



Ain Shams University  
Faculty of Engineering  
Structural Engineering Department

# **RETROFIT OF UNREINFORCED MASONRY STRUCTURES IN EGYPT WITH LOCALLY AVAILABLE ADVANCED COMPOSITE MATERIALS**

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with Locally Available Advanced Composite Materials”**

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## **Statement**

This thesis is submitted to Ain Shams University for the degree of Doctor of Philosophy in civil engineering (structural engineering).

No part of this thesis has been previously submitted for obtaining a degree or a qualification before.

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## **ABSTRACT**

Unreinforced masonry (URM) structures constitute a considerable portion of the current buildings inventory in Egypt. Many of these buildings are of historic and cultural significance. URM walls exhibit poor seismic performance under moderate and high seismic demand. The traditional retrofitting techniques are excessively disruptive to use and occupancy, visually intrusive or too cost prohibitive for practical application. Therefore, the development of effective and affordable techniques for the retrofitting of URM walls is an urgent need.

This study was carried out to develop and examine an innovative FRP rehabilitation technique. This technique is referred to as Near Surface Mounted (NSM) Glass Fiber Reinforced Polymers (GFRP), where locally produced GFRP ropes embedded in mortar filled grooves formed in the masonry joints are used as superficial reinforcement. This method has the advantage of low installation cost and effort and possible use with minimal surface intervention which make it convenient technique that can be used for old and historical masonry buildings.

The subsequent study involves three main phases. The first phase studies the bond behavior of GFRP and masonry using the NSM technique where pullout bending test under monotonic static loading condition was carried out on sixty specially developed test specimens. Parameters such as bonded length, types of bonding material, and exposure condition were investigated. The test results showed that the use of masonry mortar or polymer modified masonry mortar for anchoring the FRP to the masonry is recommended to balance between the anchoring ability and compatibility with the parent materials. Based on the experimental results, an analytical expression was proposed to compute the anchorage length of the NSM FRP braided bars using different bonding materials with the masonry.

The second phase focuses on improving the in-plane and out-of-plane behavior of URM wallettes retrofitted with GFRP braided ropes. Seventeen clay brick masonry wallettes; eight of them were subjected to out-of-plane loading, and the remaining nine were subjected to in-plane loading. Parameters such as loading direction, reinforcement scheme, bonding material, and reinforcement pattern are the variables considered in this phase. Test results showed remarkable increase in ultimate capacity, energy absorption, and ductility capacity for various reinforcing schemes. Rational design guidelines for out-of-plane strengthening of URM walls with NSM FRP systems were developed and presented.

The third phase concerns the in-plane behavior of URM shear walls retrofitted with GFRP braided ropes. Five full-scale URM shear walls were tested under monotonic increasing in-plane lateral loads. The specimens were retrofitted with different retrofitting schemes to improve the load carrying capacity, ductility and energy absorption. Test results showed that the NSM GFRP retrofitting system prevented the catastrophic failure of URM shear walls. The proposed technique is suitable technique for solid walls if an increase in the strength is needed. On the other hand, it represents an excellent solution for increasing the lateral shear strength of perforated walls. Large amount of energy being absorbed in retrofitted perforated walls confirmed the NSM FRP retrofitting technique as a superior retrofitting technique for perforated walls. A simplified pushover model was developed to predict the nonlinear response of the un-retrofitted and retrofitted URM solid and perforated shear walls. The proposed model displayed reasonable estimates for measured responses both before and after retrofitting.

**Keywords:** Unreinforced Masonry; Fiber Reinforced Polymer, Near Surface Mounted; Retrofitting; Braided Fibers; Bond Behavior; Bonding Material; Out-of-Plane Behavior; In-Plane Behavior; Shear Walls; Rocking.

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