Innovative Timber Composites:
Improving wood with other materials

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Introducing other material to increase seismic resistance

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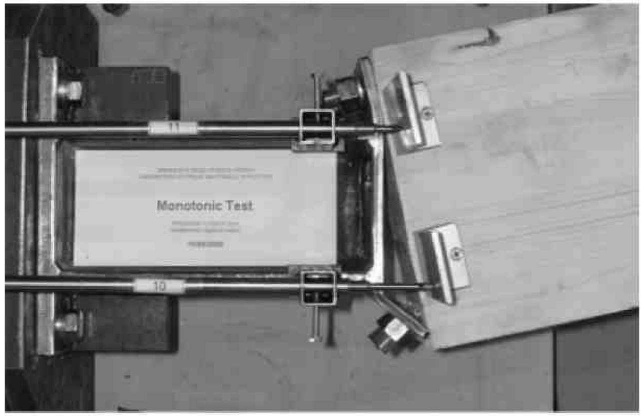
Increasing seismic performance of new timber structures

Although timber, thanks to the excellent ratio between strength and density, has been traditionally considered an interesting building material for earthquake resistant structures, compared to other building materials (steel or reinforced concrete), it shows a brittle behavior, with a poor attitude to dissipate energy.

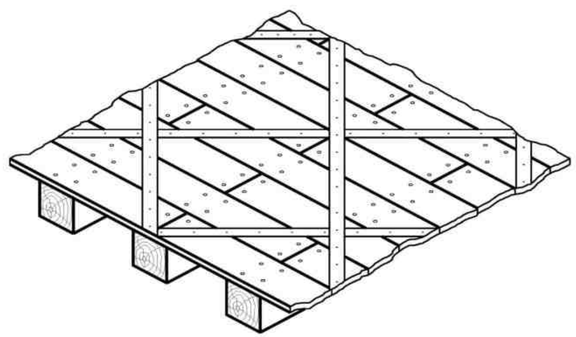
The difficulty to obtain energy dissipation in timber elements prompted the use of design approaches achieving some structural ductility via plastic deformations occurring in metallic joints manufactured with dowel-type mechanical connectors (e.g. dowels, nails, screws, and bolts).



Increasing seismic performance of old timber structures

Old timber floors often need strengthening and stiffening as they were designed to bear moderate loads and may suffer from excessive deflections with respect to current requirements. In case of lateral seismic forces, whereas the floor is not satisfactorily connected to the adjacent walls, or the in-plane stiffness is inadequate, different collapse modes involving overturning of the walls may be observed.

Learning from the effect of past earthquake on reinforced existing building, some floor refurbishment techniques have been reconsidered investigated in an experimental campaign both in laboratory and in situ.



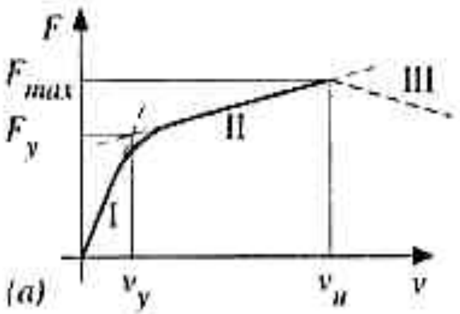
Timber structures in seismic zones
Advantages

•**Mechanical efficiency**

Material	f_k/ρ (m^2/s^2)	E/f_k
Glulam (GL24, f_k = 24 MPa)	~63.000	~480
Glulam (GL24, f_k = 36 MPa)	~80.000	~400
Concrete (R_{ck}30, $f_{ck} \approx$ 25 MPa)	~10.400	~1.200
Steel (f_k = 430 MPa)	~55.000	~480
Aluminium ($f_k \approx$ 355 MPa)	~130.000	~200

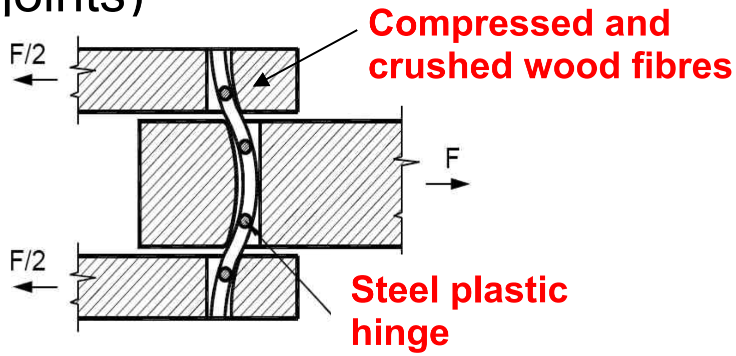
Lightness
Strength
Stiffness

•**Energy dissipation capacity**



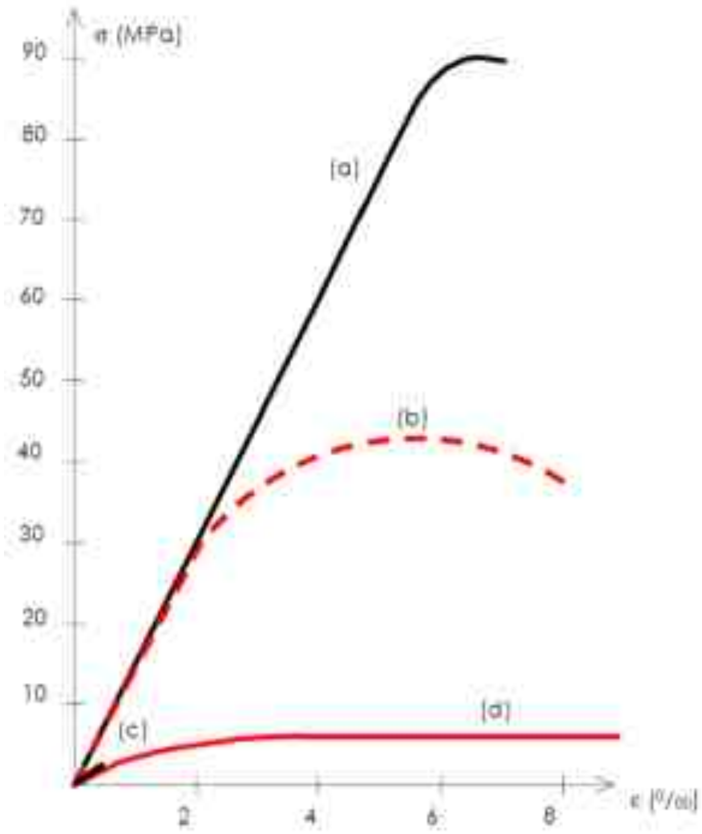
$$D_s = \frac{v_u}{v_y}$$

(Ductility concentrated in joints)



Timber structures in seismic zones

Disadvantages



Brittle behaviour in tension

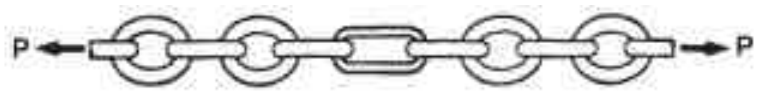
Some plastic resources in compression

⇨ **The global behavior of a timber beam is brittle**

a) Tension parallel to the grain
b) Compression parallel to the grain
c) Tension perpendicular to the grain
d) Compression perpendicular to the grain

Ductility in timber structures: rules of connections

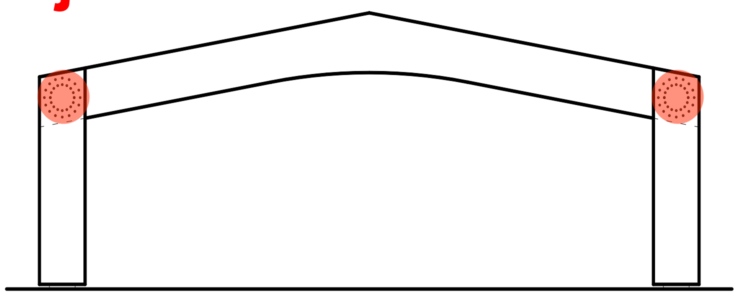
The weakest link rule



weakest component = ductile behaviour

strongest component = brittle behaviour

Dissipation concentrated in joints



Eurocode 8 EN 1998-1: 2005 8.1.3 (4)P
"Dissipative zones shall be regarded as located in joints and connections, *whereas the timber members themselves shall be regarded as behaving elastically.*"

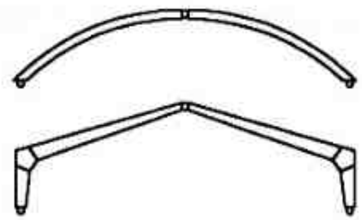
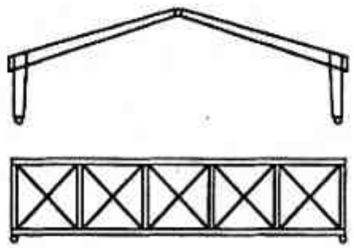
Timber structures in seismic zones

DUCTILITY FACTORS DEPENDING FROM THE STRUCTURAL TYPOLOGY

Heavy timber structures →

Light timber structures →

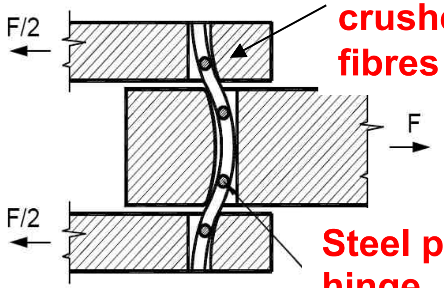
Eurocode 8 EN 1998-1: 2005

	ACTION REDUCTION FACTOR Q	EXAMPLES OF STRUCTURES	
A STRUCTURES HAVING LOW CAPACITY OF ENERGY DISSIPATION	1,5		STATICALLY DETERMINATE STRUCTURES
B STRUCTURES HAVING MEDIUM CAPACITY TO DISSIPATE ENERGY	2 – 2,5		HYPERSTATIC PORTAL FRAMES, TRUSSES WITH BOLTED JOINTS
C STRUCTURES HAVING GOOD CAPACITY TO DISSIPATE ENERGY	3 - 5		WALL PANELS WITH NAILED DIAPHRAGMS, CONNECTED WITH NAILS AND BOLTS

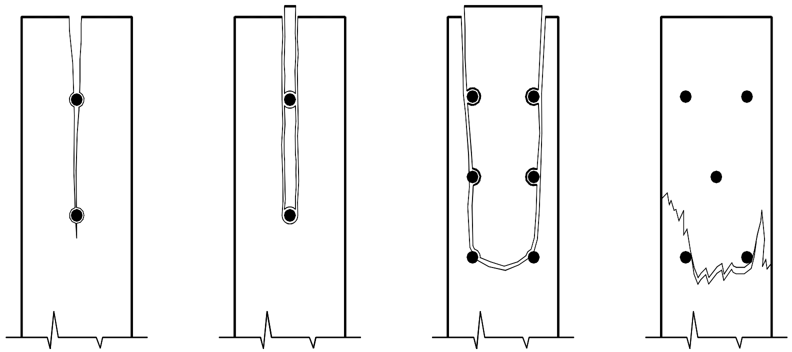
Ductility in timber structures: rules of connections

Dowel type connector

Exploiting the ductile mechanism (steel plastic hinge)



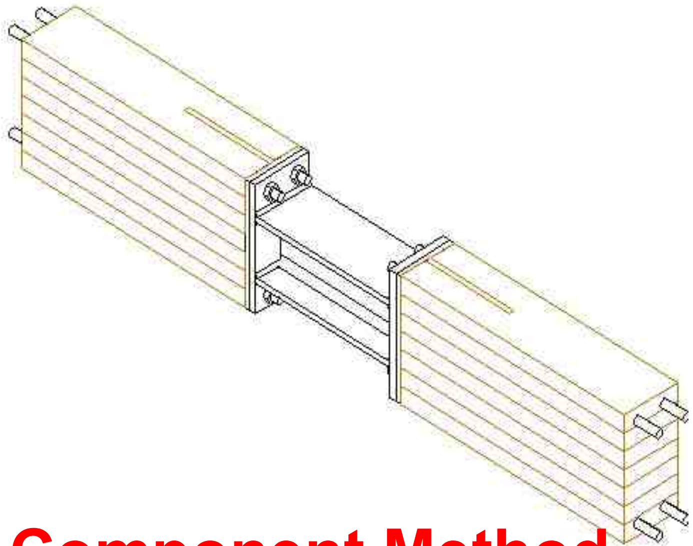
Avoid brittle behaviour non forecasted by the model



Glued in bar connectors

Ductile design exploiting the yielding of steel bar, avoiding other brittle mechanism (pull out of the bar)

Steel end plate joint in steel – to – timber connection



Design parameters

- thickness of the steel end plate
- geometry of the steel profile
- geometry of the glulam beam

Mechanical properties of the joint to be investigated

Component Method

Experimental analysis

- BENDING MOMENT $M_{j,Rd}$
- ROTATIONAL STIFFNESS S_j
- ROTATIONAL CAPACITY ϕ_{Cd}

Possibility to conceive different joint configurations, where the high resistance capacity of the single glued steel rod can be exploited to favour the ductile behaviour of the end plate connection

Steel end plate joint in steel – to – timber connection

The component method applied to steel-to-timber connections

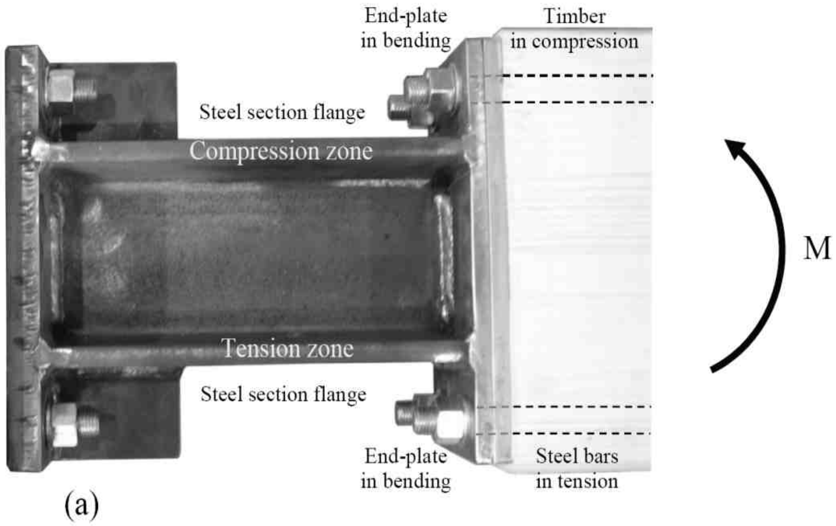
Taking into account the particular conception of the joint, in which the steel components play a fundamental role, the component method for semi-rigid joints in steel framework, can be adapted in order to carry out a feasible general model.

Method steps

STEP 1: identification of the base component of the joints

STEP 2: characterisation of the relevant mechanical properties (resistance, stiffness and deformation capacity)

STEP 3: assembly of the mechanical properties of the components in order to determine the resistance and the stiffness, and rotational capacity

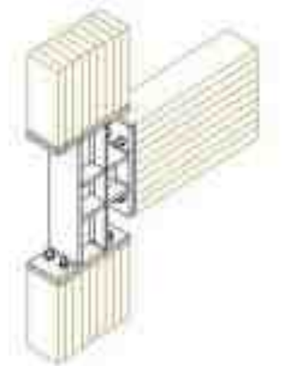


(a)

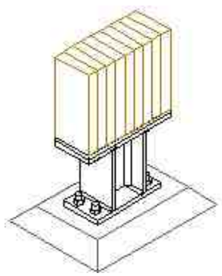
$$M_{j,Rd} \quad S_{j,ini} \quad \phi_{Cd}$$

POSSIBLE END USES

BEAM-COLUMN JOINT

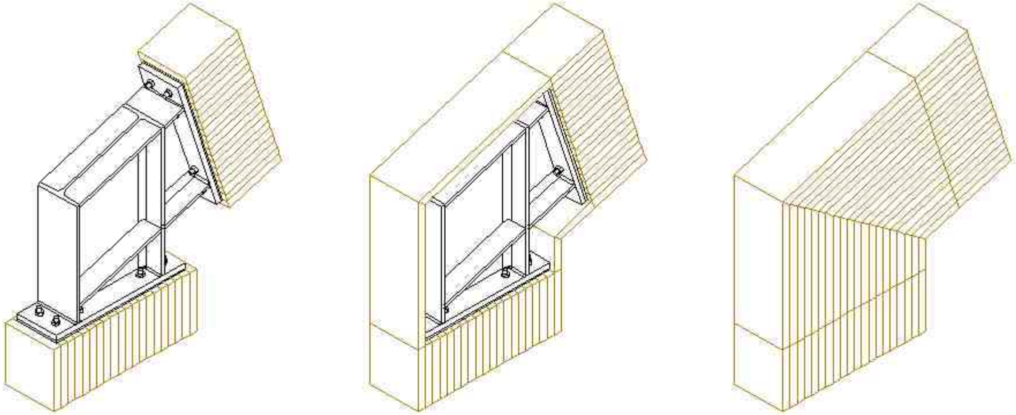


FOUNDATION FIXED JOINT



CHARACTERIST:
- pre-fabricated
- easy and fast assembly
- possibility of different joint configurazion

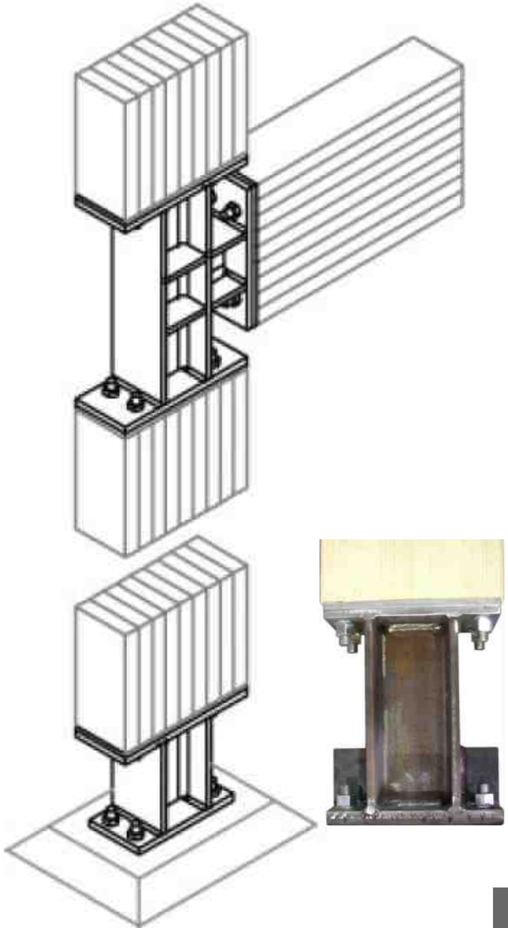
CORNER JOINT IN TIMBER FRAME



Sheathing of the joint
- estetical reason
- fire protection
- inspections are possible

Increasing seismic performance of timber structures

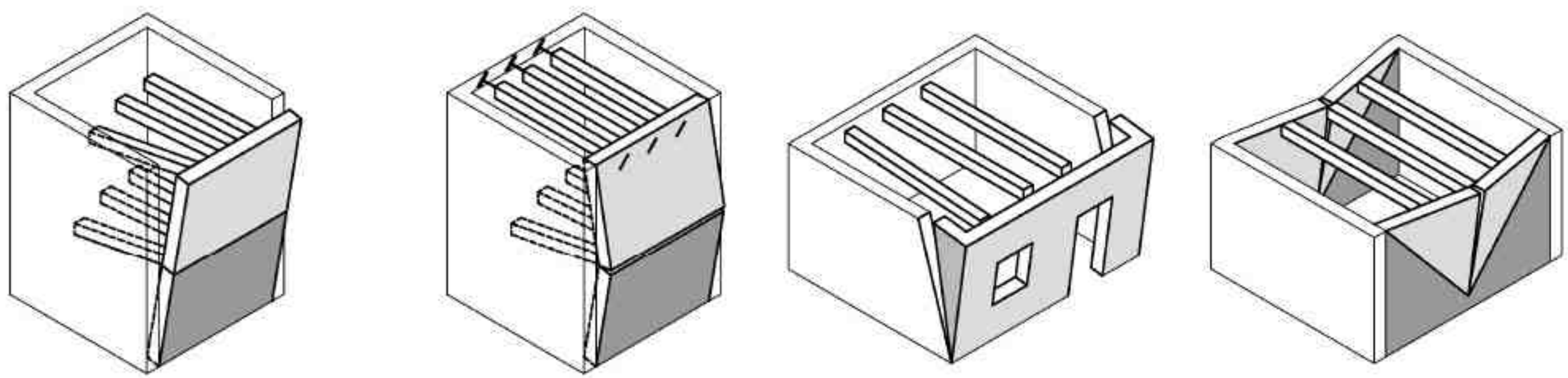
MULTI-STOREY BUILDINGS



Increasing seismic performance of timber structures

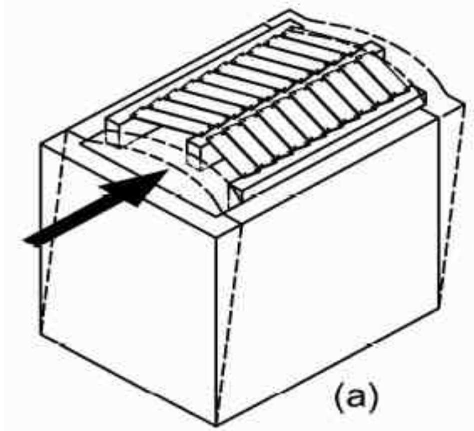
Parameter affecting the seismic response in masonry

- plan distributions,
- the texture and the quality of the masonry walls,
- the distribution and the size of the openings,
- the characteristic of the floor and the interconnection between vertical and horizontal elements.

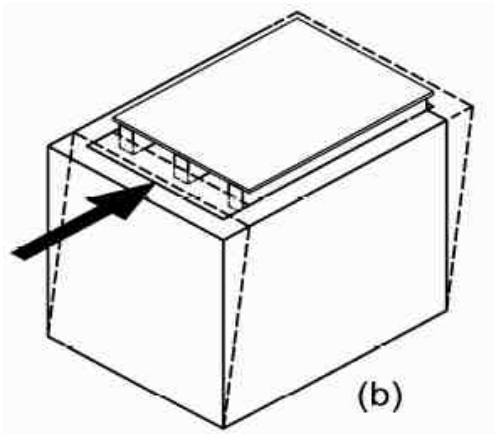


Role of the diaphragm preventing the overturning modes of masonry walls

(a)the inadequate in-plane stiffness of the floor causes overturning of the walls perpendicular to the seismic action;



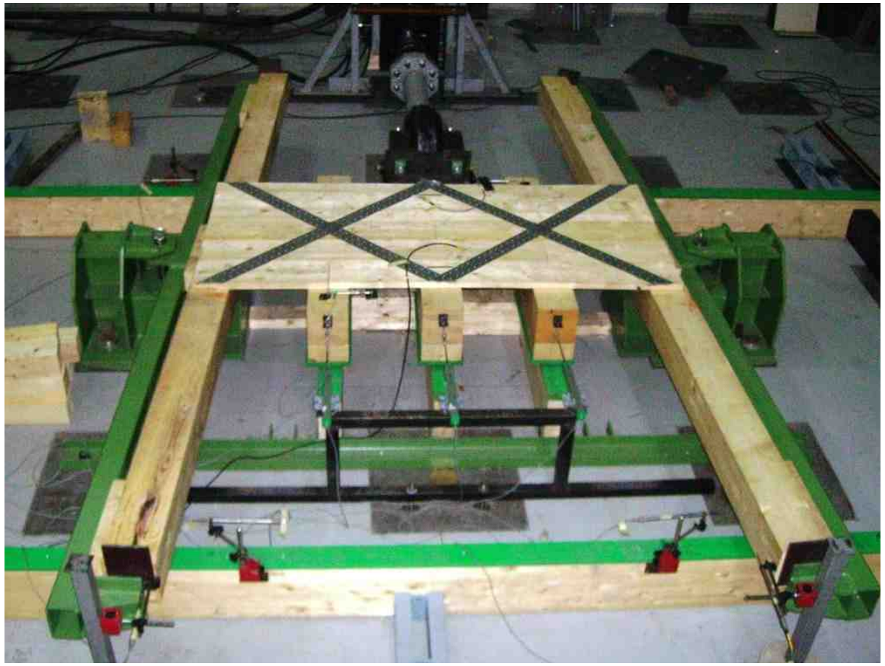
(b)a stiff diaphragm allows forces to be transmitted to the walls parallel to the seismic action.



Increasing seismic performance of timber structures

Experimental campaign in lab (UNITN)

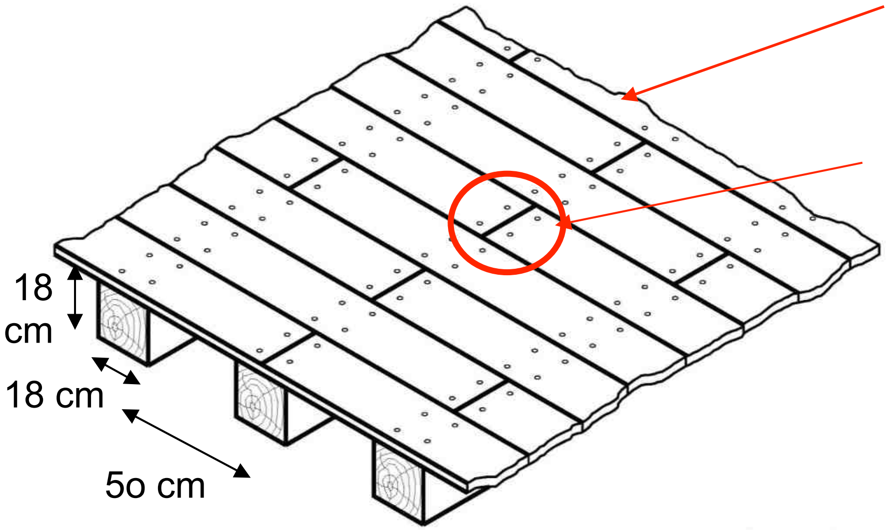
Two different specimen sizes were adopted

Small specimens	***Real size specimens***
	
Pilot monotonic tests	Ciclyc test

Timber floor typology (reference floor)

- simple supported timber floor is considered,
- section of timber beams 18 x 18 cm, spaced 50 cm

→ common configuration for the floor structure in Italian historical buildings.



simple layer of wood boards (200 mm wide × 30 mm thick)

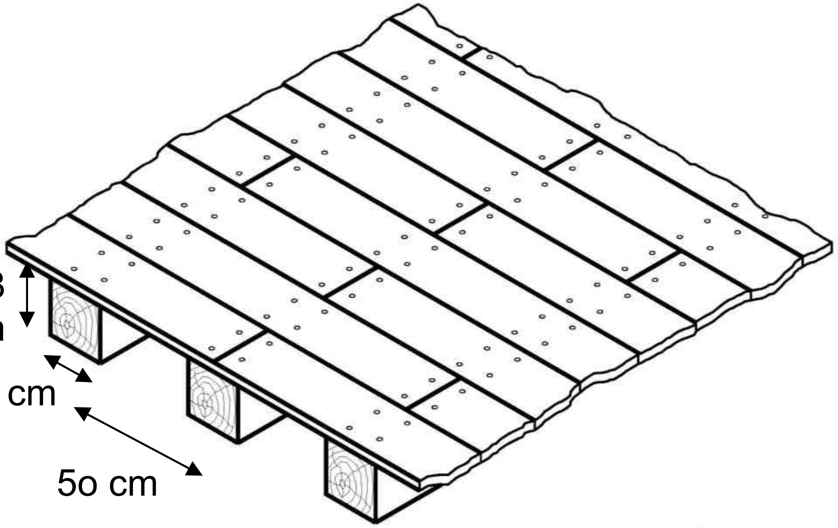
Nails Φ 2.8 × 80 (spaced 100 mm)

The deck system is composed with a simple layer of wood boards, crossly arranged and nailed to the timber beams (4 nails per intersection between board and beam).

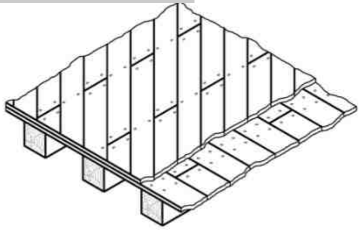
Increasing seismic performance of timber structures

Timber floor typology

- simple supported timber floor is considered,
- section of timber beams 18 x 18 cm, spaced 50 cm

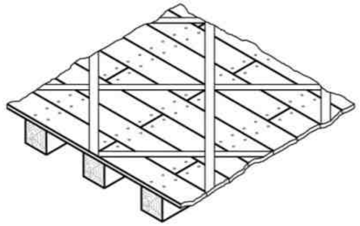


1. Double boards

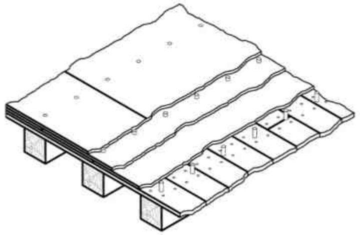


2. Steel plates

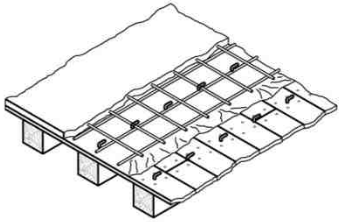
3. CFRP



4. Plywood panels



5. Concrete slab



Increasing seismic performance of timber structures

Experimental campaign in situ

NEW ZEALAND

35 DREWS AVENUE, WHANGANUI

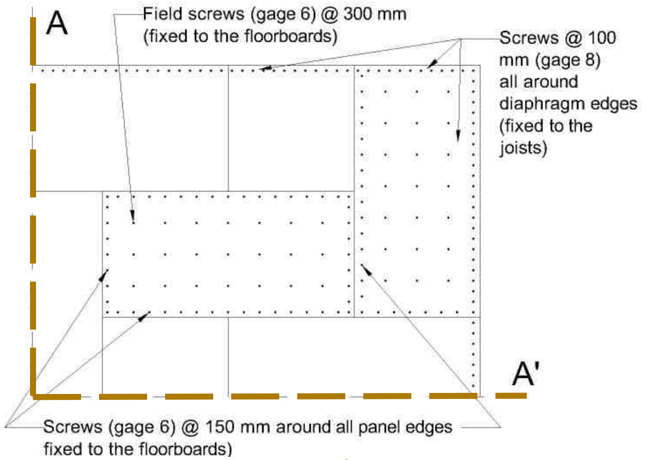
Front view

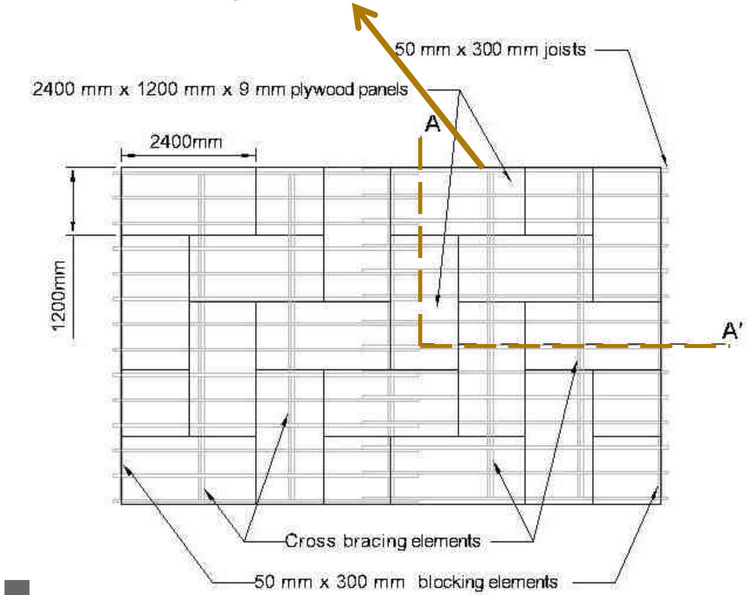
Lateral view

- Built 1913
- Lime mortar and clay brick masonry
- Two stories
- Original flexible timber diaphragms
- Derelict for > 5 years
- Up for demolition

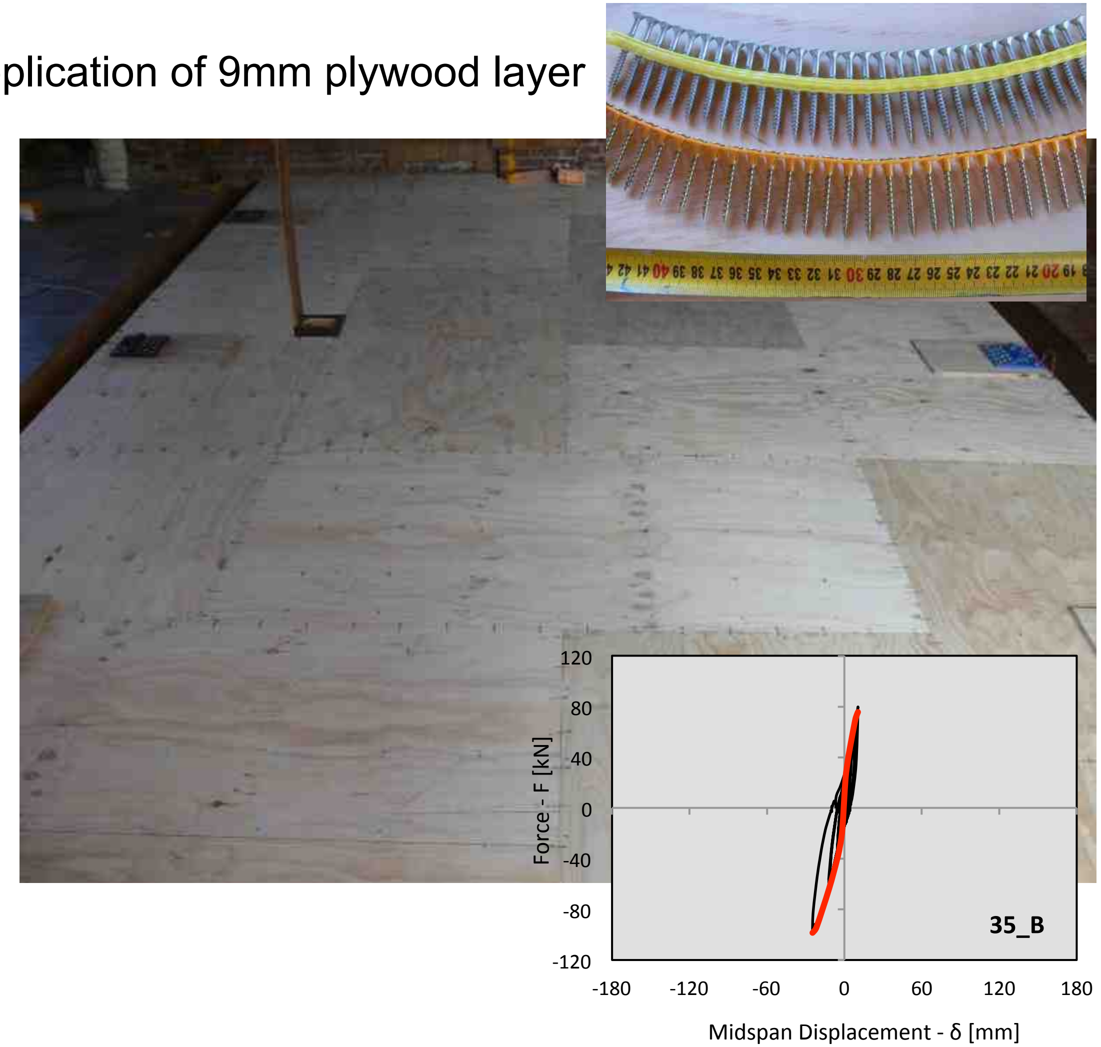
First floor interior

Increasing seismic performance of timber structures





Application of 9mm plywood layer



RETROFIT SOLUTIONS
SPECIMEN B – PLYWOOD PANELS OVERLAY