IN-LB	Inch-Pound Units
SI	International System of Units

Externally Bonded Fiber-Reinforced Polymer Systems Design and Construction for Strengthening Masonry Structures—Guide

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Fiber-reinforced polymer (FRP) systems can be used for strengthening masonry structures and masonry elements among other options such as external steel plates, section enlargement with reinforced concrete (RC) overlays or shotcrete, steel bracing, and internal steel reinforcement. FRP systems offer advantages over traditional strengthening techniques: they are lightweight, relatively easy to install, and are corrosion-resistant. Due to the characteristics of FRP materials as well as the behavior of masonry members strengthened with FRP, specific guidance on the use of these systems is needed. This document offers a description of the unique material properties of FRP and committee recommendations on the engineering, construction, and inspection of FRP systems used to strengthen masonry. These guidelines are based on the knowledge gained from experimental research, analytical work, and field applications of FRP systems used to strengthen masonry structures.

Keywords: buildings; columns; confinement; cracking; cyclic loading; detailing; earthquake resistance; fiber-reinforced polymers (FRPs); fibers; flexure; masonry; shear; strengthening; structural analysis; structural design; unreinforced; walls; wind resistance.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Masonry is a type of construction where clay units, concrete masonry units, or natural stones are laid in and bound together by mortar to form a building structure or a component in a structure. Masonry elements can be load-bearing or non-load-bearing. Masonry elements include walls, columns, pilasters, and beams.

Historically, most masonry, until the mid-twentieth century, was unreinforced. Due to damage of unreinforced masonry (URM) in the 1933 Long Beach, CA, earthquake, it was prohibited in seismically active regions, and reinforced masonry (RM) became more prevalent. During the nineteenth century, most of the URM building construction consisted of load-bearing mass-masonry walls. These walls are multi-wythe brick walls connected with brick headers, typically three or four wythes thick at the lowest stories and two wythes thick at the upper stories. From the late 1890s until the mid-1900s, URM was used in many transitional façades. These types of façades consist of steel or reinforced concrete frames that are filled with backup walls supported on spandrel beams, and an outer wythe that in many cases extends the entire building height and is supported only at grade. URM masonry elements were designed to rely on the strength of masonry alone to resist loads.

RM elements use steel reinforcement in grouted cells or embedded in horizontal mortar joints to resist tensile and shear stresses. RM construction became more common in the United States since the 1960s with the development of codes for structural masonry. However, there are examples of older RM structures built in the years following the 1933 Long Beach earthquake as a response to the poor performance of many URM buildings during this earthquake.

Unreinforced structures such as URM are particularly vulnerable to earthquakes and high winds, and many times strengthening is required to resist loads due to these events. Deterioration, change of use, structural modifications, and other factors may also necessitate strengthening of masonry structures or elements. The repair and retrofit/rehabilitation of existing masonry structures have traditionally been accomplished using conventional materials and construction techniques. Externally bonded steel plates, reinforced concrete overlays, installation of steel bars in grouted cells, and post-tensioning are just some of the many traditional techniques available. Fiber-reinforced polymer (FRP) composites have emerged as an alternative to traditional materials for strengthening masonry structures (ACI 440R). FRP materials are lightweight and resistant to corrosion. They exhibit high tensile strength and elastic modulus (carbon FRP), are impact-resistant and have electromagnetic transparency. These materials, which are available in a variety of forms including flat sheets and plates, reinforcing bars, and prestressing tendons of typically round cross section, provide the licensed design professional with flexibility in achieving desired performance.

Advantages of repair or strengthening masonry using FRP composites include easier handling and installation than other strengthening methods with resulting lower installation prices, and minimal dimensional changes to the structure. Disturbance to occupants and loss of usable space are commonly minimized. Dynamic properties of the existing structure remain unchanged because there is little weight addition or stiffness modification.

Disadvantages of using FRP may include inferior performance at elevated temperatures, requirements for protective coatings, degradation of mechanical properties after long-term exposure to certain environmental conditions such as extensive moisture intrusion and frequent freezing-and-thawing cycles, and the relatively higher level of site supervision and inspection required during construction. These disadvantages can typically be addressed by using protection systems suitably designed for the environment as well as testing to confirm the long-term design properties of FRP systems. In addition, due to different textures and uneven surfaces across masonry units and mortar joints, additional effort may be needed to properly prepare the masonry substrate to achieve adequate bond of the FRP system.

1.2—Scope

This guide provides recommendations for the selection and design of FRP systems limited to externally bonded FRP laminates and near-surface-mounted (NSM) FRP bars/strips for increasing or restoring the in-plane and out-of-plane strength of undamaged or damaged URM and RM walls and columns. Infill walls are not included in this guide.

The guide is applicable to masonry structures made of clay bricks, concrete masonry units, and natural stones using conventional types of mortar. The effectiveness of FRP systems is highly dependent on the adequate surface preparation of the masonry substrate. Masonry elements have different textures and uneven surfaces due to units and mortar joints that can affect the effectiveness of FRP systems if the masonry surface is not properly prepared.

For masonry with significant deterioration, questionable mortar bond, as well as cracking, element displacement, or both, traditional repair procedures may be required to be used in combination with FRP strengthening. Procedures and requirements for traditional methods for repair and strengthening of masonry are not covered in this guide. *Assessment and Retrofit of Masonry Structures* (Hamid and Schuller 2019) provides background and guidance for other methods for repair and strengthening.

Before starting the project, the licensed design professional should determine the design basis code (DBC) under which the evaluation, repair, and rehabilitation will be implemented. The DBC will establish the extent of the repairs and rehabilitation, evaluation methods, and design loads. The DBC is the code legally adopted by a jurisdiction, under which the assessments, repairs, and rehabilitations