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Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) Systems for Repair and Strengthening Concrete and Masonry Structures

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American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

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John Jones, Chair

Corina-Maria Aldea†

P. N. Balaguru	Ashish Dubey	Alva Peled	*Consulting Members*
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James I. Daniel	Antoine E. Naaman	Robert C. Zellers	
Antonio De Luca†	Antonio Nanni*		

*Chair of the subcommittee that prepared this document.
†Members of the subcommittee that prepared this document,
The Committee thanks Associate Member J. Gustavo Tumialan for his contribution.

Fabric-reinforced cementitious matrix (FRCM) systems for repairing and strengthening concrete and masonry structures are an alternative to traditional techniques such as fiber-reinforced polymers (FRPs), steel plate bonding, section enlargement, and external post-tensioning. An FRCM is a composite material consisting of one or more layers of cement-based matrix reinforced with dry fibers in the form of open mesh or fabric. The cement-based matrixes are typically made of combinations of portland cement, silica fume, and fly ash as the binder. When adhered to concrete or masonry structural members, they form an FRCM system that acts as supplemental, externally bonded reinforcement. This guide addresses the history and use of FRCM system repair and strengthening; their unique material properties; and recommendations on their design, construction, and inspection. Guidelines are based on experimental research, analytical work, and field applications.

Keywords: bridges; buildings; cracking; cyclic loading; deflection; development length; earthquake-resistant; fabric-reinforced cementitious matrix; fatigue; fiber-reinforced polymer; flexure; lap splices; masonry; meshes; mortar matrix; shear; stress; structural analysis; structural design; substrate repair; surface preparation; unreinforced masonry.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Fabric-reinforced cementitious matrix (FRCM) composites have recently emerged as a viable technology for repairing and strengthening concrete and masonry structures. The repair, retrofit, and rehabilitation of existing concrete and masonry structures has traditionally been accomplished using new and conventional materials and construction techniques, including externally bonded fiber-reinforced polymer (FRP) systems, steel plates, reinforced concrete (RC) overlays, and post-tensioning.

The primary reasons for considering FRCM as a suitable strengthening material stems from the cementitious matrix that shows properties of:

a) Inherent heat resistance

b) Compatibility with the substrate (that is, allows vapor permeability and application on a wet surface)

c) Long-term durability

FRCM is a system where all constituents are developed and tested as a unique combination and should not be created by randomly selecting and mixing products available in the marketplace.

ICC Evaluation Services (ICC-ES) first addressed acceptance criteria for cement-based matrix fabric composite systems for reinforced and unreinforced masonry in 2003. In 2013, this document was expanded and superseded by AC434-13, which provides guidance for evaluation and characterization of FRCM systems. AC434-13 was developed in consultation with industry, academia, and other parties. For FRCM manufacturers, AC434-13 establishes guidelines for the necessary tests and calculations required to receive a product research report from ICC-ES. Once received, the evaluated system can be accepted by code officials under Section 104.11.1 of the International Building Code (IBC 2012). Section 104.11.1 allows research reports to be used as a source of information to show building code compliance of alternative materials.

1.2—Scope

This guide covers FRCM composite systems used to strengthen existing concrete and masonry structures, providing background information and field applications; FRCM material properties; axial, flexural, and shear capacities of the FRCM-strengthened structures; and structural design procedures.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_c = net cross-sectional area of compression member, in.^{2} (mm^2)
A_e = area of effectively confined concrete, in.^{2} (mm^2)
A_f = area of mesh reinforcement by unit width, in.^{2}/in. (mm^2/mm)
A_g = gross cross-sectional area of compression member, in.^{2} (mm^2)
A_s = area of longitudinal steel reinforcement, in.^{2} (mm^2)
b = short side dimension of compression member with rectangular cross section, in. (mm)
b_w = web width, in. (mm)
D = diameter of compression member, in. (mm)
d = distance from extreme compression fiber to centroid of tension reinforcement, in. (mm)
d_f = effective depth of the FRCM shear reinforcement, in. (mm)
E_2 = slope of linear portion of stress-strain model for FRCM-confined concrete, psi (MPa)
E_c = modulus of elasticity of concrete, psi (MPa)
E_f = tensile modulus of elasticity of cracked FRCM (Avg.), psi (MPa)
E_f^* = tensile modulus of elasticity of uncracked FRCM (Avg.), psi (MPa)
f_c = compressive stress in concrete, psi (MPa)
f_c' = specified compressive strength of concrete, psi (MPa)
f_{cc}' = maximum compressive strength of confined concrete, psi (MPa)
f_{fd} = design tensile strength ($E_f\varepsilon_{fd}$), psi (MPa)
f_{fe} = effective tensile stress level in FRCM attained at failure, psi (MPa)
f_{ft} = transition stress corresponding to transition point, psi (MPa)
f_{fu} = ultimate tensile strength of FRCM (Avg.), psi (MPa)
f_{fv} = design tensile strength of FRCM shear reinforcement, psi (MPa)
f_{fs} = tensile stress in FRCM reinforcement under service load, psi (MPa)
f_l = maximum confining pressure due to FRCM jacket, psi (MPa)
f_{ss} = tensile stress in the steel reinforcement under service load, psi (MPa)
f_y = steel tensile yield strength, psi (MPa)
H_w = height of masonry wall, in. (mm)
h = long side dimension of compression member with rectangular cross section, in. (mm)
L = length of wall in direction of applied shear force, in. (mm)
ℓ_{df} = critical length to develop bond capacity of FRCM, in. (mm)
M_{cr} = cracking moment of unstrengthened member, in.-lbf (N-mm)
M_f = contribution of FRCM to nominal flexural strength, in.-lbf (N-mm)
M_m = contribution of reinforced masonry to nominal flexural strength, in.-lbf (N-mm)
M_n = nominal flexural strength, in.-lbf (N-mm)
M_s = contribution of steel reinforcement to nominal flexural strength, in.-lbf (N-mm)
n = number of layers of mesh reinforcement
P_n = nominal axial strength, lbf (N)
r = radius of edges of a rectangular cross section confined with FRCM, in. (mm)
V_c = contribution of concrete to nominal shear strength, lbf (N)
V_f = contribution of FRCM to nominal shear strength, lbf (N)
V_m = contribution of (unreinforced or reinforced) masonry to nominal shear strength, lbf (N)
V_n = nominal shear strength, lbf (N)
V_s = contribution of steel reinforcement to nominal shear strength, lbf (N)
t = thickness of masonry wall in. (mm)
ε_c = compressive strain level in concrete, in./in. (mm/mm)
ε_c' = compressive strain of unconfined concrete corresponding to f_c', in./in. (mm/mm); may be taken as 0.002
ε_{ccu} = ultimate compressive strain of confined concrete corresponding to $0.85f_{cc}'$ in a lightly confined member (member confined to restore its concrete design compressive strength), or ultimate compressive strain of confined concrete corresponding to failure in a heavily confined member
ε_{fd} = design tensile strain of FRCM (ε_{fu} – 1STD), in./in. (mm/mm)
ε_{fe} = effective tensile strain level in FRCM composite material attained at failure, in./in. (mm/mm)