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Modeling of timber floors strengthened with seismic improvement techniques

Modelowanie stropów drewnianych wzmocnionych metodami zwiększającymi wytrzymałość sejsmiczną

Key words: timber floor, in-plane behaviour, FEM, connection, diagonals, seismic improvement

Słowa kluczowe: strop drewniany, praca w płaszczyźnie, MES, połączenie, przekątne, podniesienie wytrzymałości sejsmicznej

1. INTRODUCTION

Timber unidirectional floors, composed by floorboards orientated perpendicularly to the timber beams and connected with a couple of nails at each intersection, were traditionally used for the construction of horizontal diaphragms in historic structures and still often adopted in contemporary buildings [1], [2], [3]. Nevertheless, especially in seismic area, due to the low in-plane stiffness and the frequent lack of effective connections to the masonry shearwalls [4], [5], [6], existing timber floors cannot assure a suitable “box” behaviour [2], [3] and were often the cause of brittle collapses, mainly due to out-of-plane failures [7], [8]. Consequently, in the last decades, several research works have been focused on the characterization of the in plane behaviour of unstrengthened timber floors and on the identification of dry, efficient and compatible strengthening techniques [9], [10], [11], [12], [13], [14], as well as in the improvement of floor-to-wall connections [3], [10], [15], [16]. In this context, the study of the influence of deformable floors on the seismic behaviour of existing masonry buildings is underway, but still deserves further investigations, both

at experimental [2], [4], [12], [14] and numerical level [11], [14], [17], [18], in order to better understand the influence of type, number and deformation capacity of the connections between beams and floorboards, and the effect of possible strengthening techniques on the mechanical performance of the timber floor.

Laboratory push-out tests on assemblages with various arrangements and timber-to-board connections, and selected in-plane monotonic shear tests on scaled portions of timber floors in unstrengthened and strengthened conditions, constituted the basic data for the calibration of inelastic Finite Elements (FE) models. All specimens were made of spruce wood.

Four conditions including single and double boards connected with the bearing beams of the floor with $\varnothing 2,75 \times 60$ mm nails and/or $\varnothing 6 \times 100$ mm or $\varnothing 6 \times 120$ mm screws were preliminarily examined on a total of 12 subassemblies. Calibration of load-displacement curves was performed by modeling the connections of nail and screw with the beam and the boards with non-linear elastic elements.

Then, the effect of diagonals made of wood, steel or composite materials acting as in-plane stiffen-

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ing techniques on simple-boarding floor specimens (about $2.2 \times 2.2 \text{ m}^2$) were modelled. In particular, two unstrengthened specimens and five strengthened ones subjected to monotonic shear loading, as in [14], were examined. The strengthening was made of: wooden boards 150 mm wide with thicknesses of 25 and 50 mm; $40 \times 2 \text{ mm}^2$ punched steel strip (net area of 60 mm^2); $200 \times 0.165 \text{ mm}^2$ Carbon Fibre Reinforced Polymer (CFRP) and $170 \times 0.378 \text{ mm}^2$ Steel Reinforced Polymer (SRP).

Calibrated curves on experimental push-out test results were used. The glued connections with CFRP or the SRP diagonals were assumed as perfectly efficient [19] and modelled without any inelastic interface behaviour between the planking and the strengthening composite materials. The screw connections of the punched steel strip were calibrated directly on the data of the tested timber floor.

Based of the validated models, a preliminary parametric study including the variation of the axial stiffness of a theoretical diagonal strengthening intervention was carried out.

The main results are discussed in the following.

2. EXPERIMENTAL TESTING

Data collection and laboratory tests were performed to define the materials composing the specimens, the connections made with metal fasteners and the in-plane behaviour of the unstrengthened and reinforced timber floors.

2.1. Materials

The mechanical properties of the spruce wood used in the specimens were: 455 kg/m^3 as volume mass, 44 N/mm^2 as compressive strength, 66 N/mm^2 as flexural strength and an estimated longitudinal elastic modulus of 11000 N/mm^2 , as suggested in [20]. The Moisture Content (MC) of all timber components was measured according to UNI 9091 [21] after their construction and before carrying out the tests. The average MC was of 12%.

Tensile tests on the punched steel strip provided an average ultimate load of 24.51 kN, an ultimate tensile strength of 408 N/mm^2 and a modulus of elasticity of 210000 N/mm^2 .

Properties of composites were derived from the technical datasheets: CFRP had an equivalent dry thickness of 0.165 mm, a tensile strength of 2500 N/mm^2

and a modulus of elasticity of 230000 N/mm^2 ; SRP was made with Ultra-High Tensile Strength Steel (UHTSS) and had an equivalent dry thickness of 0.378 mm, a tensile strength of 3070 N/mm^2 and a modulus of elasticity of 190000 N/mm^2 . CFRP and SRP were glued to the floor specimens with epoxy resin by means the wet lay-up procedure commonly adopted for Externally Bonded Fibre Reinforced Polymers (EB-FRPs).

2.2. Push-out specimens

The steel connections, i.e., nails and screws, were characterized by means of push-out tests carried out according to UNI-EN 26891 [22] under loading control (Fig. 1). Nails and screws were spaced according to Eurocode 5 [23]. The specimens were built with four arrangements in order to reproduce the behaviour of the connections between the timber beams and floorboards used for floor segment specimens in unstrengthened and strengthened conditions, as in [14]. Three specimens for each condition were tested.

The push-out specimen PO.F1.M simulated the symmetric connection made by 8+8 nails $\text{Ø}2.75 \times 60 \text{ mm}$ between the beam $120 \times 140 \text{ mm}$ and the two basic boards 20 mm thick (Fig. 1a). The specimens PO.F2a.M (Fig. 1b) and PO.F2b.M (Fig. 1c) simulated the symmetric connection made by the former 16 nails plus that given by 8 + 8 screws $\text{Ø}6 \times 100 \text{ mm}$ (for PO.F2a.M) or $\text{Ø}6 \times 120 \text{ mm}$ (for PO.F2b.M) connecting two extra external boards 25 or 40 mm thick, respectively. The last two subassemblies represented the connections of the strengthening configurations made with one thick retrofitting planking or diagonal elements. The specimen PO.F3.M (Fig. 1d) simulated the symmetric connection used for the application of a second strengthening planking made with boards 25 mm thick above the first strengthening deck 25 mm thick.

According to Eurocode [23], the following main parameters were evaluated: maximum load at failure F_{\max} and maximum estimated load F_{est} , modified initial slip $v_{i,\text{mod}}$ and corresponding slip modulus $K_s = 0,4F_{\text{est}}/v_{i,\text{mod}}$. Results are given in Table 1 for a single nail (PO.F1.M) or for an idealized single screw (PO.F2a.M, PO.F2b.M and PO.F3.M), thus assuming preliminarily that the weakest sliding plane between boards was always the most external one.

The global response of the push-out specimens is shown in Fig. 2 (FE modeling curves are discussed in section 3). The connections showed a good initial stiff-

Table 1. Average results for push-out tests

	PO.F1.M	PO.F2a.M	PO.F2b.M	PO.F3.M
Type of connection	nails $\text{Ø}2,75 \times 60$	nails $\text{Ø}2.75 \times 60$ + screws $\text{Ø}6 \times 100$	nails $\text{Ø}2.75 \times 60$ + screws $\text{Ø}6 \times 120$	nails $\text{Ø}2.75 \times 60$ + screws $\text{Ø}6 \times 120$
F_{\max} (N)	571	2075	2273	1970
F_{est} (N)	592	2254	2324	2021
$v_{i,\text{mod}}$ (mm)	0.476	2.442	1.914	3.279
K_s (N/mm)	588	378	503	264

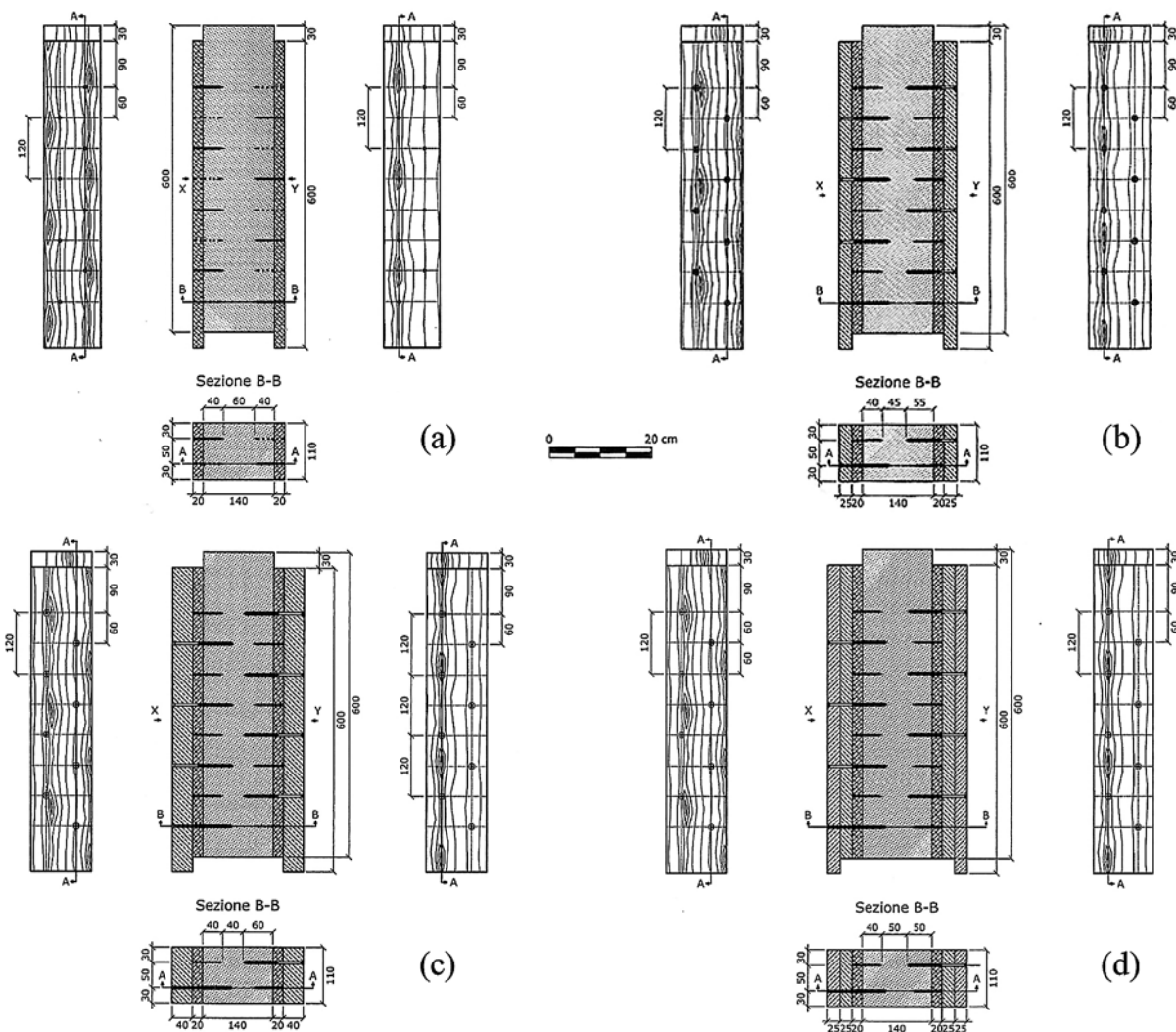


Fig. 1. Push out specimens: (a) PO.F1.M, (b) PO.F2a.M, (c) PO.F2b.M and PO.F3.M

ness, followed by a pseudo plastic branch, due to the yielding of the nails or screws at interfaces and/or the splitting of the boards. In the case of PO.F1.M the nail connection worked mainly under pure shear (Fig. 3a), whereas in the PO.F2a.M, PO.F2b.M and PO.F3.M, due to the presence of multiple boards, the connections worked mainly under a combined shear-bending stress-state. They showed the rope-effect, which at the end caused some splitting failures of the strengthening boards (Fig. 3b, c and d).

2.3. Floor specimens

Seven floor specimens were tested under monotonic shear loading with a set-up formerly implemented at the Department of Civil, Architectural and Environmental Engineering of the University of Padova [14], [24]. The specimen were positioned in a steel hinged quadrilateral, able to restrain out-of-plane movements and to reproduce a 2D vertical cantilever beam. The steel reaction beam, to which is fully connected the first timber beam of the floor, was connected to the steel basement trough three load cells with mechanical slid-

ing connections, thus providing two vertical and one horizontal simple supports. The tests were performed in displacement control. Displacement transducers were used to record horizontal, vertical and diagonal relative movements (Fig. 4) [14], [24].

Two specimens, FMSB and FM, were unstrengthened. They were representative of south-European mono-directional floors, composed by simple supported timber beams and a transversal planking. The specimens (about $2.2 \times 2.2 \text{ m}^2$), were built with components in real size: five beams $120 \times 140 \text{ mm}$ in section at 500 mm off-centre and a basic boarding 135 mm wide and 20 mm thick were used. Each floorboard was joined to every beam by means of 2 nails $\text{Ø}2.75 \times 60 \text{ mm}$, for a total of 32 nails per each beam, 10 nails per each floorboard and a total number of 160 nails per floor. Specimen FMSB was made with common raw-finished floorboards, whereas FM had a tongue-and-groove shaped connection in the floorboard thickness.

Five floor specimens were strengthened with diagonals made of various materials or arrangements.

Specimen FMWD(25) refers to a single timber diagonal strengthening. The diagonal was made of

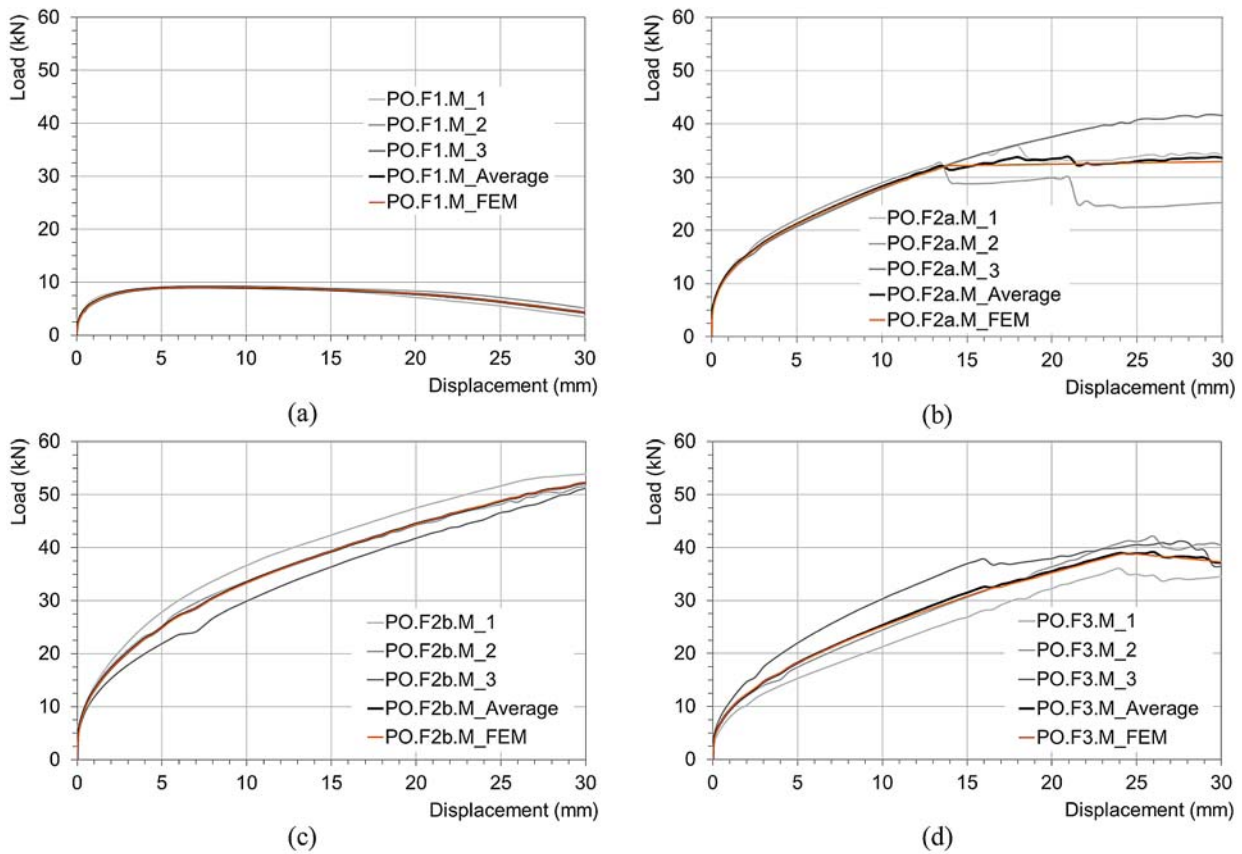


Fig. 2. Experimental behaviour of PO.F1.M (a), PO.F2a.M (b), PO.F2b.M (c) and PO.F3.M (d)

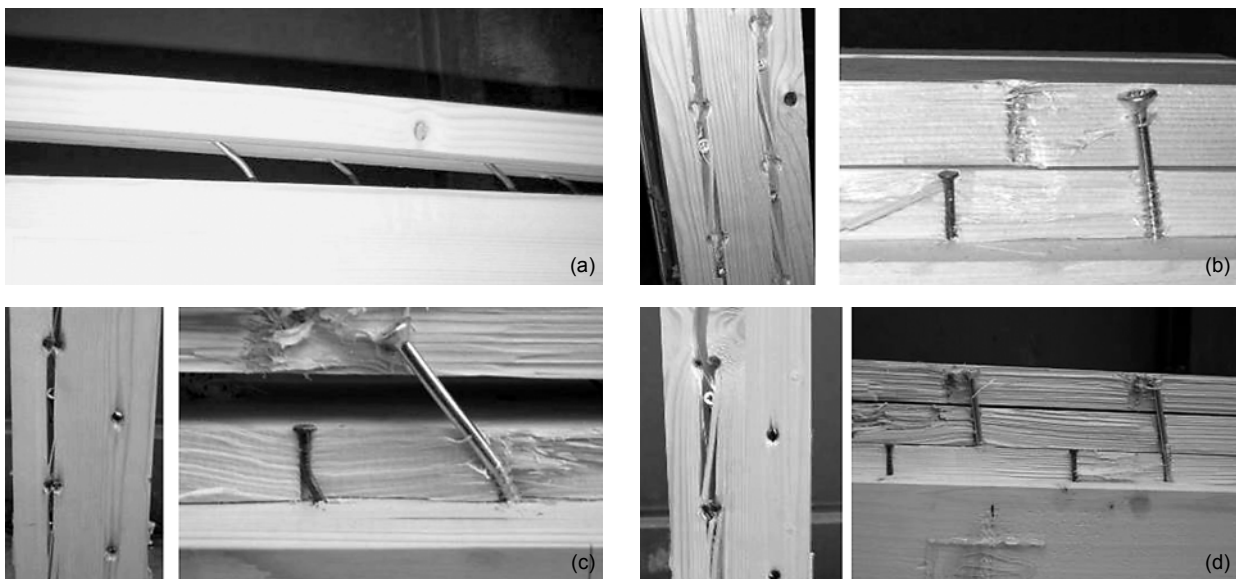


Fig. 3. Failure modes of PO.F1.M (a), PO.F2a.M (b), PO.F2b.M (c) and PO.F3.M (d)

a single large plank, 150 mm wide and 25 mm thick, connected with 2 screws $\text{Ø}6 \times 100$ mm per each beam and placed over a similar basic deck of FM. The specimen was loaded so that the diagonal plank was mainly subjected to a tensile force.

Specimen FMWD(50) was strengthened with a double timber diagonal, obtained with 2 thicker planks, 150 mm wide and 50 mm thick, connected with 2 screws $\text{Ø}6 \times 120$ mm per each beam. At the centre of

the specimen, the planks were overlapped with a half lap joint. Consequently, the central cross section (150 by 25 mm) of the two diagonal planks of FMWD(50) had the same cross section of the single diagonal board used in FMWD(25). In this specimen one diagonal was mainly loaded in compression and one in tension.

Specimen FMSD was strengthened with a diagonal punched steel strips 40 mm wide and 2 mm thick (net area of 60 mm^2), which was connected to every beam

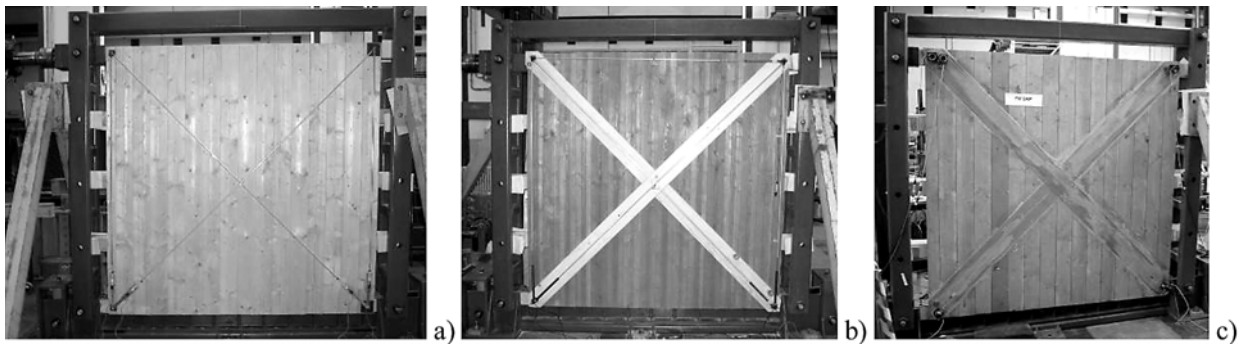


Fig. 4. View of some specimens under testing: FM (a), FMWD(50) (b), FM.SRP.D (c)

by means of 2 screws $\text{Ø}6 \times 80$ mm. The specimen was loaded so that the diagonal steel strip was subjected to a tensile force. In fact, under compressive force the steel strip tends to buckle in between two sets of screws,

thus becoming ineffective. The axial stiffness of the steel diagonal was equivalent to that of the central cross section of the diagonal timber planks (150 by 25 mm) of FMWD(25) and FMWD(50).

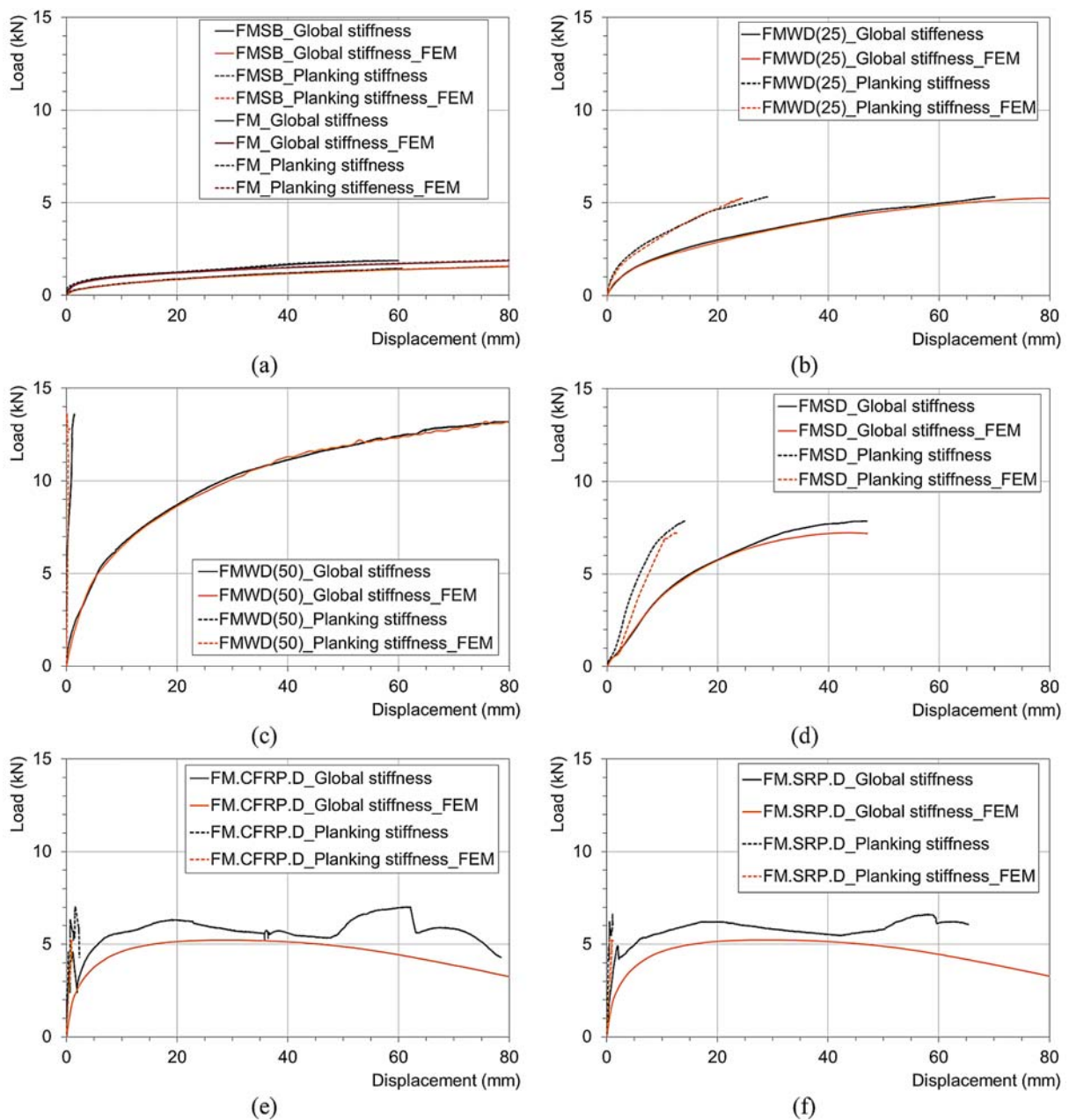


Fig. 5. Comparison of experimental versus numerical global and planking stiffness curves of floors

Specimens FM.CFRP.D and FM.SRP.D were strengthened with CFRP and SRP, respectively. The equivalence in terms of tensile axial stiffness was kept also in this case, by designing the width of the composite material. Moreover, it is worth mentioning that the wet lay-up procedure might have reasonably helped in gluing not only fibres to floorboards, but also boards to boards by filling the gaps with the epoxy primers and resins. This is itself an improvement of the in-plane capacity of the basic deck, besides the strengthening given by the fibres.

The in-plane experimental test results are widely discussed in [14], [24]. Specimens FMSB and FM showed a relative rotation between boards and beams at failure. Due to the friction of the tongue-and-groove connection, a slightly better performance was observed for FMSB. In the specimen FMWD(25), the single diagonal plank working mainly in tension was able to improve the performance of the basic floor. The combination with an additional wooden diagonal, as in FMWD(50), further improved the performance, due to the simultaneous contribution in compression. For both diagonal strengthening methods the failure occurred at the screws connecting the thick planks to the beams. Specimen FMSD (punched steel strip) showed an intermediate behaviour between FMWD(25) and FMWD(50) ones. Specimens FM.CFRP.D and FM.SRP.D provided similar maximum loads to FMSD, but a much higher initial stiffness (Fig. 5).

UNI EN 12512 standard [25] was used to analyse the in-plane results, since it is applicable to general timber structure built with metal fasteners [14], [24]. The measured data at the intrados of the floors (thus including all the inelastic behaviours) were considered, since they represent the global stiffness of the specimens and permit a more conservative type of analysis. In fact, not always it is possible to resort on the in-plane planking stiffness, due to the common lack in existing buildings of adequate boundary connections [2], [3], [5]. Fig. 5 shows both type of curves, for a comprehensive calibration of the inelastic FE models (details on the modeling are given in section 3). Table 2 lists the results in terms of global behaviour: F_{max} is the maximum load at the displacement V_{max} (equal 30 mm

for the current tests); F_y is the estimated load at yielding recorded by the global transducers and V_y is the correspondent displacement; K_y and K_u are the global initial and ultimate stiffness values, respectively. Results showed that the double wooden diagonal was the most efficient intervention in terms of strength, while the application of composite materials resulted in a much stiffer in-plane behaviour, especially in the elastic branch. This was likely due to the stiffer response of the glued connection made by the epoxy resins [14].

3. NUMERICAL ANALYSES

Numerical models were developed to reproduce the behaviour of the push-out tests, thus to calibrate the inelastic response curves of the steel (nail and screws) connections presented in section 2.2. The calibrated behaviour of the connections was then used for modelling the in-plane behaviour of unstrengthened and diagonally reinforced timber floors. The beams and the steel strip were modelled with two-node beam elements. Four-node shell elements were used for boards and composites. Nails and screws connections were modelled by non-linear elastic connection elements, which are practically spring elements with six Degrees of Freedom (DoF).

These elements served as an inelastic interface between all the construction elements (beams, boards, strips and composites) composing the floors [24]. Lastly, the connection elements were joined to the beams through rigid-link elements to respect the geometry of the fastening and supply the average experimental lever arm between steel connectors. The frictional effect between boards was modelled again by means of connection elements with a simple symmetric elasto-hardening behaviour [24]. Fig. 6 shows a schematic of the modelling strategy applied to the

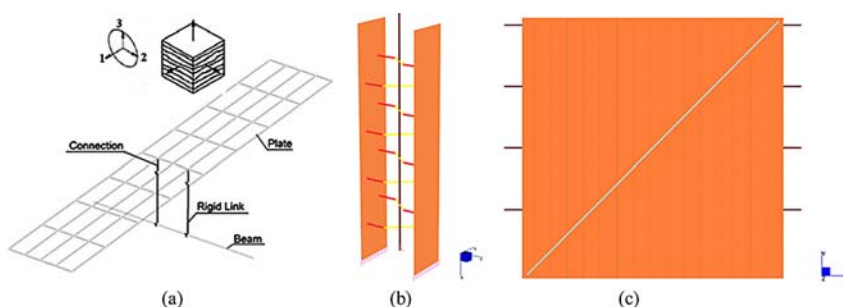


Fig. 6. Numerical model: (a) detail of connection between board and beam, (b) general view of PO.F1.M push-out model, (c) plane view of FMSD model extrados

Table 2. In-plane average global mechanical properties of timber floors

Sample	F_{max} (kN)	F_y (kN)	V_{max} (mm)	V_y (mm)	K_y (kN/mm)	K_u (kN/mm)
FMSB	1.05	0.77	30	8.61	0.08	0.01
FM	1.44	0.90	30	2.67	0.29	0.02
FMWD(25)	3.60	2.91	30	10.08	0.27	0.05
FMWD(50)	10.25	7.41	30	8.34	0.80	0.13
FMSD	7.05	6.11	30	14.93	0.41	0.07
FM.CFRPD	6.34	3.16	22.02	1.59	1.85	0.31
FM.SRPD	6.22	3.74	22.76	2.28	1.50	0.25

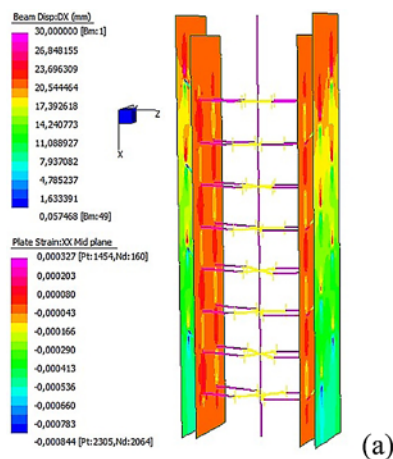
push-out PO.F1.M and the floor FMSD specimens. The beams and the boards were modelled with the same orthotropic linear elastic material and by assuming the following properties for spruce wood: $E_1 = 11000 \text{ N/mm}^2$ as longitudinal elastic modulus; $E_2 = E_3 = 367 \text{ N/mm}^2$ as transversal elastic moduli; $G_{12} = 687 \text{ N/mm}^2$ as shear modulus; $\nu_{12,13} = 0.46$ and $\nu_{21,31} = 0.03$ as Poisson coefficients.

3.1. Push-out samples

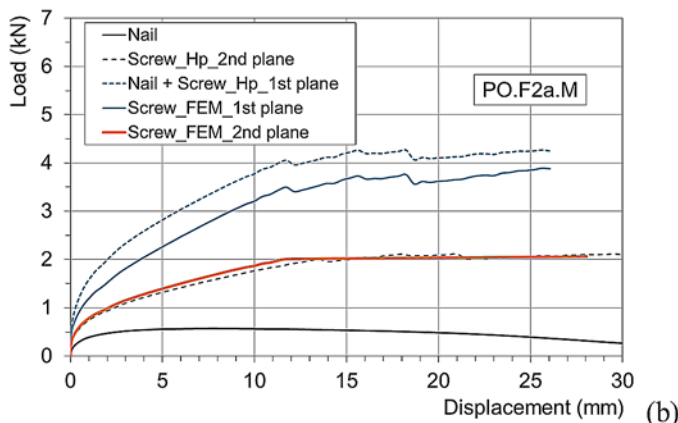
The FE model of PO.F1.M was constructed according to the modelling strategy discussed above. The con-

nection given by every single nail was modelled with a connection element described with an inelastic curve, corresponding to the average experimental response of the three specimens PO.F1.M (Fig. 2a) divided by 16, which is the number of nails per each specimen. As expected, the numerical outcome matched the experimental curve.

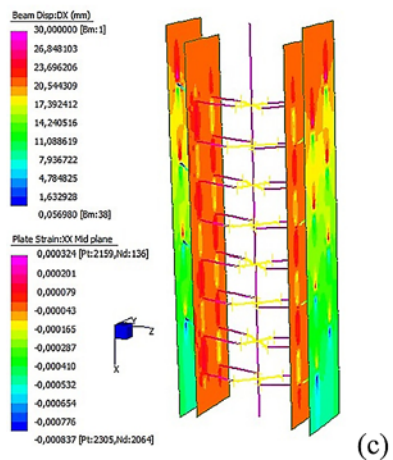
The numerical models of PO.F2a.M, PO.F2b.M and PO.F3.M were slightly more complex, due to the extra layers of boards added above the basic boarding. The connectivity between the layers of boards was made again with connection elements (Fig. 7). For the



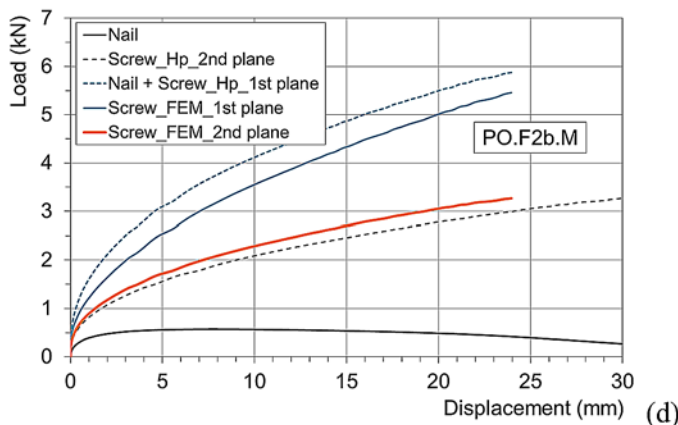
(a)



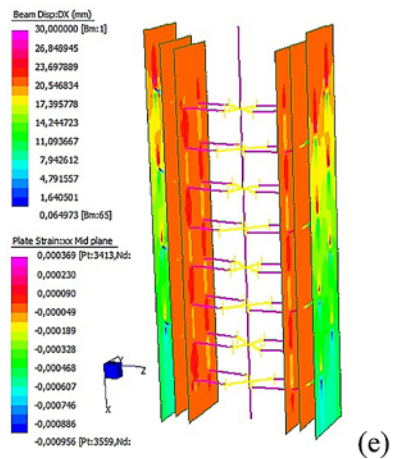
(b)



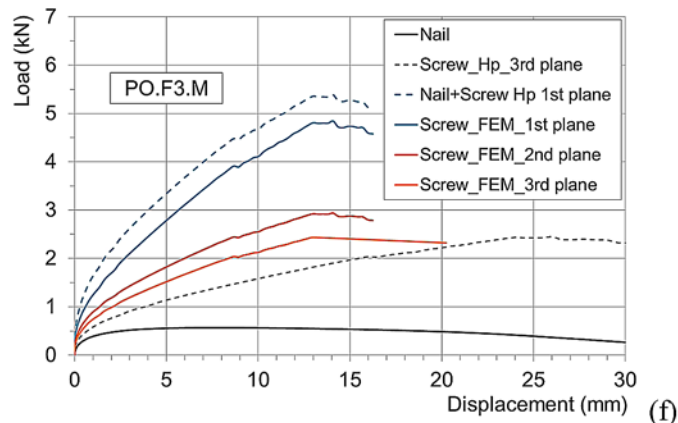
(c)



(d)



(e)



(f)

Fig. 7. Stresses along wood fibres of FE models at 30 mm displacement and calibrated curves for steel connections at different planes: PO.F2a.M (a, b), PO.F2b.M (c, d) and PO.F3.M (e, f)

PO.F2a.M and PO.F2b.M there were two main groups of connection elements belonging to two distinct planes: the first located between the beam and basic boarding, the second between the basic boarding and the strengthening board. For the PO.F3.M there was just an extra third plane of elements, due to the second strengthening board.

The calibrated curve from PO.F1.M was assigned to the connection elements simulating the nails whereas, for the connection elements simulating the screws, a dedicated curve was assigned per each plane. Each curve was calibrated according to an iterative procedure.

For the FE model PO.F2a.M (Fig. 7a,b), firstly the average experimental curve of the push-out test divided by 16 (n. of screws) was assigned as the hypothetical curve simulating one $\text{Ø}6 \times 100$ mm screw of the second plane. The hypothetical curve of the nails plus screws of the first plane was obtained as the average experimental curve divided by 16 and multiplied by the ratio of the shear capacities of the two planes, computed according to the Johansen's theory [23]. Secondly, the curve for the screws of the first plane was obtained by subtracting that of nails, while the curve for the screws of the second plane was iteratively made stiffer until matching the experimental data (Fig. 2b). The calibration process for PO.F2b.M exactly followed that of PO.F2a.M (Fig. 2c; Fig. 7c,d). For PO.F3.M the procedure was slightly longer, since a third plane was added. Few more iterative calibration steps among the three planes of connection elements were carried out until the numerical curve matched the average experimental data (Fig. 2d; Fig. 7e,f). The modelling strategy demonstrated to be simple, robust and easy to calibrate once experimental data and failure mode for push-out tests are available.

3.2. Floor samples

The calibrated curves from the push-out tests were assigned to the nail and screws steel connections. The glued connections between floorboards and the CFRP or the SRP diagonal reinforcements were modelled as perfectly efficient and modelled without any inelastic interface connection element, but with rigid links. The connections of the punched steel strip to the floorboards were directly calibrated on the data of the timber floor by means of a trial and error process. For all the other connection elements the formerly calibrated curves were used. The composite materials were modelled as elastic orthotropic materials and the steel strip as an elasto-plastic material.

The estimations of the models were compared with the experimental results obtained from the displacement transducers, in order to check the ability of each model in fine describing the in-plane behaviour of the unstrengthened and strengthened floors [24]. Results are concisely reported by the lateral load versus displacement curves at the global and planking levels.

As shown in Fig. 5, the FE models were all able to match very well the experimental curves representing the in-plane stiffness at the global (intrados) and planking (extrados) planes. The models correctly described the behaviour of the basic specimens FMSB and FM, and confirmed that the in-plane strength and stiffness of basic floors was mainly given by the number of nails, their mutual spacing and, possibly, the additional friction between boards [24]. The offset in the curves of Fig. 5a was directly connected to the friction provided by the tongue and groove finish, which contributed in resisting against the relative slide of the floorboards (Fig. 8a). The curves of specimens FMWD(25), FMWD(50) and FMSD were also nicely reproduced and the stress contours (Fig. 8b, c, d) made explicit the strut and tie mechanism characterizing the efficiency of these strengthening techniques. The numerical response of FM.CFRPD and FM.SRPD was very satisfactory. Anyhow, the models had some difficulties in simulating the glued connection made by the epoxy resins. The gap between the numerical and experimental curves may be related to the effect of gluing of the resins between the boards. Nevertheless, also in these cases, the model correctly depicted the deformed shape at failure.

3.3. Preliminarily parametric study on the variation of stiffness of diagonal strengthening

The influence of the axial stiffness of the diagonal strengthening on the in-plane response of timber floors was further examined by means of a preliminary parametric study. The numerical model of a floor strengthened with a theoretical diagonal, FMDTH, was constructed using the calibrated data of the FM specimen. The theoretical diagonal strengthening was made with a strip having a cross section of 50×2 mm² and a elastic modulus varying from 100 to 10000 N/mm², so that the axial stiffness (A_s) spanned from 10 kN to 10 MN. The strip was fully fixed to the planking via rigid connections resembling a glued connection.

Results showed that the global and planking stiffness curves started diverging after an axial stiffness of the diagonal above 150 kN (Fig. 9). Several of the experimental curves were above this value. This might be relevant for deciding at which strengthening level starting improving the connections within the timber floor and adding connection from the planking to the side walls. Moreover, the analysis pointed out the transition from an almost purely shear deformation of the floor for A_s smaller than 20 kN to an almost rocking rotation of the planking for an A_s larger than 10 MN. In between these two limits for A_s , there is a combination of the two deforming modes (see for instance Fig. 8b for FMWD(25) that resemble an A_s of 500 kN) and a progressive reduction of the failed nails connecting the boards to the beams.

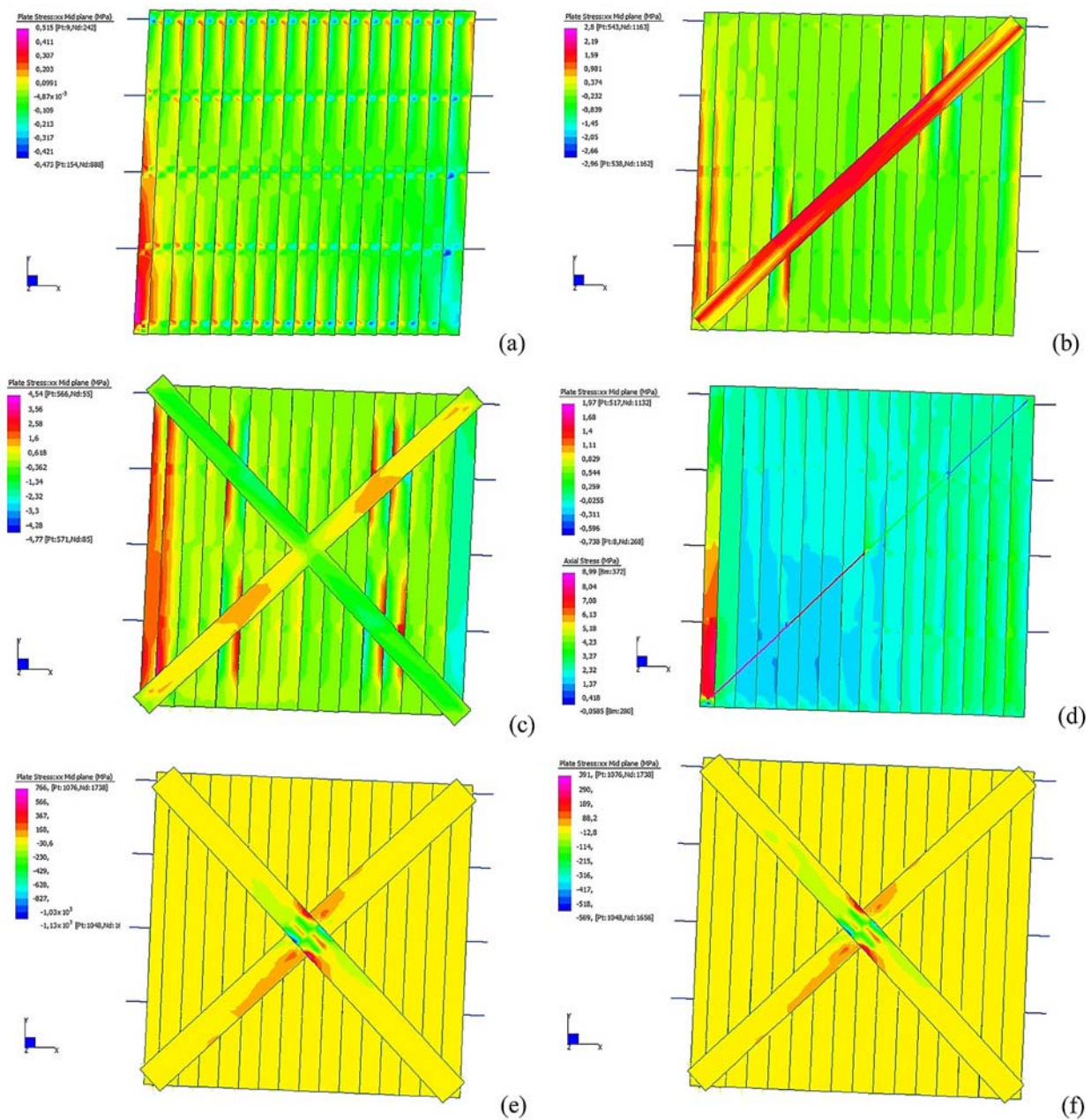


Fig. 8. Stresses along wood fibres and deformed shape of FE floor models at ultimate displacement: FM (a), FMWD(25) (b), FMWD(50) (c), FMSD (d), FM.CFRP.D (e), FM.SRP.D (f)

4. CONCLUSIONS

The relevant experimental results of a wider experimental campaign aimed at characterizing the shear behaviour of steel connections and the in-plane behaviour of timber floor specimens strengthened with diagonals made of various materials and arrangements were discussed.

A simple numerical modelling strategy for the implementation of FE models of unstrengthened and diagonally strengthened mono-directional timber floors was developed. The constitutive material models for the steel connections were derived from push-out tests on subassemblies.

The floor FE models correctly simulated the experimental data. The models were all able to match very well the experimental curves of the in-plane stiffness at the global (intrados) and planking (extrados) levels. Moreover, they correctly captured the deformed shapes along the loading steps of all floor specimens.

A simple parametric study was carried out concerning the variation of the axial stiffness of the diagonal strengthening. Results pointed out the transition in the failure and deformation modes as a function of the axial stiffness of the diagonal strip.

Further developments may concern the extension of the study to various dimensions and shapes of floors to which usually refer common buildings, to be used

as reference for design of floors and their possible in-plane improvement with strengthening techniques.

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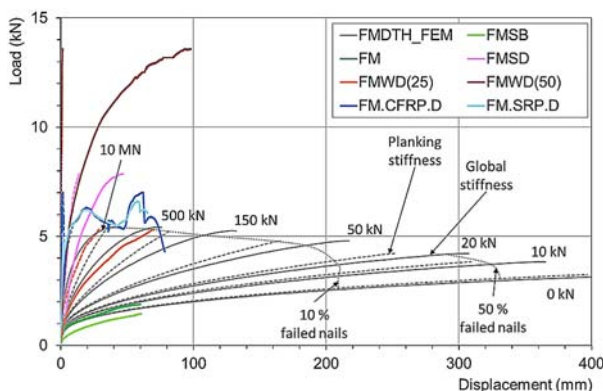


Fig. 9. Comparison between parametric curves of the theoretical floor FMDTH and those experimental

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Abstract

Timber floors in existing buildings often require the adoption of stiffening techniques to improve their behaviour under horizontal actions. Modelling of such structural elements taking into account the influence of type, number and deformation capacity of the connections between beams and boards is quite complex and still under development.

Starting from laboratory experimental results carried out on assemblages (sliding tests on timber-to-board connections) the paper focuses on the calibration of inelastic FE models aimed at reproducing the mechanical behaviour of floor specimens subjected to in-plane monotonic tests. Single and double boards connected with the bearing beams of the floor with nails and/or screws were examined on subassemblies. As regards floors, the effect of wood, punched steel strips or composite (CFRP or SRP) diagonals as stiffening techniques were studied.

A simple parametric study including the variation of stiffness of a theoretical diagonal was performed. Results constitute a preliminary set of data that may be used for design of possible improvement techniques to be applied on existing timber floors.

Streszczenie

Stropy drewniane w istniejących budynkach często wymagają zastosowania rozwiązań usztywniających, aby poprawić ich pracę w warunkach naprężeń poziomych. Opracowywanie modeli takich elementów konstrukcyjnych, z uwzględnieniem oddziaływania rodzaju, liczby i odkształcalności połączeń pomiędzy belkami a deskami, stanowi złożone zadanie i jest rozwijającym się obszarem badawczym.

Prezentując wyniki testów laboratoryjnych, przeprowadzonych na przygotowanych modelach fragmentów stropów drewnianych (testy ślizgowe dla połączeń belka-deska), artykuł koncentruje się na kalibracji nieelastycznych modeli elementów skończonych, mających na celu odtworzenie pracy mechanicznej stropów poddanych monotonicznym próbom obciążenia w płaszczyźnie. Badane próbki były zbudowane z belek nośnych, do których deski były przymocowane po jednej lub po obydwu stronach za pomocą gwoździ i/lub wkrętów. Badano wpływ zastosowania na stropach przekątnych elementów usztywniających wykonanych z drewna, perforowanych pasów stalowych lub materiałów kompozytowych (CFRP lub SRP).

Przeprowadzono proste badanie dotyczące parametrów z uwzględnieniem zmiennej sztywności teoretycznych przekątnych. Jego wyniki stanowią zbiór wstępnych danych, które mogą zostać wykorzystane w projektowaniu ewentualnych rozwiązań wzmacniających do zastosowania na istniejących stropach drewnianych.