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SOFIE PROJECT - TEST RESULTS ON THE LATERAL RESISTANCE OF CROSS-LAMINATED WOODEN PANELS

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SUMMARY

The SOFIE Project is a cooperative research project patronised by the Trento Province, Italy and coordinated and conducted by the CNR-IVALSA (Italian National Research Council – Trees and Timber Institute).
The main purpose of this project is to analyse a multi-storey building built with solid wooden panels with cross interlayers considering every single aspect of the building behaviour such as static, fire, acoustic, thermal and, particularly, seismic performance.
In this paper, results from tests on the lateral resistance of cross-laminated wooden panels are presented. Different configurations of wall panels are investigated by means of ramp and cyclic displacement schedules taking into account the influence of the anchoring system, the opening layout and the inter-storey connection.

1. INTRODUCTION

Throughout Europe, timber buildings with various constructive systems are becoming day by day a stronger and economically valid alternative to their counteracts built with concrete and masonry. Even in Italy, where until now timber structures had been less common within the residential housing market, their diffusion is increasing.

Figure 1: Cross-laminated wooden panel

Buildings made of cross-laminated wooden panels are gaining a broader acceptance even in seismic prone zones like the majority of the Italian territory. However, in Eurocode 8, the European seismic code for earthquake resistance of buildings, no recommendations are given regarding this constructive system. Neither for

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construction details nor for the seismic behaviour factor to be used in seismic design of this new typology of wooden buildings any information can be found.

The goal of the seismic part of this research project is to undertake a comprehensive investigation in order to obtain information on the overall seismic behaviour of multi-storey buildings made of cross-laminated wooden panels. This will be achieved undertaking ramp and cyclic tests on full-size wall specimens with different configurations. Contemporarily, the data obtained from tests will be implemented in a 3D non-linear model in order to obtain information by means of dynamic analysis under real earthquake excitations. Finally, a full-scale shaking table test will be performed on a three-story building at the NIED laboratory in Tsukuba, Japan, in June 2006.

In this paper, only results of the first part, i.e. results obtained from static monotonic and reversed cyclic tests on full-size wall specimens, are presented.

2. CONSTRUCTION SYSTEM, TEST LAYOUT AND PROCEDURE

2.1 Construction System

A timber building made of cross-laminated wooden wall and floor panels is a modular system where all panels (e. g. walls with openings and floor slabs) are pre-cut in the factory using the advantages of CNC-machines. On site, the single modules are then assembled connecting the panels with mechanical fasteners; mainly angle brackets with nails and/or screws. Afterwards, the interior and exterior finishing, i.e. insulation and plumbing, is carried out.

The cross-laminated panels have an overall behaviour of a massive wooden panel; they are very stiff and strong. A ramp test carried out to establish the performance of the material itself has confirmed this statement. This system is hence a very rigid system with much less energy dissipation and ductility characteristics in comparison to other conventional wood-frame constructions such as those built with the platform frame system. The energy dissipation and ductility is only occurring due to the connections concentred in few zones.

Therefore, all tests were designed in order to evaluate the behaviour of this type of construction for different connection layouts during seismic loading. Depending on the connections, a higher or lower ductility of the entire system can be achieved.

All the tests performed are representative for structural components of a three-storey house which will be the subject of a further shaking table test in Japan in June 2006.

2.2 Test Layout

All tests have been undertaken on a 2.95m wide and 2.95m high wooden panels with cross interlayers (see Fig. 1 for material). All panels have 5 layers of 17mm thickness each resulting in a panel thickness of 85mm – which is a standard panel for wall elements of 2-3 storey buildings.

All the wall specimens have been anchored using commercial anchorage systems (holdown and steel angle anchors) and only in a few cases home-made holdown anchors were used in order to obtain a higher strength.

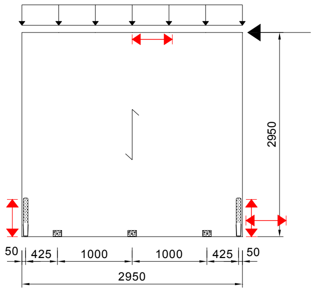
Till now, four different configurations have been tested as can be seen in Table 1 below.

Table 1: Tested wall configurations

Configuration A

Panel dimension: 2.95m by 2.95m without opening

Connection type: Connection to base with three BMF angles 90x48x3.0x116 and two holdowns
Holdown anchors in the first test *1* (see Table 2) has been "home made". The tests *2* and *3* have been carried out with a standard holdown HTT22 by SIMPSON BMF.
Annular ringed shank nails 4x60 are used to fasten the steel connectors to the panel. The quantity of nails between tests *2* and *3* has been changed in order to control failure occurring either in the holdown anchors or in the nail connection.
All other connections (upper connection to steel beam and connection to steel base) are designed to be very strong such that they are allowing for any slip.

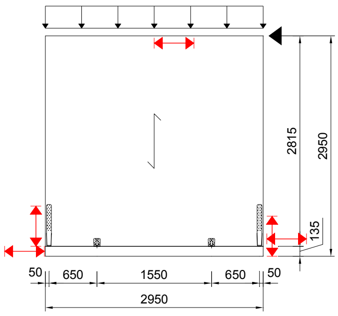


Vertical load: 18.5kN/m (based on the 1st storey wall of a real three storey building)

Configuration B

Panel dimension: 2.95m by 2.95m without opening; included a floor slab of 135mm underneath the wall panel

Connection type: Inter-storey connection (floor to upper wall) with two BMF angles 105 with reinforcement and two standard holdowns HTT22 by SIMPSON BMF
Annular ringed shank nails 4x60 are used to fasten the steel connectors to the panel. As in the test *1* the nails fixing the steel angle to the floor slab were pulled out, two additional screws were used in test *2*.
All other connections (upper connection to steel beam and floor slab connection to steel base) are designed to be very strong such that they are not allowing for any slip.

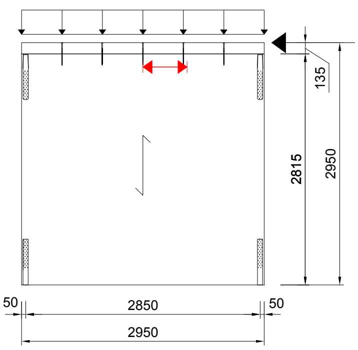


Vertical load: 10.2kN/m (based on the 2nd storey wall of a real three storey building)

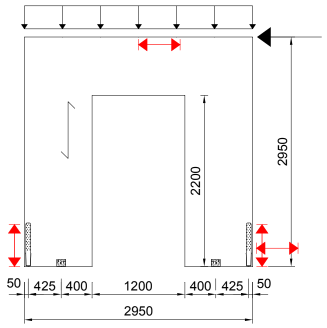
Configuration C

Panel dimension: 2.95m by 2.95m without opening; included a floor slab of 135mm on top of the wall panel

Connection type: Inter-storey connection (floor to lower wall) with inclined screws 8x260 and two standard holdowns HTT22 by SIMPSON BMF
Annular ringed shank nails 4x60 are used to fasten the holdown to the panel. It must be stated though that in this test configuration with the floor slab being on top of the wall, no uplift forces are occurring. Only the shear connection was tested.
The base connection and the connection of the floor slab to the upper steel beam are designed to be very strong such that they are not allowing for any slip.



Vertical load: 18.5kN/m (based on the 1st storey wall of a real three storey building)

	Configuration D
Panel dimension:	2.95m by 2.95m with a 1.20m or 1.80m by 2.20m central door opening
Connection type: 	Connection to base with two BMF angles 90x48x3.0x116 and two standard holdowns HTT22 by SIMPSON BMF Annular ringed shank nails 4x60 are used to fasten the steel connectors to the panel. All other connections (upper connection to steel beam and connection to steel base) are designed to be very strong such that they are not allowing for any slip.
Vertical load:	18.5kN/m (based on the 1st storey wall of a real three storey building)

The following table 2 is summarising the test carried out. A total of 14 tests were carried out under monotonic and reversed cyclic loads.

Table 2: Tests carried out

CASE	Subcase	Connections		Vertical load [kN/m]	Opening size [mxm]	Test protocol
		uplift	shear			
A	1a	Homemade with 29 nails	BMF 07716 with 11 nails	18.5	-	monotonic
	1b	Homemade with 29 nails	BMF 07716 with 11 nails	18.5	-	cyclic
	2a	BMF HTT22 with 29 nails	BMF 07716 with 11 nails	18.5	-	monotonic
	2b	BMF HTT22 with 29 nails	BMF 07716 with 11 nails	18.5	-	cyclic
	3a	BMF HTT22 with 14 nails	BMF 07716 with 11 nails	18.5	-	monotonic
	3b	BMF HTT22 with 14 nails	BMF 07716 with 11 nails	18.5	-	cyclic
B	1a	BMF HTT22 with 14 nails	BMF 7105 with 8+8 nails	10.2	-	monotonic
	1b	BMF HTT22 with 14 nails	BMF 7105 with 8+8 nails	10.2	-	cyclic
	2a	BMF HTT22 with 14 nails	BMF 7105 with 8+8 nails and 2 screws 8x140	10.2	-	monotonic
	2b	BMF HTT22 with 14 nails	BMF 7105 with 8+8 nails and 2 screws 8x140	10.2	-	cyclic
C	1a	BMF HTT22 with 14 nails	Inclined screws 8x260	18.5	-	monotonic
	1b	BMF HTT22 with 14 nails	Inclined screws 8x260	18.5	-	cyclic
D	1b	BMF HTT22 with 14 nails	BMF 07716 with 16 nails	18.5	1.2x2.2	cyclic
	2a	BMF HTT22 with 14 nails	BMF 07716 with 16 nails	18.5	1.8x2.2	monotonic

(later reference to tests is as follows.: A/1b = configuration A, test 1b)

2.3 Test Procedure

Figure 2 shows the test set-up with the actuator used to undertake ramp and cyclic testing.

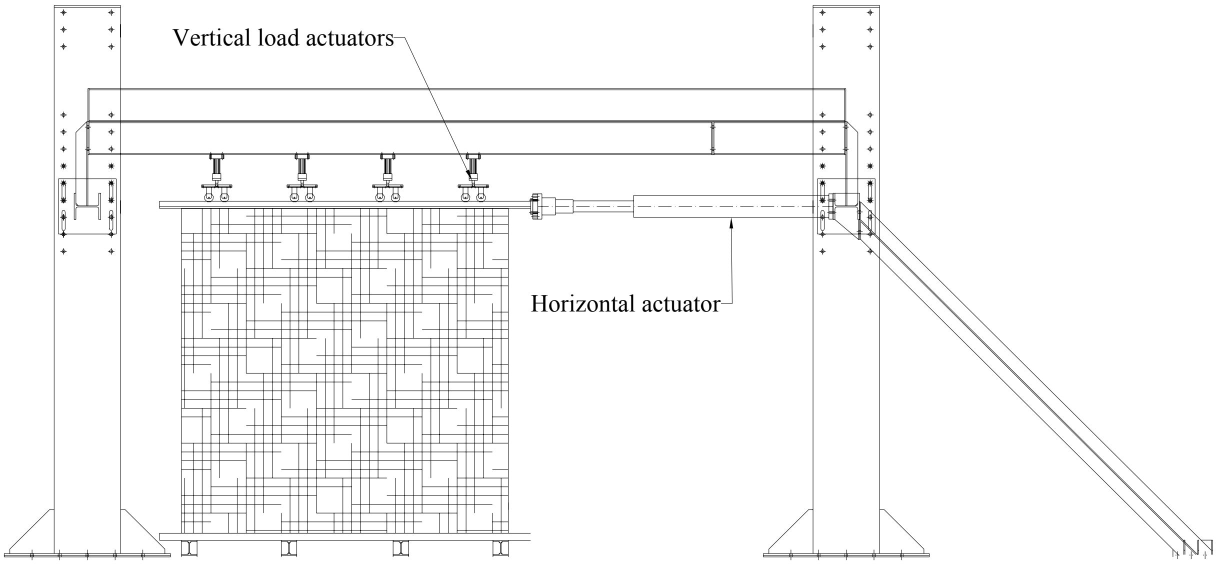


Figure 2: Test Set-up. For sake of simplicity upper stabilizing transverse steel beams are not reported.

The ramp monotonic tests were performed according to EN26891 "*Timber structures – Joints made with mechanical fasteners – General principles for the determination for strength and deformation characteristics*" in displacement control at a rate of 0.04 mm/s. EN26891 is applied with a constant displacement control and not under load control as required in the document.

The reversed cyclic tests were performed according to EN12512 "*Timber structures – Test methods – Cyclic testing of joints made with mechanical fasteners*" in displacement control at a rate of 0.04 mm/s.

The following Figures 3 and 4 show the test protocols.

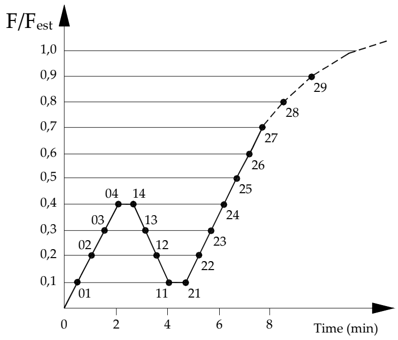


Figure 3: Test Protocol EN26891 [1]

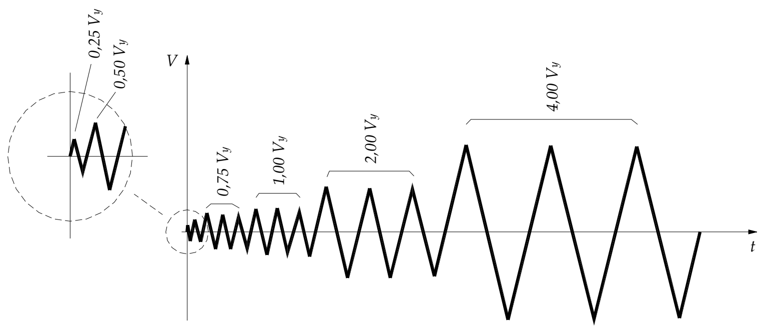


Figure 4: Test Protocol EN12512 [2]

3. OUTCOMES

The following figures show the test results in terms of load-slip curves. The displacement shown is the displacement of the actuator and not the displacement of the transducers. The displacement has been cleaned from any other error as relative slip between wall specimen with connections to be tested and the test stand.

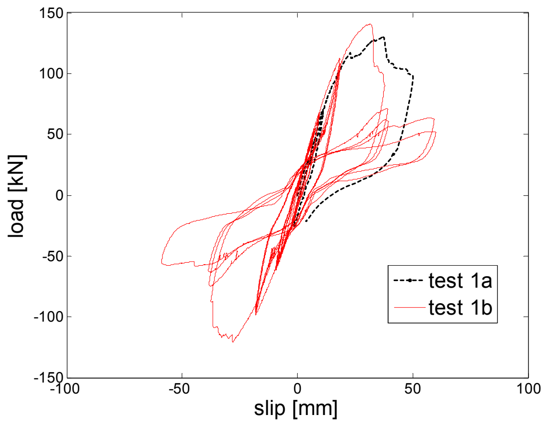


Figure 5: Configuration A, ramp and cyclic test 1

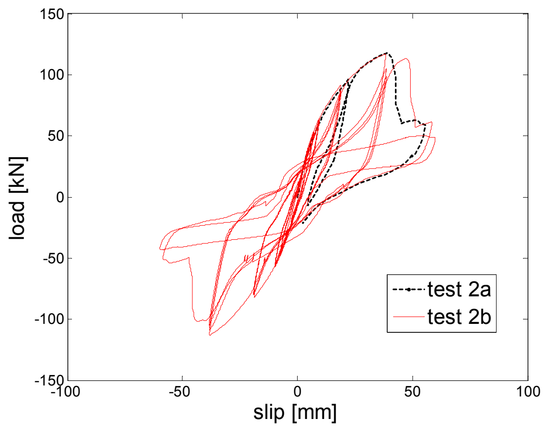


Figure 6: Configuration A, ramp and cyclic test 2

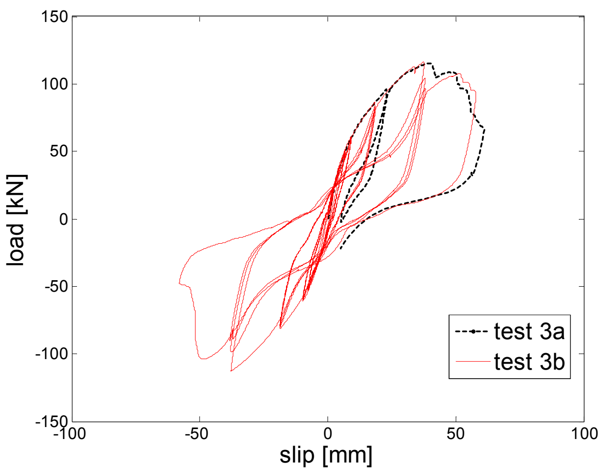


Figure 7: Configuration A, ramp and cyclic test 3

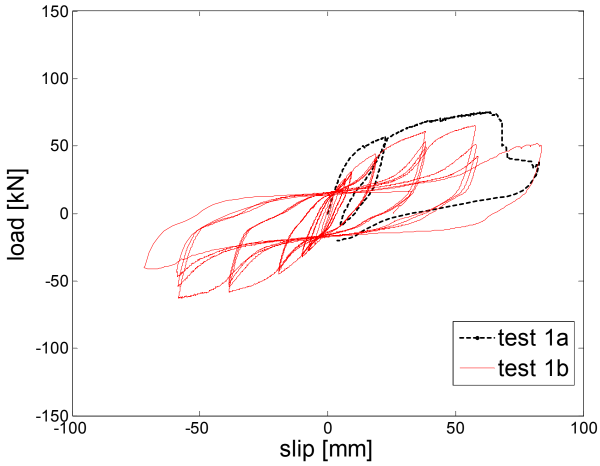


Figure 8: Configuration B, ramp and cyclic test 1

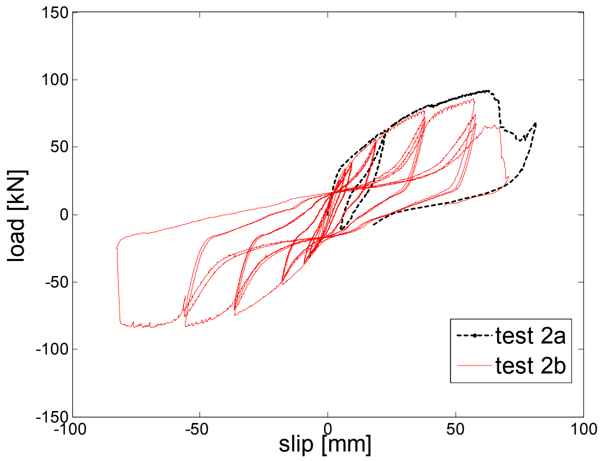


Figure 9: Configuration B, ramp and cyclic test 2

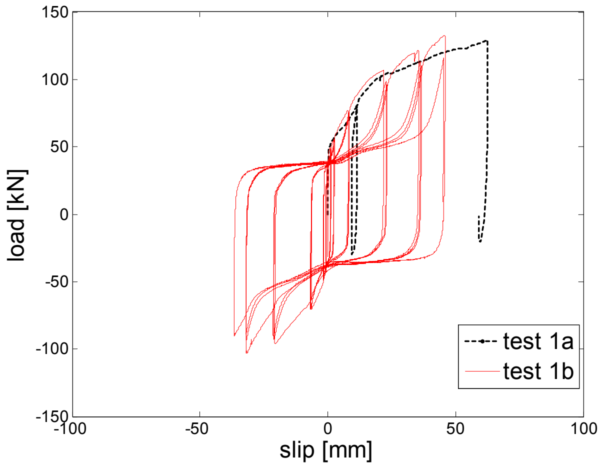


Figure 10: Configuration C, ramp and cyclic test

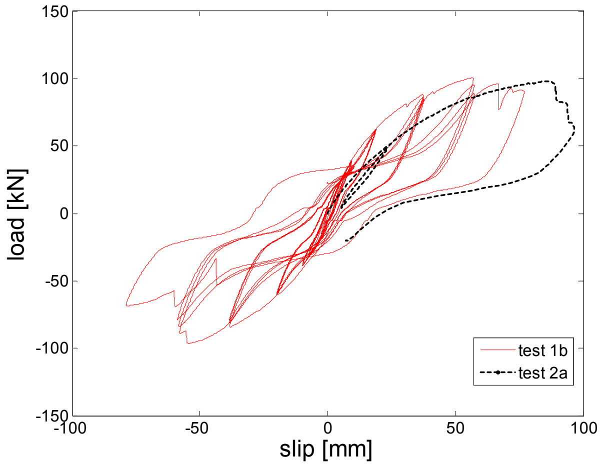


Figure 11: Configuration D, ramp and cyclic test

The test results are summarized in Table 3. In Configuration A, as it was expected, a stiffer holdown connection (with a 8 mm thick steel plate instead of the 3 mm of thickness of the BMF HTT22) lead to a higher lateral load carrying capacity but a lower ultimate displacement and a less ductile behaviour. In Configuration B the first test (B/1) showed a quite big impairment of strength (about 35% as it can be observed in Fig. 8) due to the pulling out of nails connecting the steel angle to the floor slab during cyclic test (Figure 15). Therefore in test B/2 2 two screws were inserted instead of the first two nails obtaining a significant reduction of the above mentioned impairment of strength. In Configuration C a preliminary test was carried out with 15 inclined screws proved to be too rigid. Hence, for the test 1 carried out, 9 screws were used which gave the system the ductility necessary. In Configuration D it was proved that no holdowns at the opening are necessary due to the high stiffness of the panel material.

Table 3: Test results and observed failure modes for cyclic tests

CASE	Sub.	Lateral load capacity [kN]		Ultimate displacement[1] [mm]	Secant Stiffness[2] [N/mm]	ν_{eq}[3]	Observed failure mode
		Ramp test	Cyclic test				
A	1	130.1	140.9 (120.5)	44.9	5969.4	11.0%	Yielding of nails until shear failure of nails in holdown connections
	2	117.6	117.1 (113.0)	42.6	6744.5	13.4%	Tension failure of holdown, yielding of nails and steel angle
	3	115.4	116.5 (112.2)	54.9	7260.4	13.1%	Yielding of nails, holdown and steel angle
B	1	75.4	65.2 (62.4)	68.0	5401.4	18.5%	Yielding of nails and connectors, pulling-out of nails fixing the steel angle to the floor slab
	2	91.8	85.6 (83.8)	67.1	5441.5	15.8%	Yielding of nails and connectors, slight pulling-out of nails and screws fixing the angle to the floor slab
C	1	129.0	132.3 (102.3)	62.4	6789.5	-	Yielding of screws, rolling shear failures in floor slab
D	1	-	100.6 (96.1)	-	-	12.1%	Yielding of steel angles, holdowns and nails, local failure of timber in compression
	2	98.0	-	93.7	2169.7	-	Large yielding of steel angles, holdowns and nails, local failure of timber in compression

[1] Displacement at 80% of maximum load after the maximum load is reached in the monotonic test.
[2] Secant stiffness between 10% and 40% of maximum load in the monotonic test.
[3] Equivalent viscous damping. See [2] for reference.

4. DISCUSSION AND CONCLUSION

The layout and design of the joints is influencing strongly on the overall behaviour of the structural system. All forces and displacement are concentrated on a rather small region of the panel which is then leading to local failure phenomena as shown in Figure 13 and Figure 15.The wooden panels behaved almost completely rigid.

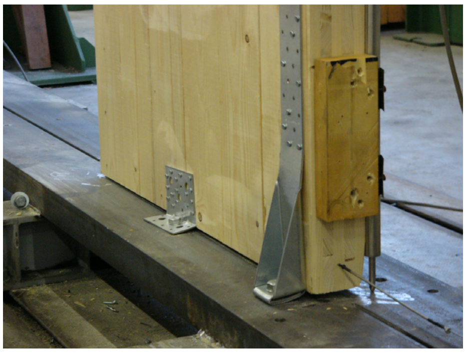


Figure 12: rigid panel with gap (D/1b)

Figure 13: local failure (A/1b)

Figure 14: holdown failure(B/1b)

Figure 15: local failure(B/1b)

Therefore, it is confirmed that all the dissipated energy is resulting from the connections (local problems are highlighted by this system: e. g. if the connections coincide with gluing errors, material failures do occur).

Nevertheless the hysteresis loops showed an equivalent viscous damping of 14% as average (12% considering only tests on the base connections) which is even greater than that observed for platform frame walls [3]. Hence this system promises to be suitable for seismic purposes. It has a high stiffness but still good ductile and dissipating performances.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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[2] EN12512, Timber structures – Test methods – Cyclic testing of joints made with mechanical fasteners CEN Brussels, 2005

[3] Karacabeyli, E. and Ceccotti, A. (1996), Test Results on the Lateral Resistance of Nailed Shear Walls *International Wood Engineering Conference*, New Orleans, USA, pp:V2,179-186