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Bending Test on Composite Timber-Steel-Concrete Floor Equipped with Innovative Collar Connectors

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Abstract In this paper a full scale monotonic static bending test on a composite timber-steel-concrete floor, equipped with innovative "collar" connectors, is illustrated. In particular, the specimen consists of two beams, made of ancient chestnut, connected to the concrete reinforced slab by means of purposely fitted upside wings of steel collars astride the beams themselves. The test is part of a comprehensive research activity, aiming at the evaluation and optimization of the collar connection device, developed within the European project PROHITECH ("Earthquake Protection of Historical Buildings by Reversible Mixed Technology", 2004-2008).

Keywords: Retrofitting of ancient timber floor, composite timber-steel-concrete floor, steel collar connector, full scale bending test

Introduction

In the context of the retrofitting of ancient wooden floors by composite timber-concrete systems, an innovative type of connector, which avoids any drilling of the beams, has been conceived (Faggiano et al. 2005, Faggiano et al. 2009a, Faggiano et al. 2009b, Calado et al. 2008). It consists of steel collars, surrounding the timber beam, composed of parts bolted each other, at appropriate folded wings, the upside ones having the function of connectors. The slipping force transmission between the collar and the beam occurs through friction between the surfaces in contact, which is guaranteed by tightening of bolts. Moreover, at the interface between the steel collar and the timber beam, a rubber layer is interposed to enhance the adherence between elements. The steel-rubber contact can be improved by gluing. Due to the bolt tightening, the steel collars also provide a transversal ringing action on the beam.

The conception and the study of the collar connector system were developed within a comprehensive research program, including both experimental and numerical investigations, in the framework of the international research project PROHITECH (Earthquake Protection of Historical Buildings by Reversible Mixed Technology, 2004-2008, coordinator: prof. F.M. Mazzolani). The whole activity includes both monotonic and cyclic push-out tests on single connection devices and both monotonic and cyclic bending tests on composite timber-concrete beams and composite floor equipped with the collar connectors. In particular it was articulated in three parts. The first part consisted of both numerical and experimental tests on single connection devices, including both monotonic and cyclic push-out tests (Faggiano et al. 2009a, Faggiano et al. 2009b). It was carried out on full-scale specimens of ancient timber beams with circular cross sections and new timber beams with rectangular cross sections, at the DIST (Dept. of Structural Engineering) of the University of Naples "Federico II" (Prof. F. M. Mazzolani coordinator) and at the DECIVIL (Dept. of Civil Engineering and Architecture) of the Superior Technical Institute in Lisbon (Prof. L. Calado coordinator), respectively. Several configurations of the devices were examined, they being obtained by varying the main parameters which affect the behaviour, such as number of steel parts, both width and thickness of collars and preloading forces in the bolts (Faggiano et al. 2009a). Results allowed identifying the types of collar that supply the better behaviour, to be used for composite systems. The second part consisted of both numerical and experimental tests on full-scale composite beams, including both monotonic and cyclic bending tests. The specimens were made of new wood beams with rectangular cross sections and equipped with the steel collar connectors (Calado et al. 2008). It

was performed at the DECIVIL, with the cooperation of the DIST. The third part consisted of a monotonic bending test on a full-scale composite floor, with ancient timber beams with circular cross sections and equipped with the steel collar connectors.

In this context, the paper presents the third part of the whole activity. First of all the main features of the tested system, together with the set-up of the test are depicted. Therefore the results of the monotonic bending test is detailed, they being discussed in terms of both force-slip relationship at the collar contact surfaces and overall force-vertical displacement of the whole slab system.

The Specimens Features

The timber-concrete composite floor (Fig. 1) consists of two beams made of ancient chestnut, with circular cross-section, 12 cm diameter, 0.70 m inter-axis and 2.00 m length. The overall floor size is 1.80×1.10 m^2 (Fig. 1a).

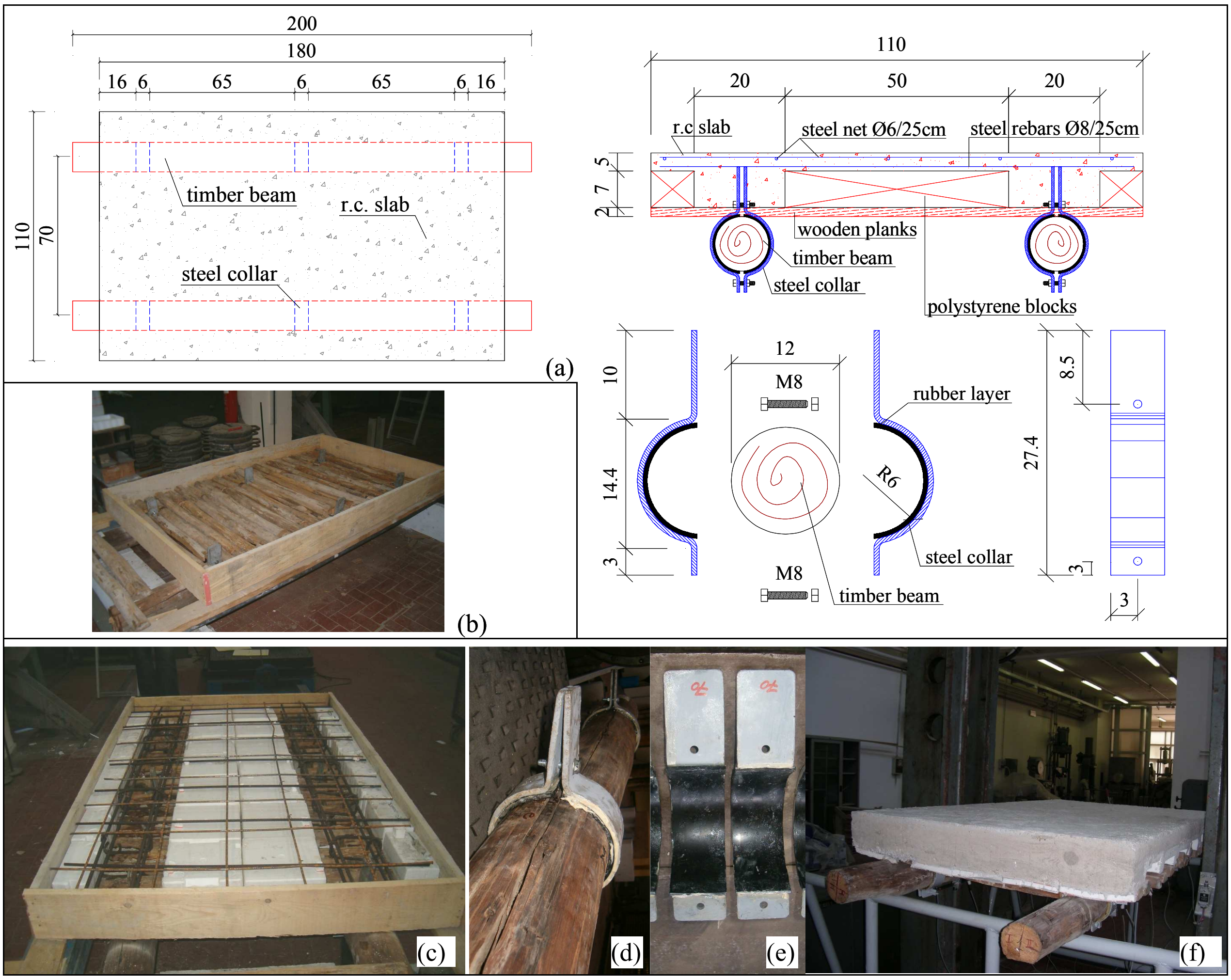

Figure 1: Geometrical characteristics and components of the composite system [cm]

The r.c. slab is 12 cm thick. It is lightened by polystyrene blocks, 7 cm thickness. The concrete slab is cast on a layer of wooden planks, 2 cm thickness, so-called "panconcelle" (Fig. 1b). The slab is reinforced by steel rebars Φ8/25 cm and a steel net Φ6/25, with C20/25 grade concrete (Fig. 1a,c).

The connection system consists of steel collars (S275 steel grade), which are composed by two parts, bolted together at appropriate folded wings, the upside ones having the function of connectors (Fig. 1a,d,e). The collar is composed by two cold formed steel semicircular shaped elements made of S275 steel grade, 60 mm width and 7 mm thickness, bolted at both upside and downside wings, 10 cm and 3 cm length respectively (Fig. 1e). Bolts 8.8 grade, 10 mm diameter, are used. At the interface between the steel collar and the timber beam, a layer of rubber (SISMI 60), 5 mm thickness, is glued

to the collars by vulcanizing glue REMA SC 2000. Three connectors are used per each beam, according to the preliminary design. With regard to this, the design of the proposed connection system is carried out by imposing the equivalence with the traditional stud connection system in terms of both strength and stiffness (Faggiano et al 2009a) and by assuming the complete wood-rubber adherence up to the attainment of the limit value of the slip resistance, and the complete rubber-steel adherence due to glued contact.

The mechanical properties and the inertial features of the timber beams, the r.c. slab and the composite section are summarized in Table 1, where the Young E, the inerzia I and the resistance W moduli, in addition to both the compression f_{ck} and the bending f_{bk} strength, have been obtained from an experimental campaign, with reference to the timber beam (Faggiano et al. 2009c, Faggiano et al. 2009d). With regards to the composite section, the concrete has been conventionally homogenized to wood, considering the equivalent coefficient n equal to 2.77, assuming a collaborating r.c. 20 cm width and 12 cm height.

In Fig. 1f the complete composite floor before the test is represented.

Table 1: Mechanical characteristics of the composite system

Structural element	E (Nmm^{-2})	I (mm^4)	W (mm^3)	f_{ck} (Nmm^{-2})	f_{bk} (Nmm^{-2})
Timber beam	11000	10170000	170000	20	32
R.C. slab	30500	28800000	240000	25	7
Composite section	11000	280000000	$W_{i,sup}$ =3491000 $W_{i,inf}$ =1551000		

Testing Apparatus and Procedure

The testing apparatus (Fig. 2a) consists of a load machine Mohr Federhaff AG, the fix down plate being the contrast frame, a jack which applies a manual controlled load, a loading cell HBM, having 740 kN capacity and 16 electric displacement transducers (LVDT) HBM with accuracy of 1×10^{-3} mm. Two steel trestles, realized by tubular section profiles, are the floor supports. The four-points scheme for the standard beam bending test is achieved by using a steel frame composed by two IPE 200 profiles connected at the middle section by a HE 180 profile, which the jack is applied on (Fig. 2b). The LVDTs are used for measuring the overall vertical displacements of the system and the relative beam-to-slab and beam-collar displacements (Fig. 3). In particular, two transducers are located at the mid-span of each beam and measure the vertical displacements (V_1 and V_2, Fig. 3a); two transducers are located on the beams and measure the beam-to-slab slip (B_1-S and B_2-S, Fig. 3b); twelve transducers are located on the beam (Fig. 3c), six at the middle longitudinal plane of the beam (from T_1,A to T_1,F), six at the intrados (from T_2,A to T_2,F), and measure the beam-collar slip (B_i-C_i). It is worth noting that the collars are labeled with capitol letters from A (CA) to F (CF) (Fig. 3).

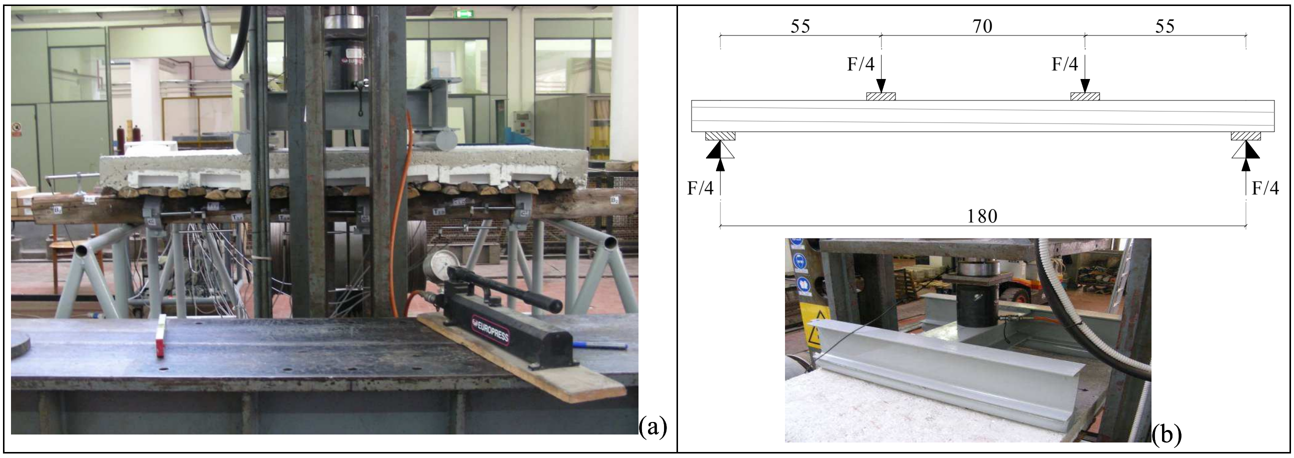

Figure 2: Testing apparatus [cm]: (a) Testing equipments; (b) Loading scheme and devices

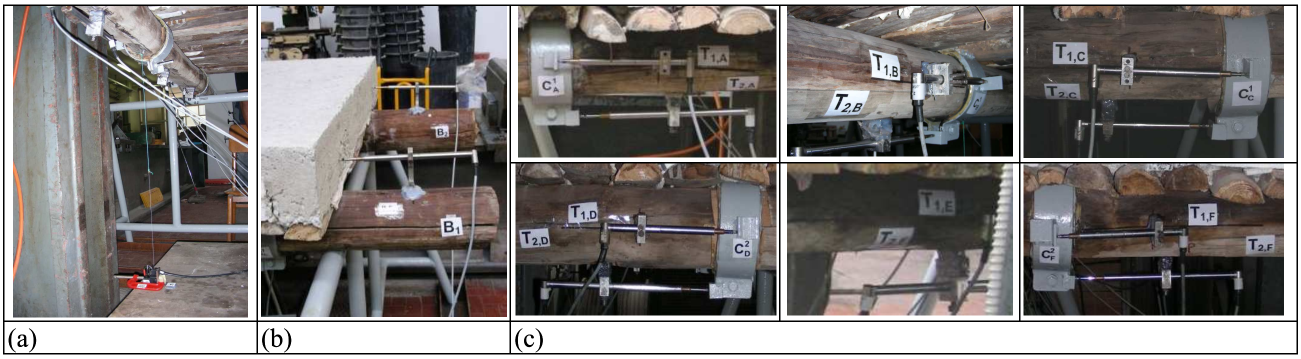

Figure 3: Transducers location: (a) Vertical transducers; (b) beam-to-slab transducers; c) collar-beam transducers

Both transducers and load cell are connected to an electronic device and to a PC, in order to allow data acquisition and recording by means of the software Catman (v. 6.2).

The test was performed in monotonic conditions aiming at evaluating the global performance of the composite timber-concrete floor and the efficiency of the collar connectors, as well as at determining the maximum load-bearing capacity and the failure modes. The load was increased up to the collapse of the system in two subsequent steps: the first one up to the maximum force, corresponding to the first failure warning; the second one, after a down load phase, up to the complete failure of the beams.

Experimental Results

The results of the experimental test are provided in terms of force (F) – vertical displacement (v) curve, as average between the two beams displacement values (Fig. 4).

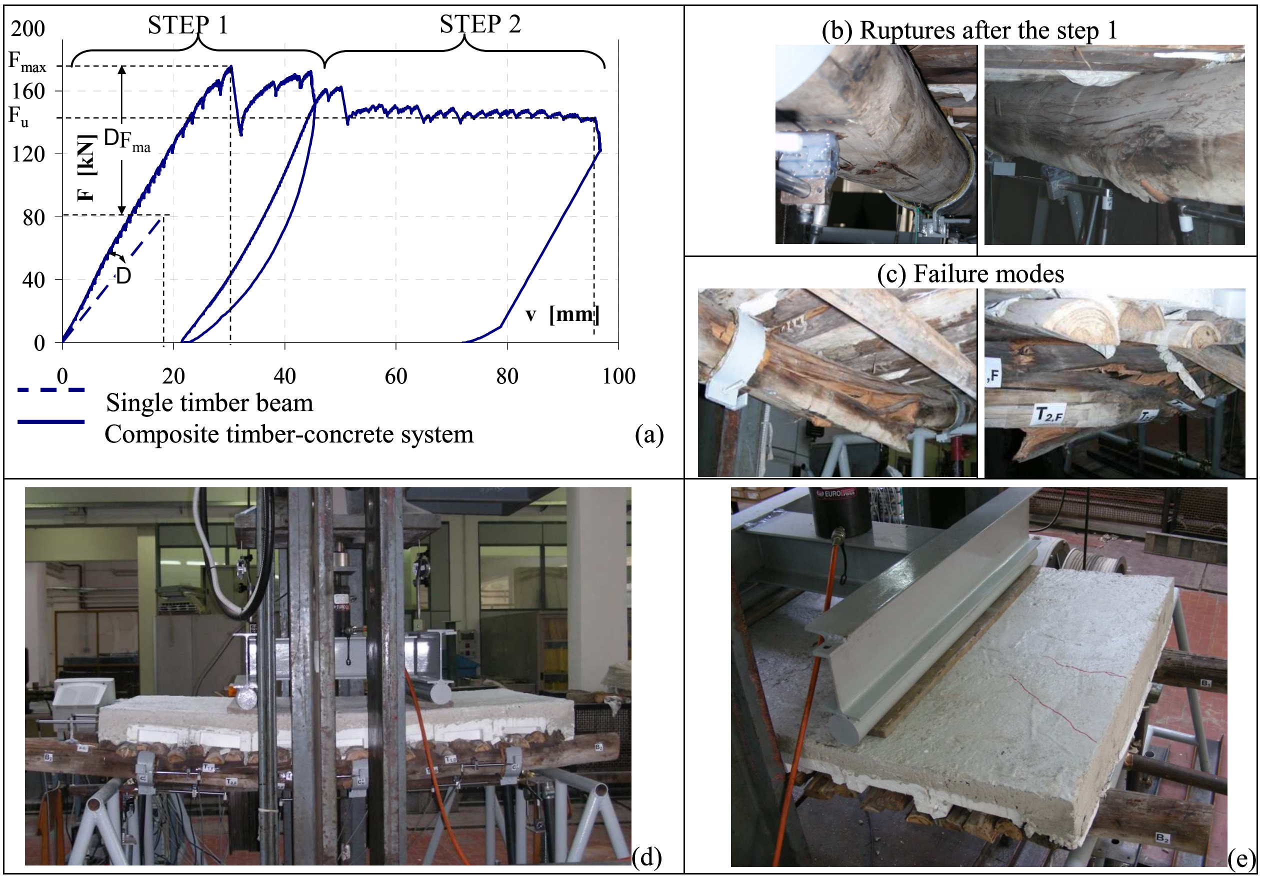

Figure 4: Bending test results: (a) force (F) – vertical displacement (v) curve; (b)-(e) failure modes

The curve shows an almost linear elastic behaviour up to the maximum reached force (F_{max}) and a significant ductility. In particular, in the first loading step the maximum force equal to 175 kN and a corresponding displacement equal to 30mm (Fig. 4a,b) are reached. The step ends after a sudden load decrease due to the failure of some fibers located at the tension side of the beams. At the end of the first step, the beam B_1 shows a rupture of the longitudinal fibers, while the beam B_2 shows a rupture of the fibers near the knot (Fig. 4a,c). In the second loading step the ultimate force (F_u) equal to about 140 kN and a final displacement equal to about 95mm are reached at the full failure of the structure. The latter is due to the complete rupture of the tension side of the timber beams, which are affected by natural defects, such as knots and slope of grain (Fig. 4c). The large ductility depends on the subsequent rupture of the tensile fibres of the wooden beam up to the full failure. At the end of the test the r.c. slab shows only few and superficial cracks (Fig. 4d,e).

In the same Fig. 4a the curve related to the bending behaviour on a single timber beam is also reported. In this case the resistant structural element is the timber beam only, and its mechanical properties have been obtained from experimental bending tests carried out on timber beams with similar both section and preservation state (Faggiano et al. 2009c). It was assumed a linear elastic behaviour up to failure, which occurs when a maximum force equal to 80 kN and a vertical displacement equal to about 18mm are reached, evidencing a brittle behaviour.

From Fig. 4a it is apparent that the timber-concrete composite system adopting the collar devices realizes an improvement of the bending behaviour as respect to the simple beam, in terms of both stiffness (ΔK, about 53 %) and strength (ΔF_{max}, about 119 %).

Shear (S) vs beam-to-slab slip (w) and shear (S) vs beam-to-collar slip (w) typical curves are shown in Fig. 5. Such curves are referred to the step 1, it being the most relevant phase, in fact in the second step, it being carried out up to collapse, the beam-to-slab LVDT were removed.

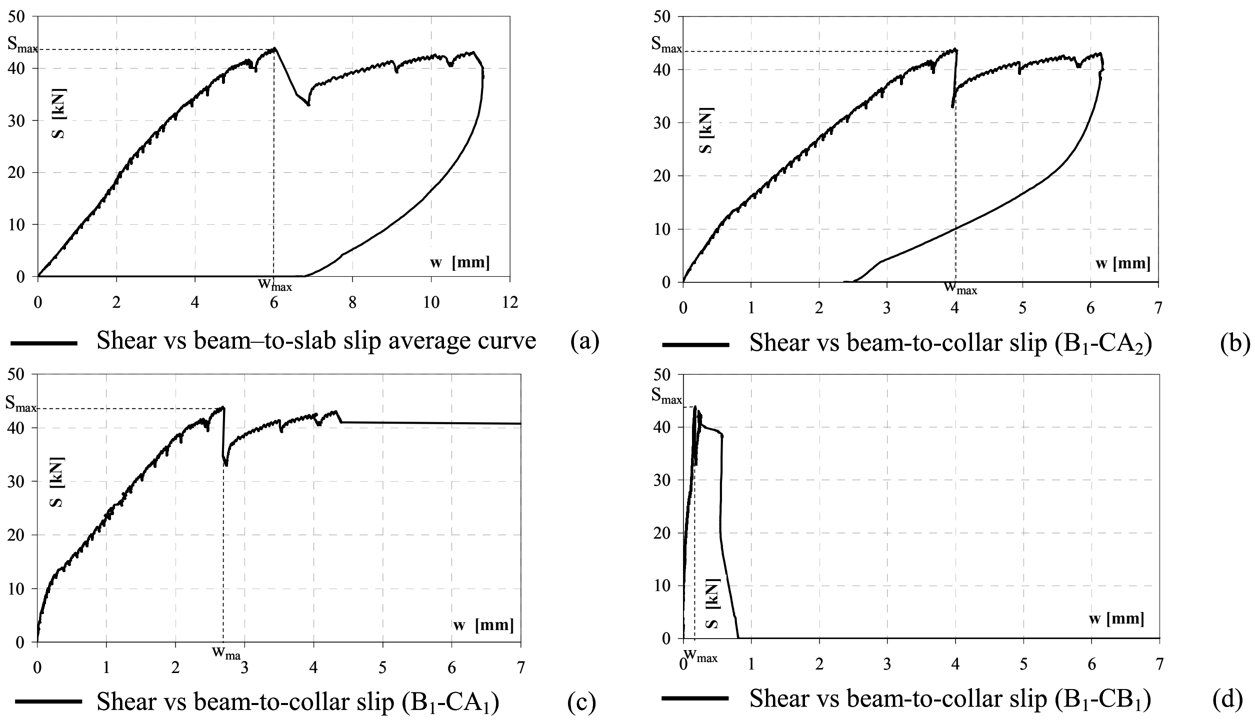

Figure 5: Bending test results: typical shear (S) – slip (w) curves

In particular, the beam-to-slab slips are plotted as average values of the ones related to both beams (Fig. 5a). The typical shear vs beam (B_i)-to-collar (C_i) slip curves are plotted with reference to the lateral (CA_1, CA_2) and central (CB_1, CB_2) collars (see Fig. 3), considering that the four lateral collars (CA_i, CC_i CD_i, CF_i) show a quite similar behaviour, as well as the two central collars (CB_i, CE_i). It is worth noticing that in any case the slip is very small: the beam-to- slab slip reaches about 6 mm (Fig.

5a); the lateral beam-to- collar slip reaches about 4 mm (Fig. 5b), it is even smaller at the middle axes of the beam (Fig. 5c) and close to zero at the central collar (Fig. 5d). In addition, the maximum shear (S) and the related slip are the maximum values obtained before the sudden load decrease, corresponding to the maximum applied force (F). The difference of about 1.5mm between the beam–to-slab and the beam-to-collar displacements can be ascribed to the presence of the gap between the slab and the beam, where the wooden planks are located.

It has to be evidenced that the slip at each collar is always smaller than the ultimate one determined from the push-out test of a single connection systems, which is equal to about 5mm, and it is reached for larger force values. Therefore, the failure is due to the attainment of the ultimate bending strength of the timber beam before the slip resistance at the beam-to-collar contact surface is reached, as the experimental evidence highlighted.

Conclusions and Future Developments

The collar connection system under study for composite timber-concrete floors appears to be very promising both in principle and in practice. In fact, it provides an improvement of the structural capabilities, as respect to the simple timber beam, larger more than 2 times in terms of strength and more than 1.5 times in terms of stiffness, together with a very ductile behaviour. In addition, the collars avoid to drill the beams and apply a ringing action to them.

These observations encourages further study for the development of such a new technology. So, future research activity should consists in additional experimental tests on composite systems, with different geometrical features, aiming at achieving an exhaustive number of tests for the complete characterization of the system behaviour. At the same time numerical simulations of the tests should be performed, leading to parametrical study necessary for the definition of design criteria and requirements. The research and applications are in progress in these directions.

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