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Experimental assessment of the mechanical behaviour of ties on brick veneers anchored to brick masonry infills

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HIGHLIGHTS

- The veneer walls are connected to the structural system, transferring the loads to it.
- The seismic behaviour of brick veneers depends of tie connection spacing and stiffness.
- This work aims at assessing experimentally the behaviour of wall tie connections.
- Tie shape and geometry are important factors regarding tensile and compression strength.
- Tie thickness influences in a great extent the compression behaviour.

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ABSTRACT

Masonry veneer walls have been used successfully in a wide variety of structures in modern building construction. However, their vulnerability under seismic actions is recognized as the result of poor material selection, design and construction practices. The knowledge of the local behaviour of ties under different loading conditions should provide important information to help in the selection of the most appropriate wall ties, improving seismic performance. An experimental campaign of different brick-tie-brick assemblages subjected to cyclic tension–compression loading is presented in this paper and the results (stiffness, strength, dissipation of energy and failure modes) are discussed in detail.

1. Introduction

Following the natural evolution of structural systems for buildings and with innovative insulation materials, alternative construction technologies have been developed for the enclosure walls, other than masonry structural walls [1]. The use of an outer envelope wall working as an exterior cladding, known as a veneer wall, has been adopted as an alternative solution to traditional building rendered façades in some European regions. The masonry veneer walls (often in brick masonry) consist of an exterior cladding separated from the structural system by an air cavity, acting as a skin of the structure. Due to their aesthetics and durability, the masonry veneer walls are found in several countries in the world as a cladding for houses as well as for medium-rise residential buildings.

The veneer walls should be connected to the structural system (backup), transferring directly the out-of-plane loads to it, without adding any resistance or stiffness to the structure, being considered as non-structural elements. The backing system, to which the masonry veneers are attached, can be composed of light wood or steel frames, structural masonry or masonry infill walls in conjunction with reinforced concrete frames. The brick veneer walls are usually attached to the backing system through distinct types of ties, generally from steel, with very different geometry, much dependent on the backing system.

Taking into account that these walls have revealed vulnerability under recent earthquakes, exhibiting extensive diagonal cracking and detachment from the backing support [2], it is important to analyse the performance of the tie connections. The seismic behaviour of brick veneers depends on various features [3]: (1) tie connection spacing and stiffness; (2) relative stiffness between the facing and backing materials; (3) support conditions of brick

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veneer and of the backup; (4) location of wall edges and openings; (5) cavity width and the type of loading applied to the wall.

The main role of ties on masonry veneer walls is the transfer of out-of-plane lateral loads from the veneer to the backup through the connection between both elements. For this, ties should have adequate resistance and stiffness in tension and in compression and shear flexibility to accommodate in-plane movements.

This work aims assessing the experimental behaviour of wall tie connections subjected to monotonic and cyclic tension-compression loading to simulate the behaviour of ties under out-of-plane loads induced in the brick veneers by earthquakes. In Portugal and in other South European countries, the brick veneers are mostly attached to brick masonry infills, enclosed in reinforced concrete frames, through steel ties [4]. Therefore, an experimental campaign was designed on assemblages composed of masonry prisms representing brick veneers and brick infills connected through selected steel ties. The assemblages were subjected to monotonic and cyclic tension-compression loads. In this work, the main experimental results are presented and discussed in detail.

2. Brief overview of experimental research on steel ties for brick veneers

Based on the role played by tie connections on the in-plane and out-of-plane performance of the masonry veneer system under seismic actions, several authors carried out experimental testing campaigns aiming at assessing the behaviour of tie connections under shear, tension and compression loading, see Table 1. Note that under earthquakes, the connectors experience complex loading patterns, where cyclic shear, tension and compression forces shall be combined. The majority of the experimental studies are related to brick masonry-tie-wood studs assemblages, which are representative of constructive systems with timber frame structures. This means that the majority of the studies point out results on corrugated sheet metal ties, specially recommended to timber framed structures.

In the experimental work carried out by Zisi and Bennett (2009) [9], the local behaviour of brick-tie-wood subassemblies was analysed (Fig. 1) by considering different parameters, namely: (1) type of bricks for veneer walls; (2) thickness of the corrugated sheet steel ties; (3) eccentricity of the nail connecting the corrugated sheet to the wood stud in relation to the bend location; (4) type of nails; (5) embedment length of the ties in the mortar joints.

From the experimental results, it was possible to observe that the cyclic behaviour was early nonlinear and was characterized by reasonable dissipation of energy (Fig. 2).

The force-displacement diagrams were characterized by pinching and asymmetry became pronounced for increasing displacements. Tie shape and bend eccentricity were found to be the most influencing factors, whereas tie location at bed joint and fastener type revealed to have minor influence in the mechanical behaviour of the connection [8]. The addition of a second nail constrains tie pivoting around a single fastener, resulting in higher resistance.

Choi and LaFave (2004) [5] and Reneckis (2009) [6] developed similar tests with similar results. Shear, tension and compression monotonic and cyclic tests were performed in order to analyse the influence of: (1) tie thickness; (2) initial offset displacement; (3) attaching method of ties (screw, nail or mechanical anchor); (4) type of loading; (5) eccentricity (with sheathing) and (6) embedment length. It was observed that under tensile loading, the tie thickness and eccentricity influence the stiffness, whereas the embedment length of the tie into the mortar joint affected mostly the strength. The tensile strength of tie connections reduced by over 50% when short roofing nails (with 38 mm of length) are used instead of 8 d nails (64 mm of length). The predominant failure mode observed in the monotonic tension tests of nailed subassemblies was nail pull-out from the wood stud, which helped to explain why tie thickness had no effect on the average tensile strength. In the cyclic tests, the nail type revealed to have significant influence leading to the development of other failure modes, namely tie fracture, yielding around the tie hole and tie buckling [6]. Workmanship of brick veneer, particularly with respect to installation of the ties, also plays an important role on the cyclic performance of the assemblies.

In the work carried out by Mertens et al. (2014) [10], brick-tie subassemblies were subjected to tension and compression monotonic loads. In the experimental campaign, the influence of the ties diameter, embedment length and attaching method was analysed. The experimental results were used to improve the design of wall ties, namely in the calculation of the number of wall ties per square meter. The results suggest also that for the tested ties in a mortar bed the buckling strength was the determining factor, while for ties with a nylon anchor this is the pull-out strength.

Steel ties were used recently to strengthen cavity brick infill walls, by providing a connection between internal and outer leaves [11]. The connection between both leaves results in higher effective thickness and, consequently, leads to greater strength to out-of-plane loads. Different tie-brick connection subassemblies were tested under monotonic tensile loads aiming at assessing their performance under tout-of-plane loads. The ties were fixed mechanically (Fig. 3a) or through grout injection on bricks holes (Fig. 3b) by using expansive grout (Fig. 3c). The connection was studied individually in each leaf and globally considering the brick-tie-brick subassemblies. It was concluded that the grout injection strongly influences the performance of the system. It was seen that the fresh properties of grout (workability and fluidity) are of major importance to make the injection in the sock sleeve easy.

Most of the research focused of the mechanical behaviour of steel ties concerns systems composed of brick veneer walls attached to timber frame buildings. Therefore, it is considered that additional research is needed to characterize the mechanical behaviour of steel ties connecting brick veneer walls to other backing

Table 1
Summary of the experimental research on wall ties assemblies.

Research [REF]	Loading type[1]		Loading action[2]			Structural system[3]	
	Mon	Cyc	Comp	Tens	Shear	WF	BM
Choi and LaFave (2004) [5]	x	x	x	x	x	x	
Reneckis and LaFave (2009) [6,7]	x	x	x	x		x	
Zisi and Bennett (2011) [8,9]		x			x	x	
Mertens et al. (2014) [10]	x		x	x			x
Sebastião et al. (2014) [11]	x			x			x

[1] Mon: Monotonic load; Cyc: Cyclic load.
[2] Comp: Compression load; Tens: Tension load and Shear: Shear load.
[3] WF: Wood Frame and BM: Brick Masonry.