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In-plane shear behaviour of traditional timber walls

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ABSTRACT

The reconstruction of Downtown Lisbon after the 1755 earthquake was based on a novel constructive system of masonry buildings with an internal three-dimensional timber-framed structure named "gaiola pombalina". This internal structure aimed at improving the global stability of masonry buildings, enhancing their capacity to dissipate energy under seismic loadings. But this structural system is not only typical of Portugal, but constitutes part of the built heritage of various countries. This paper aims at getting experimental insight on the mechanical behaviour of timber-framed walls subjected to in-plane loading, as only scarce information is available in literature, in order to assess their effective performance to seismic actions. To do this, the experimental results of cyclic tests carried out on traditional timber-framed walls with distinct typologies will be analysed, namely (1) unreinforced timber-framed walls without infill; (2) timber-framed walls without infill with Glass Fibre-Reinforced Polymer sheets (GFRP) placed at the connections; (3) timber-framed walls with brick masonry infill.

1. Introduction

Masonry and timber are materials used since ancient times in construction. Masonry buildings constitute an important percentage of the existing buildings and actions for their preservation should be taken, since a large part of historical buildings are actually in masonry. A drawback on the use of unreinforced masonry is the low resistance to tensile stresses, leading often to an inadequate behaviour under seismic actions. A historical construction solution to improve the mechanical behaviour of ancient masonry adopted in different locations at different times, namely in seismic regions, has been the reinforcement of masonry with timber. Another construction solution has been the adoption of a load bearing timber skeleton filled with masonry.

Traditional half-timbered walls are an important constructive element of many buildings and are usually composed of vertical posts and horizontal beams with bracing diagonal elements. In Portugal the half-timbered walls, known as *frontal* walls, are usually part of Pombalino buildings, which were introduced by the Marquis of Pombal, who was responsible for the reconstruction of Downtown Lisbon after the great earthquake of 1755, which partially destroyed the city.

In traditional half-timbered buildings, it is usual that half-timbered walls are also placed in parallel to external gravity load bearing masonry walls. In unreinforced masonry structures, the capacity of the building is good in terms of vertical loads, since masonry has generally an adequate compressive strength. When subjected to horizontal loads, though, shear and flexural capacity of such structures are quite low, particularly when no box behaviour is observed and walls are particularly vulnerable to out-of-plane failure mechanisms. When a bracing system is added, the lateral resistance increases, improving the seismic behaviour of the structure. The internal half-timbered walls represent the lateral load bearing walls of the structure, since due to their lightness and higher flexibility than traditional masonry walls, they are expected to perform better under seismic loads. The timber-framed walls are connected to the external masonry walls by means of the timber floor beams, which are connected both to the timber-framed and to the external masonry walls [1]. This system can be also beneficial to reduce the out-of-plane vulnerability of masonry walls.

In some recent earthquakes (Turkey 1999, Greece 2003, India 2005) half-timbered buildings showed a better behaviour than unreinforced masonry buildings [2]. In fact, this construction system is pointed out by several authors as one of the most efficient earthquake resistant structure in the world [2–4]. Its popularity is not only due to its seismic performance, but also to its low cost.

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Half-timbered structures combine the best features of masonry and timber, offering a better overall behaviour of the buildings under seismic actions.

However, even if practical evidence exists of their adequacy to resist seismic actions, the behaviour of half-timbered walls is not clearly understood and thus it is important to have a deep insight on their resisting mechanisms under lateral loading. In fact, this type of construction system has not been taken into great consideration from the scientific research community but a great number of historical buildings are actually half-timbered, which means that the evaluation of its mechanical performance, particularly to seismic actions, can be valuable. Moreover, the great variability found in these buildings in terms of geometry, materials and modifications introduced in the structures makes their seismic assessment a relevant research issue. With this respect, a possibility for the seismic assessment of half-timbered walls is the experimental analysis of these walls under static cyclic loads aiming at representing in a simplified way the seismic loading.

Few experimental studies on the behaviour of traditional half-timbered walls are available in literature [5–7], contrarily to modern timber shear walls, from which some lessons can be learned in relation to resisting mechanisms [8]. In particular, in relation to Pombalino half-timbered walls, very few experimental information is available until now. In this context, an experimental testing campaign was found in literature concerning ancient timber-framed walls tested in the scope of a rehabilitation program of ancient masonry buildings [5,9]. A real wall specimen was extracted from an existing building which was going to be demolished and tested under static cyclic loads. The hysteresis loops of the tested wall, shown in Fig. 1, are indicative of the good energy dissipation capacity of the structure. Cyclic tests were performed also on real scale half-timbered walls built according to the original geometry and using traditional connections found in existing buildings in Lisbon, namely overlapped connections [7]. Still concerning Pombalino walls, some other few experimental tests can be pointed out, such as the mechanical characterisation of traditional reduced scale timber shear walls in the scope of the analysis of distinct types of retrofitting techniques [6] and strengthening solutions applied to Pombalino buildings in Lisbon [10].

Some numerical works available in literature consider the evaluation of the seismic vulnerability of Pombalino masonry buildings, considering the contribution of the timber-framed walls [11]. Other works were carried out on Pombalino buildings as a whole, without the internal gaiola structure. These studies analysed numerically a model consisting only of the exterior masonry walls to assess the "block effect" of structural interventions made on historical buildings, i.e. the global effect that these interventions had on the neighbourhood [12]. It was seen that the structural behaviour of an isolated building is different from the behavior exhibited by a building inside a large block.

Taking into account the important gap on the evaluation of timber-framed walls, both from a national and international point of view, it is of great interest to acquire knowledge on the seismic behaviour of this construction typology. Therefore, the work presented here consists of some experimental results on the static cyclic tests carried out on a set of timber walls in order to evaluate their performance under cyclic horizontal actions. The lateral resisting mechanism and the cyclic performance to earthquake actions of such walls are studied in terms of ductility, energy dissipation, cyclic stiffness and equivalent viscous damping. It is important also to understand the behaviour of the original walls and the possible retrofitting solutions, since natural deterioration of the materials involved and changes in the use of the structures could have changed the seismic resistance of the walls and interventions could be necessary. Moreover, the application of new codes to existing timber-framed walls is not straightforward and any possible intervention aiming at retrofitting requires additional information on their seismic behaviour.

2. A brief overview on the history of half-timbered buildings

The origin of half-timbered structures probably goes back to the Roman Empire, as in archaeological sites half-timbered houses were found and were referred to as Opus Craticium by Vitruvius [13]. But timber was used in masonry walls even in previous cultures. According to [14,15] in the Minoan palaces in Knossos and Crete timber elements were used to reinforce the masonry. Half-timbered constructions later spread not only throughout Europe, such as Portugal (edifícios pombalinos), Italy (casa baraccata), Germany (fachwerk), Greece, France (colombages or pan de bois), Scandinavia, United Kingdom (half-timber), Spain (entramados), etc., but also in India (dhaji-dewari) and Turkey (himis) [13,16]. In each country, different typologies were used, but the common idea is that the timber frame can resist to tension, contrary to masonry, which resists to compression, thus providing a better resistance to horizontal loads. Besides, the timber elements are viewed as a sort of confinement to the masonry structure, improving the mechanical properties to shear loads. In general, the cross section of the timber elements in the distinct case studies was very similar (approximately 10×12 cm).

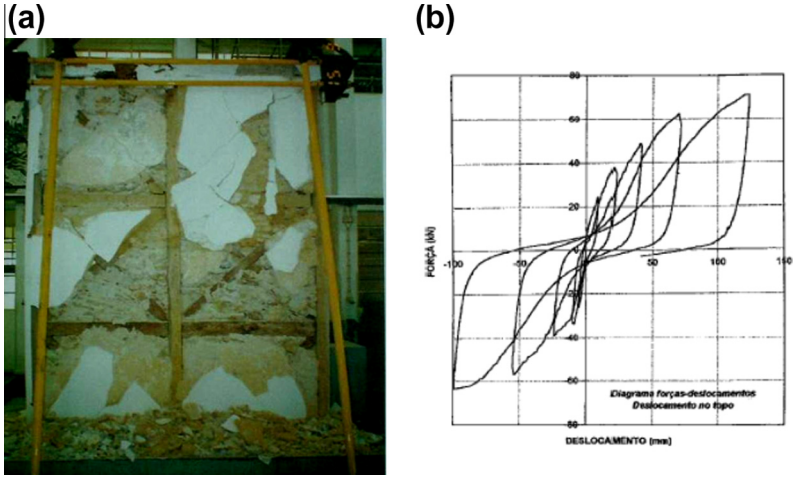

Fig. 1. Details of experimental campaign: (a) real wall specimen after test; (b) hysteresis curve obtained [2].