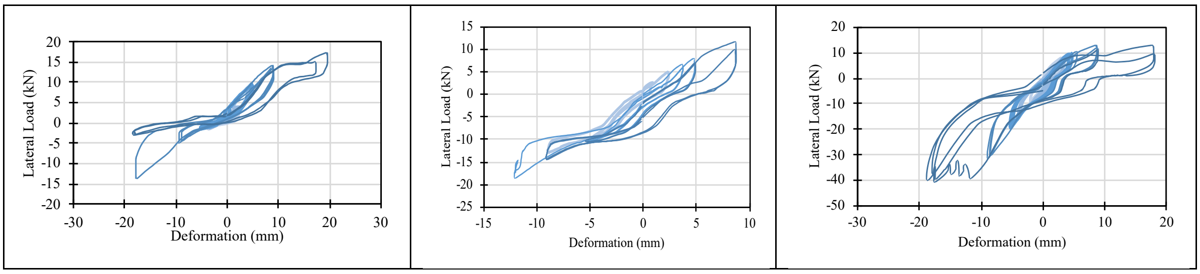


Fig. 8 –Hysteresis curves of wall joint in parallel (P) with screws [6]

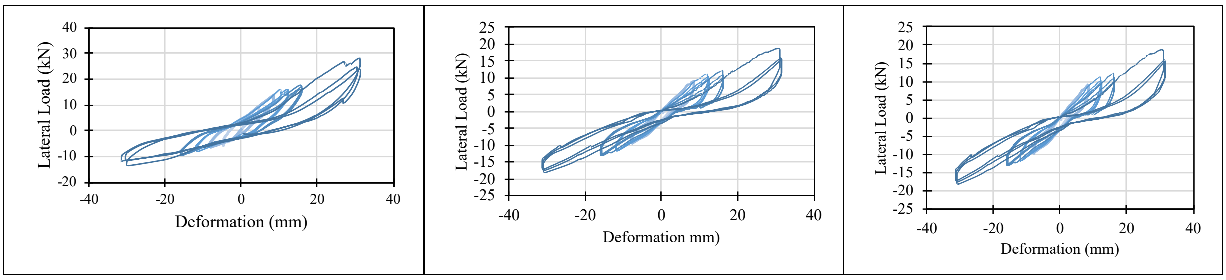


Fig. 9 –Hysteresis curves of wall joint in parallel (P) with straps [7]

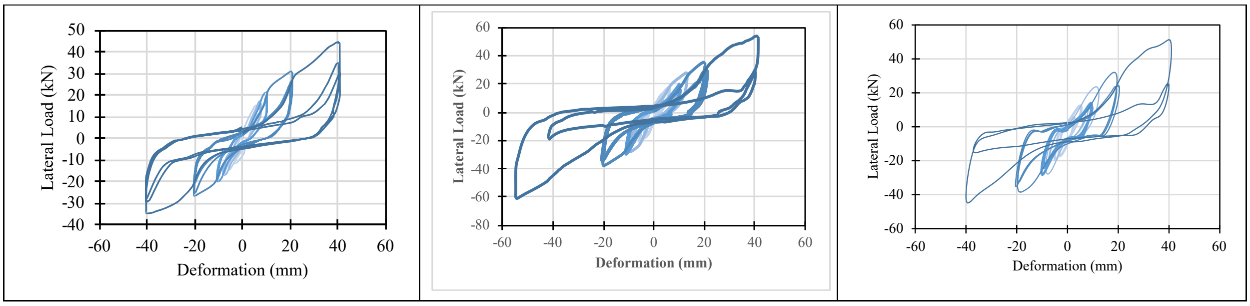


Fig. 10 – Hysteresis curves of wall joint in T [6]

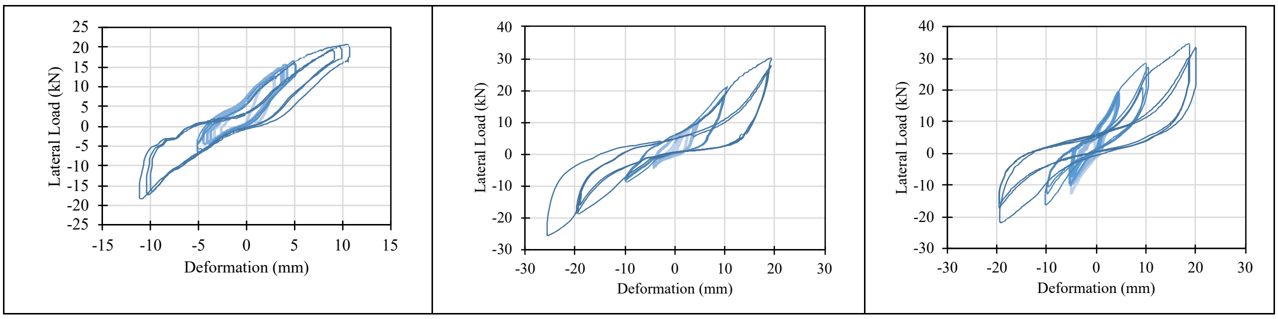


Fig. 11 – Hysteresis curves of wall joint in L [6]

Equivalent viscous damping is determined for each test sample using the information for each test sample gotten from the hysteresis curve. In Eq. (1) it is shown the relation between equivalent viscous damping and parameters of that curve.

$$\zeta_{eq} = \left(\frac{1}{2\pi}\right)\left(\frac{\Delta W}{W}\right) \quad (1)$$

Where: ζ_{eq} = equivalent viscous damping, W = work done in a cycle load-unload and ΔW = dissipated energy.

In Table 2 it is shown a summary of the average results gotten in cyclic tests for each configuration.

Table 2 – Average results of 5-ply CLT samples cyclic testing [6,7]

Item	Joint P (screws)	Joint P (straps)	Joint T	Joint L
Maximum lateral load (kN)	24,1	22,7	49,5	28,4
Max. lateral displacement (mm)	19,4	31,6	41,2	19,4
Total dissipated energy (kJ)	1.2	1,9	7.7	1.4
Equivalent viscous damping (%)	12.1	11,1	16.1	14.6

4. Previous results in three plies panels

In Table 3 results of static tests gotten in test samples of three plies with the same thickness, wall joints are shown, made of two CLT elements of 110x240x300 mm. Tests were done for the same configuration analysed in the present study, exception is the joint in the same plain, for which, only screws were used.

Table 3 – Average results of 3-plies CLT samples static testing [3,10, 14]

Kind of joint	Δu mm	Fm KN	Δy mm	Fy KN	D -
P (screws)	49.6	44,2	7.2	17.6	6.9
T	125.3	33,9	4.6	20.3	27.2
L	143.5	43,0	2.8	12.5	52.3

Results of cyclic tests done in three plies CLT test samples are included in Table 4.

Table 4 – Average results of 3-plies CLT samples cyclic testing [3,10, 14]

Item	Joint P (screws)	Joint T	Joint L
Maximum lateral load (kN)	34,5	44,2	40,8
Max. lateral displacement (mm)	30,6	38,3	35,3
Total dissipated energy (kJ)	3,8	8,4	7,0
Equivalent viscous damping (%)	15,7	13,3	11,3

5. Results Analysis

5.1 Static Tests

Results of static tests, shown in Tables 1 and 3, allow us to work out what is indicated.

5.1.1 Joint in the same plain of wall (P)

For this kind of joint, it is found that maximum deformation is produced in the case of the joint with straps in five plies panels and that the minor maximum deformation is shown in joints with screws in three plies panels. The major yield deformation is produced in the joint with straps in five plies panels and the minor occurs in the joint with screws in five plies panels. The joint in five plies panels with screws is the one that shows the major ductility and the minor for this same panel format but with straps as joint elements. This is explained because the joint with straps shows higher values for maximum deformation as for yield deformation.

The major yield strength is produced in the joint with straps in five plies panels. In the cases of joints with screws, yield strength is of similar values for three and five plies panels. Maximum strength that resists this kind of joint is greater for the case of three plies panels joined with screws and the minor for the case of joint in five plies panels with straps.

5.1.2 Joint of perpendicular walls (T)

For this kind of joint materialised with screws, it is found that the major maximum deformation is produced in three plies test samples and that in this same test sample minor yield deformation is produced. So, this test sample is the one that shows the major ductility.

In what refers to strengths, it is found that the three plies test sample is the one that resists the minor maximum strength and it is the one that shows the minor yield strength.

Results gotten in this kind of joint are explained because in the case of three plies test samples, the screws penetrate in parallel direction to the fibres of the wood of one of the pieces from which the test samples are made of.

5.1.3 Corner wall joints (L)

For this kind of joint done with screws, a similar behaviour to the joint in T is observed in what refers to deformations and to the yield strength. The value of the maximum strength that resists the joint is similar for both panel formats, three and five plies, being slightly higher for the three plies test sample.

5.2 Cyclic tests

Average results of cyclic tests, which are shown in Tables 2 and 4, allow to deduce what is indicated.

5.2.1 Joint of wall in the same plain (P)

For this kind of joint, it is found that the major maximum strength, the major total dissipated energy and the major value for equivalent viscous damping is produced in the case of joint with screws in three plies panels. The minor average value of total dissipated energy is produced in five plies test samples connected with screws. Maximum average deformation has a similar value for the cases of joints with screws in three plies panels and of joints with straps in five plies panels, being slightly higher for five plies test samples joined with straps. The minor maximum average deformation is shown in five plies test samples joined with screws.

The average maximum values of strength and of equivalent viscous damping are similar for five plies test samples, for both kind of connection elements, screws and straps, being slightly superior for the joint with screws.

5.2.2 Joint of perpendicular walls (T)

In this kind of joint materialised with screws it is found that the major maximum strength, the major maximum deformation and the major equivalent viscous damping value is produced in five plies test samples. But, the total dissipated energy is slightly minor in these five plies test samples with respect to the three plies test samples.

5.2.3 Corner walls joint (L)

For this kind of joint made with screws, it is observed a different behavior to the joint in T. In effect, the major maximum average strength and the major maximum average deformation are shown in the three plies test samples. But, equivalent viscous damping is major for five plies test samples. The average total dissipated energy in three plies test samples is highly superior to that shown in five plies test samples.

6. Conclusions

Results gotten, allow to conclude, that the joints which show the highest values in ductility correspond to joints in three plies perpendicular walls, being major for corner joints. What refers to the energy dissipation capacity, it is also found that the joint in perpendicular walls show major values, with the exception of five plies corner joints test samples. These last test samples, as well as the five plies test samples with joints of walls in the same plain are the ones which show minor total dissipated energy values.

The equivalent viscous damping gotten in the cyclic test, in samples with vertical joints of CLT walls of three and five plies, manufactured with Radiata pine, has values between 11,3% and 16,1%.The minor value is generated in corner joint (L) in three plies panels and the major in perpendicular joint (T) in five plies panels. These values are found in the rank of those reported in literature on the subject [1,15].

Then, based on the results gotten in this work and those gotten by other authors, it is possible to conclude that equivalent viscous damping of vertical joints in CLT walls do not depend on the quantity of CLT panel's plies nor the wooden species.

7. Acknowledgements

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