AN IMPROVED COMPOSITE ANCHORING SYSTEM

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ABSTRACT

Composite materials can be used to upgrade the load-carrying capacities of unreinforced masonry walls. The strength of the upgraded wall, however, is often limited by failure that occurs near the bottom of a wall due to a low capacity for load transfer between the wall and the foundation. The present paper provides information on an experimental investigation of a composite anchoring system on unreinforced concrete masonry walls. This system provides high-capacity load transfer between the fiber reinforced polymer (FRP) laminate retrofitted wall and the foundation.

Six masonry wall-concrete footing assemblages were built, strengthened with FRP laminates, and tested. On all walls, a composite anchoring system provided the only connection between concrete foundation and masonry wall. Three walls (1219 mm x 1219 mm) had composite laminate applied in edge strips to both faces and were subjected to in-plane shear and a 22.24 kN axial load. The capacity of these walls reached more than 120 kN (lateral load) before failure, which resulted from extensive cracking of the masonry units. The other three walls (406 mm x 1016 mm) had the tension surface fully covered with CFRP laminate and were tested in tension (bending) reaching a maximum load of 32 kN before failing due to masonry unit crushing. In each loading case, the anchoring system provided sufficient strength allowing the masonry units to fail before the CFRP laminate or composite anchors failed.

The results of this research reveal that strength gains due to FRP laminate upgrades on unreinforced concrete masonry walls can be fully realized through the use of a composite anchoring system.

INTRODUCTION

Strengthening existing masonry walls and repairing damaged masonry walls can be accomplished utilizing any of a number of popular techniques. For many years these methods have included surface overlays of various coatings including shotcrete; grout injection with and without reinforcing bars in the cells; and external stiffening including steel and timber bracing elements (FEMA 1997). The popularity of these techniques results from the facts that designers, contractors, and building officials are familiar with the behavior of these materials and with the specifications governing their design and construction.

In the past 10-15 years, another type of retrofit and repair method has gained acceptance. This method involves the use of fiber reinforced polymers (FRP's), or, as described in this paper, carbon fiber reinforced polymers (CFRP's), as a strengthening overlay on structural components. Extensive research has been performed on these materials applied to masonry walls with early research conducted by Seible et al. (1990) on FRP retrofit methods for unreinforced masonry (URM) walls. His results along with those from masonry research conducted by Al-Chaar & Hassan (1999), Ehsani & Saadatmanesh (1996), Ehsani et al. (1997), Triantafillou (1998), Gilstrap & Dolan (1998), and Marshall et al. (1999) revealed that shear and flexural strength in masonry walls can be increased through the use of FRP composites externally attached to these masonry elements.

In most applications, strengthening and repair methods on masonry walls require the increased capacity or the wall be accompanied by an increased capacity of the connection between the wall and its supporting member or foundation. In the traditional methods described above, the connection is strengthened by anchoring the repair materials to the foundation. These anchors often are provided by drilling, grouting, injecting epoxy adhesives, clamping with steel angles or channels, or adding additional concrete or masonry material. Currently, if strengthening or repairs to masonry walls are provided by CFRP laminates, then the connection is strengthened using these same traditional anchoring methods. Alternatively, anchoring techniques utilizing the CFRP material itself need to be developed.

EXPERIMENTAL PROGRAM

The objective of this study was to experimentally investigate unreinforced hollow CMU walls retrofitted with CFRP composite laminates using one lamination schedule and subjected to in-plane shear (shear specimens) and out-of-plane bending (bending specimens) loads. The focus of the investigation was the composite anchoring system used to connect the CFRP laminates to the foundation.

Three identical 1219 mm by 1219 mm masonry walls were constructed and tested in shear, and three identical 406 mm by 1016 mm masonry samples were testing in bending. Each specimen was first retrofitted with CFRP laminate, on the tension face only for the bending samples (Figure 1) and on both faces for the shear specimens (Figure 2). Type S mortar and CMU blocks having a width of 406 mm and a height and thickness of 203 mm were used in each specimen. The average compressive strength of the masonry units was 10.3 Mpa. In each specimen, the CFRP composite laminate was fully anchored to the base as shown in Figure 3. Details of the composite anchor are shown in Figure 4.

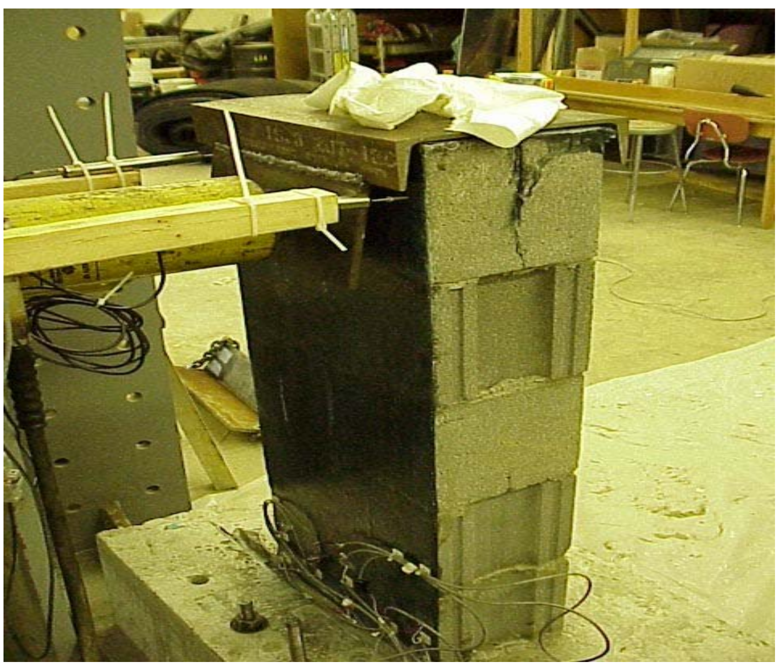


Figure 1. Retrofitted bending wall specimen

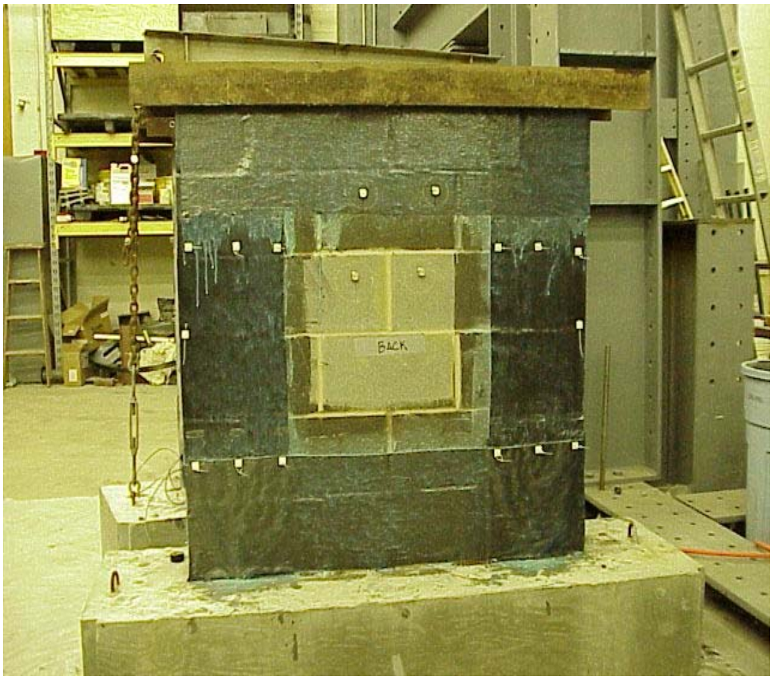


Figure 2. Retrofitted shear wall specimen

Figure 3. Composite anchor into wall foundation

The three shear specimens were loaded with in-plane loads, and the three bending specimens were subjected to out-of-plane bending. The loads were applied at the tops of the walls. Displacement transducers were used to monitor the in-plane and out-of-plane deformations of the specimens at several locations throughout the masonry walls. Strain gages were attached to the FRP laminates to record the stress level in the composite material on the specimen surface.

As shown in Figures 1 and 2, the boundary condition for the shear and bending test setups modeled cantilever walls with fixed conditions at the bottom. The wall in the bending setup was grouted and dowelled in the bottom course. In order to create a more realistic condition, an axial of 22.24 kN of axial load was applied to the shear samples. No axial load was applied to the bending specimens.

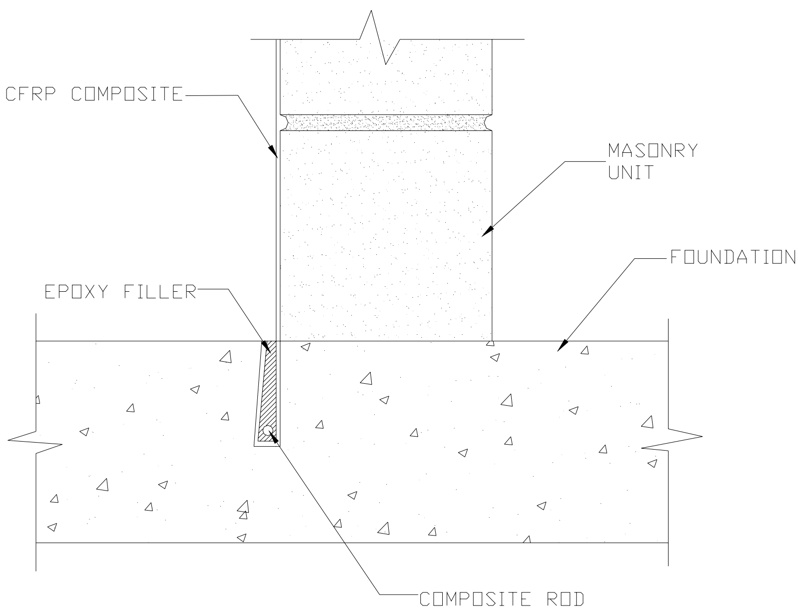


Figure 4. Details of the composite anchor

Baseline values

Shear and bending capacities of unretrofitted wall specimens were previously measured in the laboratory by Young and Gergely (2001). As expected, the unretrofitted, cantilevered shear specimens developed horizontal cracks along the mortar bed joint at the walls' lower section, while the simply supported bending specimens cracked at the specimens' mid-height. Although the walls in these previous tests were not the same sizes as the specimens in this project, the unretrofitted masonry stresses at failure should be same. Also, the unretrofitted shear walls and bending walls failed at ultimate stress values consistent with allowable stresses specified by ACI 530/ASCE 5/TMS 402 (1999). Those ultimate stresses predict failure loads to be 9.34 kN for in-plane cantilever shear and 1.67 kN for out-of-plane cantilever bending.

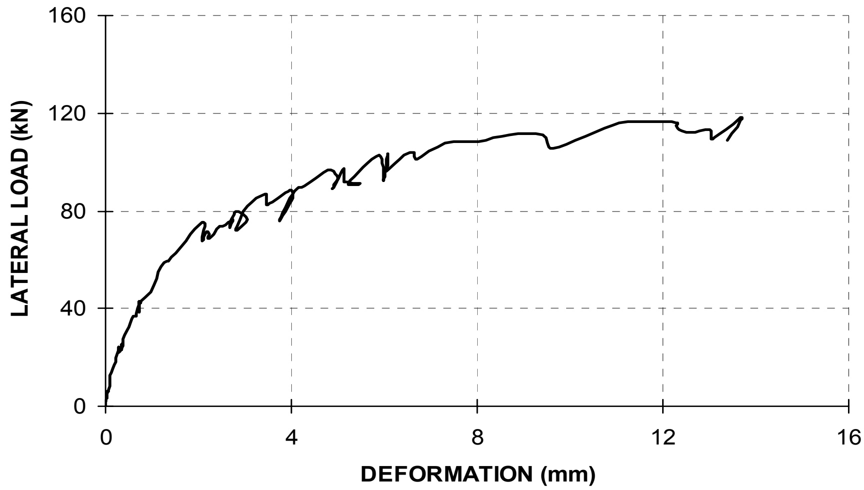
Retrofitted specimens

Inherently brittle masonry units and mortar provide masonry walls, which react to loads in a brittle manner. As a result, they fail catastrophically with little or no warning. Using linear materials, such as composites, to strengthen these non-ductile structural elements, shifts the primary focus of the wall's behavior from its lack of ductility to its increased strength. However, this shift in emphasis is reasonable only if the increased strength is continued from the wall to its foundation. Thus, a proper laminate anchorage system is required.

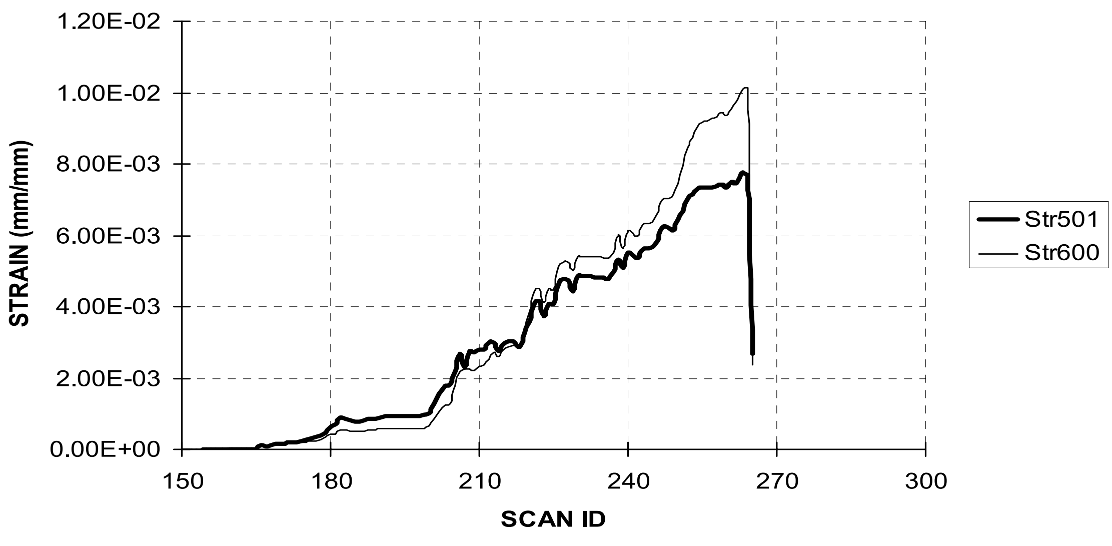
In a masonry wall CFRP retrofit design, attention must be given to height-to-thickness and height-to-width ratios of the wall, the level of axial load, and the capacity and drift demand. Similarly to any orthotropic material, however, the effectiveness of the composite retrofit also depends on the orientation of the fibers. A 45-degree [+-45] layout is the most effective (although not always the most practical) to carry shear forces in a shearwall. A laminate aligned with the height of the wall (i.e. 0-degree [0_2]) is optimal for out-of-plane, vertical bending loads. Finally, a 0-degree + 90-degree [0/90] laminate will provide an efficient method to strengthen walls supported on all four edges and subjected to two-way bending.

The traditional [+-45] layout for shear walls provides a system analogous to cross-bracing, and it behaves quite effectively. To investigate an alternative, shear wall specimens were strengthened with CFRP laminates around the perimeter of the wall (horizontal and vertical CFRP strips on the edges), thereby modeling a stiffened beam-column arrangement. Bending specimens were retrofitted with composite in a full-surface vertical alignment [0_2] on the tension surface of the wall only.

For the in-plane retrofitted shear specimens, strain gages were positioned in the maximum stress zones, and were aligned in the direction of the fibers. The shear walls, with composite laminate around the wall perimeter, reached a peak lateral load of 120 kN and a maximum horizontal deformation of 13.5 mm (see Figure 5a). Failure occurred due to extensive shear stresses in the masonry wall combined with localized damages to the load-applicator beam



(a) Load versus deformation

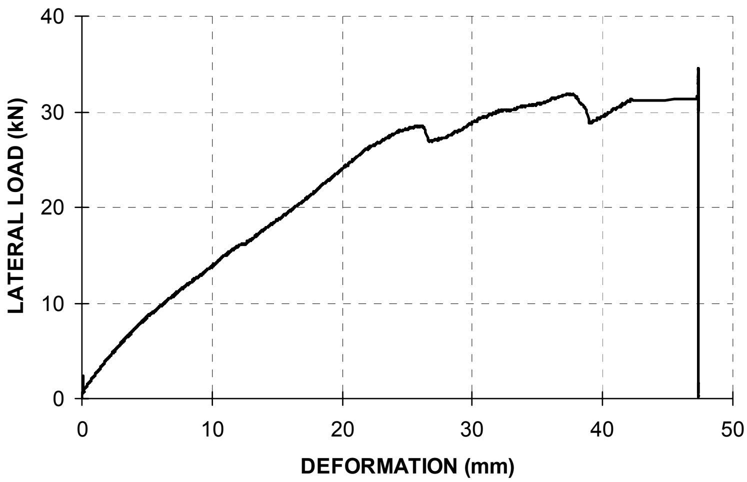


(b) Strain versus time

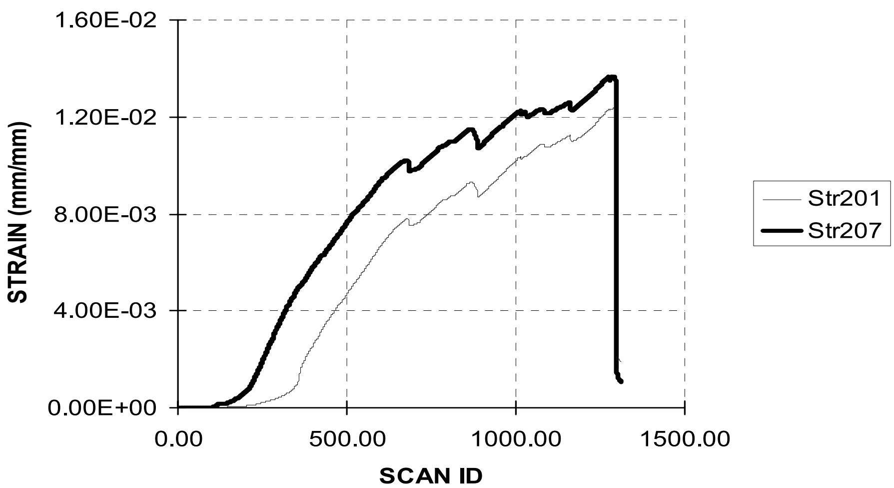
Figure 5. Results for retrofitted shear walls

at the top of the wall. No damages to the CFRP laminate or the composite anchor were observed. The peak strain in the composite laminate reached 1.0% (see Figure 5b). At 2/3 of the composite's ultimate strain of 1.5%, this laminate strain includes tension strain (uplift) as well as shear strain and is representative of only partial coverage of the wall surface by CFRP laminates.

The load-deformation curve for the wall subjected to cantilever bending and having a [0_2] composite retrofit is shown in Figure 6a. The peak lateral load was 32 kN with a maximum displacement of 47 mm. As shown in Figure 6b, the maximum strain readings in the composite



(a) Load-deformation results



(b) Strain versus time results

Figure 6. Results for retrofitted walls in bending

fiber reached 1.2%, approximately 80% of its ultimate capacity. Failure mode for the retrofitted bending specimens was due to extensive shear damage in the masonry wall. No damages were observed in the CFRP laminate or in the composite anchor. Ultimately, the masonry units inside the wall crumbled, and suddenly lost its lateral load carrying capacity (see Figure 7).

CONCLUSIONS

The experimental results revealed that a composite anchoring system can be utilized effectively with CFRP laminates to significantly increase the in-plane shear and out-of-plane bending capacity of unreinforced hollow masonry walls. Walls retrofitted with CFRP laminates and composite anchors and subjected to in-plane shear and out-of-plane bending realized 1285% and 1916% increases in capacity, respectively, when compared to the capacities of unretrofitted walls.

Figure 7. Failure of retrofitted wall subjected to out-of-plane bending

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