FABRIC-REINFORCED CEMENTITIOUS-MATRIX SYSTEMS FOR MASONRY STRENGTHENING: EXPERIMENTAL INVESTIGATION AND DESIGN RULES

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Introduction

Fabric-reinforced cementitious-matrix (FRCM) systems, made of high-strength textiles embedded into inorganic matrices (mainly cement- and lime-based mortars) and externally bonded to structural members, are a sustainable, compatible and cost-effective solution in the retrofitting of existing concrete and masonry constructions. In fact, the high strength-to-weight ratio of FRCM systems allows for a significant improvement in structural capacity with a minimal mass and stiffness increase [1-3].

The growing interest of the scientific and professional communities towards the application of FRCM in structural retrofitting has fostered the development of an increasing number of strengthening systems, nowadays available on the market. Nevertheless, any extended use of FRCM-based reinforcement in engineering practice requires answers on a significant number of issues still open to investigation.

First, for each structural application, the most suitable FRCM system must be identified. Secondly, a deeper knowledge is necessary on the seismic behaviour of FRCM-strengthened structures. Thirdly, design rules should be developed to properly account for the increase of the strength and displacement capacities provided by FRCM-based reinforcement.

This research project is a contribution to the filling of the above-mentioned knowledge gaps, with the focus on the out-of-plane and in-plane strengthening of masonry walls by means of FRCM systems.

Experimental program and analytical models

Three are the main sections of this research work. The behaviour of small-scale FRCM specimens and of full-scale retrofitted structural members is experimentally investigated in the first and second section, respectively. The third section is devoted to the proposal and validation of formulae for the design of structural members strengthened with FRCM.

As a preliminary step, necessary to fully understand the behaviour of the materials, the tensile and bond behaviours of two FRCM systems (containing either a net of basalt micro-fibres or an array of galvanized-steel micro-strands) were investigated.

At the structural level, both the out-of-plane and the in-plane behaviours were explored, the former by means of a shaking table and the latter via cyclic shear-compression tests on FRCM-retrofitted walls. The tests on the shaking table were carried out on two wall specimens (3.48m high, 1.5m wide and 0.25m thick), the first made of regular tuff blocks and the second of rubble stones, subjected to seismic out-of-plane vertical bending, before and after retrofitting with Basalt FRCM- and steel-reinforced grout. Shear-compression tests were carried out on two double-leaf rubble-stone masonry walls (1.2m high and wide, and 0.25m thick), subjected to in-plane shear and compressive forces, before and after retrofitting with basalt FRCM.

Based on the results of the experimental campaign, in order to foster the transfer of knowledge from academy to engineering practice, analytical approaches were proposed as well, for the design of out-of-plane and in-plane strengthening systems based on FRCMs, to be adopted in masonry walls. An extended experimental database was used in the calibration of design formulae inclusive of the increased strength and displacement capacity yielded by FRCM systems, within the design-by-testing approach suggested in Eurocode 0 [4].

This research project highly benefitted from the close interaction with ACI 549-0L Liaison Committee, whose recently-published ACI 549.6R-20 guide [5] in turn is based on some results of this research project.

Results

The direct tensile tests and the shear-bond tests carried out on small-scale FRCM specimens revealed a significant difference in the failure mode exhibited by basalt FRCM and steel- reinforced grout.

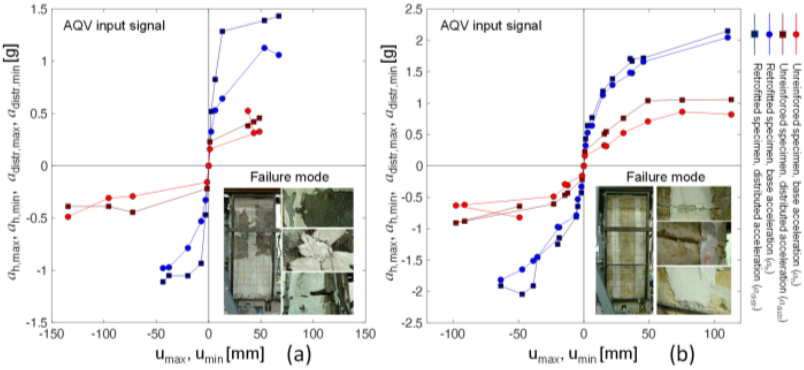

Figure 1. Plots of the acceleration vs. the displacement for a stone wall (a) and for a tuff wall (b), under the seismic input of L'Aquila earthquake (2009).

The shaking table tests proved the effectiveness of FRCM systems in enhancing the out-of-plane flexural strength of masonry walls, for either distributed or discrete reinforcement layouts. In fact, FRCM application may lead to a strength increase close to 1.5 times (Figure 1). The deflection capacity and the initial stiffness of FRCM-strengthened walls turn out to be basically unchanged with respect to that of the unreinforced specimens. Furthermore, FRCM can limit the progression of earthquake-induced damage [6].

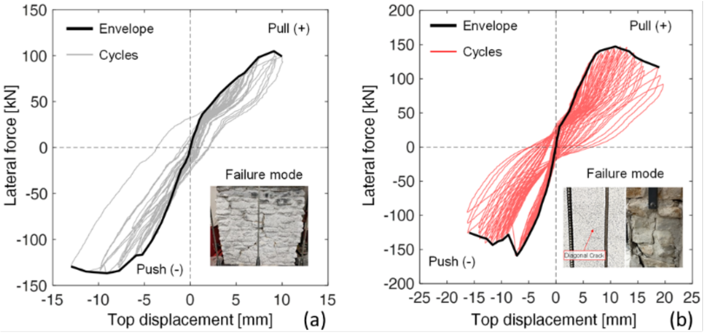

Figure 2. Lateral force vs. top displacement curves for masonry walls.

Smaller but not negligible positive effects of FRCM reinforcement on the in-plane capacity of masonry walls was observed in shear-compression tests (Figure 2). Thanks to FRCM reinforcement, the shear strength, the drift capacity and the initial wall stiffness increased by 35%, 50% and 30%, respectively, as a demonstration of the suitability of FRCM systems for seismic retrofitting [7].

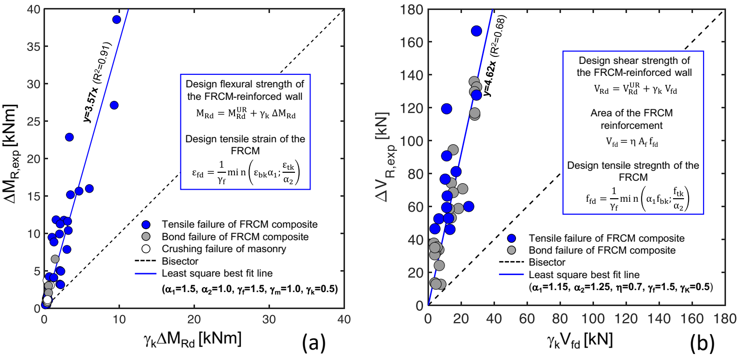

Figure 3. FRCM-retrofitted walls: (a) flexural-strength increase, and (b) shear-strength increase from the tests vs. design values.

As for design equations, a compatibility-based expression is proposed in this study for the structural assessment of FRCM-reinforced walls subjected to out-of-plane bending, whereas a simplified limit analysis-based method is suggested for the preliminary design of the reinforcement (Figure 3a) [8]. For shear strengthening, a simpler purely-additive relationship is proposed to account for the contribution of FRCM and CRM (Composite Reinforced Mortar) systems, as well as to introduce the drift capacity of the retrofitted walls (Figure 3b) [9]. Two coefficients (α_1 and α_2) are also introduced to account for the different boundary conditions experienced by FRCM composites when applied to structural members, with respect to small-scale laboratory specimens. Last but not least, a coefficient γ_k is recommended to guarantee an adequate safety level in the design at the ultimate limit state (Figure 3).

Concluding remarks

FRCM systems are a promising solution for retrofitting existing reinforced concrete and masonry structures, as demonstrated in this research project with reference to the effectiveness of FRCM systems for strengthening masonry walls under either in-plane or out-of-plane seismic loading. The results of an experimental campaign are presented and analytical relationships are formulated for the design of FRCM reinforcement.

Outlook

The long-term behaviour (durability and fatigue) of FRCM systems, the non-destructive test and control methods for condition assessment during the service life, and the combination of structural strengthening and energy saving into integrated systems are among the issues open to further investigation.

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