FRP-STRUCTURAL REPOINTING OF MASONRY ASSEMBLAGES

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ABSTRACT

The University of Missouri - Rolla and the University of Padua collaborate on research programs focusing on FRP strengthening of masonry walls. Experimental investigations are conducted on coupon masonry assemblages subjected to in-plane and out-of-plane actions. Shear and flexural laboratory tests on hollow clay brick wallets and beams are carried out in order to identify the influence of FRP reinforcement systems. Composite rebars, embedded into mortar joints following a new procedure called “FRP Structural Repointing”, demonstrate noticeable effectiveness, also offering rapid and aesthetic application suitable for masonry veneers and façades. Proposed as a reinforcement system to solve shear, flexural, and creep problems, this technology can be combined with FRP laminates when hybrid systems are required on particular surfaces. Detailed finite element models are implemented to describe failure mechanisms and predict ultimate capacities.

Keywords: Anchorage, development length, fiber reinforced polymer (FRP), finite element model (FEM), flexure, glass fiber, in-plane loads, masonry, out-of-plane loads, shear, strengthening, structural repointing (SR).

INTRODUCTION

Unreinforced masonry walls often present inadequacies of ultimate capacities and/or serviceability performances, resulting from deficiencies due to lateral load variation, occupancy change, deterioration, construction or design errors. Load bearing walls are sensitive to lateral cyclic actions, which may cause sudden loss of capacity and brittle failure due to instability; infill panels are also susceptible to pulling apart from floors or snap
through during earthquakes or blasting shocks. For these reasons, strengthening of masonry walls is of importance during building retrofitting operations.

In order to restore the original structural function of already damaged masonry members, rehabilitation techniques usually require delicate retrofit that could even be detrimental if a disturbing process is involved. Low-impact approaches based on non-intrusive and non-destructive methods of rehabilitation are in demand when induced or potential damages are fundamental issues.

Structural and architectural maintenance are preventive countermeasures taken to avoid any cause of degradation on historically or architecturally remarkable buildings. Masonry walls are the main focus of this concern. Current techniques hardly reconcile strengthening with appearance, and often tend to periodically replace deteriorated materials instead of preventing moisture infiltration and corrosion. Preservation, instead, might involve reversible installations that have to be removable once certain conditions change; for this reason many traditional strengthening methods cannot be considered for this purpose.

Repointing is the common name for a technique involving the application of short steel rods across cracks caused by creep of the masonry assemblage under long-term high-level dead loads (Binda et al., 1999). Those rods are anchored by cementitious injections. This technology aims to solve circumscribed problems and does not have a global structural function.

FRP materials exhibit several properties, such as high tensile strength and corrosion insensitivity, which make them suitable for use as structural reinforcement. While design procedures have been established specifically for the use of FRP as concrete reinforcement, the outline of masonry strengthening with composites is still in a phase of analytical and experimental basic research.

Previous works based on field experimentations (Tumialan et al., 2000) indicated that in case of out of plain cyclic loads, FRP laminates are not suitable to provide boundary anchoring to prevent pulling apart and neither can be externally applied as façade reinforcement.

It is in this contest that, with the use of advanced materials, a new technology is introduced in order to offer a valid alternative to traditional masonry strengthening systems.

**DESCRIPTION OF THE FRP STRUCTURAL REPOINING TECHNOLOGY**

This technology consists of embedding with suitable paste, continuous FRP rods in the horizontal joints of a wall previously grooved, reproducing the original form of the masonry. Color of mortar and workmanship of the joints can be accurately reproduced.

The masonry texture has to present continuous horizontal joints, with either running courses or stack bond. Obviously, in the latter case continuous embedded rods can be vertically applied, as well. The FRP Structural Repointing system includes also specially
shaped FRP elements to mechanically connect running-courses with each other and tie multi-wythe walls together. Particular splicing and anchoring issues are addressed using FRP mechanical connections.

Before application, typical material characterization tests are recommended in order to determine the basic mechanical masonry properties to identify the best approach of installation and detailing design.

Except for special cases, functional collaboration between masonry and strengthening is based on the bond properties of the filling paste. Post failure behavior can also be entrusted to the paste-masonry interface friction in order to introduce energy dissipation mechanisms.

The paste has to perform an important role in bonding, anchoring and stress transferring, but workability, surface appearance and easiness of installation are also important issues to be considered. After a material characterization and a bond test program, a designed mix of epoxy resin, quartz sand and coloring pigments was selected as best suitable paste for the considered application. This “epoxy mortar”, perfectly compatible with FRP materials, presented a very low ratio of void inclusions and when tested resulted to comply with the design requirements.

Preparation of the specimens for strengthening is a quick procedure consisting in removing with a grinder the outer part of the mortar joints to obtain grooves, whose depth has to be related to the rod diameter as indicated in previous work on bonding characterization (De Lorenzis, 2000). Application on the specimens is performed injecting the epoxy mortar with a gun; once the rods are embedded, making sure that no voids are left in the grooves, the profile of the joints is shaped using mason’s tools and reproducing the original appearance of the wall texture.

Especially for rehabilitation application or post-damage repair, some injection or reconstitution of the substrate may be necessary. Also, a preliminary primer application can be considered when interface bonding needs to be improved.

**EXPERIMENTAL PROGRAM**

**Specimen Description**

Structural repointing was applied on eight wallettes and on two masonry coupon beams; the assemblages were made of cored clay bricks. Bricks used in the tests are typically used as veneer on concrete block infill panels, in both the typologies of barrier and cavity walls.

One beam was 90 x 12.5 x 9 cm, built with running bond (i.e., discontinuous head joints) providing interlock and reinforced with one 6-mm GFRP rod. In order to isolate the effect of
interlock on the flexural strength, the other reinforced masonry beam was built with a stack bond texture (i.e., continuous head joints) and strengthened with one 6-mm GFRP rod. The rods were longitudinally embedded with epoxy mortar into the continuous bed joint between the two brick courses, and in this way reproducing an elemental part of a wall subjected to out-of-plane load and horizontally reinforced with FRP structural repointing (SR). Two unreinforced beams similar to the aforementioned were preliminary tested as reference.

As part of a larger program of shear testing on masonry panels reinforced with FRP systems (Tinazzi et al., 2000), the eight wallettes strengthened with structural repointing presented applications of rods or laminates in different set-ups. The nominal dimensions of the clay masonry panels were 60 x 60 x 9 (or 19) cm; six of them were single-wythe and the remaining two were double-wythe. In addition to them, one double-wythe and two single-wythe unreinforced wallettes were previously tested as reference.

Three single-wythe wallettes were strengthened only on one side: the first one, designated as Wall 1, presented SR of each second bed joint, while Wall 2 and Wall 3 were reinforced with SR of each joint. Totally, each panel offered eight bed joints were SR could be applied (see Fig.1). In order to investigate different strengthening configurations, which may ultimately result in some field applications (Tumialan et al., 2000), the remaining three single-wythe panels were also reinforced on the back using combinations of FRP laminates and rods. These last cases, always presenting one side SR of each joint, were respectively: vertical rods (Wall 4), large strips (Wall 5), and narrow strips (Wall 6).

Even if the grooves can be cut relatively deep and more than one rod can be embedded into a bed joint, the structural repointing is an eminently superficial reinforcement; consequently its global structural effect is expected to diminish as the ratio of the wall depth to the grooves depth increases. In order to validate this assumption, the same shear test was performed on double wythe wallettes, whose texture was typical, with running bricks alternated to headers; they were: Wall 7, reinforced with SR on both sides and Wall 8, with SR on one side and narrow strips on the other.

**Test set up**

The standard procedure ASTM C 1390 was followed for the four-point flexural test on the masonry beams. The diagonal compression test, as described in ASTM E519, was considered to represent the worst case of shear test for panel reinforced with SR. In fact, as the strengthening system is based on friction developed on the brick-paste interface, in a full-scale wall subjected at least to its own weight this friction increases the effectiveness of the reinforcement. During the test, deformations and displacements were recorded along the loaded and the splitting diagonals on both sides (see Fig.2).

**Test results**

Masonry beams: The strengthened masonry beams with interlocked or continuous joints recorded a flexural capacity 5 and 7 times higher than the respective reference specimens. Load cycles on both kinds of masonry assemblage revealed an elastic behavior
until the sliding of the reinforcement into the grooves occurred. After this limit, energy dissipation was developed by friction and flexural deformation increased.

Masonry wallettes: The failure mode characterizing the sudden collapse of the unreinforced panels consisted of the joint sliding along the compressed diagonal. Similarly, in Wall 1 the sliding was forced to occur along a mid-high bed joint, without benefit for the shear capacity. Differently, Wall 2 and Wall 3 reached a mean shear capacity 45% higher than the control walls. The failure mode was changed as joint sliding was prevented. Diagonal splitting of the panel triggered the crisis, but once cracks crossed a rod any propagation was prevented and new cracks were forced to open in a different position; their spreading on the compressed diagonal direction lead to a progressive degradation of the capacity accompanied by increase of deformations. The limit of this phenomenon was the sliding of the masonry-paste interface occurring once the rod anchoring was shorter than the development length; resulting from that was the loss of collaboration between masonry and reinforcement. This post peak different mechanism allowed larger deformations caused by progressive diagonal splitting, and dissipation of energy due to friction between the paste and bricks. In Wall 4, Wall 5 and Wall 6 the capacity increase obtained was more than 120%, and also, on both sides, cracks were forced to spread on a larger area of the face.

After failure, these latter panels were also subjected to the same shear test on the opposite diagonal, recording a shear capacity still over 60% of the reference value. Again, after failure of the second diagonal, these wallettes were tested under monotonic axial force to determine the residual load bearing capacity. Recorded values, still noticeable, were related to the damage introduced in terms of splitting deformation during the previous shear tests. Wall 7 and Wall 8 did not seem to suffer from the unfavorable geometrical condition of the reinforcement.

**NUMERICAL MODEL**

In order to better identify the stress redistribution consequent to the application of the SR and adjust design assumptions describing the physical phenomena, a micro model was implemented by a finite element code. Constitutive laws of materials, including the softening part, and failure domains were introduced as obtained from an evaluation of units and masonry assemblages. The model used is based upon the smeared crack approach and the Drucker-Prager model. The yield surface is hyperbolic with associated softening type flow. The hyperbolic domain was established fitting the experimental data available on friction. The non-linear associated plastic flow was calibrated on the experimental results of unreinforced panels, in order to simulate the sliding phenomena, at least in the initial stage.

Some results obtained are compared with the experimental data. After an almost linear phase, we observe the formation of micro-cracks. The FRP reinforcement acts to absorb...
tensile action and, keeping close cracks, permits ductility load enhancement. A view of the strain distribution in horizontal (top right) and vertical direction (bottom right) is shown together with the stress distribution (left side) at the last step of load (see Fig. 3).

CONCLUSIONS

FRP Structural Repointing has the advantage of providing remarkable structural benefits maintaining the original appearance of the masonry wall and completely complying with durability and maintenance issues. Due to the lightness of the materials involved, site equipment and handling requirements are reduced and simplified. Flexibility of the system is widened as new materials and new manufacturing processes are available. Increasing bond properties and introducing special reinforcement components can make the technology adaptable to various design requirements.

Further experimental investigations on coupon and full-scale walls could advance the knowledge of mechanisms related to particular set up, anchoring and boundary conditions. Also, in-situ tests could reveal the actual effect of the FRP Structural Repointing under service load condition. Nevertheless, from the conducted studies, field applications of the technology could be performed under appropriate supervision.

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REFERENCES


**ILLUSTRATIONS**

*Fig. 1: Geometry of the masonry wallettes (dashed line represents the insertion of Structural Repointing). Detail of the FRP rod embedded into a mortar joint.*

*Fig. 2: Strengthened masonry wallet under diagonal compression test.*  
*Fig. 3: Installation of straight and bent rods*
Fig. 3: Reinforced panel with FRP rods in the external part of the horizontal mortar joints only, strain (right) and stress (left) distribution at the last step of loading.