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RING CONNECTOR: A NEW CONNECTION SYSTEM FOR PREFABRICATION AND DFD IN CLT STRUCTURES

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ABSTRACT: the mechanical characterization of the innovative multi-directional RING connector is presented and discussed in this paper. The connector has been designed for timber-to-timber, timber-to-concrete (e.g. anchoring in foundation) and timber-to-steel (e.g. hybrid structures) joints. The RING system has been conceived starting from Design for Disassembly principles and may be adopted in timber prefabricated structures. Several monotonic tests will be presented and discussed: results showed that RING can be use in low to mid-rise timber buildings. Resistance, stiffness and ductility make the connectors a valuable alternative also in seismic prone areas.

KEYWORDS: CLT connections, multi-directional connector, experimental test, prefabrication, DfD.

1 – INTRODUCTION

There are several construction techniques to build low to mid-rise buildings using wooden elements, and Cross Laminated Timber (CLT) is one of the most used systems; the mechanical behaviour of connectors, adopted to assemble the CLT panels, is well-known thanks to various studies carried out by researches and companies all over the world [1]. Designers can choose from a wide range of connectors for wall-to-foundation, wall-to-floor, wall-to-wall and floor-to-floor assemblies. Using commercial connection systems, it is possible to design the vast majority typologies of CLT structures starting from small houses to demanding tall buildings. In the last case a valuable solution can be represented by a combination of CLT panels with different structural materials (e.g. hybrid steel-timber structures). In recent years, connectors were studied not just to characterize their mechanical properties; several non-structural requirements became crucial and therefore are studied further: acoustic interaction between joints and soundproofing profiles, durability, simple and safe on-site operations. Furthermore, it is important to consider the chance to prefabricate CLT wall/slab panels at the factory (e.g. panels provided with connectors and insulations/MEP system) and check quality of on-site execution. Moreover, it is fundamental to design CLT connection systems conceived to dismantle the timber constructions at the end-of-life of the building (i.e. reuse/recycle of the CLT elements). In the last ten years, researchers proposed some innovative connection systems [2,3,4,5] explicitly intended for Design for Disassembly (DfD) principles [6,7].

This paper presents a new connectors family based on the idea to use "pipe shaped connectors" inserted in circular grooves made in CLT panels and fastened with proper self-tapping fully-threaded screws (i.e. LBSH [8]), as shown in (Fig. 1). In particular, two connectors were conceived to meet some of the aforementioned requirements (e.g. DfD, prefabrication, safety operation on-site): RING60T and RING90C. Moreover, they make the on-site operations faster, reducing the "unprotected" time of the wooden structures and thus increasing their

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durability. RING connectors were designed to obtain resistance and stiffness like to the larger nailed connections typically used to assemble CLT panels (i.e. hold down and angular brackets). This purpose was achieved thanks to the shape and position of the RING connector: the steel pipe is inserted “inside” the CLT panels reducing eccentricity and taking advantage of the “embedment” of the whole pipe element. Finally, the simple geometry of the connector and the chance to couple the two versions of RING (RING60T for timber-to-timber and RING90C for hybrid connection) allows for various configurations of assemblies such as wall-to-foundation, wall-to-floor, wall-to-wall, floor-to-floor as well as ability to connect CLT to different materials (timber-to-concrete and timber-to-steel).

2 – RING CONNECTOR DESCRIPTION

RING connectors can be defined as “pipe shaped connectors” being made by a standard steel tubular profile (S355 steel grade according to EN10025 [9]) closed by a welded web. In RING90C the bottom part of the pipe is reinforced by a thick steel plate with a circular hole for a M16 steel bolt (timber-to-steel connection). In order to host RING connectors, CLT panels have to be worked making a proper hole (nominal diameter equal to 60mm for RING60T and 90mm for RING90C) where the connector is inserted and fastened with LBSH screws. The external edge of the pipe presents half-moon grooves that should be used by a carpenter as guide for the screws, giving the correct inclination of the fasteners (i.e. double inclination). LBSH screws connect RING to CLT panel according to a radial pattern (in-plane inclination). In addition, the screws have a secondary inclination (out-of-plane) and cross more than one layer of the CLT panel. Fasteners can be inserted and removed since the head of the screws is simply reachable also once the structure is assembled, in this way it will be possible to disassemble and remove the connectors from the timber members at the end of life of the building, respecting DfD principles [10]. Furthermore, RING90C allow to couple/decouple the CLT panels to steel profiles, concrete elements or to a second RING90C with an M16 steel bolt, making particularly easy the assembling/disassembling phases. As presented in Fig. 2, two connectors were designed: the first one, RING90C (Fig. 2, right), is a multi-functional connector developed for both wooden or hybrid structures ("90" indicates the nominal diameter of the tubular profile while letter "C" indicates that the product can be used with concrete elements or, in general, for “hybrid joints”); the latter, RING60T (Fig. 2, left), can be used only in connections between wooden elements ("60" indicates the nominal diameter of the tubular profile while letter "T" in indicates that the product is intended for timber-to-timber joints). The mechanical behaviour of the two RING typologies allows the use of connectors in combination. For this reason, the entire CLT structure can be assembled using just RING connectors instead of hold-down and angular brackets. As previously mentioned, CLT should be designed positioning proper holes to host RING connectors: the grooves being obtained by cutting of CLT master-panel at the factory with standard CNC machine. RING90C and RING60T were developed to enhance the prefabrication and therefore are intended to be pre-assembled (but can be easily installed also at the building site before CLT panels positioning). Once CLT panels are at the building site (with RING connectors already installed) it is necessary to insert five LBSH screws in case of RING60T or, still more easily, fix a M16 bolt, in case of RING90C. It follows that RING60T does not require any precision since it can be screwed directly to the second wooden element in any position; RING90C (that is bolted to the second element) needs to be coupled with predrilled hole properly designed to host M16 bolt.

Figure 1. RING connectors: RING60T (left) and RING90C (right)

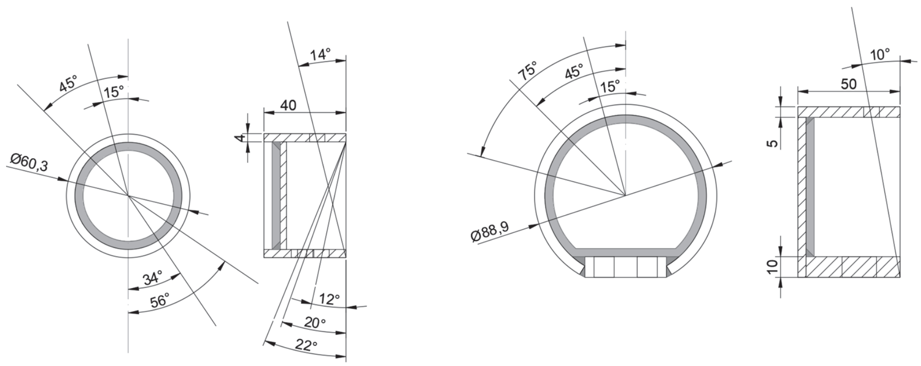

Figure 2. Geometric properties of RING60T (left) and RING90C (right)

The most important applications of RING90C and RING60T in CLT assembling are described in the following. RING connectors can be applied also in Glulam or LVL elements and used in several applications such as in CLT panel assembling (to connect CLT panels to steel profiles or concrete elements) but also for beam-to-beam or column-to-column connections (Glulam or LVL elements). This paper presents the more common applications in CLT assembling. Fig. 3 shows the typical wall-to-floor connection, in this case RING90C and RING60T are used in the traditional wall configuration where hold-down, located at the corner of the CLT wall, are substituted by RING90C and shear connectors, distributed along the panel are replaced by RING60T. At the foundation level (Fig. 4) RING offers different installation configurations; the simplest one is to connect the ground floor CLT shearwalls to steel profiles (e.g. HEB/IPE) using RING90C: the steel members, fixed to the foundation with chemical anchors, allow to level and distance the CLT panel from the ground ensuring the durability of the wooden elements. Alternatively, it is possible to anchor the CLT panels equipped with RING90 directly to the foundation, for example using precast corrugated tubes or threaded rods. RING offers several other applications as corner wall-to-wall connection (RING60T) or connection between prefabricated 3D modules (RING90C). In addition, another important potential is shown by the panel-to-panel connection (e.g. multi-panels wall or slab-to-slab rigid diaphragms). RING90C allows a fully prefabricated connection while adopting RING60T it is possible to connect the elements directly at the construction site, avoiding any pre-installation.

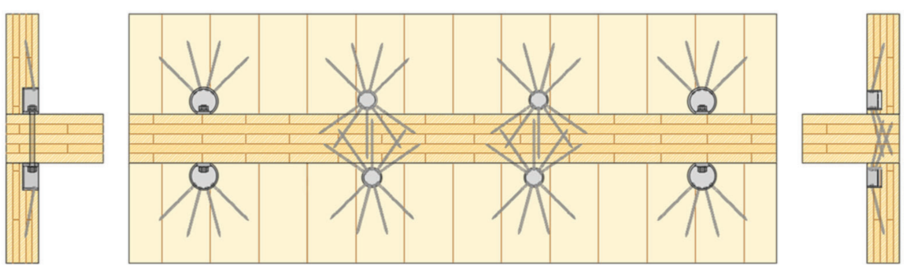

Figure 3. Combination of RING90C and RING60T for typical wall-to-floor connection

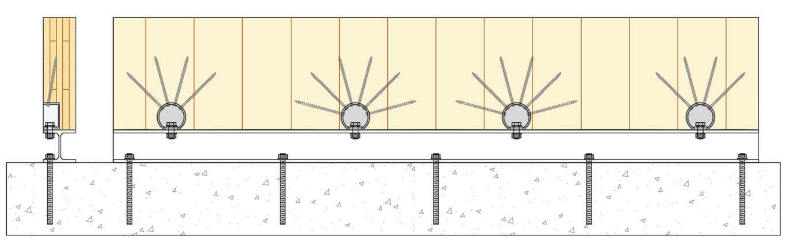

Figure 4. RING90C adopted as hold-down and angular bracket for typical wall-to-foundation connection

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3 – EXPERIMENTAL SETUP

Starting from the experimental and analytical results obtained studying the prototypes connectors (characterized by different diameter and thickness of the steel pipe, steel grade, screw's typology and hole's position), final versions of connectors, RING60T and RING90C, were defined. The preliminary tests were carried out in tensile (F1T) and in-plane shear (F2/3) configurations. Additional tests at 45 degrees configuration (F45) were conducted to understand the behaviour of connectors loaded by simultaneous F1T and F2/3 forces. After this initial phase of preliminary testing (results were discussed in [11]) a new extensive experimental campaign was designed with the aim of a full characterization of connector's monotonic behaviour. Furthermore, results obtained testing RING connectors, were used to define a European Technical Assessment (ETA) [12] following the indications given by European Assessment Document (EAD) for three-dimensional nailing plates [13].

This paper presents and discusses results obtained by the main testing campaign: a series of monotonic tests (three tests per each configuration) were carried out in F1T, F1C (compression), F2/3 and out-of-plane shear (F4/5) load configuration according to EN26891:1991 [14]. The load was applied by ±600 kN testing machine: a properly designed steel element was hinged to the loading beam and fixed to the side A of the specimen via threaded rods and steel plates in F1T tests. In F2/3 configuration the upper CLT specimen's narrow side was directly in contact with the hinged element (Fig. 5, 6 and 7). On side B the connection was bolted to the support platform of the testing machine (RING90C) or, in case of RING60T, the CLT panel was fixed with rectangular steel profiles and threaded rods. In this paper only the results obtained in F1T and F2/3 configuration were presented. All the tested connections were fastened through LBSH 7x200mm screws [8] to the narrow side of 5-layer CLT panels 100mm thick (20-20-20-20-20). RING90C specimens were fastened via 10.9 M16 steel bolt. Density and moisture content were measured for each specimen, the mean values result equal to 480 kg/m^3 and 11,6%, respectively.

3.1 TENSILE CONFIGURATION SETUP

Six tests were carried out on RING90C, three specimens with four screws (partial pattern) and three with six screws (full pattern). In the case of RING60T, specimens with the external boards of CLT panels oriented in longitudinal (3 tests) or transversal (3 tests) direction, were tested to understand the influence of panel's layup. All the tested specimens in F1T configuration are reported in Table 1.

Table 1: Tested specimens in F1T configuration

ID	Side A	Side B	CLT external boards direction
RING90C_001	4 x LBSH 7x200mm	1 x M16 10.9 bolt	Longitudinal
RING90C_002	4 x LBSH 7x200mm	1 x M16 10.9 bolt	Longitudinal
RING90C_003	4 x LBSH 7x200mm	1 x M16 10.9 bolt	Longitudinal
RING90C_004	6 x LBSH 7x200mm	1 x M16 10.9 bolt	Longitudinal
RING90C_005	6 x LBSH 7x200mm	1 x M16 10.9 bolt	Longitudinal
RING90C_006	6 x LBSH 7x200mm	1 x M16 10.9 bolt	Longitudinal
RING60T_001	4 x LBSH 7x200mm	5 x LBSH 7x200mm	Longitudinal
RING60T_002	4 x LBSH 7x200mm	5 x LBSH 7x200mm	Longitudinal
RING60T_003	4 x LBSH 7x200mm	5 x LBSH 7x200mm	Longitudinal
RING60T_004	4 x LBSH 7x200mm	5 x LBSH 7x200mm	Transversal
RING60T_005	4 x LBSH 7x200mm	5 x LBSH 7x200mm	Transversal
RING60T_006	4 x LBSH 7x200mm	5 x LBSH 7x200mm	Transversal

Four linear variable displacement transducers (LVDT) were applied at the tested specimens, two of them at each wide face of CLT panel on side A, as shown in Fig. 5. The values of displacements reported in the next tables and figures are the mean values obtained from the four LVDTs. RING90C, as reported in Fig. 5, were tested with a gap (25mm) between the steel base plate of connector and support platform of the testing machine while in RING60T specimens, the two narrow sides of CLT panels were directly in contact one each other.

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Figure 5. RING60T with vertical (left) or horizontal (centre) outer boards and RING90C (right) F1T test setup

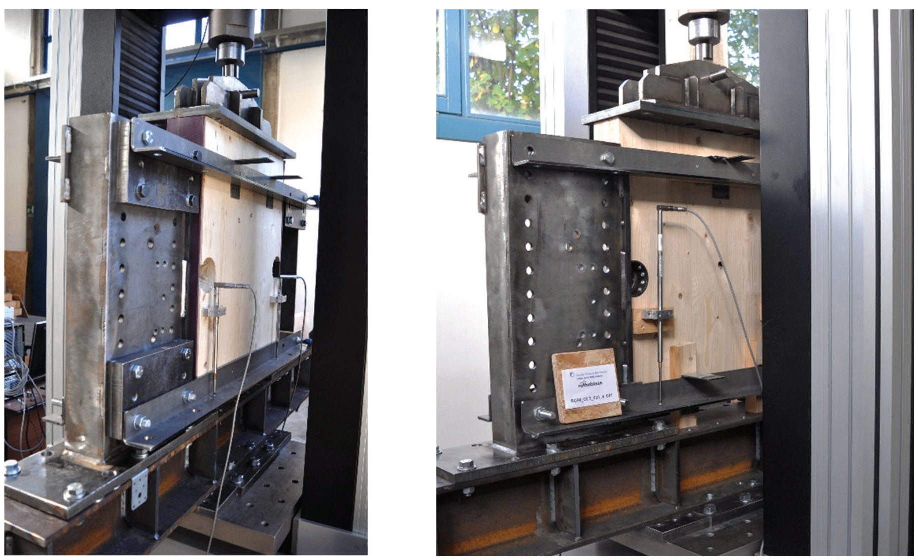

Figure 6. RING90C with (left) and without (right) resilient soundproofing profile in F2/3 test setup

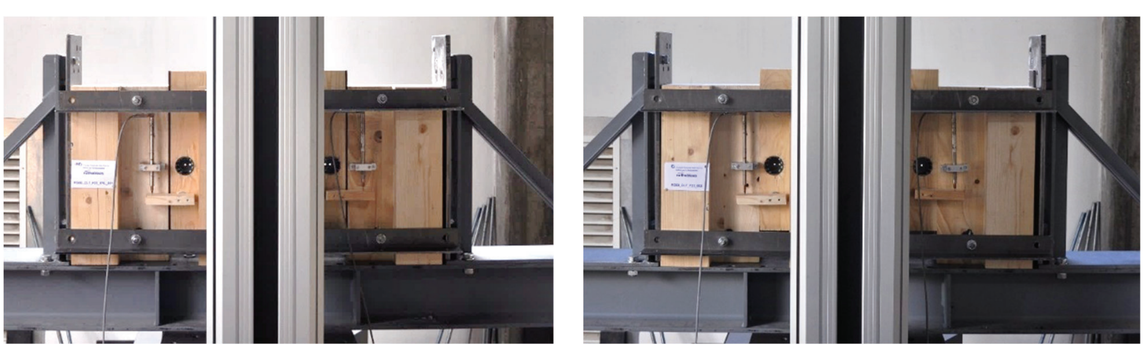

Figure 7. RING60T with (left) and without (right) resilient soundproofing profile in F2/3 test setup

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3.2 SHEAR CONFIGURATION SETUP

Nine monotonic shear tests were carried out on RING90C, three tests per each following configuration: four screws (partial pattern) and six screws (full pattern), with and without resilient soundproofing profile (interlayer 6mm thick [15] between panel and steel supports). Six tests were carried out on RING60T connector: with and without resilient soundproofing profile between panels' narrow sides. The external boards of CLT panels were in transversal direction in all cases and there was no gap between the two sides of the specimens. The tested specimens in F2/3 load configuration are reported in Table 2.

Table 2: Tested specimens in F2/3 configuration

ID	Side A	Side B	Soundproofing profile
RING90C_007	4 x LBSH 7x200mm	1 x M16 10.9 bolt	No
RING90C_008	4 x LBSH 7x200mm	1 x M16 10.9 bolt	No
RING90C_009	4 x LBSH 7x200mm	1 x M16 10.9 bolt	No
RING90C_010	6 x LBSH 7x200mm	1 x M16 10.9 bolt	No
RING90C_011	6 x LBSH 7x200mm	1 x M16 10.9 bolt	No
RING90C_012	6 x LBSH 7x200mm	1 x M16 10.9 bolt	No
RING90C_013	6 x LBSH 7x200mm	1 x M16 10.9 bolt	Yes
RING90C_014	6 x LBSH 7x200mm	1 x M16 10.9 bolt	Yes
RING90C_015	6 x LBSH 7x200mm	1 x M16 10.9 bolt	Yes
RING60T_007	4 x LBSH 7x200mm	5 x LBSH 7x200mm	No
RING60T_008	4 x LBSH 7x200mm	5 x LBSH 7x200mm	No
RING60T_009	4 x LBSH 7x200mm	5 x LBSH 7x200mm	No
RING60T_010	4 x LBSH 7x200mm	5 x LBSH 7x200mm	Yes
RING60T_011	4 x LBSH 7x200mm	5 x LBSH 7x200mm	Yes
RING60T_012	4 x LBSH 7x200mm	5 x LBSH 7x200mm	Yes

Four LVDTs were applied at the tested specimens, two of them at each wide face of CLT panel on side A, as in F1T configuration, Fig. 6 and 7. Also in this case values of displacements reported in tables and figures are the mean values obtained from the four LVDTs.

4 – RESULTS

The results of the experimental campaign conducted on RING90C and RING60T are presented in this section. The mechanical parameters of tri-linear curves (yield load and displacement F_y and u_y, maximum load and displacement F_m and u_m, ultimate load and displacement F_u and u_u) calculated according to EN 12512:2001 [16] and failure modes of each tested specimen are reported and discussed. The value of stiffness was calculated based on F_m or maximum load reached before 15 mm of displacement (F_{15}) according to [14] while the value of ultimate load was equal to the maximum between $0{,}8F_{max}$ or the value of load at failure point according to [16]. The values reported in the next tables and figures are referred to a single connector.

4.1 TENSILE CONFIGURATION RESULTS

Force-displacement curves (backbones) obtained in the experimental campaign are plotted in Fig. 8 while the results in terms of tri-linear curves parameters are reported in Table 3 for each RING60T and RING90C specimen. The influence of the panel's layup (or orientation) in the mechanical behaviour of RING60T is highlighted by Fig. 8 (left): the increasing of F_m (mean values) was equal to 19% moving from transversal to longitudinal external boards configuration. In both cases the failure mode is related to screws' withdrawal (side B), as shown in Fig. 9 (left). For the RING90C connector (Fig. 8, right), the decreasing of F_m (mean values) moving from six (full pattern) to four screws (partial pattern) was equal to 18%. As expected, the two screws at an angle equal to 75 degrees have slightly influenced F1T configuration compared to other screws at 15 and 45 degrees. All the failure modes were related to screws withdrawal (Fig. 9, centre) or screw tensile failure (Fig. 9, right), depending on the withdrawal strength parameter, which is directly correlated with CLT panel density [17].

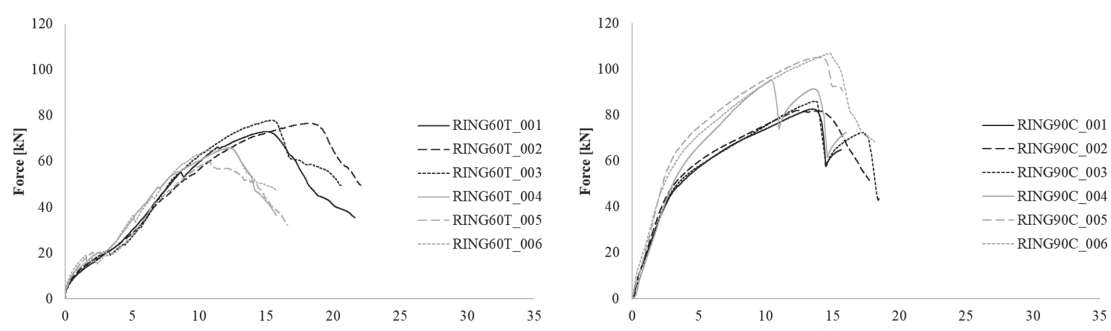

Figure 8. Force-displacement backbones F1T of RING60T (left) and RING90C (right)

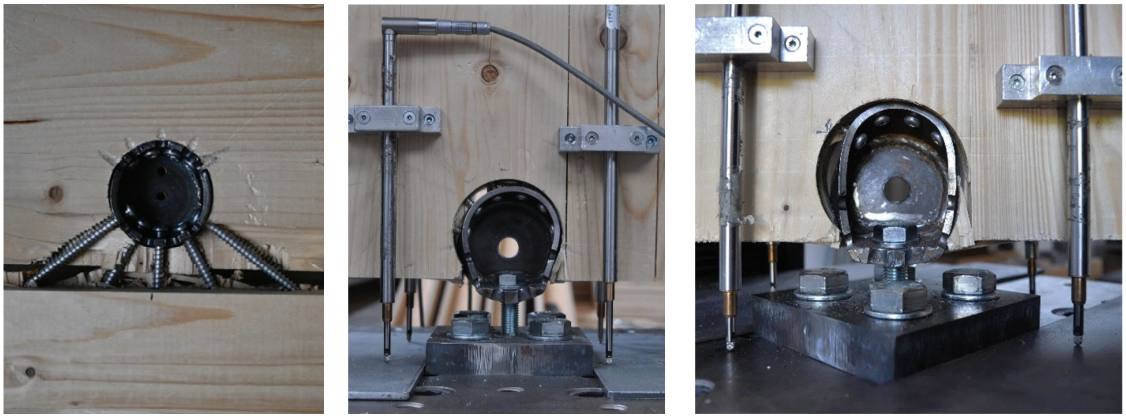

Figure 9. F1T failure modes: RING60T (left), RING90C screws withdrawal (centre) and RING90C screw tensile failure (right)

Table 3: Mechanical parameters in F1T configuration

ID RING	k [kN/mm]	F_{15} [kN]	v_y [mm]	F_y [kN]	v_m [mm]	F_m [kN]	v_u [mm]	F_u [kN]
90C 001	16,0	-	3,5	57,2	13,5	82,6	15,6	66,1
90C 002	17,9	-	3,1	56,1	12,4	82,1	16,2	65,7
90C 003	17,8	-	3,3	57,2	13,7	86,0	16,0	68,8
90C 004	17,5	-	4,6	79,5	10,4	95,5	11,1	76,4
90C 005	22,6	-	3,2	71,1	13,9	105,1	15,8	90,4
90C 006	20,0	-	3,5	73,0	14,8	106,9	16,2	85,6
60T 001	4,9	-	13,8	72,7	15,0	73,0	17,4	58,4
60T 002	4,6	72,3	15,0	75,0	18,3	76,6	20,4	61,2
60T 003	4,5	77,6	16,0	78,1	16,0	78,1	16,7	62,3
60T 004	5,2	-	11,4	65,5	12,3	66,0	13,9	52,8
60T 005	4,3	-	12,5	59,0	10,7	60,0	14,5	48,0
60T 006	5,2	-	11,4	65,2	12,3	65,6	14,1	52,5

4.2 SHEAR CONFIGURATION RESULTS

Force-displacement backbones and tri-linear curve' parameters in F2/3 configuration are reported in Fig. 10 and Table 4, respectively. RING90C connectors exhibit a marked elastic-plastic behaviour in all tested configurations (after yielding the load was maintained up to the end of the test). In case of no interlayer (i.e. no soundproofing profile) all the tests were stopped at 30mm except for RING90C_011, which was stopped just before 30mm (u_u=28,7mm).

Different failure modes were observed: withdrawal/tensile (Fig. 11, centre/right) failure of screws (depending on panel density as for F1T load configuration) and large deformation (no failure according to [16]), as shown in Fig. 11 (left).

Table 4: Mechanical parameters in F2/3 configuration

ID RING	k [kN/mm]	F_{15} [kN]	v_y [mm]	F_y [kN]	v_m [mm]	F_m [kN]	v_u [mm]	F_u [kN]
90C 007	9,1	81,0	8,2	78,5	28,1	85,2	30,0	80,4
90C 008	7,8	69,9	8,0	68,0	25,2	73,3	30,0	72,5
90C 009	10,3	-	6,8	76,6	9,5	76,7	30,0	61,6
90C 010	11,1	91,0	8,2	90,3	29,5	94,5	30,0	94,1
90C 011	8,6	83,8	9,2	82,6	17,6	87,2	28,7	69,9
90C 012	8,3	86,0	11,5	85,3	30,2	92,2	30,0	92,1
90C 013	9,0	78,0	10,8	80,9	25,2	87,6	26,4	70,1
90C 014	6,3	70,0	11,6	73,2	20,9	75,3	21,6	69,8
90C 015	6,7	87,1	12,4	85,3	17,0	90,2	18,8	72,2
60T 007	55,0	-	0,9	50,2	5,2	50,3	11,9	40,1
60T 008	55,1	-	0,8	45,5	3,7	45,6	13,5	36,4
60T 009	46,2	-	0,9	44,1	8,2	47,1	12,8	37,7
60T 010	22,1	-	1,7	39,1	10,2	39,2	30,0	34,6
60T 011	21,5	-	1,3	30,4	10,4	38,0	12,1	30,4
60T 012	21,6	-	1,5	33,0	10,4	39,1	13,8	31,3

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The last failure mode was emphasized by embedment (crushing) of wood in compressed areas; all the specimens with four screws were characterized by this failure mode. In tested configuration with interlayer none of the specimens reached 30mm of displacement; in this particular case the reduction of friction coefficient (no timber-to-timber contact) induces higher loads on screws causing tensile failure. Values of F_m was 8% lower moving from configuration characterized by no soundproofing interlayer to configuration with interlayer and the stiffness was 16% lower. RING60T connectors exhibit an elastic-plastic behaviour characterized by a high value of stiffness in configuration without interlayer, up to 55,1 kN/mm, as reported in Table 4. In the case of RING60T the influence of resilient acoustic profile in terms of F_m and k was evident, causing a reduction equal to 18% and 58%, respectively. In both configurations the failure mode was related to screw withdrawal (screw in compression) and tensile failure (screw in tension) on side B, as reported in Fig. 12.

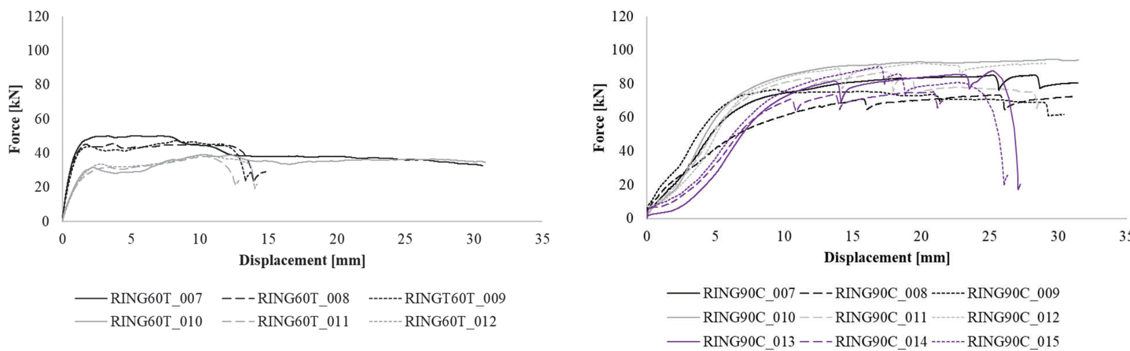

Figure 10. Force-displacement backbones F2/3 of RING60T (left) and RING90C (right)

Figure 11. F2/3 failure mode: RING90C-partial pattern (left), RING90C-full pattern (centre- withdrawal) and RING90C with interlayer (right)

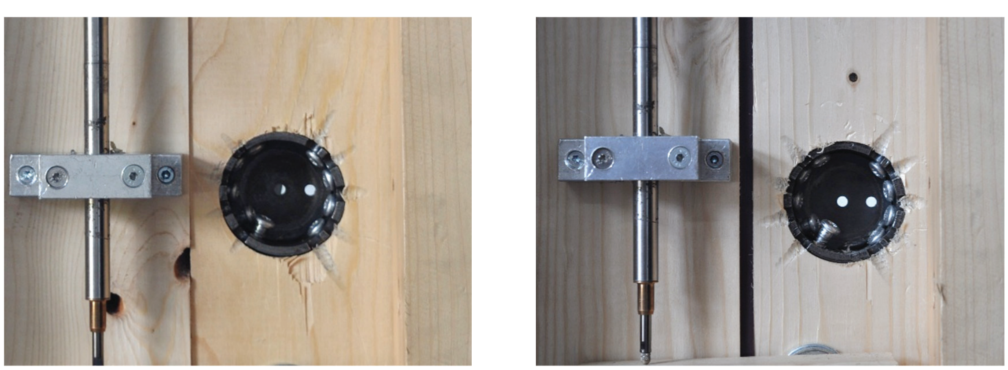

Figure 12. F2/3 failure mode: RING60T without interlayer (left) and RING60T with interlayer (right)

5 – CONCLUSIONS

The RING family connectors present several innovative aspects: the use of new LBSH fully threaded screws, the reduced connection eccentricity due to installation of RING "inside" the wooden panel/element (this property also facilitates the transportation), the proper guide for correct screw insertion (no screw's inclination mistakes are possible), the chance to pre-install the connections at the factory and the feasibility to dismantle the building at the end of life of the structure (DfD). An extensive experimental campaign carried out to characterize the multi-directional behaviour of the new connection system RING90C (timber-to-steel/concrete joists) and RING60T (timber-to-timber joists) was presented in this paper. Different setups were designed to test the connectors in tension and shear load configurations. Results demonstrate that RING are characterized by mechanical properties comparable with the larger nailed connections available in the market (i.e. angle brackets and hold-downs) and highlighted the capacity of the connector to respond both to tension and shear forces (multi-directional behaviour). In addition, RINGs are suitable for various applications (wall-to-foundation/floor, wall-to-wall, floor-to-floor) and to connect different materials (i.e. hybrid structures). The development of an analytical calculation method to extend the results (e.g. timber elements with different density and screws with different length) will be discussed in further studies.

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