Construction and Building Materials 155 (2017) 56–64

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Bonding and anchoring of a CFRP reinforced render for the external strengthening of old masonry buildings

João Guerreiro *, Jorge M. Proença, João Gomes Ferreira, António Sousa Gago

Civil Engineering, Architecture and Geo-Resources, Department Instituto Superior Técnico – Universidade de Lisboa (IST-UL), Lisbon, Portugal

HIGHLIGHTS

- An innovative strengthening solution for loadbearing masonry wall buildings.
- The strengthening efficiently is dependent on bonding and anchorage behaviour.
- The experimental campaign allowed the validation of an end anchorage detail.
- The same campaign also served to prove that continuous bonding is ensured.

ARTICLE INFO

Article history:
Received 24 February 2017
Received in revised form 5 August 2017
Accepted 9 August 2017

Keywords:
Masonry walls
Seismic strengthening
Anchorage
Bonding
CFRP
Experimental tests

ABSTRACT

This paper presents part of the results of an experimental study undertaken to develop a structural strengthening technique for old masonry buildings. The technique consisted of external reinforcement with a CFRP (Carbon Fibre Reinforced Polymer) reinforced render.

CFRP reinforced render is an innovative seismic structural strengthening material for the structural masonry walls of old buildings. It consists of a non-cementitious mortar reinforced with a carbon fibre mesh and is applied to one or both wall faces (preferably by shotcreting). The reinforced render material was developed to improve the mechanical capabilities of masonry walls subjected to "in-plane" and "out-of-plane" seismic loads. Similarly to other widely known composite materials (e.g., reinforced concrete) the composite behaviour of the reinforced masonry relies on both the anchoring as well as on the adhesion of the reinforcing material to the masonry substrate. These aspects are the main objectives of the presented experimental work.

The tests carried out in this study included the mechanical characterisation of all the materials involved, specifically of the mechanical behaviour of the reinforced composite render material, and finally focused on the bonding characteristics between CFRP reinforced render strips and masonry substrates, as well as the anchoring solution for the ends of the strips. The present experimental work is part of a research project to develop an innovative seismic strengthening technique for load-bearing masonry wall buildings.

1. Introduction

Most of the historic centres in Europe and elsewhere are predominantly composed of loadbearing masonry buildings. As repeatedly shown in previous earthquake events these buildings are known to present some weaknesses when subjected to earthquakes. These weaknesses can be further aggravated by natural deterioration that has occurred over time.

The present article reports part of the development stages of a new strengthening technique for load bearing masonry wall structures. It consists of replacing the external render (or plaster) with a non-cementitious mortar reinforced with a carbon fibre mesh applied to one or both sides of the wall. This external layer should provide tensile strength and flexibility, thereby benefitting both in-plane and out-of-plane collapse mechanisms [1–3]. Some of the critical aspects of this strengthening technique lie in the bonding behaviour (to the existing masonry wall) and in the anchoring of the ends and of any singularities [4–6]. Given this assumption, the present paper reports the experimental work carried out with the purpose of assessing the bonding behaviour and developing efficient anchoring devices for CFRP reinforced render strips.

* Corresponding author at: Av. Rovisco Pais, 1049-001 Lisbon, Portugal.
E-mail address: jg@civil.ist.utl.pt (J. Guerreiro).
URL: http://ceris.pt/?action=default (J. Guerreiro).

http://dx.doi.org/10.1016/j.conbuildmat.2017.08.043
0950-0618/

2. State-of-the-art

The oldest architectural heritage is at risk due to lack of appreciation and proper maintenance. Some of that heritage may already be irretrievably lost and some of what remains could be endangered. Their intrinsic nature and history (material and constitution) mean that these structures of architectural heritage present particular challenges for diagnosis and restoration that limit the application of current regulations and standards applicable to buildings. The recommendations [7–10] set out some of the principles of the restoration of old heritage buildings, the majority of which were followed when devising the strengthening technique under study.

The conception of this strengthening technique is largely based on another, described in [11–12]. Initially called "Sheet or composite fabric application to structural elements for bending or tensile reinforcement" or "ComRehab System", this technique involves applying a reinforcing mesh (Fig. 1) composed of strips of high performance polymer fibres (generally glass) – GFRP (Glass Fibre Reinforced Polymer) or CFRP – designed to function as external reinforcement on masonry walls. This reinforcement technique also recognises the importance of having a proper anchorage at the ends of the composite reinforcement due to the concentration of forces that tends to occur at these points. As such, the technique envisages that the ends of the reinforcing mesh are anchored in angle ties, both at their connection to the base of foundation and at the floors, to ensure the continuity of the reinforcement where there is an interior application on front masonry walls.

The ComRehab project aimed to design and study a system for strengthening old building structures, using low-cost composite materials like glass fibre composites (GFRP) [11,12]. The reinforcement system developed under the project was intended to give reinforced buildings good levels of performance for high and low intensity earthquakes, in particular, operationality for moderate severity seismic events with a short return period and for saving lives and/or preventing collapse in the event of a high intensity earthquake, i.e., with a long return period.

The effectiveness of such a strengthening technique – creation of an external layer that withstands tensile stresses – is highly dependent on the adhesion of the strengthening layer to the masonry substrate. Another critical aspect of these strengthening solutions concerns the sound anchoring of the strengthening layers (or strips). Awareness of this had already led to an extensive bond testing programme [11,12] that focused on characterising the adhesion of glass fibre reinforced polymer strips (initial version of the strengthening solution) to the masonry substrate, with or without resorting to mechanical anchorages (that also produced the side effect of confining the masonry wall).

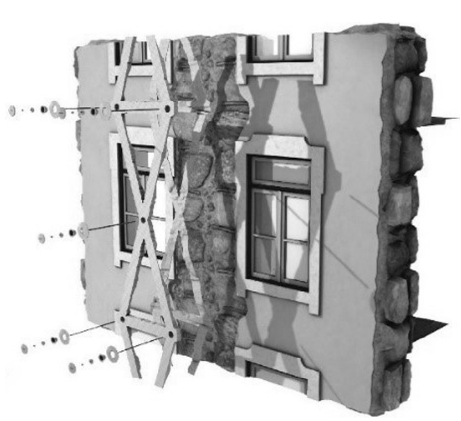

Fig. 1. Layout of ComRehab System [11].

In all, twenty-nine experimental specimens were tested using the same setup, composed of two separate blocks (Fig. 2a). There was an active block made with a mortar simulating the mechanical characteristics of masonry, and a passive block (steel, henceforth "dummy") to anchor the composite strip. The measurement of the load applied by the jack made the testing system statically determinate (Fig. 2b). These blocks were connected to each other by means of a compression hinge halfway up to enable the transmission of a compressive horizontal force between them (balancing the tensile horizontal force in the composite strip).

From this study, it was concluded that the strengthening solution for masonry walls (glass fibres bonded with epoxy resin) was greatly improved by the use of the confinement devices. This achieved greater mobilisation of loads by the fibres and prevented failure modes arising from the loss of bond between the reinforcing fibres and the substrate. These devices should also increase the lateral confinement of the walls and, therefore, their compressive resistance, and also enable greater deformation of the fibres.

An experimental programme was subsequently undertaken to develop the strengthening technique, specifically by replacing the composite GFRP strips with a CFRP reinforced render covering the whole side of the wall. Gomes [13], reports the results of an experimental programme involving a series of bond tests with a test setup similar to that of [11,12], which studied some hydraulic matrix solutions for the reinforced render material, with all of the mortars being manually applied (Fig. 3). This solution was found to have potential for the seismic strengthening of load-bearing masonry walls because of increased deformability, ductility and out-of-plane bending strength of such walls. This beneficial effect relied on the use of the confinement devices, which proved important to ensure bonding conditions between the masonry block (corresponding to an actual situation in a masonry wall) and the manually applied reinforcing material.

In the tests described in Proença et al. [12], the stiffness, tensile strength and shear strength of the resin were clearly higher than those of the masonry, and failure usually occurred through the material that simulated the masonry (failure location 1, Fig. 4). However, in some cases poor surface preparation led to failure occurring at the interface between the masonry and the bonding resin, or between the resin and the FRP, due to lack of adhesion at the surface (failure locations 2 and 4, Fig. 4). For the tests described in Gomes [13], collapse always happened at failure location 5 (Fig. 4), showing that there was good adhesion in terms of both strength and stiffness at the interface between substrate and reinforced render strip. It also showed that for the test conditions there was an inefficient internal bond between the mortar matrix and the carbon fibre mesh of the CFRP reinforced render. The absence of fracture failure of the carbon fibre mesh in those tests resulted essentially from the insufficient strength of the mortar matrix. The bonding conditions therefore had to be improved to ensure that the mortar matrix could maintain its cohesion functions in the composite until it reached the tensile strength limit of the carbon fibre (i.e. until failure).

Using a reinforcement solution based on adding a CFRP reinforced render on an existing masonry wall is to some extent similar to the ComRehab system. However, some issues of special concern about the differences in implementing the strengthening process should be emphasised, because the effectiveness of this new reinforcement technique depends largely on its execution. In essence, the basic principle is still to bond strips of composite material to the masonry wall to improve its tensile (out-of-plane flexural) strength, thereby also enhancing the in-plane behaviour.

The manual application of a new structural layer of plastering mortar encountered some difficulties in ensuring good adhesion between the CFRP reinforced render and the masonry wall if the mortar was simply laid on the masonry wall. The levels of shear