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Performance evaluation of traditional timber joints under cyclic loading and their influence on the seismic response of timber frame structures

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HIGHLIGHTS

- Joints govern the behaviour of a timber structures.
- Joints constitute the dissipative mechanism of timber structures for seismic events.
- The quality of the joint (presence of gaps) greatly alters the response of a joint.
- Strengthened joints present significantly higher stiffness and dissipative capacity.

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ABSTRACT

Timber joints represent the governing part of a timber structure, particularly when assessing its seismic response. In order to better assess the seismic capacity of traditional timber frame structures, particularly timber-framed shear walls, pull-out and in-plane cyclic tests were carried out on their joints (half-lap joints). The aim is to better understand the influence of the joints on the walls and their influence on failure mechanisms and capacity.

Their seismic characterisation was obtained via the analysis of the hysteretic behaviour and dissipative capacity of both unreinforced and retrofitted joints (using self-tapping screws, steel plates and GFRP sheets).

Results show that all strengthening techniques were able to improve the dissipative and load-bearing capacity, but care should be taken into not over-stiffening the joints, as it would lead to an overly rigid structure.

1. Introduction

Timber frame construction is a popular constructive technique that is typical of many historic city centres worldwide. They became popular both for their cheap and easy construction in areas where wood was abundant (North America, Scandinavia, UK) and for their good seismic performance (e.g. Portugal, Italy, Greece, Turkey, Peru), as timber frame walls act as shear walls.

While they are recognised as an important world cultural heritage, only recently some restoration efforts have been made and in general many buildings have been abandoned for decades. Another issue that concerns these structures is that modifications have been made in many cases without taking into account the new structural response of the structure and without considering concepts such as reversibility or re-treatability.

Different studies [1–4] have shown that the response of timber frame structures depends essentially on the resistance of the connections, since they represent the dissipative mechanism of the structure. Concerning the global rigidity of the structure it is fundamental to understand how the connections work, in particular the relative movements of the components.

Traditional timber joints are used in a great variety of timber structures and structural elements, from floors to walls to roofs. In literature, it is possible to find numerous experimental results on traditional timber connections. Various studies are available on bird's mouth connections, typically used for roofs [5–7] and on mortice and tenon joints regarding pull-out, bending and shear tests [8,9], as well as on dovetail joints with and without pegs [10] and dowel-type joints [11]. Moreover, studies exist on the characterisation of specific traditional joints, e.g. Taiwanese Nuki joints and Dou–Gon joints [12,13] and Japanese Kama Tsugi and Okkake DaisenTsugi joints [14].

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The response of traditional timber joints depends greatly on compression and friction among their elements. Due to the production process, i.e. the manual work of the carpenter, there can be some irregularities and gaps which influence their performance, therefore commonly the contact between the members is improved by strengthening the connections with metal elements. Traditional timber connections rely for their performance mainly on notches, wedges, bearing faces, mortices, tenons and pegs, while metal fasteners are less common, though nails can be inserted to improve the connection's performance. On the other hand, metal fasteners constitute an important tool in rehabilitation works.

Interventions in timber frame buildings can be necessary due to different problems, e.g. decay as a consequence of poor maintenance, change in use and therefore need of additional strength, cracks and local failures. Many examples are available on restoration works carried out on traditional timber frame buildings, and in some cases the end result is the loss of the original structural system [15–18]. While numerous studies are present on the reinforcement of joints for roofs and floors, using either traditional techniques or dowel type connections [7,19] or FRP materials [20], little information is available for vertical elements [21] and their connections in particular. In this paper, a contribution is given to the better understanding of the behaviour and the retrofitting of traditional connections for vertical elements subjected to seismic actions.

1.1. Timber frame walls general behaviour and the importance of their connections

As already mentioned, different studies showed that the seismic performance of traditional timber frame walls depends mainly on their connections. To experimentally study the seismic response of traditional Portuguese timber frame walls, typical of the so called Pombalino buildings [17], in-plane cyclic tests were performed on full scale specimens [2]. Half-lap joints were used for the connections between posts and beams, while the diagonal bracing elements were simply nailed to the main frame. In general, the walls displayed a good capacity and ductility. Results greatly depended on the level of vertical pre-compression and on the presence of infill, which could alter the response of the wall from a shear one to a flexural one. Fig. 1 presents the hysteretic response of an unreinforced infill wall (half-timber wall) for two vertical pre-compressions, namely 25 kN and 50 kN (UIW25 and UIW50 respectively). Damage was concentrated at the connections and uplifting of the non-continuous lower half-lap connections was severe, particularly for infill walls. In particular, a lower vertical load led to higher uplifts for all bottom connections (BL = bottom left; BM = bottom middle; BR = bottom right). For a full description of the experimental results, see Poletti and Vasconcelos [2].

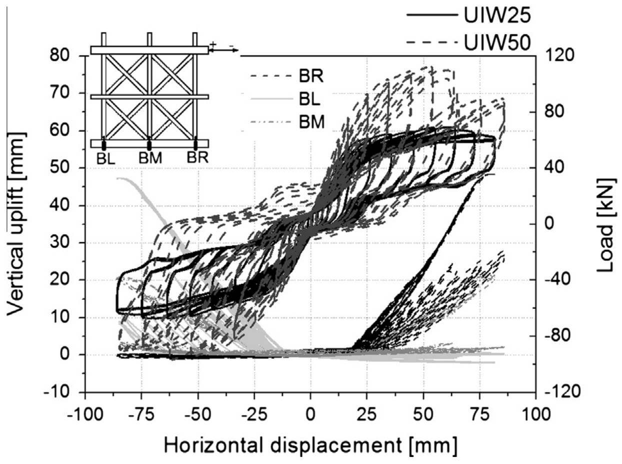

Fig. 1. Results of in-plane cyclic tests performed on traditional timber frame walls: experimental results showing influence of vertical pre-compression.

2. Experimental campaign on half-lap joints

An experimental campaign on traditional joints used in Portuguese timber frame walls was carried out in order to better study their behaviour, since they are the key elements of the walls. In order to do this, a significant connection of the wall tested was selected, namely the bottom half-lap joint which is a tee halving joint and therefore weaker than a cross halving joint. This choice was made due to the fact that during the tests on unreinforced walls, this joint governed the behaviour of the walls, as its uplifting led to the rocking movement of the wall [2].

To understand the response of these joints for vertical elements, the deformation patterns and the damage progress will be analysed in order to confirm the selection of the most appropriate retrofitting solutions which were previously adopted for the walls [22,23]. This study will help fill the research gap currently present on retrofitting of traditional timber frame walls and their joints.

To perform this study, 14 specimens have been tested for the mechanical characterisation of traditional joint in timber frame walls. Pull-out and in-plane static cyclic tests have been performed. In the following section, details about the geometry of the specimens, the test setup and procedure and retrofitting techniques adopted are presented. Subsequently, the results obtained will be analysed in detail.

2.1. Specimens

The specimen selected has the same geometry of the bottom joint in the wall, see Fig. 2 [2]. The influence of the diagonal bracing member was not considered for this study, but its effects should be studied. The bottom beam was anchored on both sides of the connection, as done in the walls, at the same distance from the connections that was used during the wall tests.

For simplicity purposes, the influence of infill was not taken into account in these tests, even though it has an important confining effect on the timber frame and adds stiffness and strength to the frame [2]. The non-consideration of the infill represents the most unfavourable condition, since the connection is weaker without infill.

The specimens were built with the same type of wood as the walls, *Pinus pinaster*. A wire nail (4.5 mm × 10 mm) was inserted in the centre of the connection, similarly to what was done in the connections of the walls [2].

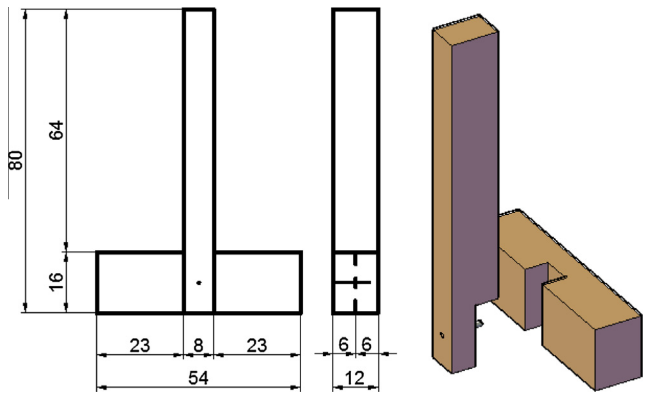

Fig. 2. Geometry of specimens tested (dimensions in cm).